Analyzing Flood Control Alternatives for the Clear Creek Watershed in a Geographic Information Systems Framework

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Abstract

Recent technological advancements in hydrologic science and geographic information systems (GIS) have played an instrumental role in analyzing flood control options in the Clear Creek watershed. The development of an effective approach addressing both flood mitigation and ecosystem preservation has been pursued by various agencies for the past 30 years in an effort to preserve one of the last pristine bayous in the Houston / Galveston Bay area. Proposed solutions to the flooding problems by the U.S. Army Corps of Engineers (COE) have focused on largescale channelization which could jeopardize the creek's sensitive ecosystem and provide limited flood protection as evidenced by the severe flooding experienced in other concrete channelized creeks and bayous in the region. The application of the Hydrologic Engineering Center's latest hydrologic and hydraulic models (HEC-HMS, HEC-RAS and HEC-GeoRas), coupled with GIS and NEXRAD radar, has allowed for the efficient analysis of proposed alternatives to the previous COE plan including voluntary floodplain property buyouts and various, smaller-scale channelization schemes.

Clear Creek is subject to extensive flooding due to poor development practices. Current and future development promises to continue an encroachment on the existing floodplain and further eliminate the natural benefits the floodplain provides. Such development has given rise to significant flood losses, especially in Friendswood, Texas, which was identified by the National Wildlife Federation's Higher Ground as the No. 10 rated community in terms of dollar value of repetitive flood loss payments nationwide. The extensive flooding in the Friendswood area, combined with its unique hydrologic, hydraulic and environmental characteristics, made this area a premier case study site.

The project goals of applying the latest HEC tools, NEXRAD and GIS to test the viability and effectiveness of specific flood control alternatives to channelization were effectively met with acceptable results. One singular combination provided the most promising results for the Friendswood area and was studied in detail. This combination consisted of a 4-mile, 10-year design storm channel through the Friendswood area with voluntary property buyouts of houses in the post-channel floodplain. NEXRAD radar was used to compliment an inadequate rain gage network for two tributaries in the study area. Results compare favorably and often improve upon those achieved by the original COE channelization plan with significantly lessened environmental impacts and acceptable downstream flows. The GIS components of the study allow for the generation of output data in a sensible and easily understood format that can be readily applied to other flood prone areas throughout the Clear Creek watershed. Additionally, the newer, mostly digital format of existing watershed data is more readily editable and will therefore efficiently accommodate expected, future changes in

watershed parameters such as percent development. Lastly, the digital format will easily accept new data from flood control agencies as it becomes available, such as slab elevations for properties in the 100-year floodplain.

Background

The purpose of this study was to apply, in a combined fashion, the latest hydrologic / hydraulic modeling tools and recently developed GIS software to the flooding problem in the Clear Creek watershed. The vast amount of digital data now available has made this type of analysis not only possible, but likely more efficient, cost-effective, and accurate. NEXRAD supplied accurate, watershed wide rainfall data for use in the hydrologic analysis of this study. The programs, HEC-HMS and HEC-RAS, allowed for the easy creation and transfer of modeling data sets dealing with Clear Creek. Lastly, HEC-GeoRAS permitted the development of digital floodplains that were analyzed in Arc View for the purpose of comparing various flood control options.

The Clear Creek watershed is a 260 square mile area located 20 miles south of Houston, Texas. This study focuses on the 164 square miles of the watershed, which are drained by Clear Creek and its several tributaries. Clear Creek itself is a tidally influenced bayou that meanders through four counties and several municipalities before terminating as it enters Clear Lake.

Clear Creek and its floodplains and tributaries are an important ecological resource from several perspectives. The creek is an estuary of Galveston Bay and thus provides critical nursery habitat for a variety of species including great numbers of mammals, birds, amphibians, reptiles and aquatic species. Additionally, it has significant fresh and saltwater wetland resources. Its riparian woodlands, which line a significant portion of the creek, are comprised of various types of bottomland hardwoods. (McFarlane, 1998) This riparian zone serves a variety of migrant bird species, provides an essential corridor for terrestrial species, and is a vital buffer for much of the surface runoff of the creek and its adjoining Clear Lake and Galveston Bay. Most importantly, however, Clear Creek represents one of the last waterways in the Houston area that has survived a significant period of urban growth relatively intact.

