August 2010 Flood Inundation Mapping Using GIS and LIDAR Data along the Squaw Creek in Ames, IA

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ABSTRACT

Recent flooding events along the Squaw Creek in Ames, IA have raised questions as to how flooding impacts may be mitigated for the Ames community as well as Iowa State University. Flood events over the last two decades have been a prevalent problem for the region and have led to high recovery costs. The most recent flood event in August 2010 is expected to cost Iowa State University $40 million to $50 million based on information released by the University. Today's technology has made flood inundation mapping a simple and accurate tool to better understand flooding impacts in watersheds. The high resolution Light Detection And Ranging (LIDAR) data available for the entire state of Iowa along with ArcGIS tools designed to work with river modeling software like the Hydrologic Engineering Center-River Analysis System (HEC-RAS) have become useful programs to map flooding conditions for different scenarios, as well as examining possible solutions to limit flooding impacts. The purpose of this study is to examine the extent of flooding in the Squaw Creek and the surrounding areas from the model's interpretation when land surface features (i.e. roads) are changed.

1. Introduction

Flooding from high precipitation storms is a major concern in many regions around the globe. To reduce the effects of these flooding events emergency management, community planners, and the general public need to have access to clear and concise information about the possibility and extent of flooding events in a given region. The constantly changing watersheds and outdated flood maps across the nation have given way to the idea that "Stage-based flood frequency analysis, when combined with Geographical Information System (GIS) for flood hazard mapping, provides an inexpensive and robust means for frequent flood hazard updates" (Heine, 2002).

There are currently ongoing inundation mapping projects for several regions in the United States. To produce an accurate inundation map, study areas need adequate elevation information of the channel and flood plain morphology as well as stream stage measurements or estimates for any rivers in the watershed. For example the Lower Mississippi River Forecast Center (LMRFC) processes and displays hydrological data using ArcView/GIS designed to be used internally and within the National Weather Service (NWS). The NWS is currently in the process of integrating the Hydrologic Engineering Center-River Analysis System (HEC-RAS) software into the Community Hydrologic Prediction System (Cepero-Perez et al. 2009). The HEC-RAS software is designed to execute one-dimensional hydraulic equations for both natural and constructed network channels. This process can be performed in either a steady state condition (unchanging flow through time) or in an unsteady state condition (flow changes with time, more realistic) (Cepero-Perez et al. 2009).

Cepero-Perez et al. (2009) conducted a study using GIS with an ArcMap 9.2 extension, HEC-GeoRAS. This is the approach that is utilized in the current study of the Squaw Creek near Ames, IA. Cepero-Perez et al. (2009) ran the HEC-GeoRAS model to produce flood extent polygons using both the steady state and unsteady state conditions. The main purpose of the Cepero-Perez et al. (2009) study, as well as this study is to find the flood extent delineation for various water surface elevations. Their study found that "accuracy decreases with distance from the lower boundary calibration point" in steady state flow. Jones et al. (1998) also stated that GIS allows users to display additional digital features such as roads, buildings, and critical facilities on flood maps. This allows for easy assessment of a given flood level potential impact.

Cepero-Perez et al. (2009) concluded that the HEC-RAS models are valuable tools for inundation mapping under proper circumstances. It was also mentioned that high resolution topographic data is needed for good flood extent calculations. Therefore, given the small scale area, data such as the Iowa LIDAR will be useful for the present study because it provides more spatially detailed maps.

The purpose of this study is to examine the extent of flooding in the Squaw Creek and the surrounding areas from the HEC-RAS model's interpretation when land surface features (i.e. roads) are changed. The model results are then compared to actual flood records and observations from the August 2010 flood. Possible changes and techniques to mitigate the flooding extent for given rainfall events in the watershed will be explored and analyzed to potentially provide guidance to city officials.

2. Data and Method

Located in north central Iowa, Ames is located in the Squaw Creek and Skunk River watersheds. The Squaw Creek eventually drains into the Skunk River on the southeast limit of the city. During the 3 day period from August 8th 2010 to August 11th 2010 the Ames area and Squaw Creek watershed experienced widespread 8 to 10 inches of rainfall based on surface observations as well as Quantitative Precipitation Estimates (QPE) from WSR-88D Radar data (Fig. 1).

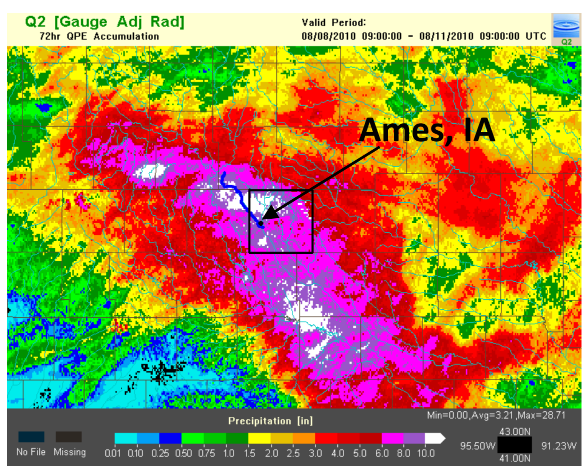

Fig. 1. QPE from National Weather Service in Des Moines, IA (Squaw Creek outlined in dark blue and Story County outlined in black).
(http://www.crh.noaa.gov/images/dmx/72hourQ2preciptotal.pdf)

The area of interest in this study includes the Squaw Creek Basin beginning at the railroad bridge near 6th Street extending south along the river and ending at the railroad bridge near Coldwater Golf Links golf course. The area examined includes the Squaw Creek itself as well as the surrounding floodplain extending out from both banks.

