Strategies to Establish Flood Frequencies Associated with Flood Event High Water Marks

June 2014

The Association of State Floodplain Managers
www.floods.org

This page intentionally left blank

The Association of State Floodplain Managers

Strategies to Establish Flood Frequencies Associated with Flood Event High Water Marks

Final Report

The Association of State Floodplain Managers, Inc.

www.floods.org

For more information contact:
The Association of State Floodplain Managers, Inc.
575 D'Onofrio Drive, Suite 200
Madison, WI 53719
Phone: 608-828-3000
Fax: 608-828-6319
E-mail: ASFPM@floods.org

Acknowledgements

The Association of State Floodplain Managers (ASFPM) produced this report with funding from the Federal Emergency Management Agency (FEMA). The commitment and support by FEMA and the entire project team was invaluable in carrying out this investigation.

The ASFPM's project team consisted of Alan Lulloff and Jeff Stone of the ASFPM Executive Office, John Buechler, Laura Danielson and Shane Hubbard of The Polis Center at Indiana University-Purdue University Indianapolis, Kevin Coulton of cbec eco engineering, inc. and Scott Morlock of the USGS Indiana Water Science Center.

Cover Photograph - Water Treatment Plant at Max Starcke Park, Seguin, TX (April 2011) – Courtesy of the Texas Natural Resource Information System (TNRIS)

The ASFPM is deeply grateful for the time and effort contributed by all the interview participants.

U.S. Geological Survey
Robert R. Holmes
Marie Peppler
Dave Eash

U.S. Fish and Wildlife Service
Brian Huberty

Federal Emergency Management Agency
Vincent Brown

U.S. Army Corps of Engineers
Terry R. Zien
Richard Pruitt

Indiana Department of Natural Resources
Dave Knipe

Texas Water Development Board
Melinda Luna

Johnson County, Iowa
Ed Bartels
Greg Parker
Rob Winstead

This page intentionally left blank

Table of Contents

1.0 INTRODUCTION 1

1.1 Assessing the Risks Associated with Flooding 1

1.2 Uncertainty in Flood Flow Estimates 3

1.3 Project Goals and Objective 4

2.0 APPROACH 5

2.1 Interviews 5

2.2 Interview Results 5

3.0 USING HISTORIC FLOOD ELEVATIONS TO REDUCE UNCERTAINTY 7

3.1 Historic Flood Elevations at Streamgages 7

3.2 Documenting Historic Flood Elevations via High Water Marks 7

3.3 Using High Water Marks to Reduce Uncertainty 7

3.4 Using High Water Marks to Improve Flood Awareness 8

4.0 HIGH WATER MARK CHARACTERISTICS 9

4.1 Observations of High Water Marks 9

4.2 Location of High Water Marks 12

4.3 Age of High Water Marks 12

4.4 Accuracy and Reliability of High Water Marks 13

4.5 Field Documentation of High Water Marks 15

4.6 Compilation of High Water Marks 16

5.0 FLOOD DISCHARGE AND FREQUENCY 20

5.1 Overview 20

5.2 Flood Wave Propagation 20

5.3 Stage-Discharge Relationships and Rating Curves 21

5.4 Flood Frequency Definitions 23

5.5 Flood Frequency Analysis 24

6.0 ESTIMATION OF FLOOD FREQUENCY FOR HIGH WATER MARKS 26

6.1 Overview 26

6.2 Generalized and Detailed Approaches 26

7.0 RECOMMENDATIONS 38

REFERENCES 39

Appendix A. Interview Participants 43

Appendix B. Interview Questionnaire 44

Appendix C. Reducing Uncertainty Using High Water Marks 46

Appendix D. High Water Mark Field Sheet Examples 48

Appendix E. High Water Mark Profiles 50

List of Tables and Figures

Table 1- Uncertainties of high water mark ratings………………………………………………………..….14

Figure 1- USGS station on the Scioto River near Dublin, Ohio 2
Figure 2- Calibration and Validation defined 3
Figure 3- Agencies that participated in high water mark interviews 6
Figure 4- A high water mark being installed. Courtesy of Brian Jacobson, City of Roseville, CA..............................8
Figure 5- HWM from dried mud and debris. Courtesy of Georgia Water Science Center..10
Figure 6- HWM from silt on a building during June 2008 flooding. Coralville, Iowa...10
Figure 7- HWM from debris. Courtesy of NWS, Binghamton, NY 11
Figure 8- HWM from beaver gnawing on tree limb during prolonged flood event on Sacramento River. Courtesy of Tom Griggs, River Partners...11
Figure 9- Digitized flood boundary from orthophotos taken during flood crest (a) and the predicted flood elevation intersected with terrain data (b) 12
Figure 10- HWM from water saturated on the bark of trees. Courtesy of Illinois DNR...13
Figure 11- The Cedar River flooded, froze and receded. The maximum level remained on trees as an ice ring. Courtesy of Iowa Water Science Center..13
Figure 12- Irregular debris pattern, June 2013, Coralville, Iowa...14
Figure 13- Example of HWM form and site sketch...15
Figure 14- HWM upload into USGS Short Term Network 17
Figure 15- Map display of HWM with the USGS Short Term Network 18
Figure 16- Texas high water mark database in TNRIS...19
Figure 17- Detaile data for high water marks. 19
Figure 18- Illustration of flood wave propagation..20
Figure 19- Flood crest elevation profile (Matthai, 1969)..21
Figure 20- Uniform flow and loop rating curves. (Kennedy, 1984) 22
Figure 21 - Specific gage analysis. (Jones et al., 2012)..23
Figure 22- Flood frequency curve with uncertainty distributions. (Ford et al., 2008)................................24
Figure 23- View of StreamStats interface for Massachusetts. (Ries et al. 2008)..25
Figure 24- Generalized approach for estimating flood frequencies of a HWM..26
Figure 25- PeakFQ flood frequency curve output. (Flynn et al., 2006)..30
Figure 26- Example of USGS StreamStats watershed delineation. (Ries et al., 2008)...............................31
Figure 27- Description of regression equations for streamflow statistics...32
Figure 28- Example of USGS StreamStats peak flow statistics. 33
Figure 29- Example of a flood frequencyplot...34
Figure 30- Example of NRCS soil map showing flood frequency. (Hoover, 2013)...................................35
Figure 31- Inundation map flooding of June 2008 for the White River at Spencer, Indiana (Source:USGS) 36
Figure 32- Detailed approach for estimating flood frequency of a HWM..37

1.0 INTRODUCTION

1.1 Assessing the Risks Associated with Flooding

Floods are the leading cause of natural disaster losses in the United States, having cost approximately $50 billion in property damage in the 1990s and accounting for more than two-thirds of federally declared natural disasters (National Research Council, 2009). Direct average annual flood damages have jumped from approximately $5 billion per year in the 1990s to nearly $10 billion per year in the 2000s, with some years far beyond that.

Preventing and/or reducing losses is critically dependent on providing reliable information to the public about the risk associated with flooding (FEMA 2001). To accomplish this prevention or reduction of losses, accurate prediction of the flood elevations and inundation area and distribution of the information to emergency managers, city planners, and the public is necessary. Accurate prediction of the flood elevations and inundation area is also needed for developing and quantifying flood insurance rates. Flood inundation maps that incorrectly designate property outside the area predicted as flood prone can have significant impacts. Owners of this property likely will not be adequately protected by flood insurance. Without the proper insurance, these property owners have to deal with the financial impact of uninsured flood damages when the property eventually is inundated by flood waters.

Establishing flood elevations and mapping flood inundation areas involves determining flood flows, determining how high flood flows will get along a stream and how much land will be inundated. The first step in the process – determining the flood flows associated with a flood frequency can be the most challenging. Low frequency events are especially difficult to predict.

Flood flows are best established at streamgages (Figure 1). Gages provide the two most fundamental items of hydrologic information about a river. These are stage, which is water depth above some arbitrary datum, commonly measured in feet, and flow or discharge, which is the total volume of water that flows past a point on the river for some period of time, usually measured in cubic feet per second or gallons per minute.

Long-term records are critical to tracking changes in flow over time. The U.S. Geological Survey (USGS) has operated a gaging network to collect information about the nation's water resources for over a century (since 1889). The USGS collects a suite of measurements over the full range of streamflow conditions—extreme lows to extreme highs—with a relatively high level of certainty at 8,000 sites around the nation.

These data provide reliable, impartial, timely information that is needed to understand the Nation’s water resources to help public officials, community leaders and the general public understand and utilize the complex science associated with flooding, droughts, sea level rise, water pollution, endangered species, ecosystems and recreation. The streamgage network grew rapidly in the early 1900s, and stabilized in the 1950s to 1960s. Unfortunately, funding challenges since then have resulted in an erosion of this valuable national network.

The current USGS stream gage network is supported by funding through the USGS Cooperative Water Program, the USGS National Streamflow Information Program, other federal water and environmental agencies and more than 850 state and local funding partners. Streamgages are often in danger of being discontinued as a result of local, state, and/or federal budget cuts. Since 1990, more than 600 USGS streamgages with records of more than 30 years have been discontinued. USGS recently discontinued another 216 gages due to shortfalls in funding and another 75 are at risk (USGS 2014). Thus the number of streamgages nationally can fluctuate from year to year.

Not only does this gage network provide valuable water resources information about the streams on which they are located but a robust gage network is also vital to support ongoing USGS science that provides critical streamflow estimates at ungaged locations. These USGS applications that provide streamflow estimates at ungaged locations are essential because it is not economically feasible to measure water elevations on all rivers and streams in the U.S.

Observed high water marks that document historic flood events can be valuable data to reduce the uncertainty associated with predicated flood elevations and inundation areas on the extensive portions of the nation's streams that do not have stream gages. These HWMs are an extremely valuable compliment to the nation's streamgage data.

Figure 1- USGS station on the Scioto River near Dublin, Ohio

1.2 Uncertainty in Flood Flow Estimates

As indicated previously, flood flows are best established at a streamgage. A major challenge is that most streams in the U.S. do not have a gage. For these streams flood frequency estimates at gaged sites can be regionalized (extended in space) to develop estimates at ungaged sites (U.S. Geological Survey, 2013). The USGS has used this technique to develop and publish regional regression equations for every state in the nation. These equations can be used to estimate streamflow statistics, including recurrence interval flood discharges for ungaged streams.

The equations that form the most recent publication for each state are compiled in the National Streamflow Statistics (NSS) computer program. In addition, for many states, a web mapping application called StreamStats has been developed that uses geospatial technology to automate and speed up the process. StreamStats allows users to run the application at user-selected sites on streams to obtain drainage basin characteristics for the contributing watershed and streamflow statistics at the site.

Flood flow estimates associated with a certain frequency of occurrence can also be simulated using hydrologic engineering models. Hydrologic models use drainage area, soil types, land cover and stream slope data to estimate flood flows.

Calibration vs. Validation

Calibration is the adjustment of a model's parameters, such as roughness, and hydraulic structure coefficients, so that it reproduces observed data to an acceptable accuracy. For regulatory flood elevations, the acceptable level of accuracy is 0.5 feet.

Validation is the process of confirming that model results adequately correlate with observed data.

Figure 2- Calibration and Validation defined

Once the flood flow is determined, hydraulic engineering models are then used to estimate flood elevations and these elevations are matched with terrain data to estimate the area inundated. Usually the result of this flood engineering study is a single deterministic estimation of flood elevation and area inundated associated with the flood flow. In reality, the prediction of the flood flow, flood elevations established and terrain elevations used to determine the areas inundated are all somewhat uncertain.