The city of Friendswood, Texas presents a challenging flood control problem due to its location in the watershed and the presence of a significant number of repetitive loss properties due to floodplain development. Floodplain encroachment has made Friendswood the No. 10 rated community in terms of dollar value of repetitive flood loss payments nationwide according to a recent study conducted by the National Wildlife Federation entitled Higher Ground. Additionally, Friendswood claims 18 of the top 200 single-family homes nationwide whose flood insurance payments have exceeded their property value. Another 20 of these homes are located within the Clear Creek watershed. (NWF, 1998) This portion of the stream receives flows from four of its six major tributaries with each of their significant flows constrained to a narrow floodplain and channel. Figure 1 is an ArcView image created for this study, which shows a close-up of Clear Creek through Friendswood. The figure illustrates the location of the repetitive loss properties in and around the 100-year floodplain in addition to the number of insurance claims made by each property between the years 1978 and 1995. (NWF, 1998)

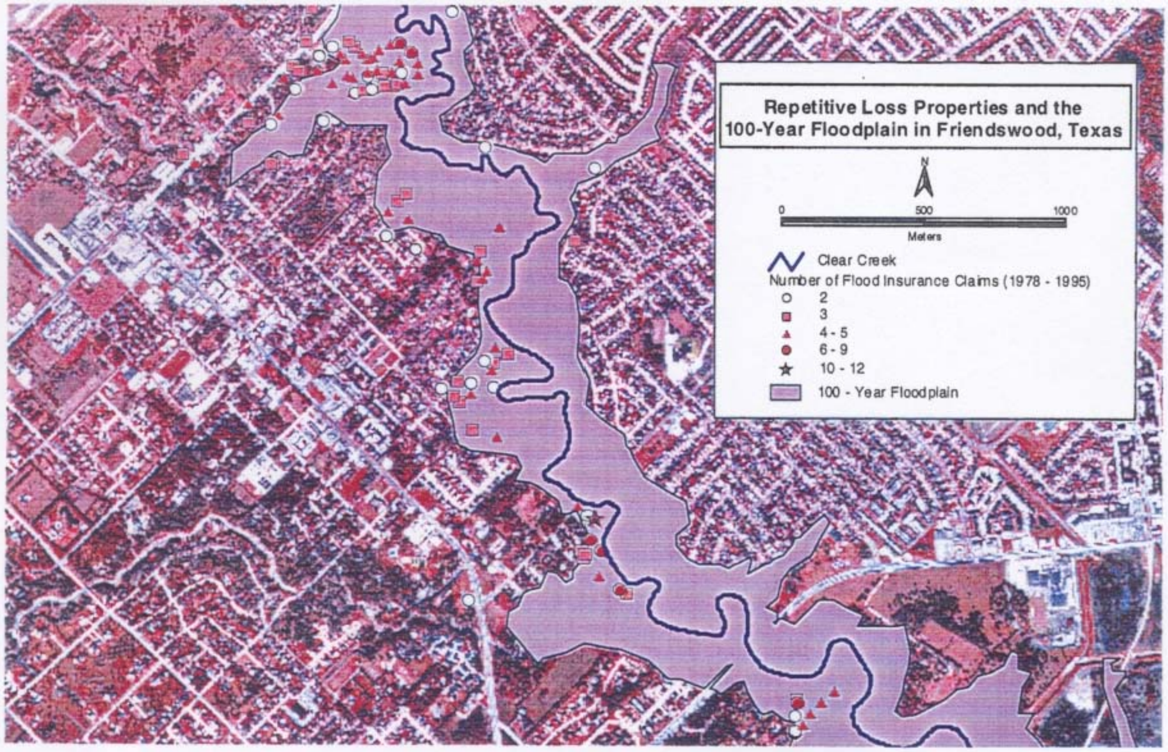

Figure 1: Repetitive Flood Loss Properties in Friendswood, Texas

Previous Flood Control Plans

The Clear Creek Federal Flood Control project has had a lengthy and involved history of formulation and reformulation. The original plan, with funding initially approved by Congress in 1968, consisted of an earthen, grass-lined channel that would have extended the full length of the creek from the upper end of Clear Lake, westward to its origin in Fort Bend County. The result would have replaced approximately 41 miles of existing, winding channel with a 31-mile straight channel designed to accommodate 100-year flows. The plan remained dormant until 1979 when Tropical Storm Claudette caused an unprecedented $90 million worth of damages throughout the watershed by flooding over 5,000 structures. (COE, 1982) This enormous storm was in excess of a 100-year event and claims the national 24-hour rainfall record of 43 inches at Alvin, Texas. Despite this impressive event, post authorization