High Water Mark Data Collection for El Paso County and Incorporated Communities, Texas

FEMA-1658-DR
FEMA IDIQ Contract
EMT-2002-CO-0052
Task Order J030

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Disaster Response Flood Recovery Data
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February 23, 2007

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ABBREVIATIONS AND ACRONYMS

Acronym	Definition
FEMA	Federal Emergency Management Agency
DFIRM	Digital Flood Insurance Rate Map
GPS	Global Positioning System
HMGP	Hazard Mitigation Grant Program
HWM	High Water Mark
HWM ID	High Water Mark Identification Number
KELP	El Paso International Airport
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
QA	Quality Assurance
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

GLOSSARY OF TERMS

Term	Definition
Debris Line	Defines the extent of flooding where debris such as parts of houses, docks, cars, or other non-natural materials are carried by flood waters with some velocity and then dropped as the flood waters lose velocity and begin to recede.
Disaster Declaration	The formal action by the President that makes a State eligible for major disaster or emergency assistance under the Stafford Act.
Flagging	Marking or otherwise documenting the horizontal and vertical location of a high water mark so that the high water mark data are preserved for future surveying. This information will then be available even if the homeowner cleans the property or it rains and therefore eliminates the visible high water mark.
Hazard Mitigation Grant Program	A FEMA program that provides grants to States and local government to implement long-term hazard mitigation measures after a major disaster declaration. The program may be used to fund projects that will reduce or eliminate losses from future disasters by providing a long-term solution to a problem.
High Water	The maximum elevation that flood waters reach as a result of a storm event.
High Water Mark	A physical mark, such as a mud line, that designates the location and elevation of flood waters from a storm event.
Individual Assistance	Federal assistance provided to families or individuals following a major disaster or emergency declaration, which includes cash grants for housing (hotel or motel expenses reimbursement, rental assistance, home repair and replacement cash grants, and permanent housing construction assistance in rare circumstances) and other needs (medical, dental, and funeral costs; transportation costs; and other disaster-related needs).
Mitigation	Any measure that reduces or eliminates the long-term risk to life and property from a disaster event.
North American Datum of 1983	Used as the standard map horizontal coordinate system default by the majority of GPS devices.

Term	Definition
North American Vertical Datum of 1988	The most widely used vertical control datum in the U.S. today. It was established by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations. The general adjustment of NAVD 88 was completed in June 1991.
Point	A point associated with a discrete geographic location where data pertaining to the study were taken.
Public Assistance	Federal assistance provided to state and local governments, Native American tribes, and certain non-profit organizations after a disaster declaration. Public Assistance includes supplemental Federal disaster grant assistance for the repair, replacement, or restoration of disaster-damaged publicly owned facilities and the facilities of certain private non-profit organizations. This includes emergency work and permanent work.
Water Mark	A mark, usually on structures, left by flood waters.

EXECUTIVE SUMMARY

A high water mark (HWM) study was conducted for El Paso County and Incorporated Communities in Texas following the severe flooding from July 31 through August 4, 2006. This study is part of the Federal Emergency Management Agency (FEMA) Task Order J030, which was contacted to MAPVI. MAPVI is a joint venture partnership with URS Corporation acting as the managing partner.

The purpose of this study was to record the maximum water elevations, or HWMs, resulting from the flooding events. Collecting HWM data not only documents the event, but also provides necessary data for flood risk assessment, hazard mitigation, flood delineation, and flood frequency determination. These studies can enable decision-makers to improve disaster preparedness and limit future disaster impact.

The United States Geological Survey (USGS) recorded data on HWMs immediately after the flooding. A total of 45 HWMs were investigated and surveyed by the USGS in Sparks Arroyo (east of Socorro near I-10) and on the Fort Bliss Military Reservation. The majority of the Sparks Arroyo HWMs were debris lines located on August 5 and surveyed on August 6. Debris lines both inside and outside of detention ponds on the Fort Bliss Military Reservation provided HWMs, which were located on August 1 through August 5 and surveyed on August 4 and 5. The USGS survey team used a Real-Time Kinematic Global Positioning System (RTK GPS) base and rover to survey the HWMs.

URS investigated and flagged 7 HWMs on December 12, 2006. Although HWMs weather away quickly after a flood, they can be found months later in protected areas such as inside a building. Distinct mud lines were found inside abandoned residential homes in the City of El Paso in the Fiesta district (near the intersection of North Mesa Street and Thunderbird Drive) and the Mowad district at the northwest edge of the city (near the intersection of Doniphan Drive and Mowad Road). On December 13, a URS survey crew surveyed the flagged HWMs using a combination of a RTK GPS base station and conventional survey methods. The HWMs were surveyed to the accuracy of 0.25 foot vertically and 10 feet horizontally with a 95% confidence level.

HWMs were only identified in four local areas by the USGS and URS. Therefore, to broaden the study, photographs were acquired that had been taken both during and after the flooding. These photographs, which were received from a number of individuals, displayed flood water levels across the county. Although precise flood water levels cannot be taken from the photos, water elevations can be approximated based on the images for additional flood studies.

The HWM data collected for this study show the severity of the 2006 summer flooding. This study provides communities with accurate information about the flood event to assist in their recovery and mitigation efforts. Valuable data become available when a flood of this magnitude occurs. Collecting this information enables communities to reassess flood risk and ensure that the rebuilding process will protect properties from future flooding disasters.

