Panel Decision & Report

SRP TXHC051512 - Harris County, TX

December 6, 2012

National Institute of
BUILDING SCIENCES

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Summary

Based on the submitted scientific and technical information, and within the limitations of the Scientific Resolution Panel (SRP), the SRP has determined that the Community's (Bridgeland's) data does not satisfy NFIP standards, thus FEMA's data is not corrected, contradicted, or negated.

Introduction

This report serves as the recommendation to the Federal Emergency Management Agency (FEMA) administrator from the National Institute of Building Sciences (NIBS) Scientific Resolution Panel (SRP). SRP's are independent panels of experts organized, administered and managed by NIBS for the purpose of reviewing and resolving conflicting scientific and technical data submitted by a community challenging FEMA's proposed flood elevations. The SRP is charged with helping to efficiently resolve appeal and protest issues between FEMA and communities by acting as an independent third party in the effort to obtain the best data possible for the community's Flood Insurance Rate Maps (FIRM's).

Panel

Panel ID: TXHC051512
Panel Name: Harris County, TX
FEMA Region: VI
Panel members:

- **Dr. Lee Azimi, P.E.,** Land Development Engineering, Division Manager, DeKalb County, GA.

  Dr. Azimi brings over 27 years of experience in academic research, as consultant and educator in the areas of civil infrastructure management, design, construction, and water resources engineering. He has served on numerous committees and regional councils and as a technical advisor for water resources protection and conservation and development of technical, regulatory, and policy standards. He currently works in the north Georgia metro area and his activities include management and administration of regional flood hazard mitigation and mapping program.

- **Mr. Martin Brungard, P.E., D.WRE,** Senior Project Manager, SYMBIONT, Indianapolis, IN.

  Mr. Brungard has over 27 years of experience in engineering consulting. He holds advanced degrees in civil and environmental engineering with specialization in water resources engineering. He was formerly chief of hydraulic and hydrologic design for two of the five Everglades Restoration projects in South Florida that were performed in conjunction with the South Florida Water Management District, Army Corps of Engineers, and Florida Department of Environmental Protection. He was also chief coastal structure reviewer for Letter of Map Revision (LOMR) applications for FEMA. Mr. Brungard's experience includes extensive 1-D and 2-D hydraulic modeling assignments.

- **Mr. John Miller, P.E., CFM, CSM**, Water Resource Engineer, Princeton Hydro, Lambertville, New Jersey.

  Mr. Miller has 19 years of consulting experience in his work as a site development engineer and water resources engineer. Mr. Miller is a licensed Professional Engineer, Certified Floodplain Manager and a Certified Stormwater Manager and has provided expert testimony before land use boards in New Jersey and Pennsylvania. He was the founding Past-Chair of the New Jersey Association for Floodplain Management. He was appointed to two groups reporting to the Governor of New Jersey (Task Force in 2005 and Commission in 2010) to address persistent major flooding in the Delaware River and Passaic River basins. Mr. Miller has modeled stream hydrology in HEC-2 and HEC-RAS and has defined floodway and floodway fringe along numerous streams, analyzing the effect of proposed structures and fill, and the removal of structures in and along streams.

- **Dr. David T. Williams, P.E., P.H., D.WRE, CPESC, CFM, F.ASCE,** President, DTW & Associates, Fort Collins, CO.

  Dr. Williams has a variety of work experience which includes National Technical Director for Water Resources for PBS&J, co-founder and President of WEST Consultants (a nationally recognized water resources engineering firm), the U.S. Army Corps of Engineers, and adjunct professor at San Diego State University. His professional experience covers more than eighteen years as a hydraulic engineer with the U.S. Army Corps of Engineers at the Waterways Experiment Station (WES) in Vicksburg, MS, both the Nashville and Baltimore Districts, and the Hydrologic Engineering Center (HEC) in Davis, CA. He has been a frequent short course instructor for the American Society of Civil Engineers (ASCE) and other professional and public organizations such as ASFPM and Floodplain Managers Association on computer training using FESWMS-2DH, HEC-2, HEC-RAS (Steady and Unsteady), HEC-HMS, Bridge Scour and HEC-6. In addition, he has taught short courses on channel bed scour for toe protection design, sediment transport, stream restoration, fluvial geomorphology and streambank protection. His professional society activities have included past chairs of the ASCE/EWRI Committees on Sedimentation, Computational Hydraulics, Probabilistic Approaches and Stream Restoration as well as past President of the International Erosion Control Association (IECA).