planning studies conducted by the COE found that the project lacked broad public support because of the negative aesthetic and environmental impacts associated with the original channel. As a result, the channelization plan was reduced in scope and finally initiated in 1986 when the Galveston and Harris County Flood Control Districts signed as local sponsors as required by the Water Resources Development Act of that year.

A review of the COE'plan was initiated in 1997 by local sponsors, headed by the Harris County Flood Control District (HCFCD). The review was conducted to address concerns regarding the latest COE plan, including but not limited to: the fact that the project was based on outdated and flawed technology, concerns over worsening downstream flood conditions, and significant environmental impacts on the riparian forest as well as Clear Lake. (HCFCD, 1997) The 1997 restudy and increasing pressure by local sponsors caused the COE to initiate a

General Reevaluation Report on the Clear Creek Federal Flood Control Project. This reevaluation is currently underway and has provided an excellent opportunity for additional research and implementation of the latest technology in an attempt to formulate an acceptable flood control plan for the Clear Creek area.

Overall Methodology

Five basic implementation steps were utilized in developing the databases and models to permit analysis of different flood control alternatives for a portion of the Clear Creek watershed. Figure 3 illustrates the overall methodology. First, NEXRAD rainfall data for an October 1994 rainfall event was obtained and utilized as input to the hydrologic model. Second, a new hydrologic model, in the HEC-HMS format, was developed based on an existing HEC- 1 model of the hydrologic study area. The hydrologic study area is shown in Figure 2. Subwatersheds were patterned off of existing HEC-1 maps. Third, the resulting peak flows from hydrographs generated by the hydrologic model were used as input to a HEC-RAS model created for a specific portion of Clear Creek. The extent of the hydraulic study area is also illustrated in Figure 2. The hydraulic model was created in conjunction with the HEC-GeoRAS extension using widely