1. INTRODUCTION

This report documents a high water mark (HWM) study conducted in El Paso County and Incorporated Communities, Texas, following the severe flooding that occurred during the period from July 31 through August 4, 2006. The study is part of the Federal Emergency Management Agency (FEMA) Task Order J030 to develop countywide flood recovery data for El Paso County and Incorporated Communities. The FEMA task order was contracted to MAPVI in response to the August 15, 2006, El Paso County Disaster Declaration FEMA-1658-DR. MAPVI is a joint venture partnership comprised of URS Corporation, Greenhorne & O'Mara, and Spectrum Mapping, with URS acting as the managing partner. URS conducted the El Paso HWM study, which included field surveys and compiling data from the United States Geological Survey (USGS), United States Army Corps of Engineers (USACE), City of El Paso, and El Paso County.

High water marks are indicators left behind by flood waters showing the maximum elevation reached by the water during a flood event. The purpose of this study is to record these high water marks and document information relating to the flooding event. This report includes a description of the storm conditions, a summary of the disaster declaration, and the methodology and results of the HWM study. Collecting HWM data documents the event and provides the necessary data for additional studies, such as flood risk assessment, hazard mitigation, flood delineation, and flood frequency determination. Communities and governments in turn can use the flood elevations and results of the studies to improve disaster preparedness and limit the impact of future disasters.

1.1 Background

An unusual weather pattern during the summer of 2006 led to the severe flooding across El Paso County. According to the National Weather Service, an upper level low pressure system formed and remained over southern New Mexico and far west Texas from July 27 through August 4. This is a very rare event to occur over the area during the July and August monsoon season. The low-pressure system caused an inflow of very moist saturated air from Mexico to converge over the region for a prolonged period of time. One thunderstorm after another formed and slowly moved over the area, dropping excessive precipitation repeatedly over the same saturated ground.[1]

Thunderstorm activity enhanced considerably as the storms moved near and over the Franklin Mountains. This produced not only extremely heavy rainfall but torrential runoff from the mountains. In the city, the northwest and central regions sustained the worst flooding damage.[2] The excessive runoff poured down city streets, undercut building foundations, and overtopped drainage structures. The Rio Grande reached its highest level since 1912, completely filling its channel and even breaching its banks in

[1] "Federal Flood Assessment Conference, Recommendations and Proceedings, September 6, 2006;" Convened by Congressman Silvestre Reyes, Organized by Peter Brock, Edited by Dr. Ari Michelsen.
[2] "Flood Report: Floods of 1 Aug, 4 Aug & 13 Sep 2006, Sparks Arroyo, Horizon City, Basin A, Socorro & Clint, TX;" Department of the Army, Albuquerque District, Corps of Engineers; September 2006.

Sunland Park, New Mexico, and Juarez, Mexico.[3] With the Rio Grande filled to capacity, water coming down from the arroyos backed up and overtopped the arroyo banks, causing additional flooding. The prolonged rain event persisted for several days and poured rain down on some areas more than once, adding to the flooding problem.

The magnitude of the rainfall events was unusual for this area. The National Weather Service Weather Station at the El Paso International Airport (KELP) officially received 6.84 inches of rain during a 9-day period, from July 27 to August 4. This equates to 73% of the annual average of 9.43 inches. Table 1 shows a summary of the rain recorded at KELP for the four major storm events that occurred during the period from July 31 to August 4. Unofficially, some sites around the area received 7 to 10 inches of rain in a 48-hour period, which amounts to nearly a year's worth of rain in 2 days. Some unofficial sites received nearly 15 inches of rain during the week of July 31.[4] These unofficial sites typically are rain gauge locations maintained by local citizens and business owners. KELP officially recorded 12.11 inches of rain in 60 days from July 5 through September 3. The last time a storm event of this magnitude occurred was July 9, 1881, when 6.5 inches of rain fell at the official measuring site downtown.[5]

Table 1. Major Rainfall Events Recorded at El Paso International Airport

Day	Rainfall (inches)	Duration (hours)
7/31/2006	0.62	3
8/1/2006	2.84	15
8/3/2006	1.14	6
8/4/2006	0.95	4

The torrential rainfall caused widespread destruction to property across El Paso County and Incorporated Communities. The devastating flooding and mudslides displaced families by destroying an estimated 300 homes.[4] The rains flooded homes and building, damaged property and infrastructure, and washed vehicles away. Many roads were washed out while others were closed for hours, including Interstate 10, leaving the El Paso vicinity literally cut off.[3] The disaster was more than the local and state governments could handle alone.

1.2 Declaration of Disaster

On August 15, 2006, President George W. Bush issued a major disaster declaration, under the authority of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), for damage in certain areas of Texas resulting from the flooding beginning on July 31, 2006.[6] The declaration provides the necessary federal funding

[3] Southwest Weather Bulletin, Autumn-Winter 2006-2007 Edition; National Weather Service.
[4] Press Release; Texas Department of Housing and Community Affairs; October 12, 2006.
[5] "Federal Flood Assessment Conference, Recommendations and Proceedings, September 6, 2006;" Convened by Congressman Silvestre Reyes, Organized by Peter Brock, Edited by Dr. Ari Michelsen.
[6] http://www.fema.gov/news/dfrn.fema?id=6586

assistance to help recover from the disaster as quickly as possible. The Texas counties that were designated for Disaster Declaration FEMA-1658-DR, as of August 28, 2006, are shown in Figure 1 on the following page.