LIDAR data for this area were available for downloading from the Iowa Geographic Map Server (Orthoserver). The 1 meter resolution elevation data were imported into a GIS, ArcMap 9.3, in a GRID format. Using the HEC-GeoRAS software available for ArcGIS 9.3 (http://www.esri.com/), the process of preparing geographic data for export provided a detailed and accurate profile of the river and nearby floodplain. After evaluating the size and extent of the study area, it was determined that 39 cross section profiles would provide an effective coverage for proper flood inundated areal extent (Fig. 2). Geometric data including stream centerline, main channel banks, and cross sections were drawn directly onto the LIDAR Digital Elevation Model (DEM) by simply analyzing the elevation data on the DEM. Different Manning's n values for both the channel and floodplain assessed from ground observations and satellite images were also drawn in ArcMap. Polygons of common ground cover could be produced in ArcMap and assigned the appropriate Manning's surface roughness coefficients (n). These values are later used in HEC-RAS with Manning's equation to determine the velocity (V) in m/s and flow area (A) in m^2/s for different regions of the flood plain with the model calculating flow area (A), hydraulic radius (R), and channel slope (S) (all in SI units).

$$Q = VA = \left(\frac{1.00}{n}\right) A R^{\frac{2}{3}} \sqrt{S} \qquad (1)$$

University Blvd was treated as a levee in the model and levee (road) elevations were assigned using the DEM. This was done to limit the one dimensional HEC-RAS model from allowing flood water to inundate regions to the east before the road was overtopped. Unfortunately the HEC-RAS limitation of only allowing one levee on each side of the stream channel, did not allow for proper analysis of other raised elevation roads such as Lincoln Way and South 4th Street. These roads were observed to have a significant impact on the flood flow in the study area (C. Karstens, personal communication).

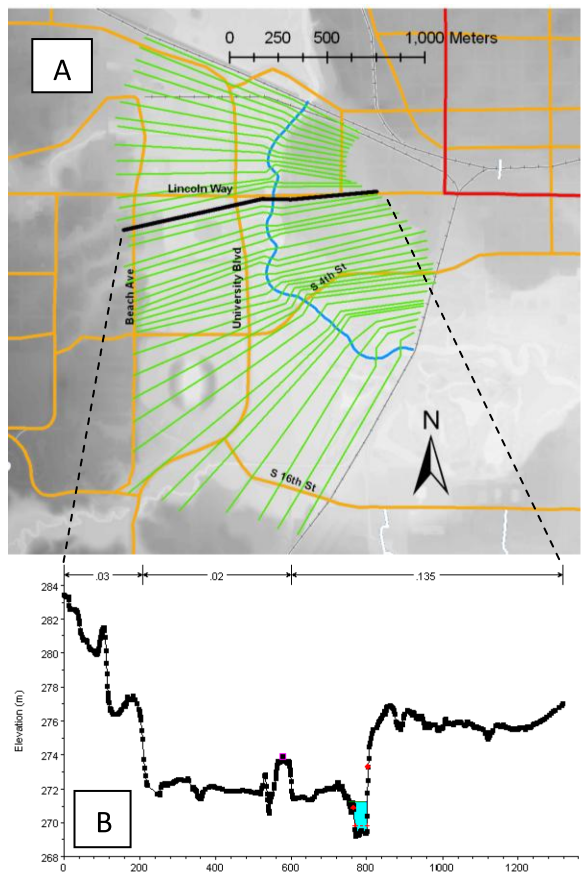

Fig. 2. A) LIDAR image with analyzed cross sections (green lines) for the study area near the Squaw Creek with nearby streets (orange lines). B) HEC-RAS cross section where stream gauge instruments are located

The geographic data were then exported out of ArcMap, and imported into the river model HEC-RAS developed by the U.S. Army Corps of Engineers. The cross sections had to first be analyzed for possible errors and limited to 500 data points along the extent of each cross section. This had a large limiting effect on the cross sections created from the 1 meter resolution data. The software downsized the cross sections into 500 points by interpolating between the over abundant data points. For simplicity of the model and lack of measurements, the bridges and small culverts in this watershed were ignored. This is understood to have some affect on the model results.

Known flow conditions such as discharge values during the duration of the flood event were also needed to initialize the model. A known rating curve for this reach of Squaw Creek was available from the United States Geological Survey (USGS) and was used in the model to convert simulated discharge to river stage. A USGS river monitoring station (id number: 05470500) is located in this reach 65 feet downstream from the Lincoln Way Bridge. The stage vs. discharge data from this monitoring station for the August flood event was also available from the USGS. Data for every 2 hours during the period beginning on 9 August at 12:00 am to 13 August at 12:00 am (total of 54 data periods) were entered into the model and was assumed to be the stage vs. discharge for stream flow entering and exiting the study area. The flood stage for this reach is reported to be 9 feet, and the observed peak stage during the August 2010 flood was 18.13 feet which occurred at 8:00 am CDT on 11 August. Of the 54 time steps selected, 39 were conditions at or above flood stage. The limitation of only having one river monitoring station in this reach of the Squaw Creek led to some assumptions that should be considered when analyzing the model's results. River discharge data is needed at the beginning and ending points of the reach in the model (just upstream discharge needed for subcritical steady flow). Because discharge values were only available for the station near Lincoln Way it was assumed that the discharge values were also valid for the starting point upstream. This assumption was made based on the idea that there was only limited additional water being added to the stream in the study area region.

HEC-RAS was run in steady state river conditions with subcritical flow. The one dimensional results were analyzed for each of the cross sections and compared to observations of peak inundation. These observations consisted of oblique aerial photographs and videos taken during the flood's crest and were used to manually digitize and create a peak inundation dataset. Flood extent and flow similarities/ differences between the model results and actual records were noted before being exported out of HEC-RAS.

The exported HEC-RAS results were then imported into ArcGIS to begin the process of inundation mapping of the flood event. Using the elevation data from the DEM a water surface for each of the 54 time periods was generated. These water surfaces were also compared to the observational inundation dataset for similarities and differences.