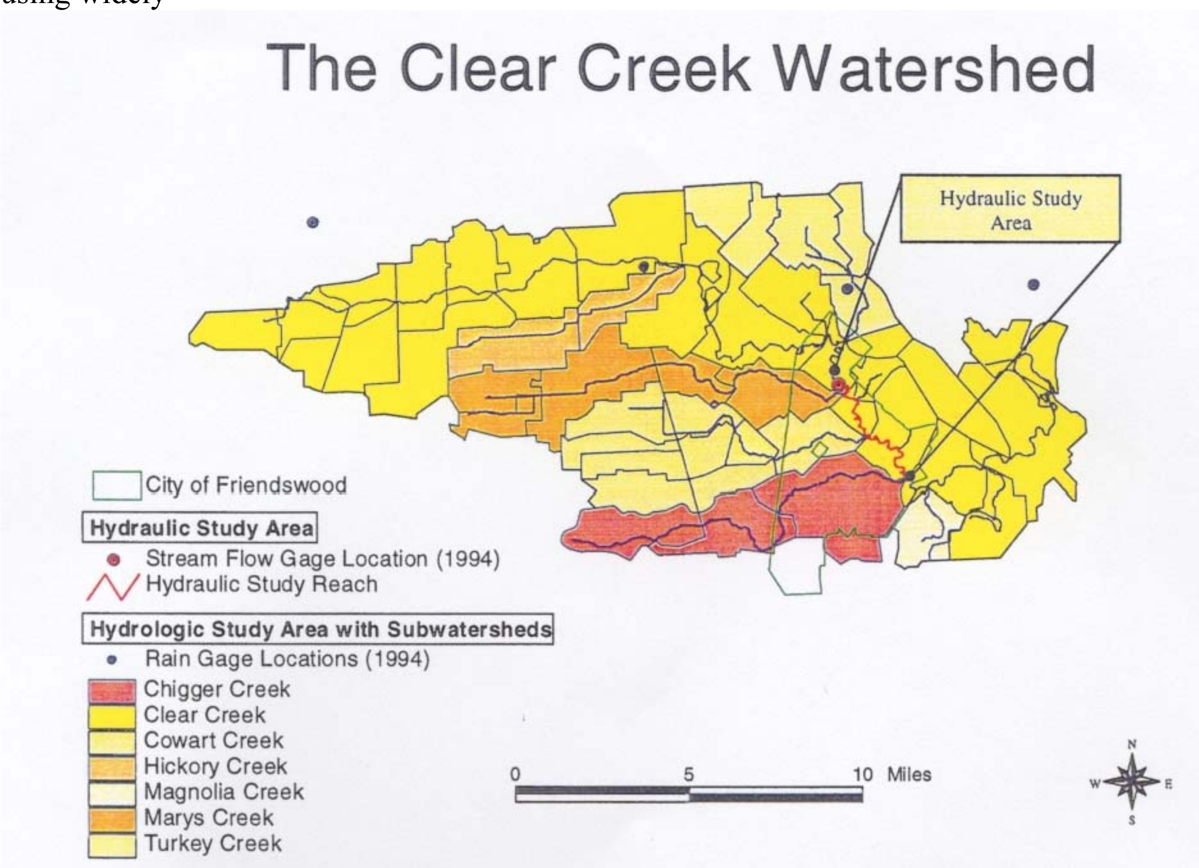

Figure 2: Clear Creek watershed schematic illustrating subwatersheds, tributaries, hydrologic and hydraulic study areas, and the City of Friendswood.

available 10-meter resolution digital elevation models. Fourth, HEC-GeoRAS was used to convert the resulting water surface elevations into specific digital floodplains. Finally, these digital floodplains were then combined with additional GIS data (such as the repetitive loss property information illustrated earlier) to analyze the effectiveness of two general flood control alternatvies including small- scale channelization schemes and floodplain property buyouts.

Next Generation Radar (WSR-88D)