Federal assistance, including Individual Assistance, Public Assistance, and the Hazard Mitigation Grant Program, is available to counties as they are listed in the original declaration and subsequent amendments. The declared counties and levels of assistance as of the last update shown on the FEMA website on September 1, 2006, are described in Table 2.[7]

Table 2. Federal Assistance for Declared Counties

Federal Assistance	Declared Counties
Individual Assistance Assistance to individuals and households:	El Paso County
Public Assistance Assistance to State and local governments and certain private nonprofit organizations for emergency work and the repair or replacement of disaster-damaged facilities:	El Paso and Hudspeth County
Hazard Mitigation Grant Program (HMGP) Assistance to State and local governments and certain private nonprofit organizations for actions taken to prevent or reduce long term risk to life and property from natural hazards:	All counties in the State of Texas are eligible to apply for assistance under the Hazard Mitigation Grant Program.
Other:	Additional designations may be made at a later date after further evaluation.

1.3 Task Objectives and Scope of Work

As part of the disaster response, FEMA contracted MAPVI under Task Order J030 to develop flood recovery data for El Paso County and Incorporated Communities. The objective of the task is to provide communities with accurate information about the flood event to assist in their recovery and mitigation efforts. When a flood occurs, valuable data become available that enable communities to reassess estimates of flood risk. Updated flood risk data are necessary to ensure that the rebuilding process will protect properties from future flooding disasters. Tools, such as flood recovery maps, produced from the new data also assist communities in planning and managing rebuilding efforts.

[7] http://www.fema.gov/news/eventcounties.fema?id=6825

FEMA-1658-DR, Texas
Disaster Declaration as of 08/28/2006

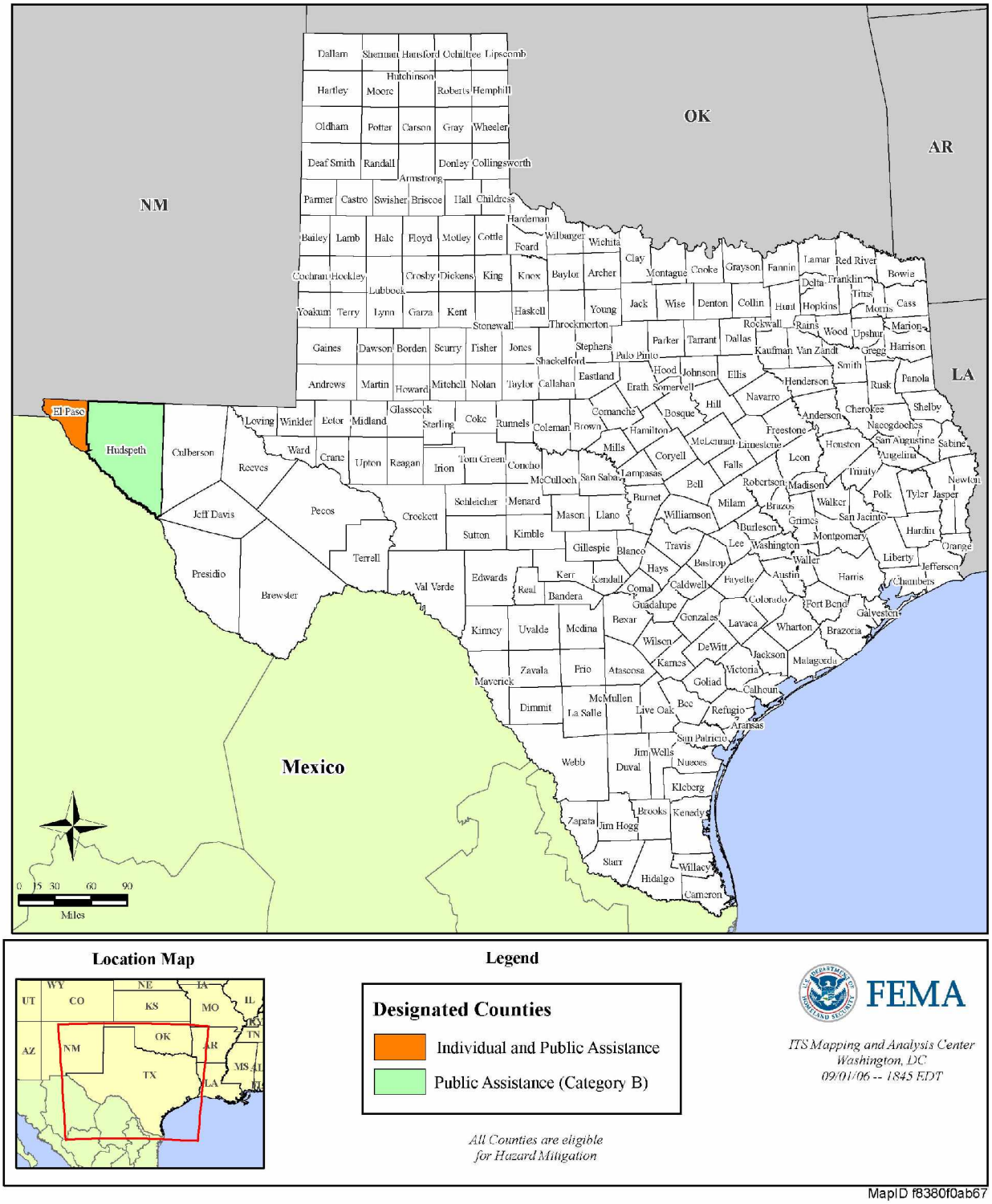

Figure 1. Disaster Declaration Map

The FEMA Task Order J030 requires the collection of high water marks, field reconnaissance of flooding sources, flood frequency determination, and the development of flood recovery tools. URS conducted the HWM study, and this report was developed as a result of the collection of high water marks. HWM data collection is an important initial step in documenting the event and providing the necessary data for flood risk assessment, recovery, and mitigation.