Engineers use high water marks (HWM) to reduce the uncertainty associated with the flood flows used and the flood elevation established in flood engineering studies. HWMs can be used to validate flood flows generated using USGS regression equations or calibrate mathematical engineering models that estimate flood flows and associated flood elevations. However, though historic HWMs may be available for a stream on which flood inundation maps are being developed, the HWMs often are not used in the flood study process. This is because the engineering modeling results are intended to represent the one percent annual chance flood elevation. In order to correlate the HWM with the modeling results the flood frequency associated with the flood event is needed.

Flood frequencies are determined by the comparing the magnitude of the volumetric streamflow (discharge) that has occurred at a location over time. To determine the frequency of the flood event, where that event fits in with the full range of events needs to be established.

Obtaining the stream flow associated with a HWM can be done with the greatest confidence at a streamgage because gages have:

1. A published rating curve. The stream cross sections at streamgages have been surveyed and flows have been established for the full range of probable elevations at that location (aka a rating curve). By comparing the elevation of the HWM with the elevations on the rating curve, the flow associated with the event can be determined.

2. A multi-decade period of record. To determine the relative frequency of the flood flows associated water elevations at a gage a significant period of record is needed. To determine the flow associated with a low frequency event (e.g. a one percent annual chance event) a period of record in excess of 25 years is generally deemed necessary to have a statistically valid analysis[1].

Confidence in the estimated flood frequency of a flood event decreases on a given *gaged* stream with increasing distance upstream or downstream from the location of the gage where elevations have been recorded. Estimating the discharge and associated flood frequency with a flood event on a stream with no gage is more uncertain than those established on gaged streams because there is no direct reference for comparison. The same can be said for synthetic hydrologic engineering models. With no historic flood elevations for comparison; the amount of uncertainly associated with the output of a synthetic engineering (mathematical) model cannot be quantified.

For this reason, federal, state and local governments collect high water marks associated with major flood events to provide a reference baseline of actual historic flood elevations. However, one of the limitations associated with high water marks and historic flood inundation maps is that the frequency of the associated events is often unknown. The remainder of this report provides a methodology to address this issue in order to estimate the flood frequency of a historic flood event.

1.3 Project Goals and Objective

Flood inundation studies are conducted for coasts and rivers, and high water marks are collected in both settings. While some best practices regarding the collection and dissemination of information related to the coastal environment are included in the report, the focus of this study was on using HWMs to reduce the uncertainty associated with riverine flood studies. The goal of this project was to document best practices in computing or estimating flood frequencies associated with documented flood events on ungaged streams. The objectives in achieving were to:

- Acknowledge the inherent uncertainty and error in streamflow estimation,
- Interview floodplain managers to understand current practices and needs related to this investigation and
- Establish a reasonable and repeatable methodology to assign a flood frequency to a given high water mark.

This project was carried out through a combination of interviews, evaluation of existing technologies and methods, and evaluation of currently available options for establishing flood frequencies.

[1] NR116 of the Wisconsin Administrative Code requires gages used for flood frequency analysis to have at least 27 years of flows records.

2.0 APPROACH

2.1 Interviews

The Association of State Floodplain Managers (ASFPM) interviewed personnel at agencies across the country that are responsible for collecting high water mark (HWM) data from federal, state and local governments (Figure 3). ASFPM used membership collaborations to identify the list of potential interviewees. Two such agencies, the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE), each have extensive experience collecting HWM data. During the interview process, participants were asked a series of questions about their agency's HWM data collection. Questions were also asked about current methodology, collection procedures, data storage, and data usage. Participants were then asked about the future of HWM collection and their thoughts on including new technologies such as smartphones and newly emerging Geographic Information Systems (GIS) and remote sensing techniques. These interviews form the basis of this report. Interview attendees are listed in Appendix A.

A copy of the interview questionnaire is included in Appendix B. Questions had multiple choices based on the interviewee's experience. For example the question, "Does your agency have a program to collect and make available HWMs or historical flood inundation boundaries?" had two possible answers: "If yes, please explain the collection process and storage and dissemination of this information. If no, where do you obtain HWMs or historical flood inundation information?"

2.2 Interview Results

The interviews were conducted in August 2013. Several important findings were discovered during the interview process. There are many agencies at the federal, state and local levels across the nation collecting HWMs during high flows. When HWMs are collected in the field, most agencies use the Lumia et al. (1987) methodologies to collect and rate them. Agencies use a form during the collection process that also collects additional information. Many of these field sheets record information about the surrounding area, occasionally a sketch of the HWM, and comments about information such as the current weather and site condition. Additionally, when agencies collect HWMs it is often at benchmarks along a stream. Benchmarks are permanent structures such as bridges and culverts that are surveyed and provide a reference point so that HWMs can be collected at the same location over time and over multiple high water events.

High water mark data is stored in two ways. Some agencies record and store HWM data on paper field sheets. Others have developed digital databases or other such systems that store HWMs on a computer or server system. The HWMs are then used by agencies to revise and refine flood inundation maps or to provide decision support during high water events. HWM data is publically available by request for all of the agencies that were interviewed in this study. One critical thing to note, however, is that there is no system for coordinating the collection and dissemination of HWM data nationally. Consequently, HWM data resides at individual agencies and in some cases on the standalone computers of individuals at these agencies. Because of this limitation, HWMs are not being used to their full potential. To rectify this, the USGS has recently begun to develop a centralized system for disseminating HWM data and is seeking to expand the capacity of this system. All agencies are contemplating solutions for how to incorporate new digital technologies (smartphones, GIS) to help streamline the collection of HWMs.

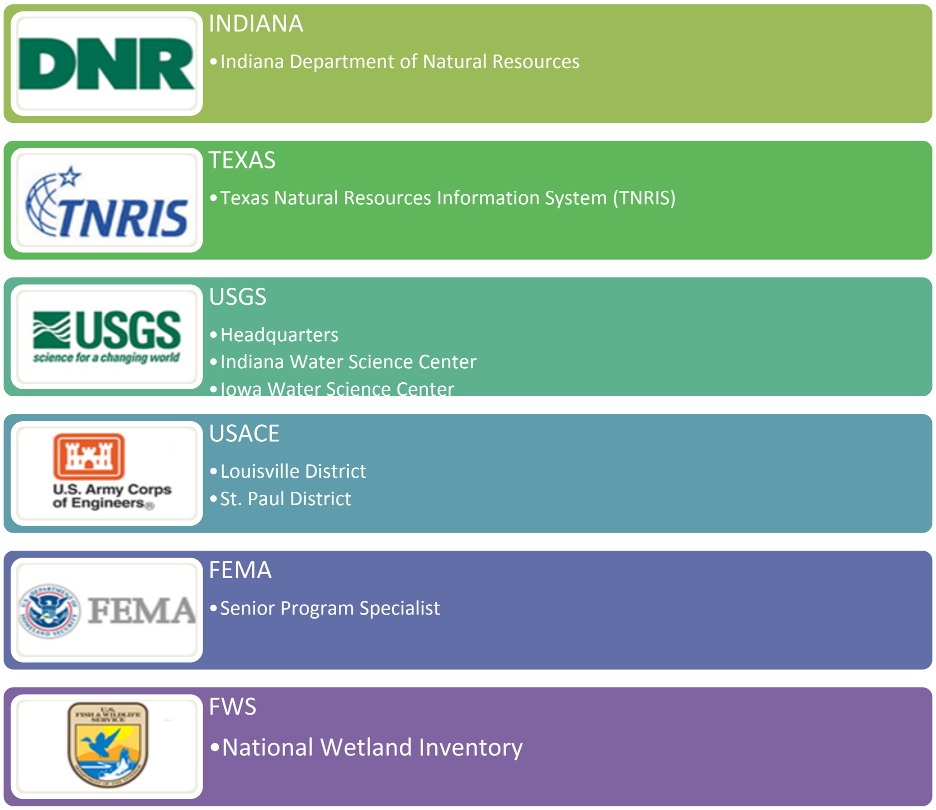


Figure 3- Agencies that participated in high water mark interviews

One important practice that was discussed includes the dissemination and visualization of data and information using a Geographic Information Systems (GIS) framework. The interviews identified GIS best practices as well as new initiatives for spatial organization and retrieval of historical flood data. GIS web services provide for centralized management of and effective user access to HWM elevations and descriptions, flood photographs, aerial imagery, and other related geospatial data.

3.0 USING HISTORIC FLOOD ELEVATIONS TO REDUCE UNCERTAINTY

3.1 Historic Flood Elevations at Streamgages

As indicated previously, the preferred method for determining the highest water level during a flood event is the use of a streamgage. There are many types of streamgages. A *crest-stage gage* uses regranulated cork housed within a pipe When the pipe is inundated during high-flow events and the water recedes, the cork is left on a staff inside the pipe at the highest point of the flood event. The protected mark that is left shows the peak water surface elevation (USGS 2013a). A *staff gage* is manually read by an on-site observer who records the observed height of the water. An *automated local evaluation in real-time* (ALERT) streamgage transmits a signal when preset flood levels are met. *Continuous gages* record water levels on a regular time interval using a mechanical or electronic data logging device; this type makes up the vast majority of the USGS network and provides the most data. The continuous data over the entire range of flows at the station site are collected and archived for historical purposes and are usually transmitted in near real-time for operational purposes such as flood warning. Additional information on the types of streamgages can be found by contacting the agencies that support and monitor them (e.g. USGS, USACE) or by visiting online resources (HERE, for example).

3.2 Documenting Historic Flood Elevations via High Water Marks

As stated previously, it is common for federal, state and local governments to collect high water marks following major flood events. HWMs are used in a wide variety of activities that support flood response, mitigation, and awareness. One of the most important uses of HWMs is their collection for the purpose of gaining a historical perspective. The marks serve to document how high water has risen as a means to identify the range of possible flood elevations for a given community; this information is invaluable for helping identify flood risk and design infrastructure in areas that can flood. Agencies such as the USGS and USACE collect HWMs along streams and rivers at *benchmarks*—well-established, permanent landmarks (e.g. bridges, roadways, buildings) in a community. This establishes a record at fixed locations over time. In some USACE districts the HWMs are used to develop a relationship between the elevations behind a water control structure like a dam and the water elevations downstream to provide communities with a planning tool when high water is expected. However, most high water marks are collected throughout a watershed after a flood event. With the advent of cell phones with cameras the number of photographs and videos collected after flood events has grown astronomically. Photos and videos can sometimes be used to determine the flood elevation at a location by determining the elevation of flood waters on an item visible in the photos or video.

3.3 Using High Water Marks to Reduce Uncertainty

High water marks are commonly used as validation and calibration points within a hydraulic engineering model. Marks are plotted against the flood water surfaces computed by the model to compare the model results with observation data for an actual flood event. This provides the engineer with the means for calibrating the model to fit with observation data. For example, the USACE will compare the hydraulic model output associated with the flood frequency that matches a HWM and adjust the inputs to the engineering model until the results is within 0.5 ft of the HWM elevation. In this manner, HWMs help reduce the uncertainty associated with the results of a flood engineering study. An example is provided in Appendix C to stress the significance of the potential uncertainty in flood elevations estimated in a flood inundation study. Using HWMs for calibrating modeling not only reduces the uncertainty but also significantly reduces the uncertainty associated with the accuracy of the flood elevations and flood hazard mapping being provided to a community in a mathematical sense. Identifying a historic event to which the modeling can be calibrated personalizes the data for the community. The engineer that produced the flood hazard map can for example state: “this mapping is consistent with the extent of flooding that occurred in the community in July 2001”.