- **Mr. Joseph Wilson, P.E., P.H.,** Hydro Division Manager, Allgeier, Martin and Associates, Inc., Rolla, MO.

  Mr. Wilson has over 26 years of consulting experience specializing in hydrology and hydraulics. He has extensive experience with the National Flood Insurance Program including floodplain mapping and map revisions. He has experience performing stream discharge measurements, hydrologic analysis, flood frequency analysis, water-surface profile analysis and earth dam and reservoir design. He taught Engineering Hydrology and Water Resources as a Teaching Fellow at the University of Missouri - Rolla. Mr. Wilson's current research involves temporal and spatial distribution of statistically significant rainfall events in the Midwest.

Basis for Appeal

By letter dated April 14, 2011, Brown & Gay Engineers (BGE), on behalf of Bridgeland Development, LP (the Community), submitted an appeal of the preliminary revised Flood Insurance Rate Map (FIRM) issued for Harris County Texas by FEMA on September 30, 2010. Data for the preliminary revised FIRM was developed by the Harris County Flood Control District (HCFCD). BGE's appeal was primarily focused on base flood elevations (BFEs) and floodplain boundaries proposed by FEMA for Cypress Creek, downstream of Katy-Hockley Road.

Data Submitted

The following data used to generate the challenged flood elevations and the contesting data submitted as part of the Harris County, TX appeal have been provided to the panel:

Bridgeland

1. Appeal Letter dated April 14, 2011.
2. Bridgeland Development Appeal, Vol-1 of 2, March 2011.
3. Bridgeland Development Appeal, Vol-2 of 2, March 2011.
4. Analysis of Manning N Values, February 2011.
5. Bridgeland Development Appeal Vol-2 of 2 Appendix I: RAS Steady & Unsteady Models.
6. Bridgeland Development Appeal Vol-2 of 2 Appendix H: MIKE October 1994 & 1998 Flood Models.

HCFCD

1. Harris County Cypress Creek Timeline and Overview.
2. 2011-08-24 Meeting with BGE Notes.
3. 2011-06-16 Request for Additional Data from BGE.
4. 2011-09-09 BGE Letter.
5. 2011-05-26 Workshop with HCFCD Notes.
6. 2011-11-23 Cypress Creek Sensitivity Analysis.

7. 2011-12-05 Cypress PMR Memorandum.
8. 2011-08-23 Cypress HWM Memorandum.
9. Attachment - Additional Renderings.
10. Attachment - HCFD Flood Files.
11. Attachment - Supplemental Survey with Exhibits.
12. Attachment - Video Frames of Katy-Hockley Bridge 1998 Flood.
13. 2012-01-06 Cypress-Creek Field Reconn Documentation-082611.
14. 1% Flow Comparison Table.
15. 1% WSEL Comparison Table.
16. WSEL Q 100-yr and Rating Curve Comparison Options 1 to 5.

FEMA

1. Appeal Resolution Letter, March 2, 2012.
2. Cypress PMR Memo December 5, 2011.
3. Sujeeth Study Cypress Creek, December 14, 2009 Power point.
4. Cypress Creek Memo November 23, 2011.
5. Cypress Creek Watershed Update Exhibits.
6. Cypress Creek Watershed Update Final Models.
7. Cypress Creek Watershed Update Final Report, January 2011.
8. Cypress Creek Watershed Update HCFD Models.
9. Harris County SRP Request, April 10, 2012.
10. Harris County Submittal Agreement, May 7, 2012.
11. Howard Hughes Corporation Letter to FEMA, March 28, 2012.