The scope of work for HWM data collection requires: obtaining information about the flood event, contacting agencies performing similar studies, determining areas in need of HWM data, flagging and surveying HWMs in the field, and summarizing the data for publication. Information about the flood event is collected through research and interviews with local officials and residents. During this time, various agencies are also contacted to determine if other HWM studies have been performed to incorporate their data and prevent duplicate efforts.

Areas in need of HWM data collection are established through coordination with federal, state, and local officials. An initial overview and assessment of the flooding is used to identify flooding sources and stream reaches that experienced flooding. In general, HWMs are collected in areas where severe flooding occurred. Particular emphasis is placed on areas that experienced record or near-record flooding and where buildings, infrastructure, or agricultural lands were damaged.

After determining the HWM areas, field teams are assembled to locate, flag, and survey the HWMs. For each HWM, pictures and detailed notes are taken to preserve the information surrounding each mark. These notes include the date, location, feature description, flooding source, flood zone designation, HWM type and quality, survey date, survey coordinates, and survey accuracy. The HWM locations are surveyed using GPS and/or conventional methods. The flood event data, HWM information, and survey locations are then summarized into a report to document the study.

2. METHODOLOGY

The area identified for the HWM study is El Paso County and Incorporated Communities. MapVI received the notice to proceed on November 14, 2006. At this time, URS contacted various government agencies to determine heavily flooded areas with the potential for high water marks. These agencies were also asked whether similar studies had been performed to prevent overlap and allow data sharing.

The USGS indicated they had collected HWMs in two locations. They surveyed high water marks and cross sections in Sparks Arroyo (east of Socorro near I-10) following the flooding on August 4, 2006. The USACE used the USGS data at Sparks Arroyo to help develop a post-flood assessment report for its flood control projects. The USGS also surveyed high water marks at detention ponds on the Fort Bliss Military Reservation during and after the flooding from August 1 through August 4, 2006. Fort Bliss personnel used the data to determine the effectiveness of their detention ponds. The

HWM data collected by the USGS are included near the end of this report in Tables 4 and 5. Maps of the HWMs surveyed by the USGS are shown in Appendix A, and photos of the Sparks Arroyo study are displayed in Appendix C. No photos were provided for the Fort Bliss study.

URS concentrated their efforts outside of the USGS coverage to prevent HWM data duplication. After interviewing local officials, URS collected HWMs in two locations. URS surveyed HWMs inside abandoned homes in the Fiesta district in the City of El Paso (near the intersection of North Mesa Street and Thunderbird Drive). URS also surveyed HWMs in and around abandoned homes in the Mowad district at the northwest edge of the City of El Paso (near the intersection of Doniphan Drive and Mowad Road). The HWM data collected by URS are included near the end of this report in Table 6. Maps of the HWMs surveyed by URS are shown in Appendix A, and the collection form and datasheets are presented in Appendix B. Photos of the Fiesta and Mowad district study are displayed in Appendix D. The following sections describe in detail the method and equipment used by both the USGS and URS.

2.1 USGS Methodology

The USGS flagged and surveyed HWMs in Sparks Arroyo and on the Fort Bliss Military Reservation. At both locations, the USGS team flagged HWMs from the August 1 and August 4 flood events; however, the August 4 event cleared most of the August 1 high water marks. The USGS crew then surveyed the HWMs using the same Global Positioning System (GPS) equipment at both locations. The USGS methodology at each site is described below. As a note, URS is not responsible for the accuracy of the USGS data.

Sparks Arroyo

According to the USGS unpublished Sparks Arroyo report prepared on August 22, 2006, a four-person team surveyed a reach starting approximately 1,150 feet upstream of the intersection of Sparks Arroyo and Interstate-10 and ending approximately 7,150 feet upstream of their starting point. The four-person team flagged HWMs on August 4 from the August 1 flood event. On the evening of August 4, another flood event occurred in the Sparks Arroyo drainage area, causing the initial HWMs to be destroyed.

Each flood event caused the channel to become wider and shallower. The HWMs from the August 4 event were physically higher in elevation than those from the August 1 event. This is possibly due to a larger flood event on August 4. However, the channel geometry changed significantly as the channel is primarily sand with minimal vegetation. Therefore, the higher elevation HWMs from the August 4 event may not necessarily represent a higher peak discharge. HWMs were located again on August 5 and surveyed in on August 6.

HWMs in Sparks Arroyo were difficult to find due to its sandy channels (see photos in Appendix C). In the downstream half of the reach, fair to poor quality HWMs were

found on both banks of the channel. In the upstream half of the reach, the channel widens and debris lines were found. The majority of the HWMs flagged were debris lines in this upper section. The USGS flagged and surveyed twenty-four HWMs in Sparks Arroyo (see Figure A-2).

On August 6, the same USGS team surveyed their HWMs in Sparks Arroyo using a Trimble Real-Time Kinematic 5800 series GPS base and rover system. The GPS base station was set up on a known National Geodetic Survey (NGS) benchmark, while the rover was positioned at each HWM location to record an accurate coordinate position and elevation. The data points were surveyed horizontally in the North American Datum of 1983 (NAD 83), Universal Transverse Mercator (UTM) Zone 13, and vertically in the North American Vertical Datum of 1988 (NAVD 88), both in meters. The survey points were also converted to latitude and longitude coordinates using Corpscon Version 6.0.1 to provide consistency with the HWMs obtained by URS. Their elevations were converted to U.S. Survey Feet to also coincide with the URS HWMs.