The basis of this study also involves examining options to mitigate flooding effects in this reach of Squaw Creek. The options that were studied are removing University Blvd, raising University Blvd by 4 feet, and raising University Blvd until the flood was contained to the east of the road. The term "removing" implies that the current road elevation would be lowered to the ground elevation on either side of the road. Raising University Blvd would represent the road as a built up levee in the model. When considering the overall effectiveness of using University Blvd as a levee system, the hypothesis proposes that there is not a reasonable or economical height to increase

University Blvd. South 4th Street is also hypothesized to be a raised elevation feature that may be damning water to the north, but this idea could not be properly analyzed considering the limitations of this model, and is left for future analysis.

3. Results

The first task in obtaining results from the input data was to attempt to replicate the August 2010 flood along this reach of Squaw Creek. Using the stage and discharge values from the USGS river monitoring station, the model output showed similar flood coverage for the crest of the flood (Fig. 3). For visual and statistical comparison, the aerial flood images from the Des Moines Register and aerial video footage from KCCI Channel 8 in Des Moines were used to develop a polygon of inundated flood area in the study area. This polygon could be easily displayed with the model results to analyze areas of difference between the two (Fig. 4). The total estimated area using the images for reference was calculated to be 1,639,626 m^2. This is only an estimation because there are significant areas in the study region where aerial images were not available or not adequately visible for precise recording. This is especially the case in the area east of the river where neighborhoods and tree cover obscured aerial images.

The model flood inundated calculated areal coverage was approximately 1,486,170 m^2 which is 9.4% less than the observed flood inundated coverage. Looking at Fig. 4, it is clearly visible that the largest difference between the model's inundated area and observed is in the southwest region of the study area. There is also a noticeable inaccurate cutoff of the flood extent in the parking lot northeast of the intersection of University Blvd and South 4th Street. This is a limitation of the model not being able to determine what happens to the flood waters between nearby cross sections that do not overtop University Blvd. A possible explanation for the difference in the southwest section of the study area may be the model's lack of ability to account for the buildup of water north of South 4th Street. Areas to the north appeared to have similar results for the model and observed inundated area, but the lack of flow over University Blvd in some locations indicates the model's flood stage is slightly lower than the observed crest flood stage. The model's flood level also never flows over South 4th Street which would also indicate a lower flood stage than the observed stage.

Next, University Blvd was removed from the model's data by removing the effects of a levee which enabled the cross sections in HEC-RAS to become inundated west of the road before overtopping the raised road level (Fig. 5). When looking at the time period where the flood crest took place, the model's inundated area looks very similar to the data for the previous case where University Blvd was accounted for. These two cases are probably similar at this time period due to the fact that during this period most of University Blvd was overtopped by the flood level so it was essentially ignored by the model. The model results for this removed University Blvd situation resulted in an inundated areal coverage of 1,440,066 m^2. This is 12.2% less than the observed value. When analyzing the model output for the reproduced flood and the removed University Blvd situation, the most pronounced difference between the results is the slight decrease in river stage in the removed University Blvd case. This is probably occurring because the lack of University Blvd acting as a levee will not allow the water to build up before overtopping the raised street. Figure 6 illustrates the differences in the interpreted flood and the observed flood. This image clearly shows the slightly lower flood crest from the model results.

The next case that was examined in this study involved raising the elevation of University Blvd by 1.22 meters (4 feet). The purpose of this change was to inspect the possibility of better containing flood waters to prevent the inundation of Hilton Coliseum and the Iowa State Center. The model was again ran using the flood conditions measured in the August 2010 flood and then exported to GIS for inundation calculations (Fig. 7). As hypothesized the 4 feet elevation increase in University was unable to contain all of the flood water east of this road. Figure 7 shows the inundation of University Blvd east of the ISU Soccer Complex all the way to the Lincoln Way and University Blvd intersection. Due to the cross section limitation in the model the inundation area around Hilton Coliseum and the Iowa State Center the flood extent does not appear in this region. However, it is assumed the area around these structures is inundated from the flood water overtopping Lincoln Way north of this area. Flood stage levels are higher in this situation due to the containment of water in a smaller area in the northern section of the study area (fig. 8). Figure 8 shows the elevated road was still inundated by the input flood values. There is relatively high elevation land along the eastern bank of the Squaw Creek. This elevated surface extends roughly 700 meters south from the railroad bridge on the northern end of the study area. It is possible this containment of water between the elevated land and the raised University Blvd allows water to build up until the lower elevation University Blvd is overtopped. This may be evidence against the use of University Blvd as an effective levee for major flood events. Further study is needed to better determine this effect. It was also shown in the model results that raising University Blvd to mitigate flooding, has only minor increases on the inundation of neighborhoods north of South 4th Street. One possible reason for only seeing slight increases in flood inundated area in the neighborhoods north of South 4th Street may simply be explained by the large extent of lower elevation land in the surrounding flood plain downstream from South 4th Street. This lower elevation land may be allowing flood water to spread out over a large area which does allow water to build up to the north.

The final case that was examined was aimed at finding what height University Blvd would need to be raised to contain the August 2010 flood and prevent the inundation of areas to the east of University Blvd. The height of University Blvd was increase by .33 meter increments until the flood was contained by the model. At an increased elevation of 1.67 meters (5.5 feet) the flood was successfully contained to the east of University Blvd (Fig. 10). Figure 9 also shows the contained flood stage east of University Blvd for the same cross section used in figure 8. With this larger buildup of water contained along the Squaw, it would also be important to analyze the effects this would have on the flow upstream and downstream. When analyzing this result, it is also important to understand the constraints of the HEC-RAS one dimensional model which is being ran using the current rating curve for this reach of the watershed.

4. Conclusions

Five major floods (stages above 15 ft) have occurred since 1990, and there have been several discussions on how to prevent damages from flood waters. Based on the data and results of this study, it can be determined that major flooding events such as the August 2010 event are not easily mitigated by using University Blvd as a levee system.

It can be concluded that a substantial increase in the elevation of University Blvd is needed to effectively mitigate major floods. There may be more reasonable and economical solutions upstream on the Squaw Creek watershed to mitigate flooding events.