Summary of Panel Procedures

An SRP kickoff meeting was held on September 24, 2012 via web-based teleconference presentation. The Institute Director, Ms. Dominique Fernandez, explained the SRP procedures, Panel members were introduced, and a Panel Chair, Dr. Lee Azimi was selected. Panel progress schedule for SRP report completion, coordination of communications with the Institute and the Panel, and the roles in completing the final report were discussed. The Chair's responsibility for leading the Panel review of Community, HCFCD, and FEMA submissions was discussed. The Panel was tasked to review the technical information and the appeal data provided. The Panel was tasked to keep their deliberations tightly focused on scientific and technical issues and correctness of the appeal data. All subsequent Panel meetings were held via web-based teleconference calls.

A first Panel meeting was held on October 12, 2012 to review the appeals items, review Panel progress, clarify Panel questions, and discuss and divide individual Panel member's scope and responsibilities leading to the final Panel report.

The oral presentation meeting was held on November 2, 2012 with the Panel, the Institute, the Community, HCFCD, and FEMA. The Community, FEMA, and HCFCD made presentations. Panel members asked questions to all parties to clarify issues and evaluate the disagreements.

The second Panel meeting was completed on November 6, 2012 to discuss the presentations, review technical procedures, and discuss preliminary Panel decision.

The third Panel meeting was held on November 16, 0212 to discuss the final Panel report format, present Panel disposition, and review technical information and process time lines leading to a final report.

A draft report outlining the SRP procedures, technical data reviewed, and presentations from Community, HCFCD, and FEMA was prepared by the Panel Chair and distributed to Panel members. A vote was held within the scope of the Institute's regulations, and the Panel's final decision was based on a unanimous vote of the five Panel members. Based on the member votes, a final report (this report) was prepared containing conclusions regarding the overall technical correctness of the information submitted to the Institute by the Community, HCFCD, and FEMA.

Recommendation

Based on a unanimous Panel vote, the Panel recommends denial of the Community (Bridgeland) protest. The Community's data does not satisfy NFIP mapping standards defined in FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners (NFIP standards).

Rationale for Findings

Hydrologic analysis, storage effects, & reconciliation of H&H analyses

BGE, on behalf of Bridgeland, challenged the Physical Map Revision (PMR) hydrologic and hydraulic (H&H) modeling and analyses in relation to percent ponding parameter (DPP) selection and the existence of storage in the rice farming areas. The Bridgeland appeal stated that most of the DPP values were largely overestimated in the PMR study and that the values were increased significantly from the effective study without appropriate justification since little or no active rice farming exists in the watersheds to reflect that ponding created by the former rice fields slowed down the runoff. Bridgeland primary reason was the concern with the type of modifications that were proposed for the PMR HEC-RAS models to achieve the high water mark elevations. Bridgeland asserted that the decision made to modify the hydrology, resulted in a consistent decrease in the calculated runoff. In Bridgeland's opinion, this decrease in peak runoff resulted in even more unreasonable changes in the HEC-RAS model.

FEMA G&S (Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping) states the following:

"The Mapping Partner must calibrate the model where practicable and fully document the process in the hydrology report, including dates, measurements, and locations of measurements of historic storms; parameters revised and rationale for revising; and input and output data for the calibrated model. This calibration should be performed using historic storms that exceed the 10-percent-annual-chance event where practicable."

"The most useful data relative to historic floods are high-water marks, and these data can be used to calibrate the Manning's "n" values. Wherever possible, the Mapping Partner should calibrate hydraulic models using measured profiles, reliable high-water marks, or reliable stage information at stream gages for past floods. Models should match known high-water marks within 0.5 foot."