Fort Bliss

According to an interview with the USGS, Fort Bliss personnel marked areas on a map they wanted investigated for HWMs. These areas included detention ponds and areas that experienced ponding outside of detention ponds. Fort Bliss personnel wanted to document the maximum height reach by the flood water in the detention ponds and in unexpected ponding areas.

A local USGS employee started flagging HWMs on August 1, after the August 1 flood event, and continued flagging intermittently through August 4 during the prolonged flood events. On August 4, the Sparks Arroyo USGS field crew met up with the local USGS employee in Fort Bliss to survey previously flagged HWMs and flag additional marks. The USGS crew was rained out that afternoon and collected the rest of the HWMs on August 5. The HWMs flagged in Fort Bliss were primarily debris lines that ranged from good to poor quality.

The USGS team surveyed the flagged Fort Bliss HWMs on August 4 and August 5. If more than one HWM was flagged at the same location, the highest water mark was surveyed. This occurred when a successive flood event rose above a previously flagged HWM and created a new mark. The USGS team surveyed the Fort Bliss HWMs using the same equipment used in Sparks Arroyo, which is a Trimble Real-Time Kinematic 5800 series GPS base and rover system. The base station was set up on a known NGS benchmark, while the rover was positioned at each HWM location to record an accurate coordinate position and elevation. Occasionally, when the rover did not receive a good signal from the base, a fast static method was used. This method involves taking the base station off the known point and placing it at the HWM to record the coordinate location. To maintain the coordinate accuracy, extra post processing was performed on these points.

The USGS surveyed twenty-one HWMs on the Fort Bliss Military Reservation (see Figure A-3). The data points were surveyed horizontally in the North American Datum of 1983 (NAD 83), Universal Transverse Mercator (UTM) Zone 13, and vertically in the North American Vertical Datum of 1988 (NAVD 88), both in meters. The survey points were also converted to latitude and longitude coordinates using Corpscon Version 6.0.1 to provide consistency with the HWMs obtained by URS. Their elevations were converted to U.S. Survey Feet to also coincide with the URS HWMs.

2.2 URS Methodology

On December 11, 2006, URS deployed a two-man crew to investigate and flag any remaining HWMs in El Paso. Upon arrival, the crew met and interviewed city and county personnel to collect available information about the summer flooding. During the interview, the local officials noted heavily flooded areas to help limit the search for high water marks. Photos were also provided to document local flooding and help estimate flood water levels in these areas (see Appendices E and F). Using this information, the crew proceeded into the field to search for HWMs.

The flagging team visited sites throughout the county that experienced severe flooding. At each site, they checked for high water marks on both natural features and man-made structures but focused their attention on abandoned buildings. High water marks weather away quickly after a flood, but if protected from the elements inside a building, can still be found months later. As a note, the elevation of HWMs outside the house may be higher than elevations of HWMs inside the house. This effect may be due to either higher wave energy outside the house than inside or water levels outside not equalizing with water levels inside before flood waters recede.

On December 12, the flagging crew collected seven high water marks inside or just outside of abandoned residential homes. Two high water marks were recorded in the Fiesta district (near the intersection of North Mesa Street and Thunderbird Drive), and five high water marks were recorded in the Mowad district (near the intersection of Doniphan Drive and Mowad Road). All seven of these high water marks were obvious mud lines left behind by the flood waters.

The Fiesta district had three condemned homes, and high water marks were recorded in two of the homes that had the most distinct mud lines (see Figure A-4). The Mowad district had forty-four damaged and condemned homes, but to sample the area, high water marks were recorded from five homes showing distinct mud lines (see Figure A-5). For each chosen building, the HWM was determined by locating an obvious mud line or a supporting group of mud lines. The flagging mark was then left in a location that would allow for easy location and survey.

For each HWM, the flaggers filled out a datasheet with detailed information about the data point, as shown in Appendix B. This information included data, such as flooding source, structure address, and HWM type and quality. As displayed in Appendix D, the

flagging team also took several digital photos of each HWM documenting the data point, mud line, and structure.

On December 13, a three-man URS survey crew met and followed the flagging team to survey the HWMs located earlier. The HWM locations would not support direct GPS observations inside the buildings, since GPS equipment requires a clear view of the sky to obtain satellite information. Therefore, the survey crew used a combination of static GPS and conventional survey methods to determine an accurate coordinate position and elevation for each HWM. The survey crew used a Trimble Real-Time Kinematic 5700-5800 series GPS base station to set control points outside of the residential homes. Then conventional survey techniques referenced off the GPS control points were used to survey the HWM inside the home or under an overhang. The GPS control points were later tied into known benchmarks provided by El Paso County. The first floor elevation, or lowest adjacent grade (LAG), next to the HWM was also surveyed for each residential structure. This information was obtained to determine the structure elevation for possible later damage assessments, FEMA studies, or flood insurance needs. The survey information was recorded on the bottom of the same datasheet used earlier by the flagging crew, as shown in Appendix B, page B-1.

The HWMs collected by URS were surveyed horizontally in the North American Datum of 1983 (NAD 83), State Plane Texas Central (FIPS 42003), and vertically in the North American Vertical Datum of 1988 (NAVD 88), both in U.S. Survey Feet. The HWM points were surveyed to the accuracy of 0.25 foot vertically and 10 feet horizontally with a 95% confidence level. The survey points were also converted to latitude and longitude coordinates using Corpscon version 6.0.1 to provide consistency with the HWMs obtained from the USGS.