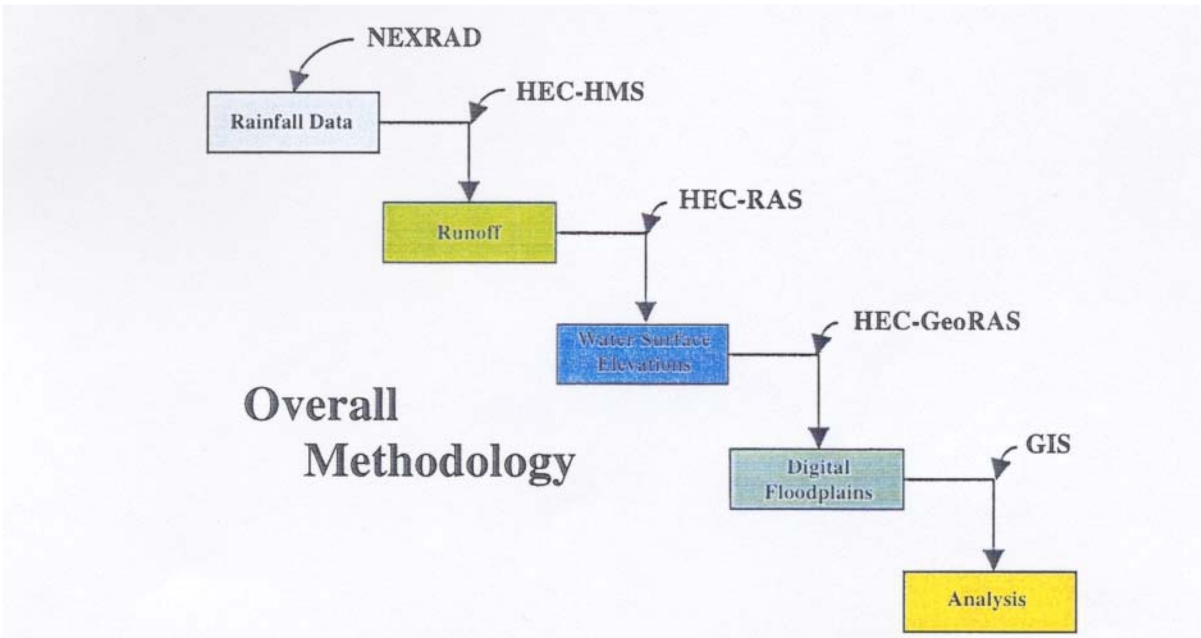

Figure 3: New Technologies and Overall Methodology

There are two primary advantages in applying NEXRAD technology in obtaining rainfall estimates in the Clear Creek watershed. The first is the ability to provide complete, watershed wide coverage. (Bedient et al., 2000) This coverage proves particularly useful in the more poorly monitored, southern portions of the watershed. Raingage coverage for the watershed is illustrated in Figure 2. The second is the ability to permanently store this data in an archived status for future analysis. This feature allowed for the repeated and careful analysis of past storm events such as the one experienced in Clear Creek during the dates of October 14-19`h, 1994. (Vieux and Bedient, 1998)

Perhaps the most important disadvantage of NEXRAD lies in the fact that it provides an estimate of rainfall intensity as opposed to a direct measurement. Attempts to gage-adjust radar rainfall estimates should always be made unless a preliminary hydrologic analysis shows a minimal effect on the hydrographs of interest. (Mimikou and Baltas, 1994) Gage adjustments were not performed for the October 1994 storm event based on excellent matches between the observed and modeled outfall hydrographs. (Vieux and Bedient, 1998)

Both total storm rainfall amounts and rainfall hyetographs were calculated for each subwatershed utilizing NEXRAD and GIS data for the October 1994 storm event over the entire Clear Creek watershed. The resulting data was comparable to results that would have been obtained by 48 individual rain gages spread throughout the watershed, with one rain gage in each particular subwatershed. Rainfall hyetographs were developed at 30-minute intervals to coincide with the modeling time step used in the hydrologic model.

Developing the HEC-HMS Model

The COE's HEC-HMS- is a Windows-based program with significant improvements over its predecessor, HEC-1. HEC-HMS (version 1.0) was released in March of 1998. The latest version, version 2.0.3 released in June of 2000, has eliminated many of the stability problems that plagued the first few releases. Several more versions are expected over the next 5 years, each with additional modeling capabilities. The COE expects HEC-HMS to gradually replace the older, DOS-based HEC-1 within this same timeframe, as fewer COE studies will be initiated utilizing the HEC-1 format.

Various sub-models were created for the Clear Creek HEC-HMS model. The baseline basin model was created by importing an existing HEC-1 formatted hydrologic model of the area, originally developed by the Dannenbaum Engineering Corporation (DEC). The meteorologic models were created by entering design storm criteria and by entering formatted NEXRAD radar data for the October 1994 historical storm (as discussed in the previous section). One control model was created to establish a 30-minute computational time step for all hydrologic calculations. The import feature of the HEC-HMS software sucessfully reformatted the HEC-1 model. A thorough verification of the basin parameter data found no major discrepancies between the two formats. The resulting basin model consisted of 48 subwatersheds, 38 reaches and 7 overflow diversions.

Hydrologic model calibration was performed utilizing the October 1994 storm event and streamflow data from the United States Geological Survey's (USGS) Clear Creek Flow Gage #08077600. The location of the flow gage is illustrated in Figure 2. Observed peak flow for the event was 7518 cfs at 2130 on October 18`h, 1994. This compared well to the modeled peak flow of 7712 cfs at 1930 of the same day, resulting in a 2.6 % flow difference. However, the modeled and observed total storm discharge difference was approximately 18.4%. This significant difference, combined with the convenient location of the stream flow gage relative to the selected hydraulic study region, prompted the use of the observed stream gage data as input to the hydraulic model. This removed any inaccuracies in the hydrologic portion of the study upstream of the gage. However, as can be seen from Figure 2, both Marys Creek and Cowarts Creek drain to the hydraulic study region downstream of the flow gage. Therefore, NEXRAD data and the hydrologic model were used to model the runoff for these two tributaries' respective subwatersheds. Additionally, the hydrologic model of the entire watershed (including the effects of subwatersheds upstream of the gage) would be used for design storm floodplain studies of the 5, 10, 25 and 100-year events in the hydraulic model.