3.4 Using High Water Marks to Improve Flood Awareness

High water marks are excellent tools for risk communication. The Federal Emergency Management Agency’s (FEMA) “Know Your Line: Be Flood Aware” program, carried out in conjunction with seven other federal agencies, has been developed to reinforce public awareness of flood risks to communities. Member communities construct HWM displays in their area as a means to educate the public on their specific flood risks and raise local awareness. The overall goal of the program is to encourage communities to take action to mitigate their risks from future flooding. These outreach efforts can help communities identify flood mitigation needs and prompt them to work to reduce their risk. To support community risk reduction efforts, the federal government has hazard mitigation funding available for communities to implement measures that reduce their risks.

Figure 4- A high water mark being installed. Courtesy of Brian Jacobson, City of Roseville, CA

4.0 HIGH WATER MARK CHARACTERISTICS

4.1 Observations of High Water Marks

After high water has receded, natural marks depict the levels it reached (Figure 5). Floodwaters place natural markings on objects from the silt, debris, and ice in the water and the effects of water itself on structures (e.g. warping wood). Caution is advised when documenting high water marks (HWM) because not all observed indications of flooding may represent the peak water stage of the flood event. For example, the image to the left in Figure 5 represents a relatively stable object upon which to observe and record a HWM (tree trunk and short-stemmed plants), while the image to the right represents a highly unstable object (flexible tree branch susceptible to movement by floodwaters). HWMs observed on these unstable objects should be examined carefully. Some common indicators of high water are:

- Mud or silt lines – lines of sediment that are suspended in the water and left on trees, structures, streambanks, or buildings (Figure 6).
- Debris lines – lines or piles of debris such as leaves and sticks that are left on land (Figure 7).
- Debris snags – debris left in trees or shrubs.
- Ice debris – ice remnants that can mark high water during the cold weather months in northern climates.
- Seed lines – lines of seeds, fibers, and other miniscule debris that were floating on the water and subsequently left on trees or structures.
- Wash lines – lines where soil has been washed away from banks that are bare of vegetation, typically in arid regions.
- Eroded banks – where the top of the erosion area approximates the highest water level.

Other indicators of high water are much less common. For example, Figure 8 shows a clue to floodwater stages where beaver gnawed on a tree limb during the course of a prolonged flood event. Benson and Dalrymple (1967) provide a comprehensive description of the identification and rating of HWMs. These various temporary HWMs listed are surveyed and an elevation is obtained.

There are a variety of means for collecting HWMs; these can be categorized as either *direct* or *indirect* methods. Direct methods are those techniques that require an instrument that is used at the point of maximum water elevation for the measurement. An important element of marking high water during peak flows is the flagging of the HWM with a durable marker. For a HWM on a tree or wooden structure, typically a round disc is nailed to the tree or structure, with the nail driven at the peak stage level. The USGS and other agencies have plastic or metal HWM tablets designed specifically for this purpose. HWMs are also flagged by driving a stake in the ground, in the case of debris lines on the ground; by using surveyor's tape to denote the stage elevation (for example, tying the tape to a branch containing a debris snag); or by using spray paint or a paint crayon to denote the HWM elevation on rock or a structure such as a bridge abutment. If rain has occurred before HWMs can be flagged, it is common to seek out those marks that persist longer for being sheltered by thick tree canopies, bridge decks, or that are located inside structures that were flooded. A very important consideration for personnel flagging HWMs is that they gain the permission of property owners before flagging marks on private property. In searching out and identifying HWMs for a particular flood, care must be taken to not misidentify a secondary, lower peak that occurs during some floods. It is best practice to always look higher when a HWM is located to ensure that it is not one of these lower peaks.

Figure 5- HWM from dried mud and debris. Courtesy of Georgia Water Science Center

Figure 6- HWM from silt on a building during June 2008 flooding. Coralville, Iowa

Figure 7- HWM from debris. Courtesy of NWS, Binghamton, NY

Figure 8- HWM from beaver gnawing on tree limb during prolonged flood event on Sacramento River. Courtesy of Tom Griggs, River Partners

Indirect methods of collecting high water marks measure the height of the water remotely using tools such as GIS. One method is to georectify aerial photos taken during the peak of flooding. The inundation boundary is digitized and its edges are intersected with terrain models to obtain an elevation along the boundary (Figure 9). In cases of floods that have occurred decades in the past, a historical photo that either captures the peak crest of the flood or that includes a HWM on a landmark is used to find that same landmark today; the historic high water elevation can then be measured against it. In some cases anecdotal evidence is used. Residents within communities are often able to describe the height of the water from historic floods, and this information can be used to reconstruct the exact elevation of high water.

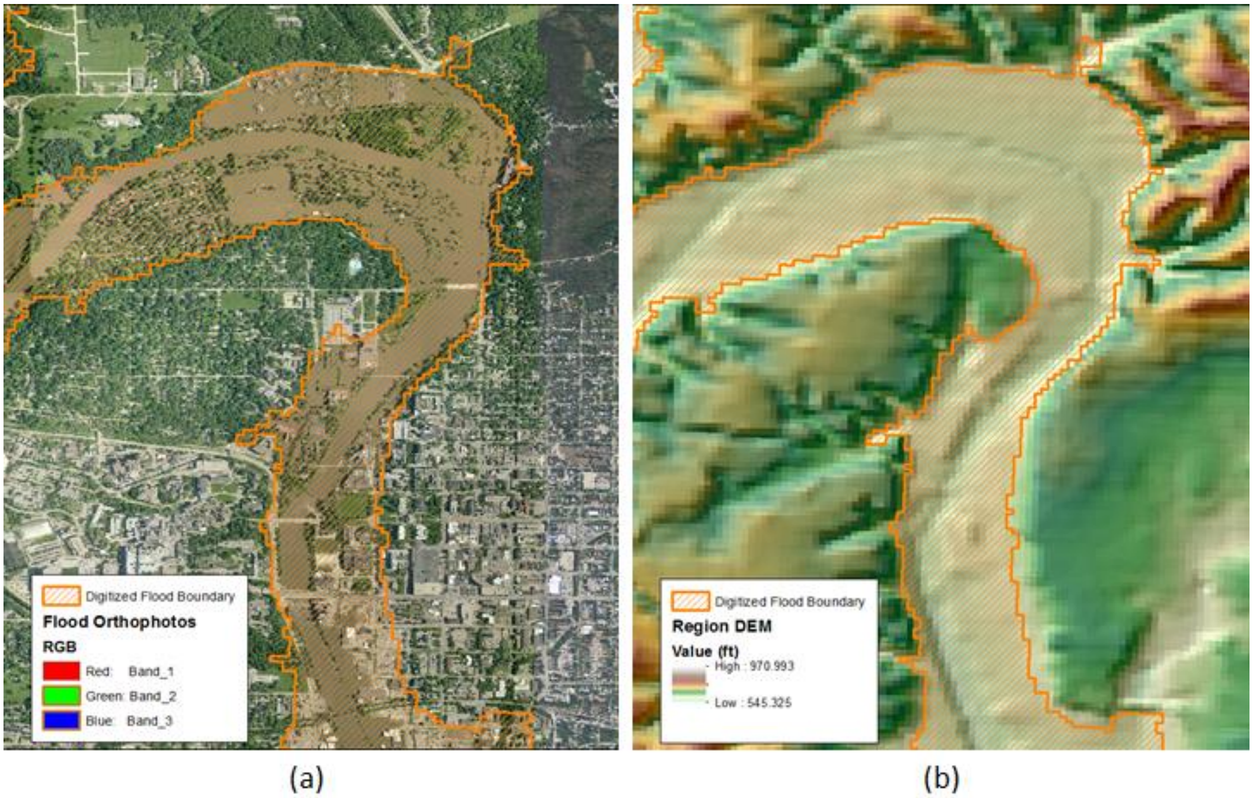


Figure 9- Digitized flood boundary from orthophotos taken during flood crest (a) and the predicted flood elevation intersected with terrain data (b)

4.2 Location of High Water Marks

High water marks are taken in various locations within the floodplain. *Lateral* HWMs are perpendicular to the flow and are taken in the stream channel, within the floodplain, or the floodplain fringe. A *longitudinal* HWM is parallel to the flow of water and is taken along the flood source. *Structural* HWMs are taken on objects such as bridges, culverts, houses, buildings, and so on. *Non-structural* HWMs exist as a natural result of high water, and include debris, erosion lines, and silt lines, among others.

4.3 Age of High Water Marks

Age is an important factor in the collection of high water marks. Many HWMs have a short-term lifespan while others persist for much longer. Rainfall or a secondary crest of water commonly causes some HWMs to disappear. Water marks that are a result of the saturation of an object are typically short-lived and will disappear once evaporation occurs (Figure 10). Other short-term HWMs include marks such as silt lines or ice debris (Figure 10). Erosion lines, heavy debris lines, and scour marks, on the other hand, can all leave a semi-permanent mark on structures and within the floodplain that withstand weather and other natural factors. Because of the sensitivity of short-term HWMs it is important that these marks are collected quickly during or immediately after the flood.

Figure 10- HWM from water saturated on the bark of trees. Courtesy of Illinois DNR

Figure 11- The Cedar River flooded, froze and receded. The maximum level remained on trees as an ice ring. Courtesy of Iowa Water Science Center.

4.4 Accuracy and Reliability of High Water Marks

High water marks have been collected for decades in the U.S. Agencies complete post-flood reports to document various aspects of a flood after the fact. FEMA, for example, completes a mitigation assessment report and will in some cases refer to the HWMs that were collected during and after the disaster (FEMA 2013). USGS state water science centers and state floodplain management programs also routinely collect HWMs following flood events. The USGS Iowa Water Science Center, for example, performs HWM collections for the Iowa Department of Transportation to assist in their calculation of hydraulic designs for new and old infrastructure. Local newspapers also document flood events, including dates and times of flooding, images of flooding, and flooding impacts.

Historic HWMs can provide a reference for the maximum flood elevation associated with an actual flood event and can be used to calibrate and/or validate synthetic hydraulic engineering models that attempt to simulate flood events. However, while HWMs can substantially reduce the uncertainty associated with hydrologic and hydraulic modeling, they should be used with the recognition that their accuracy and reliability can vary. As mentioned previously, some HWMs are distinct while others are more ambiguous. The location of a HWM can determine its accuracy. HWMs that are collected where water is ponding (low velocity environments) may be higher than the elevations taken in a stream channel, where velocities are higher. Moreover, HWMs taken around ice or debris jams may also be recorded higher because of the backing up of water. Under normal circumstances HWMs can be rated depending on the quality of the mark. Lumia et al. (1987) established a rating system that is still used by many agencies. Recently the USGS updated estimates of HWM uncertainty (Table 1).

HWM classification	**Coastal storm surge HWM uncertainty (ft.)**	**Upland rivers HWM uncertainty (ft.)**
Excellent	0.05	0.02
Good	0.1	0.05
Fair	0.2	0.1
Poor	0.4	0.2
Very poor	>0.40	>0.20

Table 1. Uncertainties of high water mark ratings. (Rydlund and Densmore, 2012)

Excellent and good marks are generally seed lines or marks that are in protected environments. Debris lines and mud lines are considered fair marks, while irregular debris patterns are poor marks (Figure 12). Field conditions at the time of collection can also determine the quality of the mark; notes made at field sites provide additional information here. For example, if a modeler is using HWM data to calibrate a flood inundation model and one of the data points is inconsistent with the model results, comments at the time of data collection in the field may provide additional information about the quality of the mark. Examples of HWM field sheets are included in Appendix D.