"The Mapping Partner performing the hydrologic analysis should base the test for significance on the confidence limits of the more recent analysis. Plus or minus one standard error, which is equivalent to a 68-percent confidence interval, should be used to determine if the effective and new base flood discharges are significantly different. If the effective base flood discharges are within the 68-percent confidence interval (one standard error) of the new base flood discharges, the new estimates are not considered statistically different and there is no need for a new study based only on changes in the flood discharges. If the effective discharges fall outside the 68-percent confidence interval (one standard error) of the new discharges, the estimates are considered significantly different and a new study may be warranted based on changes in the flood discharges."

"When the effective flood discharges fall within the 68-percent confidence interval (one standard error), the Mapping Partner performing the hydrologic analysis may use the flood profiles for the effective study to evaluate the effect of new flood discharges on the effective BFEs. If the new flood discharges yield BFEs that differ from the effective BFEs by more than 0.5 foot or if the floodplain boundaries will be significantly changed in flat areas, a new study should be conducted. Often a new study is warranted without significant changes in flood discharges because of substantial changes in hydraulic conditions, like the channelization or construction of new hydraulic structures such as bridges."

By plotting the observed annual peak stages recorded by Katy-Hockley USGS gage between years 1976 and 2010, HCFCD showed that the effective Base Flood Elevation (BFE of the 100-year event), was equaled or exceeded 17 times during the 35-year record period. This observation supported an apparent up-trending non-stationarity in climate records which can be interpreted as evidence of increases in frequency of infrequent storms leading to more frequent and higher peak flood discharges in the Cypress Creek watershed. This suggests that the effective BFE is too low at Katy-Hockley bridge and justifies HCFCD's higher BFE for the PMR. HCFCD presented aerial photos and videos of the flooding events demonstrating that the Katy-Hockley bridge deck appeared overtopped at the reported bridge deck elevation of 162.20 feet during the 1998 flood (high water mark at that location was 162.8 feet).

HCFCD, using LIDAR topographic and photographic information, reported that the upper Cypress Creek hydraulics are dominated by a large overflow area upstream of Katy-Hockley Road, and an extensive network of abandoned agricultural berms which flood the rice fields or capture stream flows. HCFCD reported that the DPP values were revised to reflect the ponding created by the former rice fields which is an important factor in storage during an infrequent storm event that slowed down the runoff.

HCFCD reported that the 1994, 1998, and 2001 peak flood records were used as the major flood events to calibrate the PMR model. The Katy-Hockley bridge and the USGS stage hydrograph rating curve were used as the basis for calibration. The updated HEC-RAS model was used to calibrate a "modified observed" hydrograph by adjusting the DPP parameter, the Manning's 'n' values and fitting the observed USGS rating curve. This appeared to conform to the episodic flood observations and demonstrated that the rating curve extrapolation would bend significantly after reaching the channel banks to account for the spread of flow into the overbanks.

In determining statistical significance, HCFCD performed the flood frequency analysis using years 1976-2010 flood records, and plotted the flood frequency curve and the 68% confidence interval based on one standard error spreads. Plotting points of effective base flood discharges and the proposed base flood discharges showed that while the effective models were too low in predicting the updated frequency curves, the PMR HEC-HMS base flood discharges fell within the acceptable statistical confidence limits.

Bridgeland stated that the HEC-HMS model PMR hydrology should be rejected and used the current effective model to serve as the starting basis for Cypress Creek and tributaries floodplain storage, release parameters, and flood discharge determinations. This model was then modified per their documentation. Bridgeland did not update the flood frequency curves and did not incorporate any of the recent flood events of record information citing erroneous flood discharge and stage measurements leading to inaccuracies in rating curves. Bridgeland did not agree with the HCFCD calibration methodology and stated that Manning's 'n' values used in the models were inconsistent with previous Harris County Flood Insurance Studies. Instead, Bridgeland selected to use Manning's 'n' values from a report prepared by a consultant as the basis for the Manning's n values for the alternative HEC-RAS model.

While Bridgeland disagreed with PMR study methodology, it did not offer or perform analysis of statistical significance and did not support their preferred approach with alternative hydrologic and hydraulic calibration and validation using historical observations in accordance with the previously stated FEMA G&S guidelines.