Possible further study of this case might involve running the model in unsteady flow conditions which would take into account the change of flow entering and leaving the study area reach. More stream gauge data is crucial for performing this type of analysis.

By becoming familiar with the ArcGIS and HEC-RAS software it is apparent that these are useful tools that can be used to better understand and prepare for flood events. It is also important to have accurate and numerous stream gauge data to have the model perform at its potential. The addition of more stream data particularly on the ends of the river reach in the study area may have provided better results in this study. Important flood plain characteristics such as bridges and culverts would have also provided more accurate results in this case. There may also be newer and improved river models available that can better analyze flood inundation situations especially on small scale cases and complex urban cases like the one examined in this study.

5. Acknowledgements

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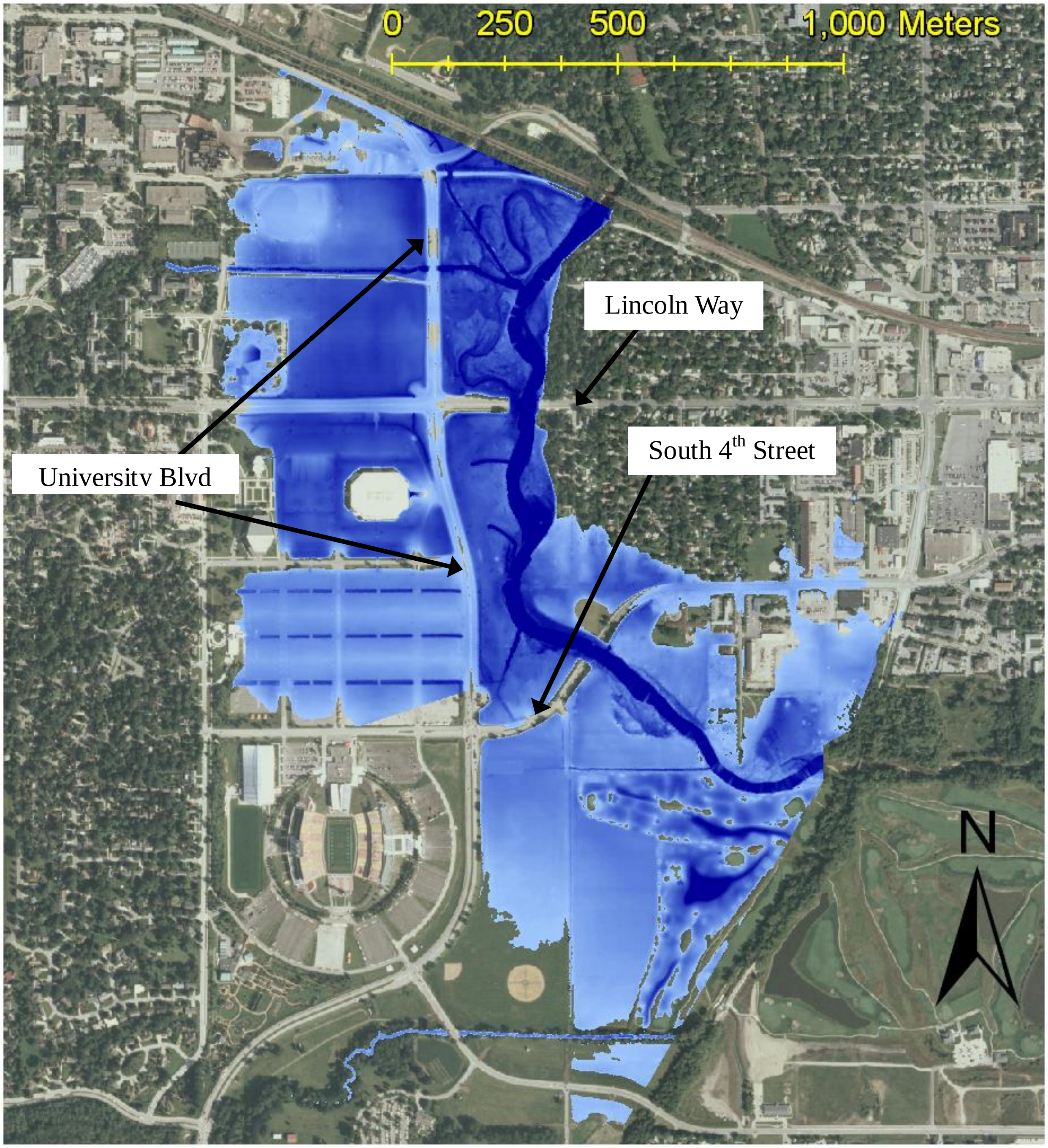

Fig. 3. Model output for observed August 2010 flood.