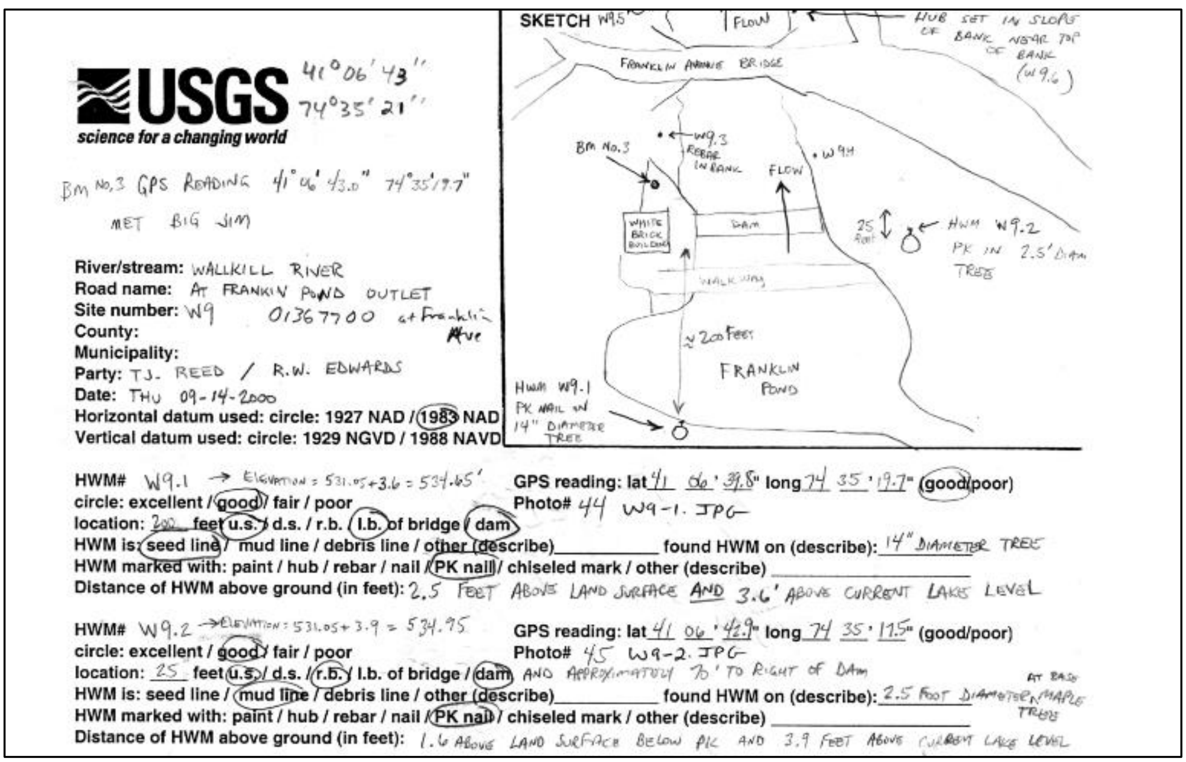
Figure 12- Irregular debris pattern, June 2013, Coralville, Iowa

4.5 Field Documentation of High Water Marks

The first step in collection and dissemination of HWM data is to document in the field each individual HWM that is flagged. USGS HWM flagging crews normally carry field note forms (Figure 13) that are used to document marks. Typical information contained includes:

- Description and location of the HWM.
- Type of mark – e.g. seed line, mud line, debris line.
- Location of mark – described in reference to a landmark e.g. northing and easting distance from a road intersection, lat/long coordinate of the mark as obtained from DGPS instrumentation or a hand-held GPS receiver.
- Type of flagging used – e.g. tablet affixed by nail, paint crayon line, wooden stake set in the ground.
- Estimated uncertainty associated with the mark – Rydlund and Densmore (2012) provide uncertainty classifications for HWMs produced from coastal storm surge and from upland streams as do Lumia et al. (1987); see previous section.
- Miscellaneous notes of significance, such as property owner and contact information, and any logistical or safety issues associated with the mark location.

In addition to these notes, photographs of flagged marks are very helpful in documenting HWMs and can greatly assist survey crews in locating marks. It is recommended that digital photos be tagged with a file name that is easily relatable to a flagged mark, e.g. containing the coordinate of the mark or a common designation for the mark used in the field notes. Site sketches, maps or aerial photos containing the locations of flagged marks are also helpful.


USGS science for a changing world
41°06'43"
74°35'21"
BM No.3 GPS READING 41°06'43.0" 74°35'19.7"
MET BIG JIM

River/stream: WALLKILL RIVER
Road name: AT FRANKLIN POND OUTLET
Site number: W9 01367700 at Franklin Ave
County:
Municipality:
Party: T.J. REED / R.W. EDWARDS
Date: THU 09-14-2000
Horizontal datum used: circle: 1927 NAD / 1983 NAD
Vertical datum used: circle: 1929 NGVD / 1988 NAVD

HWM# W9.1 → ELEVATION = 531.05+3.6 = 534.65' GPS reading: lat 41 06' 39.8" long 74 35' 19.7" (good/poor)
circle: excellent / good / fair / poor Photo# 44 W9-1. JPG
location: 200 feet u.s. / d.s. / r.b. / l.b. of bridge / dam
HWM is: seed line / mud line / debris line / other (describe)____ found HWM on (describe): 14" DIAMETER TREE
HWM marked with: paint / hub / rebar / nail / PK nail / chiseled mark / other (describe) ____
Distance of HWM above ground (in feet): 2.5 FEET ABOVE LAND SURFACE AND 3.6' ABOVE CURRENT LAKE LEVEL

HWM# W9.2 → ELEVATION = 531.05+3.9 = 534.95 GPS reading: lat 41 06' 42.9" long 74 35' 17.5" (good/poor)
circle: excellent / good / fair / poor Photo# 45 W9-2. JPG
location: 25 feet u.s. / d.s. / r.b. / l.b. of bridge / dam AND APPROXIMATELY 70' TO RIGHT OF DAM
HWM is: seed line / mud line / debris line / other (describe)____ found HWM on (describe): 2.5 FOOT DIAMETER MAPLE TREE AT BASE
HWM marked with: paint / hub / rebar / nail / PK nail / chiseled mark / other (describe) ____
Distance of HWM above ground (in feet): 1.6 ABOVE LAND SURFACE BELOW PK AND 3.9 FEET ABOVE CURRENT LAKE LEVEL

Figure 13- Example of HWM form and site sketch

The elevations eventually determined for each HWM must also be recorded. Documentation for HWM elevations should include:

- Description and location of the HWM.
- Method of elevation determination e.g. conventional vertical level survey, description of the GNSS approach used.
- Associated information from the elevation determination e.g. level survey notes, GNSS receiving instrumentation used, estimate of the accuracy of the elevation calculation.

Another form of HWM documentation is photographs and videos. Technology that is easier to carry (e.g. video recording-enabled smartphones) facilitates the recording of images of HWMs in the field. More and more of these devices are coming equipped with GPS technology so that HWM data can be stamped with a location, date, and time. This has prompted some agencies to consider the possibility of having the public record HWM data using their own smartphones and upload it to a central location. Like written notes, photographs and videos provide context to the quality of the HWM.

4.6 Compilation of High Water Marks

To date there is no nationwide system for centrally storing high water mark data. HWM data are housed in a variety of ways by agencies in the U.S. The USGS publishes its results in scientific reports that are accessible to the public via its website (Mastin, Gendaszek, and Barnas, 2010). However, each USGS office has its own way of storing and cataloging HWM data. Some offices keep a digital record of HWM data while other offices keep it in the original written field notes. The USACE operates in much the same way. Field notes also contain more information than just the HWM elevations, as described above. This information can be valuable for determining the quality of marks in the same area in the future. While not always easily assessable, all data, whether digital or analog, is generally publically available.

More recently some dedicated HWM websites have been constructed. For example, the USGS has developed Storm Tide Mappers website to provide HWM data that it has collected. This system was most recently used to record storm surge and riverine HWM data collected during Hurricanes Irene and Sandy. These HWM data were then used to create a continuous surface of high water, which was used to estimate the damages and losses from the hurricanes (USGS 2013b). The Storm Tide Mappers website was developed to include historical and current HWM data as well as a system for incorporating real-time HWM data. Such real-time HWM data proved to be extremely helpful in delivering aid to flood impacted citizens during Hurricane Sandy. At the time of this writing, the USGS is internally testing a new web application called the Short-Term Network (STN). The STN allows crews to upload HWM data to a server (Figure 14), where it is be stored in a database and displayed on an interactive map (Figure 15). It is anticipated that the STN will become the primary means of HWM data storage and dissemination for the USGS.