2.3 Quality Assurance

URS reviewed the HWM data collected for quality assurance (QA). The QA process involved examining the data from URS field datasheets and verifying surveyed elevations. The data taken from the datasheets and typed into a database were verified and checked for proper entry. The flood zone designation noted on the datasheets was verified by mapping the HWM locations on the most current FEMA Digital Flood Insurance Rate Maps (DFIRMs). URS survey elevations were checked for reasonableness by mapping them against 2005 Texas Department of Transportation 3-foot contours.

3. RESULTS

The HWM data collected for this study show the severity of the El Paso summer flooding, even months after the events. Although the limited number HWM data points collected in localized areas do not provide a broad coverage across the county, the additional information and photos shown in the proceeding Appendices provide good estimates of flood water levels for documentation and additional studies. The HWMs

that were flagged and surveyed give an accurate record of the flood elevations in those localized areas. Table 3 shows the number of HWMs surveyed across El Paso County.

Table 3. URS and USGS Surveyed HWMs

Team	General HWM Location	Number of HWMs Surveyed
URS	Fiesta District	2
URS	Mowad District	5
USGS	Sparks Arroyo	24
USGS	Fort Bliss	21
Total		**52**

3.1 Chronicle of Flooding Events

The information collected at the four HWM locations noted above describes flood events in four separate areas. A summary of each event, based on the information gathered during the HWM study, is explained below.

According to a local official, the Fiesta district flooding appeared to be caused by the drainage canal not being able to contain the immense volume of water rushing down from higher elevations.[8] The runoff from the mountains and local streets converged, overtopped the drainage canal by a few feet, undercut the foundation to a Blockbuster store near the intersection of North Mesa Street and Thunderbird Drive, and slammed into the two houses downhill from the video store. The velocity of the flood water could be seen by the large cobbles, great sediment load, tipped trees, and mangled fence metal. The flood water left distinct mud lines about 3.5 feet up on the walls in the two homes where HWMs were surveyed.

The Mowad district flooding was caused by flood waters overtopping the banks of the adjacent arroyo. According to a local official, flood water flowing down the arroyo was prevented from draining into the Rio Grande, which was filled to capacity from the excessive rainfall. The water in the arroyo backed up and rose until it poured over the channel banks into the low-lying district.[8] Water flooded homes leaving mud lines up to about four feet inside houses. In the district, the land slopes down about three feet from the east to the west. This was clearly represented by the HWMs left in the homes. The flood waters left distinct mud lines about one foot up on the walls of homes to the east, while homes in the west had mud lines about four feet up on their walls. The water destroyed nearly everything inside the homes.

The Sparks Arroyo flooding caused significant changes in the geometry of the arroyo channel. Sparks Arroyo changed dramatically from each flood event due to the highly erosive and depositional nature of its sandy channel. Local residents informed the USGS

[8] Phone interview; The City of El Paso, Texas; December 12, 2006.

team that prior to the August 1 flood event Sparks Arroyo was approximately 10 feet wide and 8-10 feet deep. After the August 1 event, the channel was approximately 50 feet wide and 4-6 feet deep, and after the August 4 event, the channel was approximately 70 feet wide and 3-5 feet deep. The structural integrity of fences and some homes next to the arroyo were compromised after the August 4 flood event.[9]

The HWMs surveyed on the Fort Bliss Military Reservation noted the extremely elevated water levels in the detention ponds and on the grounds. Flood waters pouring off the reservation lands from the excessive rainfall emptied into detention ponds and filled them to the highest levels ever seen. Flood water rose up on the banks of the detention ponds and filled them to a capacity more than intended. The detention ponds worked properly, however, as water never overtopped any roads. A dam nearby was in danger of failing but ultimately held back the extremely large volume of water behind it. HWMs were recorded to note the maximum capacities these engineering structures have ever withstood. Outside of these structures, flood water collected in areas never designed as ponding locations. HWMs were also recorded in these areas to note the location and elevation of the ponded water.[9]

3.2 High Water Mark Data Collected

The HWM data collected for this study document the separate flood elevations that occurred in the four localized areas noted above in Table 3. The data collected by the USGS and URS are discussed below and summarized in the tables and appendices that follow.

3.2.1 *USGS Data Collected*

The USGS flagged and surveyed HWMs in Sparks Arroyo and on the Fort Bliss Military Reservation, which are shown graphically in Appendix A. The USGS flagged HWMs immediately after the flooding. The flagging team was rained out at both locations on August 4 and had to re-flag areas the following day. The team re-flagged areas in Sparks Arroyo after the seemingly larger August 4 flood event removed the previously flagged HWMs. In Fort Bliss, the team re-flagged areas after the new flood event raised the water in the detention ponds to a higher level. The HWMs were based off the flaggers' best judgment of the height of the flood water. During the Sparks Arroyo HWM study, photos were taken and are displayed in Appendix C. These photos were tied back to their respective HWMs by comparing a handheld GPS coordinate (noted in a USGS photo presentation) with the survey coordinates listed in Table 4 below. Therefore, these photos may or may not represent the HWM described in the caption underlying each picture.

After the flood events, the same flagging team surveyed in the flagged locations. The USGS HWM survey data are stored in a digital database. The Sparks Arroyo HWM

[9] Phone interview; U.S. Geological Survey; January 26, 2007.

survey data are presented in Table 4, and the Fort Bliss HWM survey data are shown in Table 5. High water marks are listed in the tables with unique point identifiers (HWM ID).

Table 4 contains the USGS HWM survey data for Sparks Arroyo. The HWM ID numbers generally increase from downstream to upstream. The data is sorted by the HWM ID value for reference convenience.