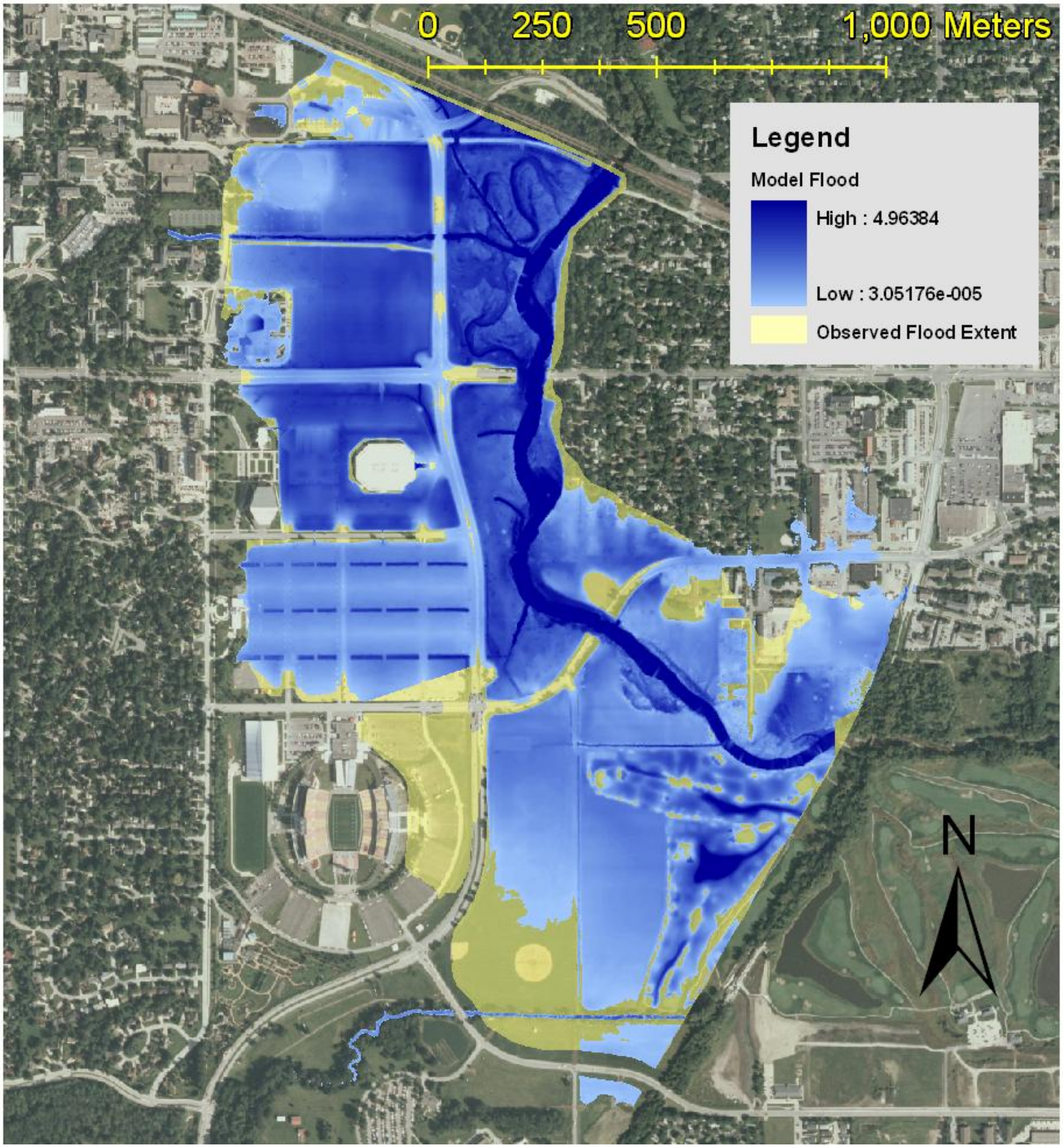

Fig. 4. Model flood under current topographic situations for August 2010 flood conditions with actual observed flood extent displayed in background (yellow shaded region).

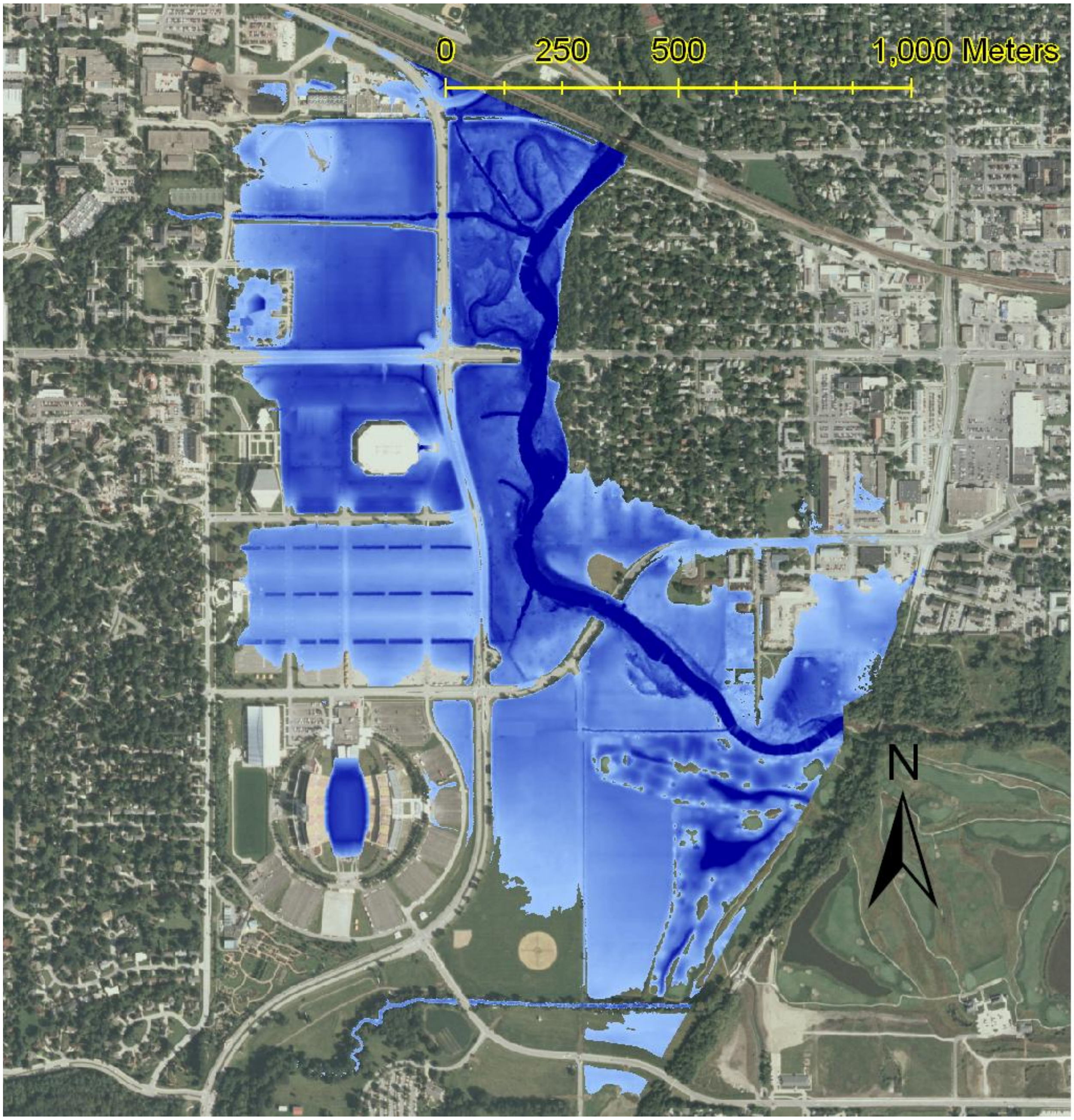

Fig. 5. Model flood with University Blvd raised removed.