Developing the HEC-RAS Model and Analyzing Channelization Scenarios

The Corps' River Analysis System (RAS) is a Windows-based program that contains an integrated package of hydraulic analysis programs designed to supercede its predecessor, HEC-2. HEC-RAS is nearly identical to HEC-2 computationally, with only a few minor changes.

A new HEC-RAS hydraulic model of a 6.5-mile reach of Clear Creek was successfully created using entirely digital topographic data in a GIS format and the HEC-GeoRas program. All cross-sectional elevation data for profile generation in HEC-RAS were extracted from a Digital Terrain Model (DTM) in a Triangulated Irregular Network (TIN) format. The TIN was created from a 10-meter resolution Digital Elevation Model (DEM). Although 10-meter resolution DEMs are not as widely available as the 30-meter resolution DEMs, previous work in this field shows that the 30-meter resolution DEMs provided insufficient topographic detail for accurate hydraulic results, especially in extremely flat areas. 10-meter DEMs are available, at cost, from several GIS software and data warehouse companies on the internet. Although actual survey data (from an existing HEC-2 model) was available within the channel banks at specific cross-sections, the DTM was purposefully unmodified to determine if acceptable results could be achieved.

Comparisons between the surveyed and DTM data were conducted for every cross-section. Although the elevation data outside the channel banks compared favorably, there were some discrepancies between the data sets for elevation data between the channel banks. However, favorable hydraulic model results were still obtained. This was attributed to the fact that the DTM data often displayed a smooth channel bottom - resulting in DTM elevation points both above and below that indicated by the survey data.

A total of six different geometric data files were created to represent a variety of hydraulic conditions being investigated. These ranged from the baseline bathymetry of the creek as it exists presently to a variety of altered conditions representing proposed channel modifications for flood control. The various scenarios represent attempts to model the effects of a small-scale channelization scheme through the Friendswood, Texas area. The schemes included: two shorter length, straightened channels with 30 meter and 10 meter bottom widths respectively (SC30 and SC10); two longer length, straightened channels with the same 30 meter and 10 meter bottom widths (LC30 and LC 10); the existing channel (baseline); and one 50 meter bottom width, winding channel that followed the existing channel bed (LW50). The short channel scenarios affected the upper 4-mile portion of the studied 6.5-mile natural reach, while the longer channels affected the upper 5.5-mile portion of the study reach. The shorter and winding channel scenarios were developed in an attempt to minimize the impact on riparian forests located at the downstream portion of the study area. Additionally, the relatively narrow bottom channel widths were chosen to minimize impacts on the riparian forest located along the entire hydraulic study reach length.

Results of the hydraulic model revealed that, as expected, only the longer channel scenarios reduced the water surface elevation sufficiently to remove several of the upstream

Table 1: Water Surface Elevations for Various Channelization Schemes

Location	100-Year Design Storm Water Surface Elevations for Proposed Channel Modification Scenarios (meters, MSL)					
	Baseline	LW50	SC30	SC10	LC30	LC10
FM 2351	**7.40**	6.60	6.32	6.42	6.06	6.20
FM 528	**6.29**	5.89	5.98	5.97	5.65	5.70

properties from the 100-year floodplain. Table 1 shows the water surface elevations at two points along the study reach for each of the channelization scenarios. The FM2351 location is at the upstream portion of the reach and near the stream gage. The FM528 location was approximately 3.5 river miles downstream of that location.

Nevertheless, both the LC30 and LC 10 were still ineffective at removing all properties from the residual, post-channelization 100-year floodplain. These remaining properties could now be identified as potential candidates for property buyout if an accurate digital floodplain of both the pre and post-channelization floodplains could be developed. Additionally, calibration of the hydraulic model was still required, and since no accurate high water mark was available for the 1994 historical storm, another method of calibration would be needed.

Using HEC-GeoRAS and GIS for Digital Floodplain Delineation and Scenario Analysis

As is often the case in hydraulic analyses, the lack of an observed high-water mark during a storm event makes the calibration of any hydraulic model a difficult task. While an exact maximum WSE was not known for the October 1994 storm event, the significant number of Repetitive Loss Properties (RLPs) present in the Friendswood area allowed for their use as a general indication of the extent of flooding for any corresponding event. A repetitive loss propety database was obtained for the Friendswood area and geocoded into ArcView. In a similar manner, all properties in the 100-year floodplain (as designated by the latest Flood Insurance Rate Maps (FIRMs) for the area) were identified and geocoded. Additionally, a GIS database of these houses was developed that indicated the number of times each property had flooded, the approximate value of each property, as well as other information easily available from the Federal Emergency Management Agency and county appraisal districts.