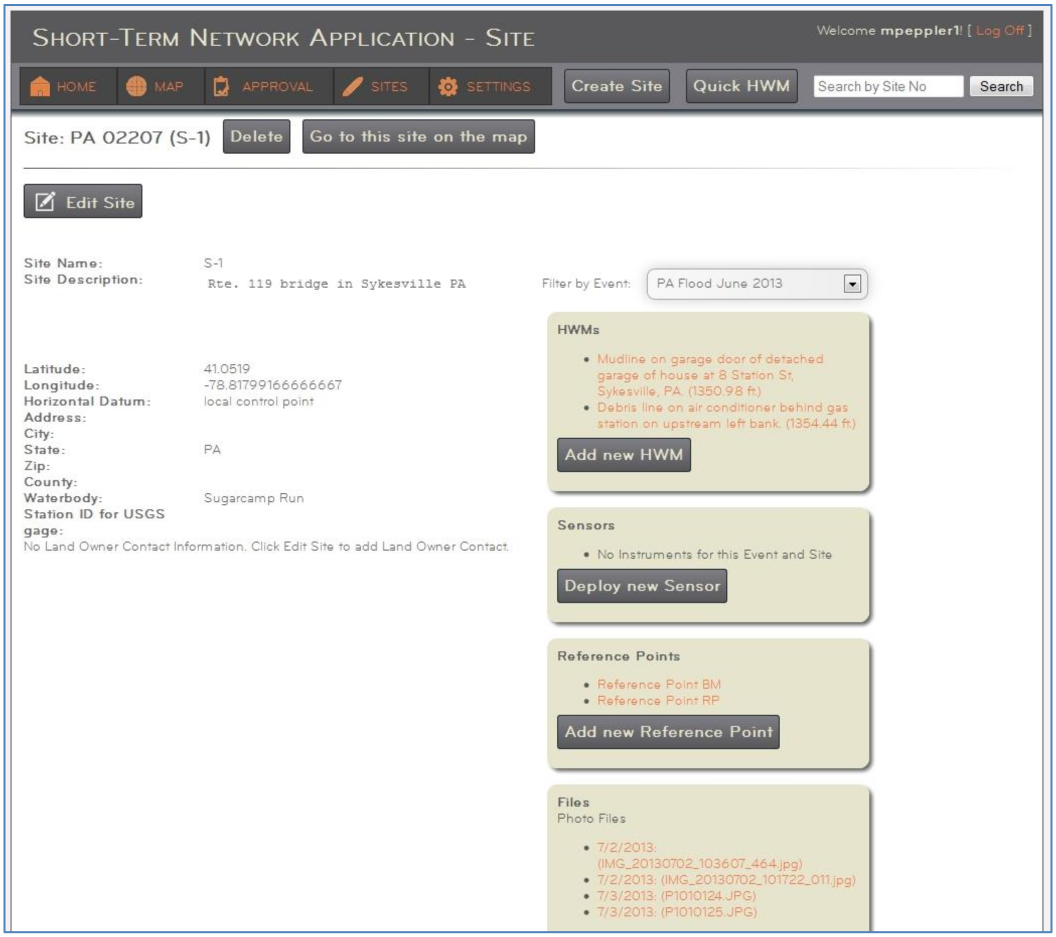


Figure 14- HWM upload into USGS Short Term Network

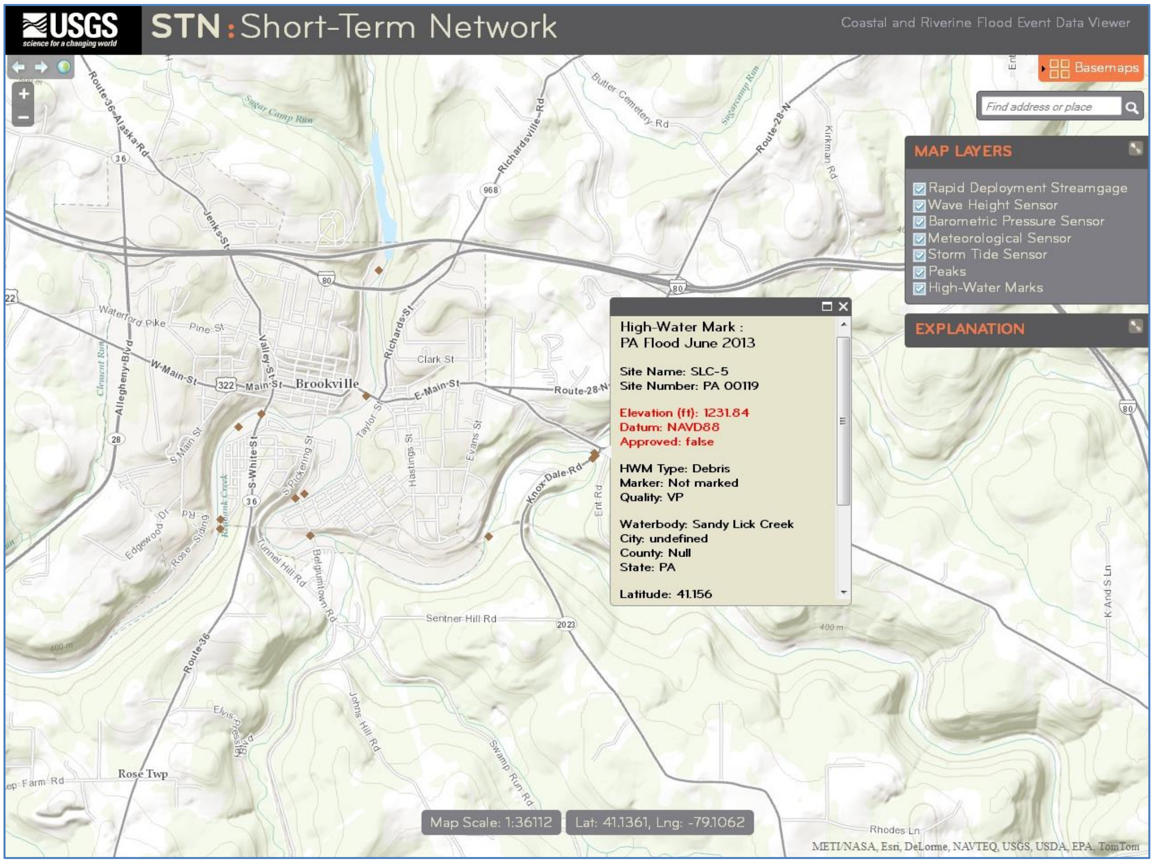


Figure 15- Map display of HWM with the USGS Short Term Network

An excellent example of a system developed by a state is the Texas Natural Resources Information System (TNRIS). TNRIS is used to archive, maintain and distribute current and historical geospatial datasets for the state of Texas. This collection of maps, photos, documents and other datasets has been compiled from multiple sources. Through collaboration with federal agencies, local governments and the private sector, the state floodplain management program has compiled a collection of over 15,000 HWMs that are now accessible in one location. Figure 16 is a map of HWMs in southern Texas that shows the density of the HWMs in the system. The green triangles on the map illustrate HWMs contributed by the Harris County Flood Control District (HCFCD) – a major contributor of HWM data in the state. Figure 17 shows the level of detail when the user zooms in to a single HWM point location.

Other sources of HWMs are found in communities themselves. Some communities have marked landmarks with the peak elevations of floods to remind residents of the risk that exists. Businesses that have been repeatedly flooded sometimes mark flood elevations inside the building to show patrons how many times the building has flooded and to what level. Historic photographs and personal accounts also help determine the high water from past floods. The public is often a valuable source of information because they are directly impacted by floodwaters and can often recall specific details about how high the water rose. Local newspaper can be a valuable source of historic flood photographs.

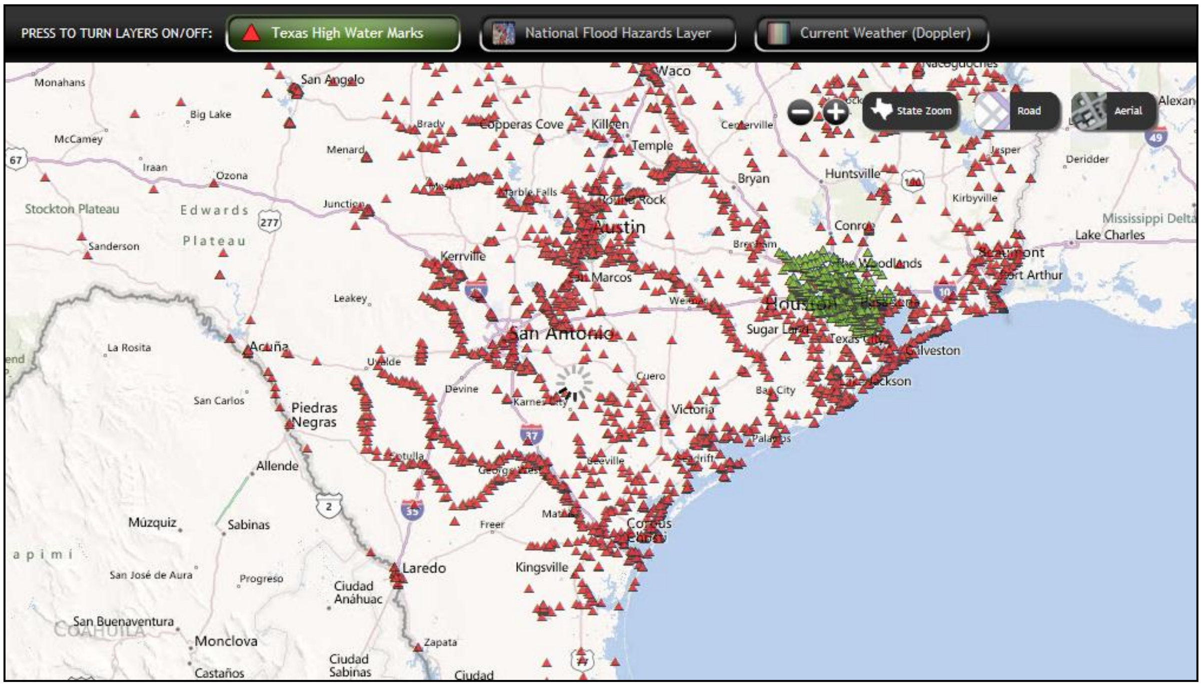


Figure 16- Texas high water mark database in TNRIS

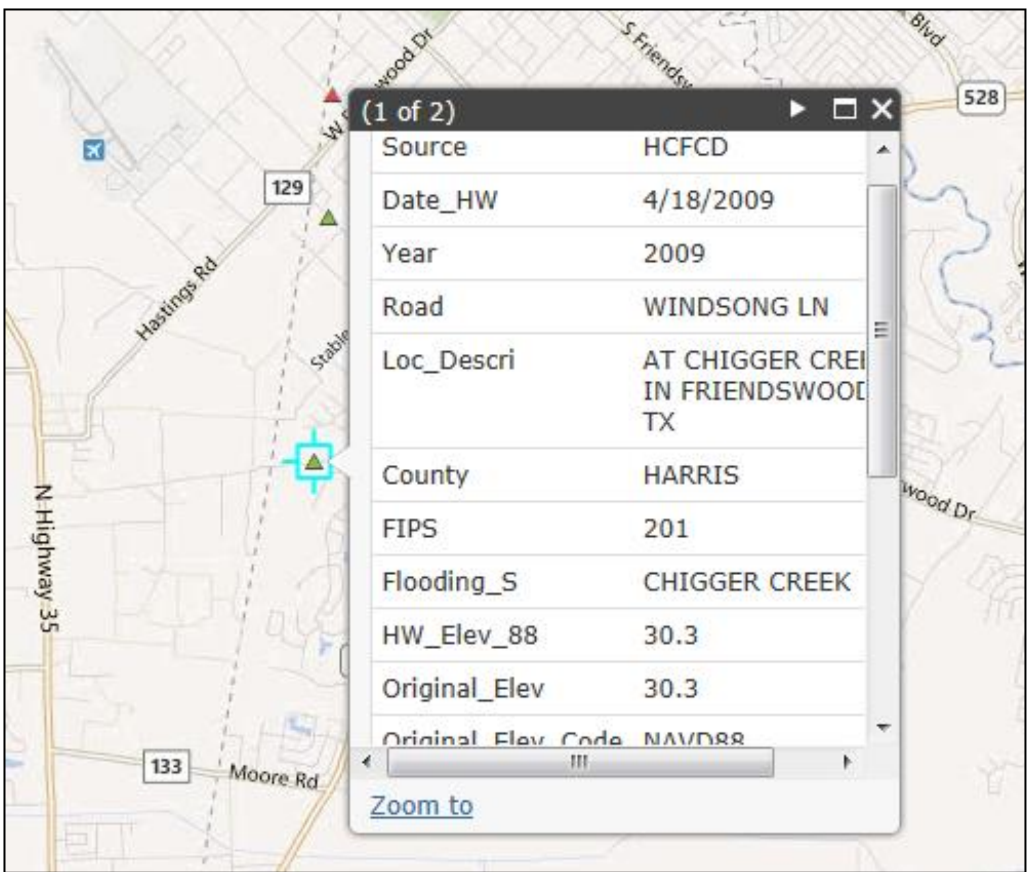


Figure 17- Detailed data for high water marks.

5.0 FLOOD DISCHARGE AND FREQUENCY

5.1 Overview

Since the main objective of this report is to evaluate ways to compute or estimate flood frequencies associated with documented flood events on gaged and ungaged streams, it is necessary to first review the physical processes that comprise a flood event and the statistical basis for establishing the frequency, or return period, of the peak discharge of the flood event.

5.2 Flood Wave Propagation

Flooding is a dynamic response to precipitation and/or snowmelt contributions of water into a watershed and the subsequent runoff of this water through the stream system. At any given point along the stream system, floodwaters rise and fall during a flood event relative to a position along the stream channel. This movement of the water surface characterizes the *flood wave* as it propagates downstream (Figure 18).