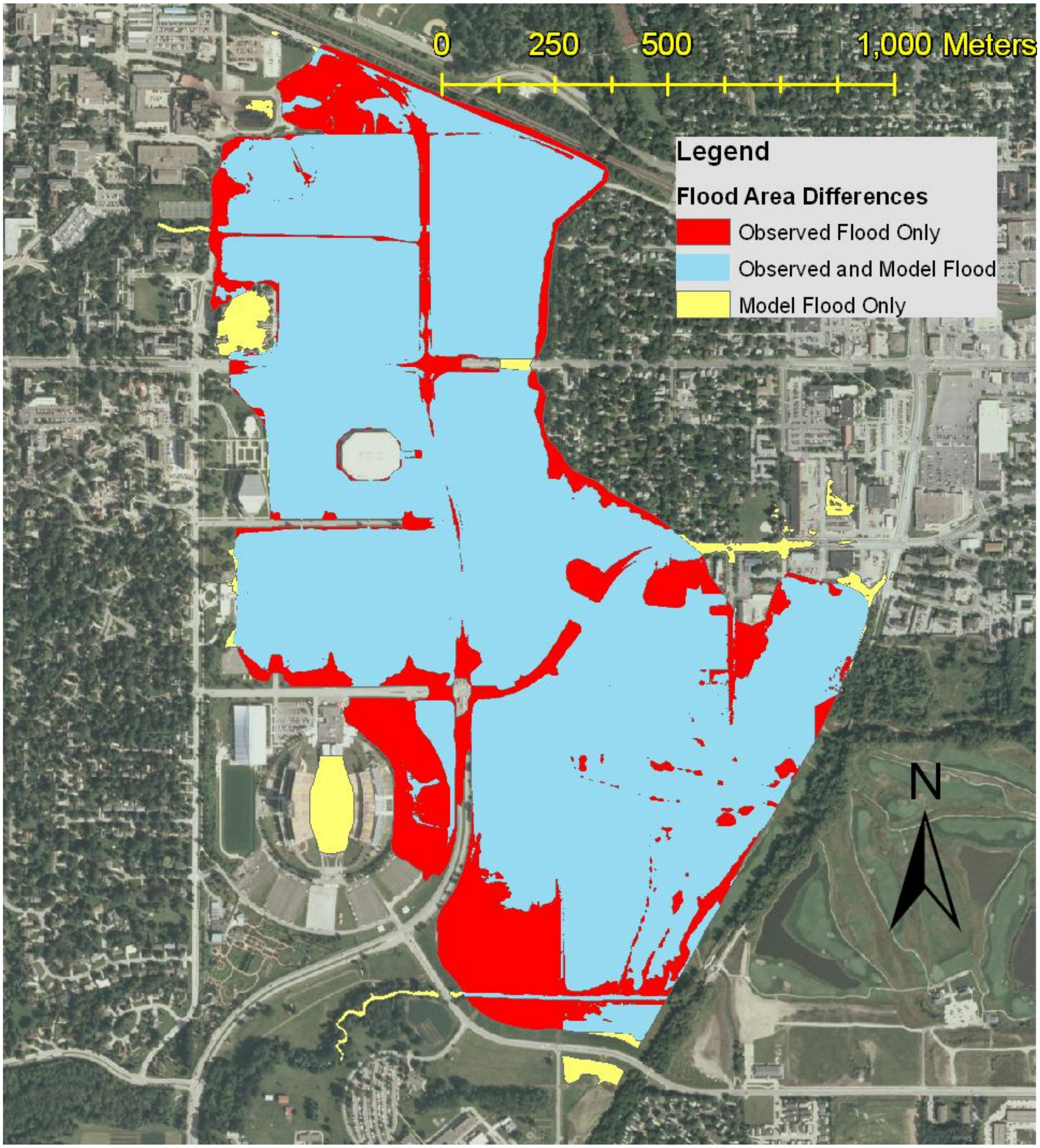

Fig. 6. Differences between modeled flood and observed flood with University Blvd removed.