As a result, a geospatially correct database was developed that showed the location of the FEMA designated 100-year floodplain properties as well as the location of the RLPs in the Friendswood area. This database provided two calibration opportunities for our hydraulic model. The FEMA properties provided a match goal for our 100-year design storm floodplain while the RPLs claiming flood damages in October of 1994 would serve as a match goal for the historical storm floodplain. Additionally, once the extent of the floodplain for various scenarios was determined, the approximate dollar costs for floodplain property buyouts could be calculated.

HEC-GeoRAS is an ArcView extension which includes a designed set of procedures, tools and utilities for the processing of geospatial data for use with HEC-RAS, linking the data development and display capabilities of a GIS with a powerful hydraulic modeling program. The extension allows users to create a HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DTM) and selected complementary data sets such as river reaches, right and left overbanks and others. It should be noted that HEC-GeoRAS does not generate hydraulic structures such as bridges and culverts. These must be entered into the hydraulic model separately. Post-hydraulic analysis results generated by HEC-RAS can then be exported back to HEC-GeoRAS and converted to a GIS format for spatial analysis and floodplain mapping. Two additional ArcView extension, Spatial Analyst and 3-D Analyst, are required to achieve the full functionality of the Geo-RAS extension.

HEC-GeoRAS and the previously discussed DTM of the area were used in conjunction with the water surface elevations generated by HEC-RAS to develop digital floodplains. Floodplains were developed for a variety of scenarios including the existing (pre-channelization) 5, 10, 25, and 100-year floodplains, the October 1994 event floodplain, and those resulting from the channelization scenarios discussed earlier. This allowed for calibration of the hydraulic model as discussed above.

An analysis of various flood control options was now possible. Three different scenarios were investigated. The first involved determining the costs for buyout of all properties for each of the design storms analyzed. Table 2 shows the number of properties identified in each of the modeled design storm floodplains and the FIRM 100-year floodplain. The cost for buyout of all of these houses is also shown.

Table 2: Calculated Dollar Costs for Conducting Complete Property Buyouts for the Corresponding Design Flooplain

Floodplain	Number of Properties in Floodplain	Cost for Complete Buyout (Millions of Dollars)
FEMA 100-Year	274	35.2
Modeled 100-Year	262	35.0
Modeled 25-Year	138	19.0
Modeled 10-Year	87	12.2
Modeled 5-year	39	4.9

The second scenario was to rely completely on the channelization schemes. However, as mentioned earlier, given the imposed limit on bottom channel width and channel slopes, none of the scenarios investigated completely alleviated flooding. Therefore, a third scenario was created which combined the channelization schemes LC30 and LC 10 with buyouts of the properties in the residual floodplain.

Figure 4 (included at the end of this report) shows a sample HEC-GeoRAS digital floodplain in ArcView. A significant amount of information is contained in the illustration. The background map is a 1-meter resolution Digital Orthophoto Quarter Quadrangle (DOQQ), which aided in the accurate location of the floodplain properties. The figure also illustrates the effect of the LC30 channel improvement scenario on the modeled 100-year floodplain. The property database is geospatially represented and those properties in both the pre and post-channelization floodplain can be identified. ArcView allowed for the automatic calculation of the number of residual floodplain properties as well as for the cost of buyout of these homes. Lastly, the channel right-of-way and straightening is illustrated along with the original winding creek bed.

An economic comparison of the various channelization scenarios was not completed in time for this report but is possible given the information collected. Work remaining to be done includes a full discussion of the propagation of error associated with this type of analysis as well as accurate cost estimates for constructing the various channels. Once this is completed, it should be possible to conduct a benefit-cost analysis of each scenario.