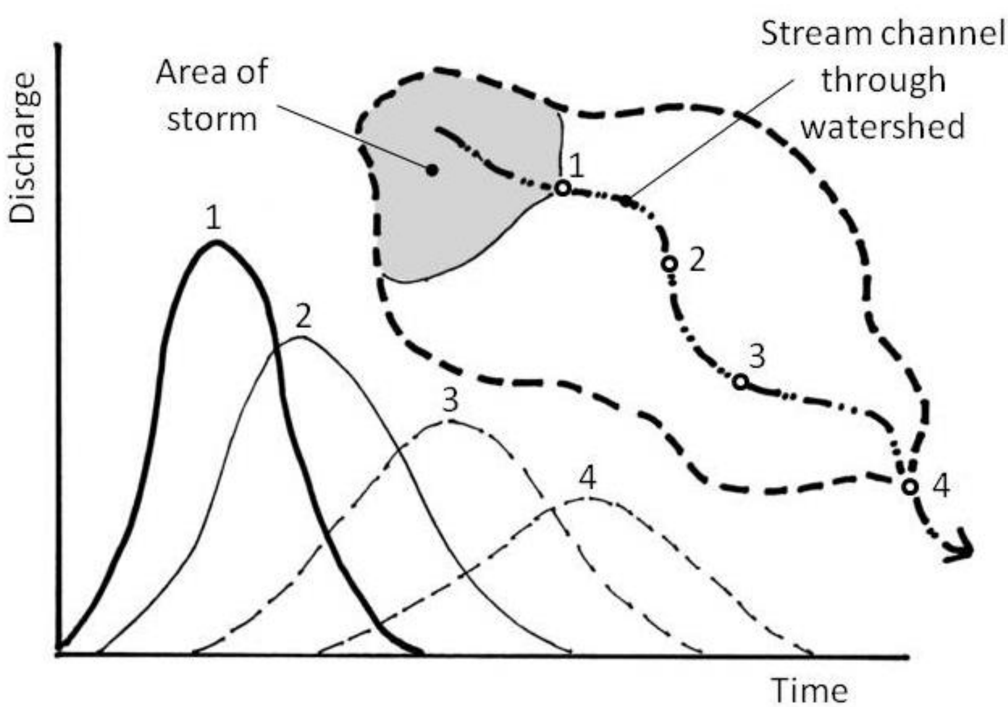


Figure 18- Illustration of flood wave propagation

For each flood event the flood wave is unique and ever-changing, being formed as a function of the volume, rate, and distribution of precipitation entering a watershed and the response of the overland runoff of that water to a stream system based on topography, land cover, drainage network, and other factors. Once within the stream system, floodwaters flow downstream and the crest, or maximum height, of the flood wave tends to decrease as the geometry of the channel and floodplain increases in area. The progressive downstream passage of the flood wave crests creates a profile (Figure 19) that shows the maximum stages of flooding. High water marks capture these crest stages for a given flood event along a stream.

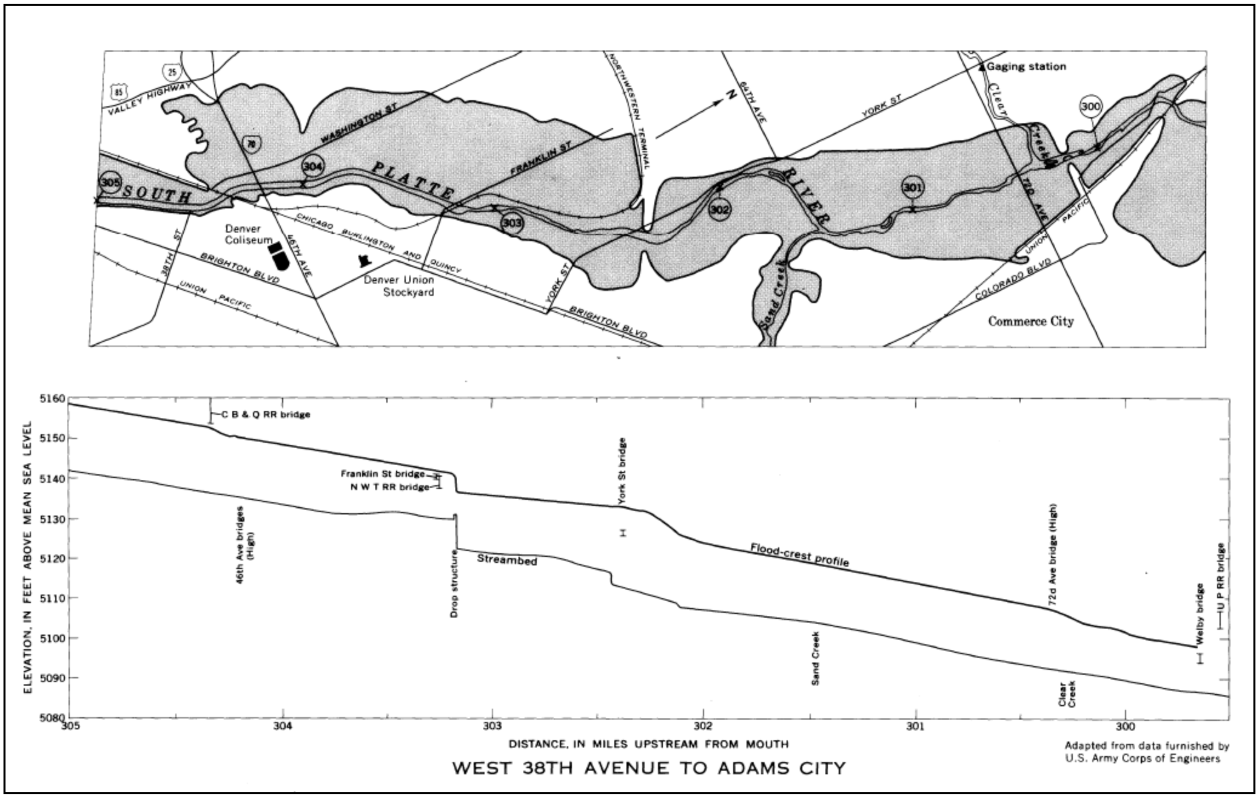


Figure 19- Flood crest elevation profile (Matthai, 1969)

5.3 Stage-Discharge Relationships and Rating Curves

A stage-discharge relationship associates stages, or flow depths, to discharges at a given cross-section on a stream channel. In other words, it relates flood wave depths at a cross-section to volumes passed. As stated previously, the graphical plot of stage versus discharge is termed a rating curve (Figure 19). This information is typically available at streamgage locations and can be developed at ungaged locations where a high water mark is recorded.

Rating curves are typically developed from discharge measurements collected at a cross-section over a period of time and at different stages, with a unique stage for each discharge value assuming a uniform flow condition, that is, the depth of flow is similar (uniform) and parallel to the channel bottom. While this condition may occur in constructed canals, it rarely occurs in natural stream channels because the discharge is a function of more than depth alone—for example, changes in channel shape and vegetation cover. For a given stage the discharge tends to be greater as the flood wave arrives and less as it passes, tracing a closed loop that is generally centered along the uniform flow rating curve, with the deviation from this curve caused primarily by the return of overbank flow to the main channel (Figure 20). This loop rating is most pronounced at cross-sections where flooding occurs across wide floodplains (Chow, 1959).

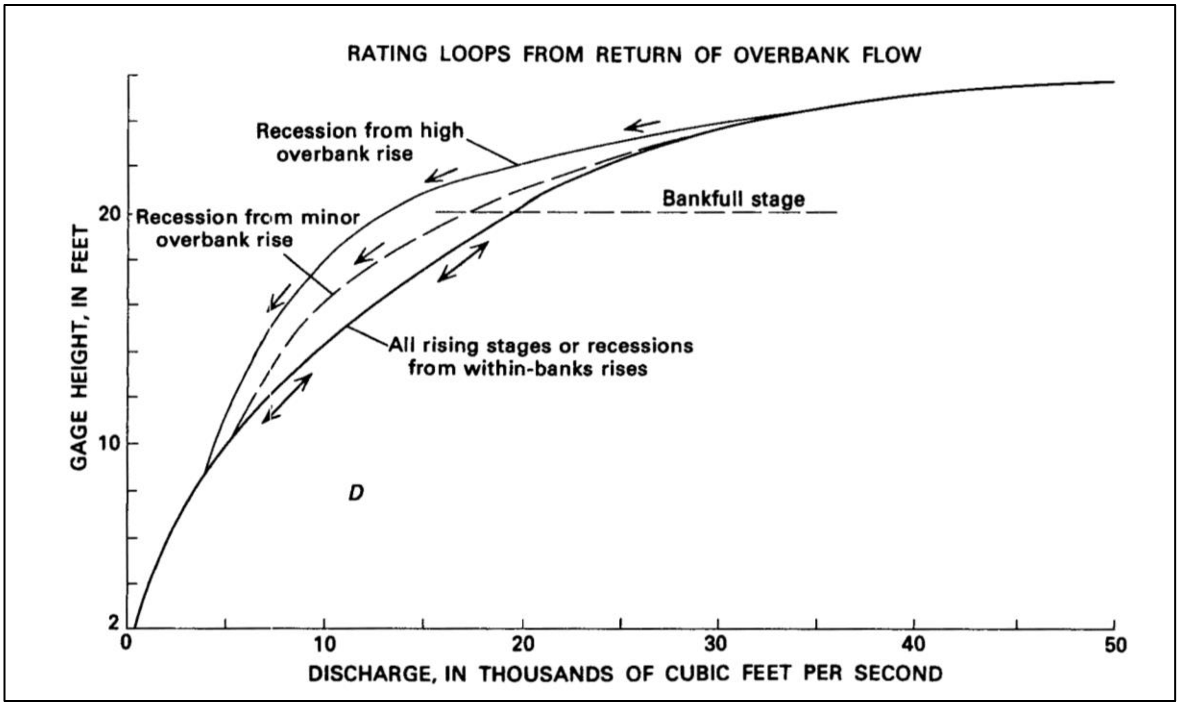


Figure 20- Uniform flow and loop rating curves. (Kennedy, 1984)

While there are theoretical methods to approximate the loop pattern, in practice a single relationship is developed and referenced for a cross-section. Besides the non-uniform flow of waters in a natural channel, other factors can affect the stage-discharge relationship and rating curve, such as dredging, alluvial (moving) channel conditions, variable backwater, aquatic vegetation, and ice.

This discussion is intended to illustrate the complexity of floodwater movement and the uncertainty involved in translating HWMs to stages and hence to discharges on natural stream systems. It is also intended to reinforce the need to understand the exact time during a flood event that a HWM is recorded and, in the absence of a recording streamgage, the added benefit of collecting multiple stage measurements during a flood event, if possible.

When using older HWMs to reconstruct a flood stage and estimate discharge, it is important to reference the rating curve in use at the time when the HWM was recorded, so that the potential need to reconstruct the hydraulic geometry of that stream reach can be identified. Where rating curves have been established at gage locations, repetitive streamflow measurements are made to check the stage-discharge relationship. If a subsequent measurement indicates a change in the rating—often due to a change in the streambed—the change or *shift* is applied mathematically as temporary adjustments to a defined rating. The shift adjustments are applied to the rating as streamflow measurement data become available, resulting in an adjusted rating. Some ratings may change as often as weekly, while others may not change for months or years. Ratings often change after flood events when stream channel and floodplain changes occur. Current shifted rating tables are available via the National Water Information System; however, historic rating tables are only available upon request from the USGS (Parham, 2013).

Changes to the stage-discharge relationship at a stream cross-section over time can be seasonal (associated with vegetation growth), episodic (dredging), or chronic (erosion or sedimentation). The long-term trend in these changes can be assessed by performing a specific gage analysis (Klingeman, 1973). The analysis involves compiling historic rating curves and tracking the stages (in relation to a common vertical datum) that are associated with specific discharges. This analysis assumes changes in streambed elevation over time and, if the date of a HWM is available, can identify the particular rating curve to reference to properly estimate a discharge and, in turn, the associated frequency of the historic flood event.

Figure 21 shows the results of a specific gage analysis of five discharge values for the South Fork Coquille River in Oregon from 1938 to 2010. The general decreasing trend in stage for the specific discharges indicates the long-term occurrence of channel incision and/or widening, while the periodic rise in stages coincides with historic flood events and may indicate a condition of short-term sediment deposition (Jones et al., 2012).