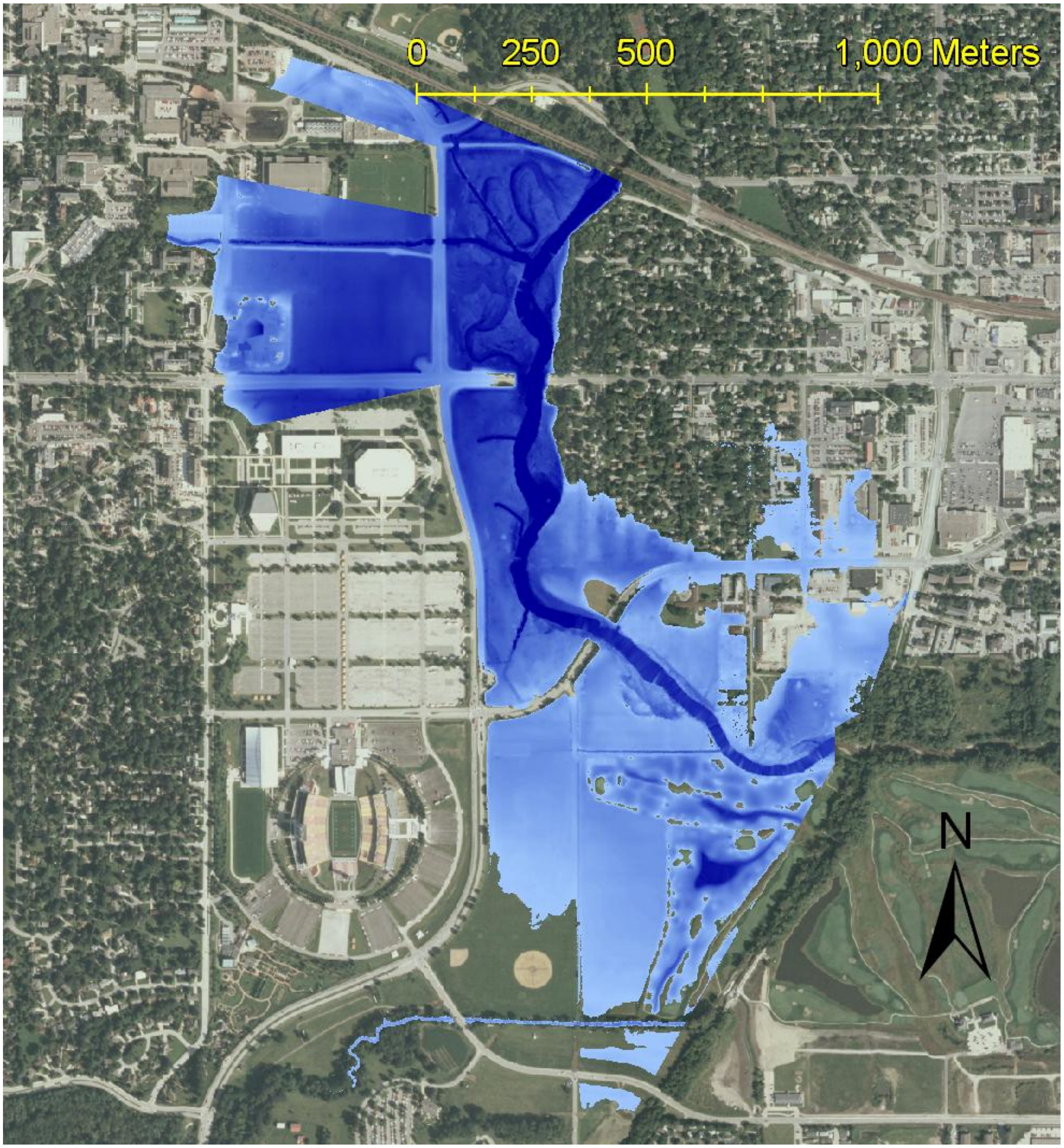

Fig. 7. Model flood with University Blvd raised 4 feet.

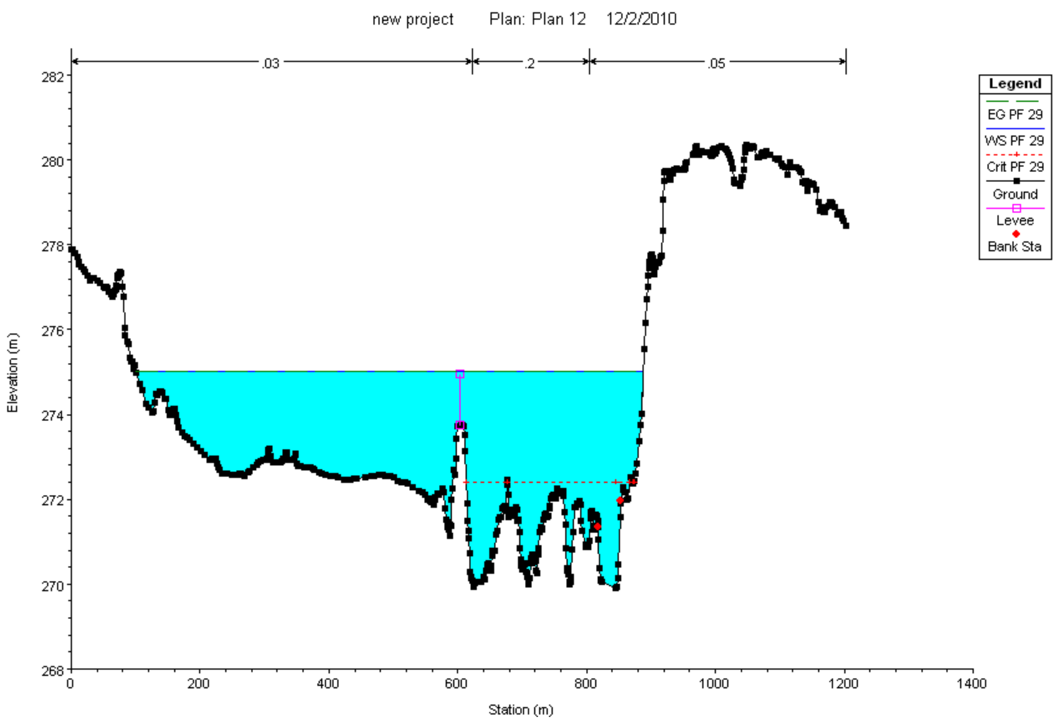

Fig. 8. Model cross section near ISU Soccer Complex with 2010 flood values and University Blvd raised 4 feet (flood crest overtopping University Blvd.