Selection of Manning's 'n' values

HCFCD reported that Manning's 'n' values for overbank flow (floodplain) areas ranging from 0.24 to 0.99 produced acceptable calibration of their hydraulic model in comparison with observed high water marks and flows. Bridgeland's appeal indicated that the research performed by their consultant showed that Manning's 'n' values for overbank flow areas should range between 0.04 and 0.33. The appeal presented an analysis of Manning's 'n' values for Cypress Creek performed by River Research and Design, Inc. to support that claim. That analysis included methodologies that are apparently based on turbulent flow conditions and did not consider the 'effective' 'n' values for flow significantly impeded or "ponded" by the agricultural levees. The following paragraphs show that the assumption of turbulent flow skews Manning's 'n' values lower than would be exhibited in a laminar or transitional flow regime.

The authors of the textbook, Treatment Wetlands (Kadlec and Wallace, 2009), performed an analytic review of the open-channel flow theory and methodology presented in the textbook Open-Channel Hydraulics (French, 1985) and showed that the maximum calculated open-channel 'n' value would be 0.29 when the highest values for all of the method's contributing factors are used. Using observed flow and level data from operating wetland flow-ways, the authors of Treatment Wetlands found that the open-channel 'n' value was approximately an order of magnitude lower than their observed data. The Treatment Wetlands authors highlight the following in their discussion: "Clearly, open-channel, turbulent flow information is inadequate to describe the densely vegetated, low-flow wetland environment". The authors also report observed Manning's 'n' values over 2.5 in some mature wetland flow-ways.

Another reference citing the shortcomings of common references for Manning's 'n' values comes from an Army Corps of Engineers reference (Fischenich, 1997) that states: "Non-uniform velocity distribution and low Reynolds numbers are common in densely vegetated channels and floodplains, making the use of Manning's Equation rather dubious. As a consequence, 'n' values in the range of 0.10 to 0.30 are common and values exceeding 1.0 are possible. Engineers must condition themselves to accept these 'high' resistance values, and the existing handbooks and tables should be revised to include conditions under which extreme resistance values can be encountered."

A final example of high Manning's 'n' values in practice is for the design of treatment wetland flow-ways for the Everglades restoration projects in Florida. The South Florida Water Management District (Goforth, 2002) observed and documented a depth-dependent friction factor response in those wetland flow-ways. The Manning's 'n' values ranged between 0.5 for water depths greater than 3.75 feet and 1.5 for water depths less than 1.5 feet. The friction factor was found to vary proportionally between those depths. The design maximum flow velocity through those wetlands was 0.1 feet/second, which places the flow regime in a transitional range.

The existing transverse levees found within the Cypress Creek floodplain may impede flow through the floodplain and reduce flow velocity sufficiently to move the flow regime from turbulent into a transitional or laminar condition. Therefore, an assumption of typical turbulent-flow Manning's 'n' values appears to be questionable for the Cypress Creek floodplain. The analysis of floodplain friction factors by River Research and Design is based on methods from Chow, Agricultural Research Service, and Federal Highway Administration. All of those methods appear focused on flow velocities that are likely to produce a turbulent-flow condition and could under-represent the floodplain friction.

In hydraulic modeling, floodplain areas are sometimes classified as ineffective flow areas to better represent their apparent low contribution for flow conveyance. This practice appears to be somewhat comparable to employing high Manning's 'n' friction factors in vegetated areas when low velocities are produced. Either modeling approach could significantly limit the flow conveyance through the floodplain and the use of high 'n' values to simulate ineffective flow as recognized by the developers of HEC-RAS (HEC, 1995).

The limitation of friction values to those typically observed in open-channel flow does not appear to be justified by the literature review. Values exceeding the 0.33 maximum cited in the River Research and Design analysis have been observed and documented in practice. Portions of the engineering community are apparently unaware that Manning's 'n' values can exceed the values typically quoted for open-channels and in floodplains with moderate to high flow velocity.