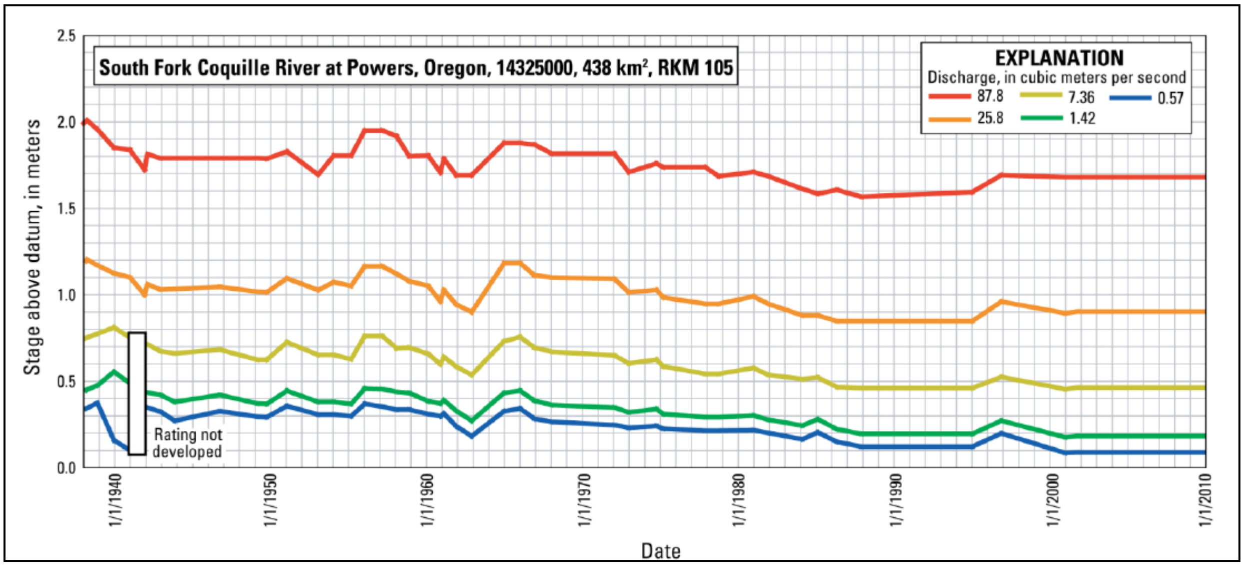


Figure 21 - Specific gage analysis. (Jones et al., 2012)

To summarize, flooding is a dynamic process characterized by a flood wave, and a high water mark is intended to capture the crest, or maximum, stage of that flood wave at a particular location along the stream system. This flood stage can be associated with a discharge through the application of a stage-discharge relationship, defined graphically as a rating curve. The estimation of discharge using HWMs from historic flood events should be done with knowledge of the exact time the HWM was observed, so that the proper stage-discharge relationship is referenced at gaged locations or reconstructed at ungaged locations.

5.4 Flood Frequency Definitions

The severity or *magnitude* of riverine flooding can be categorized several ways. The National Weather Service, for example, designates at its flood forecast locations severity categories of *minor*, *moderate*, and *major* based on societal impacts (National Weather Service, 2013). Perhaps the most common method for categorizing the magnitude of a flood in the United States is by either the recurrence interval or the annual exceedance probability. The recurrence interval (e.g. "100-year" flood) is the average interval of time within which the given event will be equaled or exceeded once (American Society of Civil Engineers, 1949). The annual exceedance probability (e.g. "one-percent annual chance" flood) is the reciprocal of the recurrence interval, and is defined as the probability that an event magnitude will be exceeded or equaled in a given year (Hodgkins et al., 2007). Because of potential confusion with the *recurrence interval* terminology, the USGS and other agencies are encouraging the use of an *annual exceedance probability* (AEP) instead (Holmes and Dinicola, 2010). A flood frequency analysis is used to assign AEPs to a range of flows at a given location on a stream. The Annual Exceedance Probabilities usually generated are the 10, 4, 2, 1, and 0.5 percent annual chance (which is equivalent to the 10, 25, 50, 100 and 500 year flood event). This involves analyzing the record of past annual hydrologic events to estimate future probabilities of occurrence.

5.5 Flood Frequency Analysis

A frequency analysis of hydrologic data from gaged locations is intended to assign the magnitude of an extreme event to a frequency of occurrence using probability distributions. Annual maximum (instantaneous peak) streamflows are selected as the hydrologic data and the logarithms of these values are fit to a Pearson Type III distribution, an annual exceedance probability distribution. The methods used for the analysis and plotting of flood frequency data follow Bulletin 17B guidelines (Interagency Advisory Committee on Water Data, 1982). One primary result of a flood frequency analysis is a plot of the flood frequency curve (Figure 22). The data are typically displayed on a semi-log plot with the annual exceedance probability as a percent on the x-axis and the annual peak discharges on a log y-axis. Upper and lower confidence limits are usually plotted to express the inherent uncertainty of the data.

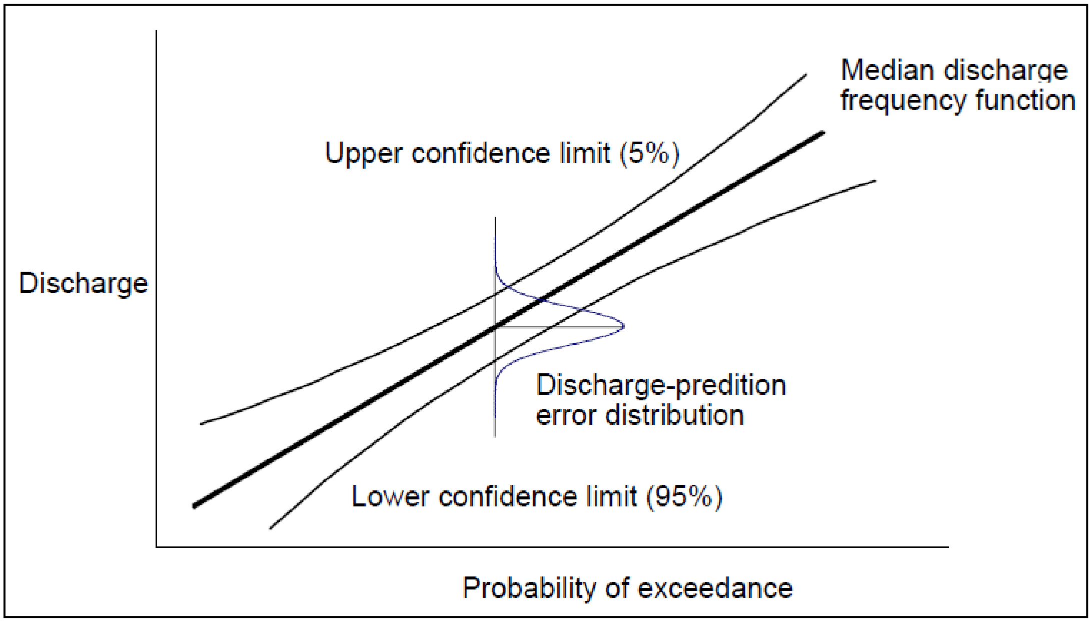


Figure 22- Flood frequency curve with uncertainty distributions. (Ford et al., 2008)

Flood frequency estimates at gaged sites can be regionalized (extended in space) to develop the same estimates at ungaged sites (U.S. Geological Survey, 2013). For ungaged locations, the USGS has published regional regression equations for every U.S. state for use in estimating streamflow statistics, including recurrence interval flood discharges.

The equations that form the most recent publication for each state are compiled in the National Streamflow Statistics (NSS) computer program. For many States, a web mapping application called StreamStats has been developed. This program is now incorporated into the USGS StreamStats web-based Geographic Information System (GIS) for many states (Koenig, 2013). StreamStats allows users to easily obtain streamflow statistics, drainage basin characteristics, and other information such as high water mark locations for user-selected sites on streams (Figure 23). For states that have not yet implemented StreamStats, the NSS program has made regional regression equations available for performing flood frequency analyses.

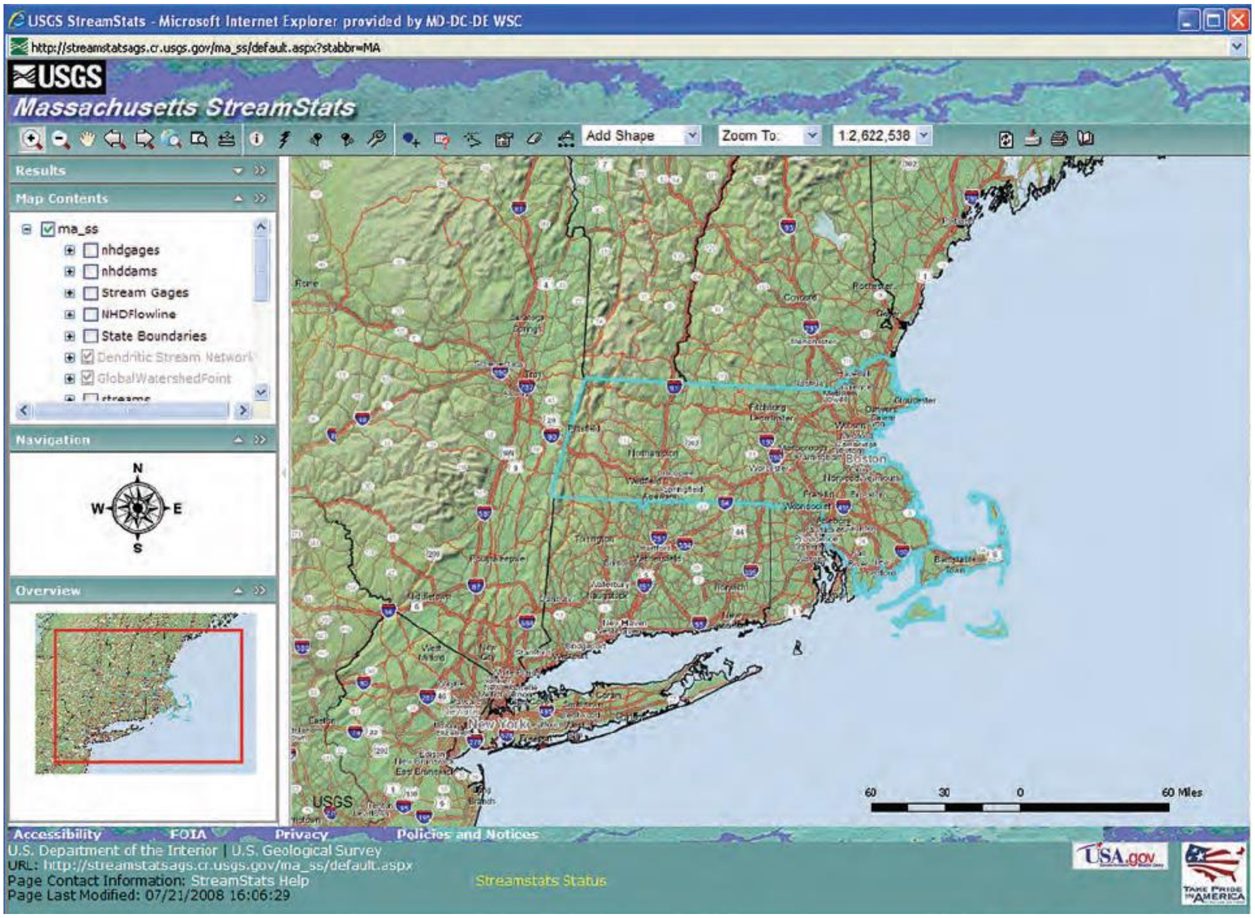


Figure 23- View of StreamStats interface for Massachusetts. (Ries et al. 2008)

6.0 ESTIMATION OF FLOOD FREQUENCY FOR HIGH WATER MARKS

6.1 Overview

Challenges in estimating the frequency for a flood event documented by a high water mark (HWM) are twofold. It includes the need to relate the HWM to a discharge, and the discharge in turn to a frequency, or annual exceedance probability. This approach is relatively straightforward where HWMs have been observed at or near a streamgage location; however, at ungaged locations the approach is more complicated.