Conclusions

The latest HEC modeling programs, NEXRAD, and recently available GIS software such as HEC-GeoRAS have been effectively combined to begin addressing the flooding problems in the Clear Creek watershed using widely available digital data. Various channelization schemes and floodplain property buyout plans were modeled and analyzed. Preliminary results indicate that combining small scale channelization with floodplain property buyouts serves as an effective flood control alternative while minimizing the drastic environmental impacts associated with large scale channelization schemes. This novel, combined approach has permitted an accurate enough analysis to allow for the identification and quantification of individual properties in the floodplain. Although not currently a watershed-wide solution to flooding, the same approach can be implemented at other reaches along Clear Creek where flooding is extensive, given that the digital data used in this study is available for the entire watershed. As the digital data (DEMs, DOQQs, etc.) used in this study become available at greater resolution and lower cost, this type of approach promises to become even more feasible. Further studies should include an analysis of error and its propagation through the various processes discussed in the approach.

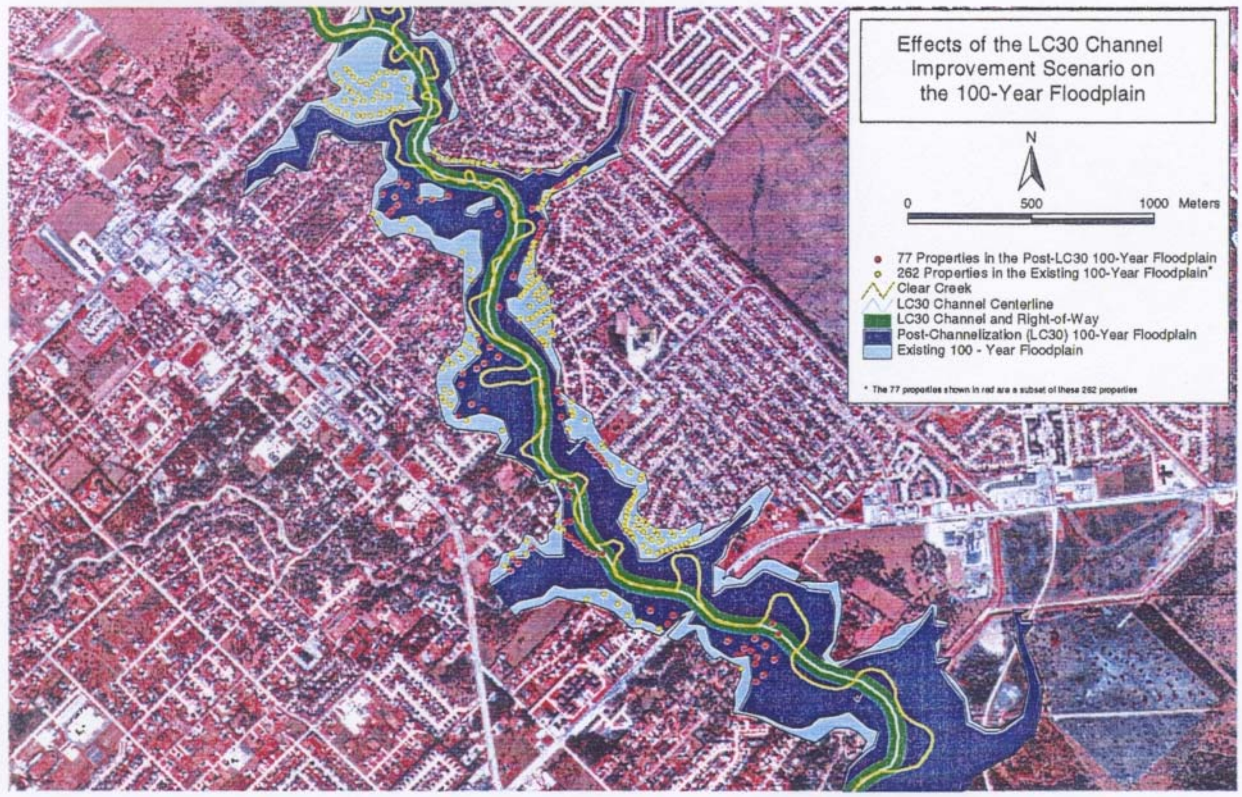

Figure 4: ArcView image displaying the hydraulic study area along with the combined LC30 channel and property buyout flood control scenario

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