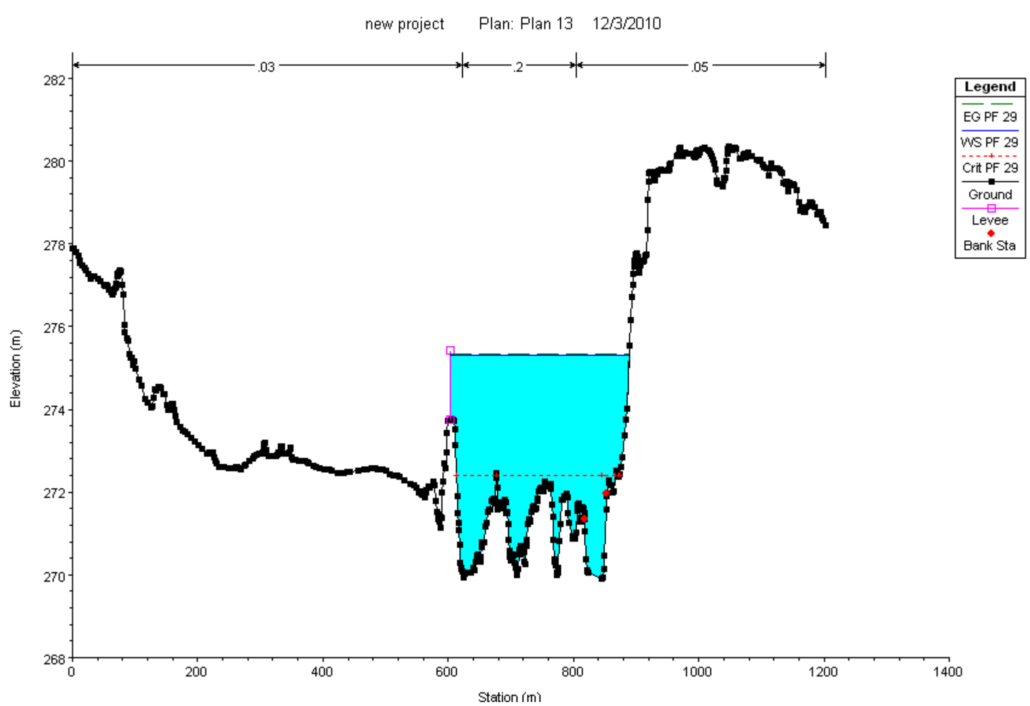

Fig. 9. Model cross section near ISU Soccer Complex with 2010 flood values and University Blvd raised 5.5 feet (flood crest contained by University Blvd).

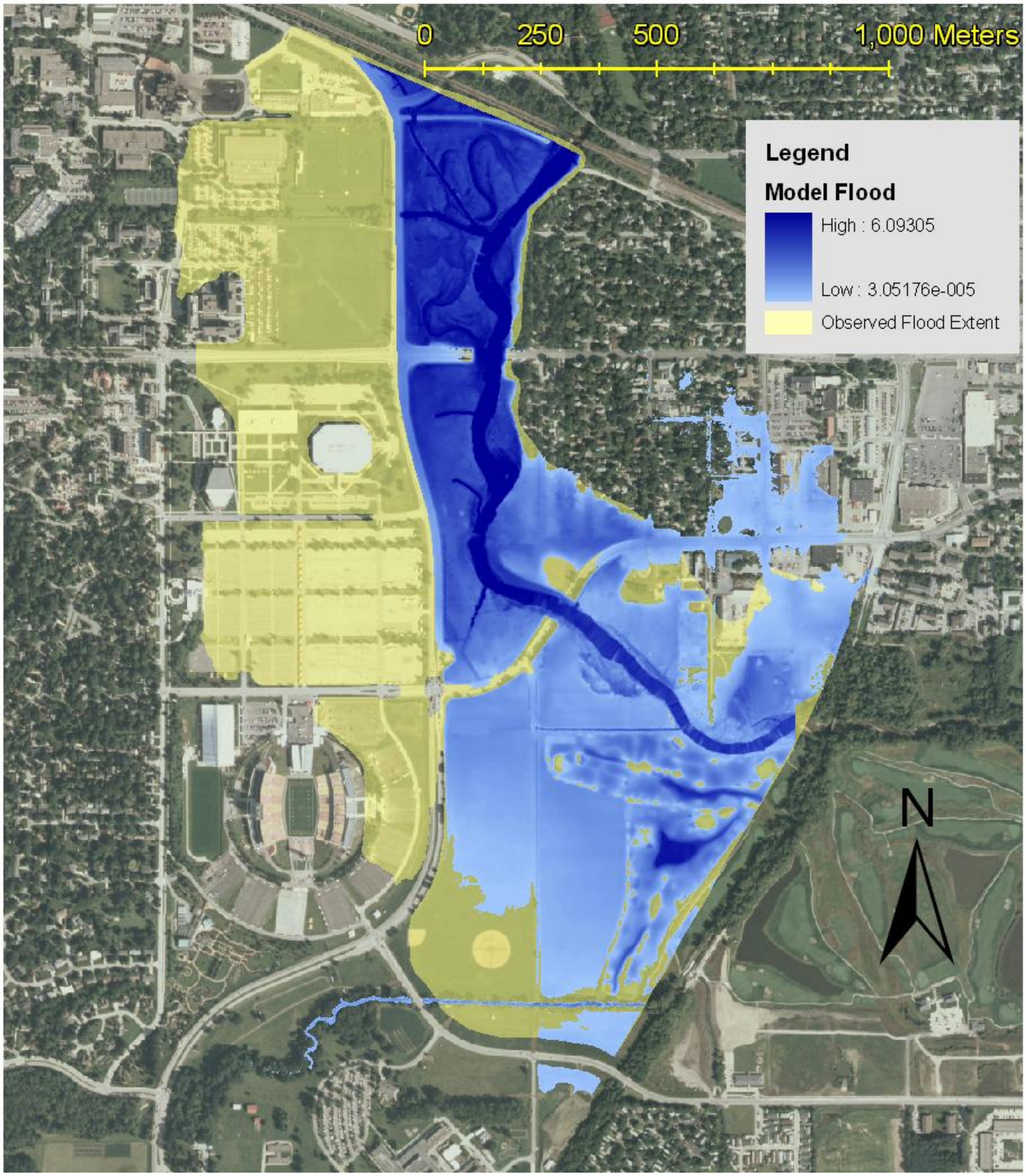

Fig. 10. Model flood with University Blvd raised 5.5 feet to contain August 2010 flood conditions with actual observed flood extent displayed in background (yellow shaded region).