Where low velocity flow can be expected, the practice of assigning ineffective flow areas in floodplains may be a result of the apparent mis-information that many hydraulics engineers have regarding the upper limit of Manning's 'n'. This practice appears to compensate for the reduced flow transmission that would be properly modeled if the floodplain friction factor was increased beyond the typical open-channel and floodplain values cited in literature. Therefore, the implementation of elevated Manning's 'n' values in vegetated floodplains is justifiable for the hydraulic modeling in this case.

The Bridgeland citation of a standard FEMA or HCFCD engineering practice or guideline to limit friction factors in floodplains to typically published values or methods does not appear prudent or warranted since it appears those values are intended for moderate to high flow velocity regimes. The low velocity conditions expected in the Cypress Creek floodplain do support the application of elevated Manning's 'n' values.

Important aspects of the hydraulic analysis of the Cypress Creek overbank areas are the movement of the water through a rather complex overbank topography, the 2-D horizontal movement of the water in these areas and the relative peaks and volumes of the water leaving Cypress Creek to the Addicks reservoir watershed. These hydraulic phenomena should be properly analyzed using the proper hydraulic tools as well as properly using these tools. The results affect the calibration of the submitted hydraulic model for floodplain delineation.

Modeling Agricultural Berms

HCFCD employed ineffective flow areas to represent the land enclosed by agricultural berms in its HEC-RAS steady state hydraulic model of Cypress Creek. Former rice fields in the floodplain are bounded by earthen berms both parallel and perpendicular to the creek and could create cells of nearly stationary water. HCFCD defined these cells as permanent ineffective flow areas when calibrating its model to high water marks recorded in 1994 and 1998. This technique is appropriate even though there may be small breaches in the berms. Interpretation of video taken in 1998 supports the conclusion that the overbank areas have very low velocities. The topography in the PMR model was later checked by field surveyed points and new 2008 LIDAR flight data with updated modeling runs supporting HCFCD's original PMR.

Bridgeland challenged HCFCD's method of defining ineffective flow areas. Bridgeland asserts that the agricultural berms are not flood control structures and are not maintained and as such, should be discounted. In lieu of using ineffective flow areas, Bridgeland accounted for the perpendicular berms using a four-cross section approach, typical in single-bridge modeling. This technique permits flow within the former rice field cells in the appeal model cross sections that were based on the field survey data. Bridgeland purported that the four-cross section approach adequately features the areas that are ineffective for the 1% annual chance event.

The use of ineffective areas in the HCFCD HEC-RAS PMR model best represents the flow dynamics confined by the agricultural berms. The Bridgeland appeal failed to successfully argue why this method should be deemed invalid. Due to known water surface elevations and calibration to this historical data, the four-cross section approach does not account for the dead storage bounded by the agricultural berms which was necessary to produce the higher historical elevations. Both HCFCD and Bridgeland recognize the significance of the agricultural berms in the calibrated modeling. Despite being a relic of past agricultural practice, the berms are considered in the PMR analysis because they physically persist over time as confirmed in the 2008 LIDAR and verified by field observations in 2011. There is insufficient proof to overturn the HCFCD analysis based on the evidence provided to the SRP.

Another issue presented by Bridgeland was regarding the selection of DPP or percent ponding estimates used in the hydrologic analyses. Given the magnitude of hydraulic impediments presented for agricultural berms and Manning's 'n' values presented above, it appears that the differences in percent ponding used in the Brideland or HCFCD models will not significantly alter the conclusion of this SRP.

Use of 1-D and 2-D models for Cypress Creek Floodplain Analyses

HCFCD stated that it used the 2-D hydrodynamic portion of the SOBEK suite of hydraulic programs to model the overbanks but no details were provided in the oral presentation. It was uncertain if HCFCD used the model to aid in determining any flow to the Addicks reservoir area. It stated that a combination of HEC-HMS and unsteady state HEC-RAS models were used to determine the volume and flow rate exiting Cypress Creek for 3 flow events, the 1994, 1998 and the 100-year floods.