Table 4. USGS Sparks Arroyo HWM Survey Data Summary

HWM ID	Survey Latitude	Survey Longitude	Elevation (feet) NAVD 88
USGS_SA_1	31.671183	-106.244556	3777.6
USGS_SA_2	31.671222	-106.244478	3778.1
USGS_SA_3	31.671551	-106.244109	3780.9
USGS_SA_4	31.672246	-106.241589	3800.0
USGS_SA_5	31.672722	-106.239357	3814.5
USGS_SA_6	31.673752	-106.238561	3820.5
USGS_SA_7	31.673816	-106.238455	3821.4
USGS_SA_8	31.676452	-106.234810	3846.6
USGS_SA_9	31.678054	-106.232963	3860.7
USGS_SA_10	31.678445	-106.232756	3861.5
USGS_SA_11	31.679050	-106.231698	3869.3
USGS_SA_12	31.679476	-106.231665	3869.2
USGS_SA_13	31.679831	-106.231187	3872.4
USGS_SA_14	31.679847	-106.230639	3874.6
USGS_SA_15	31.680023	-106.230536	3875.6
USGS_SA_16	31.680201	-106.230426	3876.7
USGS_SA_17	31.680460	-106.230507	3876.1
USGS_SA_18	31.680366	-106.230284	3877.2
USGS_SA_19	31.680783	-106.229627	3881.5
USGS_SA_20	31.681175	-106.229543	3883.7
USGS_SA_21	31.681346	-106.227857	3889.8
USGS_SA_22	31.681783	-106.227154	3894.1
USGS_SA_23	31.682303	-106.226744	3896.7
USGS_SA_24	31.682415	-106.226651	3897.2

Table 5 contains the USGS HWM survey data for the Fort Bliss Military Reservation. The HWM ID is used only to distinguish the points and do not have any relation to the point location. The data are sorted by the HWM ID value.

Table 5. USGS Fort Bliss HWM Survey Data Summary

HWM ID	Survey Latitude	Survey Longitude	Elevation (feet) NAVD 88
USGS_FB_1	31.828612	-106.426437	3870.1
USGS_FB_2	31.828627	-106.426521	3870.1
USGS_FB_3	31.828905	-106.419464	3870.2
USGS_FB_4	31.828745	-106.419462	3870.7
USGS_FB_5	31.828720	-106.419587	3870.1
USGS_FB_6	31.827734	-106.419406	3866.3
USGS_FB_7	31.827544	-106.420795	3865.8
USGS_FB_8	31.827478	-106.420888	3865.7
USGS_FB_9	31.827228	-106.420933	3865.8
USGS_FB_10	31.809970	-106.420185	3880.5
USGS_FB_11	31.809175	-106.419982	3880.5
USGS_FB_12	31.812408	-106.423001	3877.2
USGS_FB_13	31.812406	-106.423234	3877.5
USGS_FB_14	31.812406	-106.423259	3877.5
USGS_FB_15	31.823936	-106.430881	3870.9
USGS_FB_16	31.823950	-106.430881	3870.8
USGS_FB_17	31.824682	-106.430659	3870.8
USGS_FB_18	31.805055	-106.425057	3877.1
USGS_FB_19	31.806649	-106.425179	3877.4
USGS_FB_20	31.801988	-106.437911	3849.7
USGS_FB_21	31.801981	-106.437989	3849.8

3.2.2 *URS Data Collected*

Due to the delayed notice to proceed, only a few HWMs remained months after the flooding. These HWMs were found in and around abandoned residential structures. URS flagged and surveyed HWMs in the Fiesta district and the Mowad district, which are shown graphically in Appendix A. The flaggers used their best judgment to document the height of the flood water inside and outside of the homes. Information was collected about each HWM and entered onto one-page forms. These forms included the location, flooding source, zone designation, point description, surveyed coordinates, and elevation. The collection form and datasheets are shown in Appendix B. Photos were also taken of each HWM and are displayed in Appendix D.

The flagged HWMs were surveyed the next day by a URS survey team. For each HWM, the survey team collected the HWM elevation along with the first floor elevation of the structure. The finished first floor elevation was obtained to determine the structure elevation. The URS HWM survey data are stored in a digital database and presented in Table 6. Each point is listed with a unique HWM ID and is sorted by this value in the table. The HWM IDs listed with an "a" or "b" are the first floor elevations of the structure. The "Description" column in Table 6 notes the difference between the HWM survey elevation and the structure first floor survey elevation. The "URS_4" HWM was surveyed inside a garage. Therefore, both the finished garage floor and house first floor elevation was surveyed for this point. The "URS_5" HWM point was surveyed on the outside of a garage. Therefore, this point is also accompanied by the finished garage floor elevation.

Table 6. URS HWM Survey Data Summary

HWM ID	Survey Latitude	Survey Longitude	Elevation (feet) NAVD 88	Description
Fiesta District				
URS_1	31.829957	-106.533033	4035.0	HWM1
URS_1a	31.829941	-106.533058	4031.6	HWM1 Finish Floor
URS_2	31.830155	-106.533164	4035.0	HWM2
URS_2a	31.830125	-106.533210	4031.1	HWM2 Finish Floor
Mowad District				
URS_3	31.898148	-106.594601	3768.0	HWM3
URS_3a	31.898124	-106.594603	3766.8	HWM3 Finish Floor
URS_4	31.897764	-106.595323	3765.6	HWM4
URS_4a	31.897768	-106.595291	3764.4	HWM4 Finish Floor Garage
URS_4b	31.897755	-106.595246	3764.9	HWM4 Finish Floor
URS_5	31.898202	-106.596738	3764.8	HWM5
URS_5a	31.898207	-106.596730	3761.9	HWM5 Finish Floor Garage
URS_6	31.898057	-106.597097	3764.7	HWM6
URS_6a	31.898039	-106.597059	3761.0	HWM6 Finish Floor
URS_7	31.897304	-106.596731	3764.8	HWM7
URS_7a	31.897310	-106.596707	3760.6	HWM7 Finish Floor

3.2.3 *Additional Data Collected*

During the El Paso HWM study, many photos were collected which capture active flooding events or the results of such events across El Paso County and Incorporated Communities. These pictures were gathered to help provide flood water elevation estimates across a broader region of the county than what is covered by the surveyed HWMs. The majority of the photos were acquired after a broadcast email was sent out by the City of El Paso requesting any available digital pictures of the flooding. The photos obtained with a locality reference are shown in Appendix E. These photos were

collected from El Paso County, City of El Paso, USACE, presentations included in the "Federal Flood Assessment Conference, Recommendations and Proceedings, September 6, 2006" report, and the general public.

Aerial photography was also taken during and after the flooding from military helicopters called in to assist with rescue efforts. The photographs helped assess the flooding situation and were sent to emergency personnel in the basement of the El Paso City Hall, which was set up as a central command center during the flooding crisis. These aerial photos were obtained from the El Paso City and County Office of Emergency Management and are displayed in Appendix F. The photographs are not accompanied by any locality reference but are included in the report to show an aerial view of the flooding extent and aftermath.

3.3 Discussion and Application

The HWM data collected for this study demonstrate the severity of flooding in El Paso County and Incorporated Communities. Due to the magnitude of the rain events, the USGS collected flood data immediately after the storm events to study the flooding effects in certain areas. This information is comparable to the HWMs collected by URS at the sites where HWMs were still preserved. Even though the HWMs were only collected in a few localized areas, the additional flood photos obtained during the study help broaden the flood data coverage.

The method used by the USGS to collect HWMs varies slightly from the method used by URS. The USGS flagged HWMs during and after severe rain events and, therefore, were able to capture a large number of fresh HWMs, mainly debris lines, before they weathered away. URS started after the notice to proceed and was fortunate to find HWMs months after the flooding. All of the HWMs collected by URS were mudlines in and on abandoned residential structures in areas identified by city and county officials.

The focus of the USGS study was to survey cross sections and record HWM locations and elevations to model the flood event. Therefore, sketches and photos were taken, but additional notes about the HWMs were not recorded. The focus for URS was to document detailed information about each HWM. Therefore, URS took photographs and filled out a datasheet for each HWM. The critical information, however, was captured by both the USGS and URS, which was the location and elevation of each HWM.

The survey method used by the USGS and URS also varied slightly. The USGS used a RTK GPS base station set up on a NGS bench mark and moved the rover to each HWM location. The nearest benchmark, however, was sometimes a couple miles away. This occasionally caused bad communication between the base station and rover, in which case, the base station was pulled from its known location and placed over the HWM for a fast static recording. The URS survey crew used a combination of static GPS and conventional survey techniques to record HWM elevations inside of enclosed structures. The GPS base station used to set control outside of the homes is identical to the one used

by the USGS. URS tied their control points back to known benchmarks to maintain coordinate accuracy.

The HWM elevations collected by the USGS and URS cannot be compared against each other since the HWMs were created in different areas and from separate flooding events. Both organizations, however, were surveying the HWMs for specific studies and therefore attempted to maintain the best accuracy possible. The URS data meet the accuracy noted at the end of Section 2.2 (URS Methodology), and the USGS is responsible for the accuracy of their data.

The HWM data collected at Sparks Arroyo, the Fiesta district, and the Mowad district would be useful for a riverine study. The HWM elevations are fairly consistent within each localized area, and the flooding source at these three locations came from arroyos and drainage channels. The Fort Bliss data, however, may not be useful for a riverine study, due to the variation in the HWM elevation across Fort Bliss. The flooding source was water draining from surrounding areas into primarily detention ponds. The detention ponds drain different land areas, and therefore, contain different water elevations, which is not a good representation for a riverine study.

The flood information collected by the USGS and URS has many applications. The USACE can use the data collected in Sparks Arroyo to assess the area for the possible development of flood control structures. The HWMs surveyed at Fort Bliss will provide a record of where water ponded outside of detention ponds and the holding capacity of detention ponds during a record flood event. The Fort Bliss data can be analyzed to determine if the flood structures are sufficient or if changes need to be made. The flood information recorded in the Fiesta district documents an area in danger of flash flooding. Drainage structures may be assessed in the area to determine how to mitigate damages from future flooding. The HWMs collected in the Mowad district give an accurate record of flood water elevations possible if the adjacent arroyo overtops again. This helps communities and developers reevaluate flood risk in low-lying areas.

The flood photos and aerial photography acquired during this HWM study provide a great reference for documenting areas prone to flooding. The photographs record areas where flash flooding occurred or where flood waters ponded. These pictures provide a broad general assessment of the flooding across the county. This information can be used to determine where flood control structures are needed or how to rebuild areas to prevent future flooding disasters. Flood water elevations can also be estimated off the photographs to help with flood frequency calculations, flood risk assessment, and other flood studies.

HWM studies relay important information to communities to help them rebuild and recover after a major flooding disaster. When severe flooding occurs in areas unaccustomed to heavy rainfall, documentation of the event is essential for providing a historical account that can be referred to for mitigating flood hazards in the future.