Bridgeland stated that it used a combination of a 2-D model (MIKE-21) and unsteady HEC-RAS to determine the volume and flow rates exiting Cypress Creek. Detailed discussion of this modeling effort was presented in the oral presentation. Bridgeland summarized its results for the 1994 and the 100-year floods and omitted the 1998 flood because they did not have the HCFCD's results for comparison.

The results of the two teams' efforts in determining the volume and flow rate leaving Cypress Creek and going to the Addicks reservoir area are presented below with the total peak Q assumed to be the sum of each outlet location peak Q:

	1994 Event		100-year Event	
	Volume exiting (Acre-feet)	Peak Q exiting (cfs)	Volume exiting (Acre-feet)	Peak Q exiting (cfs)
Bridgeland	25,515	12,438	22,778	12,574
HCFCD	23,510	8,972	22,550	12,241

For the 1994 event, the modeling results are similar, except for the peak discharge exiting. This could cause a difference in the HEC-RAS modeling calibrations in the downstream areas. For the 100-year event, the differences are very small.

For determining the flow pattern of water in the overbank areas, a 2-D model is generally superior to a 1-D model. If water storage is an important phenomenon, both modeling methods should be performed in unsteady mode, as was indicated by both the HCFCD and Bridgeland. However, a properly applied 1-D unsteady model through a mostly ponded and relatively flat floodplain can produce results that are similar to a 2-D application in volume of storage, timing, and peak flows.

For the 100-year simulated flood event to determine the flow exiting Cypress Creek and going to the Addicks reservoir area the Bridgeland and District results are very similar in both volume and peak discharges, indicating that the resulting flow in the downstream areas would be similar. The differences in the modeling methods utilized, with their similar results, signify that other issues are causing the significant downstream differences.

The use of 1-D or 2-D modeling of the overbank areas, as pointed out, becomes a moot point if the 1-D unsteady model is properly applied and represents the physical situation.

In this instance, the driving forces in the proper application are the modeling of the agricultural berms and using the proper Manning's n values. These are addressed in the previous portions of this report.

Validity of the High Water Marks & Katy-Hockley Rating Curve

HCFCD utilized high water marks for calibration of the steady state hydraulic model of Cypress Creek. The high water marks were based upon the 1994 and 1998 floods of record. A single high water mark was recorded by the USGS for each event, independent of the floodplain mapping project. Aerial photographs and video evidence tends to support the high water elevations overtopping the Katy-Hockley Bridge deck. The bridge deck has an elevation of approximately 162.2 feet. This is within a foot of the high water mark elevations.

The original USGS rating curve for the Katy-Hockley gage did not reasonably represent the stage-discharge relationship for out-of-bank flows. The highest flow actually measured by the USGS was approximately 2300 cfs and was confined to the channel. During the calibration process the issue with the out-of-bank rating was recognized and the rating curve adjusted with the concurrence of the USGS. It appears that the calibration process relied on the same data set for both the calibration and verification of the model. It is well documented that calibration to a single event does not imply accuracy of a model over a range of events. This does create concern for the applicability of the calibrated model to other events.

Bridgeland presented the opinion that the high water marks were unreliable and therefore should be ignored. Considering the video and aerial photo evidence supporting the recorded high water marks, ignoring the high water marks seems inappropriate. The Bridgeland's resulting flood frequency values and rating curve do not appear to be consistent with the observed data at the Katy-Hockley gaging station.

The calibration process for the HCFCD model represents approximations and limited to available observations, however, Bridgeland failed to present sufficient evidence that the HCFCD calibration should be rendered invalid. Based upon this analysis, there was insufficient evidence to overturn the HCFCD mapping based on the high water marks issue raised in the Bridgeland appeal.

References

FEMA, November 2009. *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C. Guidance for Riverine Flooding Analyses and Mapping*.

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