6.2 Generalized and Detailed Approaches

A generalized approach for estimating the flood frequency for high water marks is shown in Figure 24. The remainder of this section describes the detailed approach, as summarized in the schematic in Figure 32.

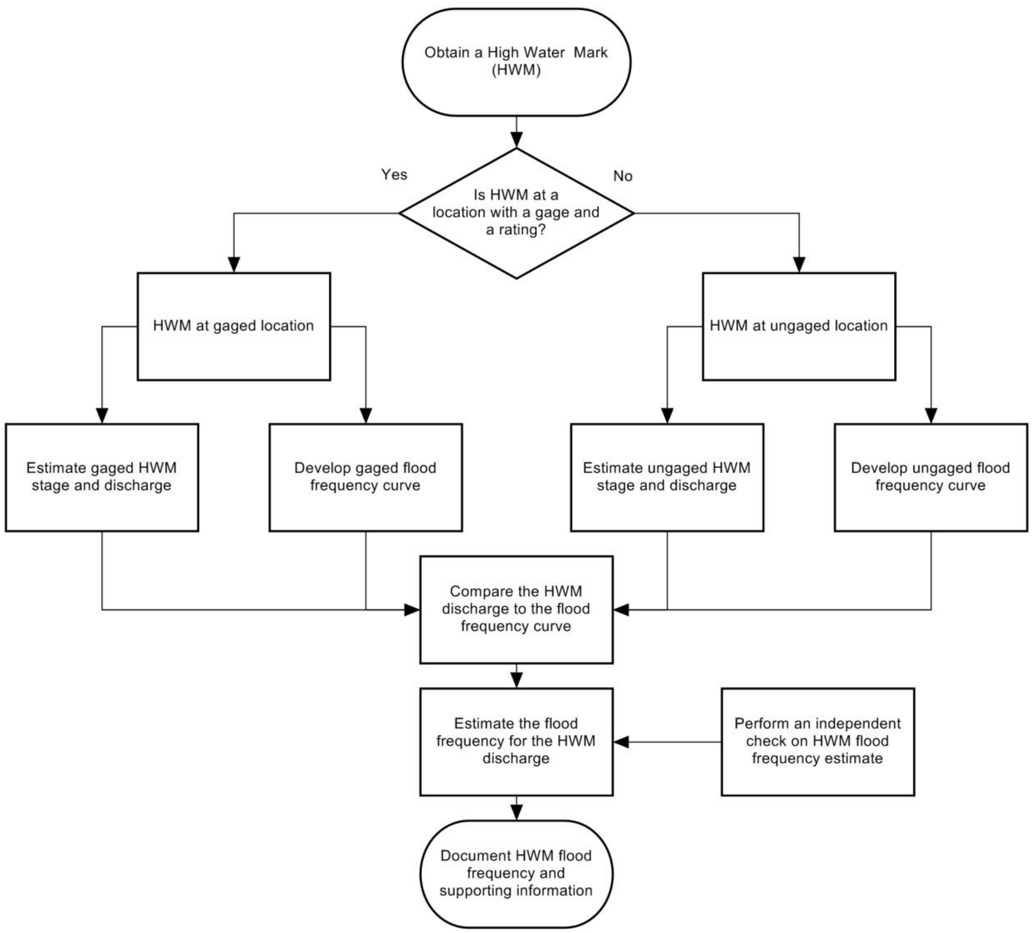


Figure 24- Generalized approach for estimating flood frequencies of a HWM.

Obtain a HWM

The sources of HWMs and their associated characteristics and quality have been discussed in Section 4.0. Of most importance is to understand the location, type, age and quality of the HWM.

Associate the HWM to a Gaged or Ungaged Location

If possible, HWMs should be obtained at or near streamgages with a current rating. The uncertainty associated with a flood frequency estimate for a HWM increases significantly without the benefit of a direct stage-discharge relationship. The next two sections provide guidance for estimating discharges and flood frequency curves at both gaged and ungaged HWM locations.

Estimate Stage and Discharge for a HWM at Gaged or Ungaged Location

As previously mentioned, this is a two-step process in which the flood stage indicated by a HWM is associated to a discharge through the application of a stage-discharge relationship, defined graphically as a rating curve. Depending on the location of a HWM and available data resources, the discharge associated with the HWM in some instances may be easy to obtain with a high degree of accuracy; when it is not, estimates obtained are subject to substantial error.

The age of the HWM is important for associating the stage at that mark to the channel-floodplain geometry. If the HWM was obtained during a recent flood event, the current rating curve from a gaged location can usually be used for estimating the HWM stage. Otherwise, a field survey can be conducted along an ungaged stream reach to establish the channel-floodplain geometry and HWM stage. If the HWM is associated with a historic flood event, its timestamp should be referenced to identify the proper historic gage rating curve to use. In the case of a HWM on an ungaged stream reach, the proper historic channel-floodplain geometry and/or hydraulic conditions should be reconstructed. For example, if the flood frequency of a historic HWM is desired on an ungaged stream reach where a setback levee project has been built since the flood of interest, the construction of the historic rating curve should be done with the levee located in its previous alignment. The time of day during which a HWM is obtained may be important also. For example, if the HWM is on a stream reach affected by variable dam releases, the regulated discharge at the time it was obtained should be considered in reconstructing the stage-discharge relationship and rating curve.

Methods that can be used to estimate the discharge associated with a HWM using streamgage information include the following:

Active continuous streamgage – The U.S. Geologic Survey (USGS) maintains a network of more than 8,000 streamgages across the nation. Most streamgages provide continuous records of both stage (referred to as *gage height* when stage is referenced to the streamgage vertical datum) and streamflow. Streamflow is computed from a unique rating for each gage. (A rating is a relation between gage height and discharge developed over time through streamflow measurements taken over a range of gage heights.) If a HWM is located relatively close to a streamgage, it may be possible to make a reliable estimate of the peak discharge associated with it based on the computed discharges at the streamgage. The USGS disseminates streamflow data through a number of outlets, which include:

- Provisional real-time data on the web
- Instantaneous streamflow data from the Instantaneous Data Archive
- Annual peak-flow data from the USGS National Water Information System, and
- A customized rating curve builder available at the USGS Water Watch website.

Crest-stage gage – If the HWM is in the vicinity of a crest-stage gage (CSG), the rating for that CSG could be used to compute the streamflow for the mark if the mark is referenced to the gage datum.

Discontinued streamgage or crest-stage gage location – There are many discontinued (inactive) streamgages and CSG sites across the nation. Even when a site is inactive, if the mark can be referenced to the gage datum, it may be possible to use a previously-used rating from that site to estimate the streamflow associated with a HWM. However, it should be emphasized ratings are dynamic and can change drastically, particularly following large floods. The USGS keeps ratings current at active streamgages through frequent measurements of streamflow across a range of stages. For discontinued stations, the USGS is likely not maintaining a current rating through recent measurements, thus there is a potential for larger errors in the rating.

Methods that can be used to estimate the discharge associated with a HWM on an ungaged stream reach include the following, presented in order of increasing uncertainty in results:

Indirect measurements of streamflow – The USGS has developed methods for making *indirect* measurements of streamflow, which depend upon setting HWMs in specific locations at the measurement site. Indirect determinations of streamflow make use of the energy and continuity equations for computing flow; specific forms of these equations vary by the type of flow, such as unobstructed open-channel flow and flow through culverts and bridge openings (Rantz et al., 1982). The data required for the computation of streamflow by indirect methods are obtained in a field survey that, depending on the method, includes the elevation and location of HWMs corresponding to the peak stage, cross-sections of the channel along the reach, selection of roughness coefficients, and description of the geometry of structures such as culverts or bridges (Rantz et al., 1982). Brief descriptions of four indirect streamflow measurements are provided below (Morlock et al., 2008). Detailed descriptions can be found in Bodhaine (1968), Dalrymple et al. (1967), Davidian (1984), and Matthai (1967).

- In the contracted-opening method, the abrupt drop in water surface elevation between a bridge approach section and the contracted section under the bridge is used to compute flow.
- In the culvert method, the peak flow through a culvert can be determined from HWMs that define the culvert headwater and tailwater elevations.
- In the slope-area method, flow is computed on the basis of a uniform-flow equation involving channel characteristics, water surface profiles, and a roughness coefficient.
- In the step-backwater method, computer models are used to compute the water surface elevation at a series of stream cross-sections for a specific value of flow. Model input parameters include cross-section geometry, roughness coefficients, bridge configuration data (bridge opening geometry and roadway elevations) for modeled reaches with bridges, water surface elevation at the cross-section furthest downstream, and streamflow. Streamflow is determined by inputting flow values iteratively until water surface elevations at model cross-sections match surveyed HWM elevations.

Drainage-area ratio estimation method – This method assumes that the streamflow at an ungaged site is the same (per unit area) as that at a nearby, hydrologically similar streamgaging station, and is used for transferring known flow values from one point to a location where flow is unknown (Mann et al., 2004). An equation for calculating streamflow from this method is $Qug = Qg \times (Aug/Ag)$, where *Qug* is the streamflow at the ungaged location, *Qg* is streamflow at the gaged location, *Aug* is the drainage area above the ungaged location, and *Ag* is the drainage area above the gaged location. This method is generally best used for transferring flows within the same drainage basin. The USGS StreamStats program includes an *Estimate Flows Based on Similar Gages* tool that performs this computation along the same stream; however, the California State Water Resources Control Board (SWRCB) also uses the method for transferring flows from one basin to another by incorporating a precipitation index into the drainage area ratio equation: *Qug = Qg x (Aug/Ag) x (Iug/Ig)*, where *Iug* is the mean annual precipitation above the ungaged site and *Ig* is the mean annual precipitation above the gaged site (Mann et al., 2004). Using this method, a range of discharges from a gaged site can be transferred to the ungaged HWM location to develop a rating curve, using the third or fourth indirect method described above, against which the stage of the HWM can be compared to estimate the discharge.

Hydrologic methods – These methods involve the use of precipitation-runoff estimates in simple equations or numerical models. In a manner similar to the drainage-area ratio estimation method, discharges are estimated for the ungaged HWM location by simulating the precipitation-runoff process for a range of precipitation events. The result is a range of discharges that can be used to develop a rating curve, against which the stage of the HWM can be compared to estimate the discharge.

- The rational method is a simple rainfall-runoff equation designed for estimating peak flows in small (less than one square mile) drainage basins (Bedient and Huber, 1992). The rational equation is defined as: *Qpeak = C x I x A*, where *Qpeak* is peak flow (ft3/sec), *C* is a dimensionless runoff coefficient less than or equal to one, *I* is rainfall intensity (inches per hour), and *A* is watershed area (acres) above the point of interest.
- Streamflow estimation from a precipitation-runoff model is a technique that can simulate streamflow at a point for a given precipitation amount based on the drainage area above that point and hydrologic factors in the watershed such as antecedent conditions. Recent advances in models and in hydrologic data could improve the accuracy of streamflow estimates from hydrologic models. Models can now take advantage of a wealth of Geographic Information Systems (GIS) based data such as high-resolution ground elevation data and soil and vegetation composition data.

Develop a Gaged or Ungaged Flood Frequency Curve

At gaged locations, annual peak discharge data for USGS streamgages are maintained in the National Water Information System (NWIS) database. These data can be input to the USGS PeakFQ program, which calculates annual maximum peak flows for annual exceedance probabilities (AEPs) from 50-percent to 0.2-percent. Output from the PeakFQ program establishes the relationship of AEPs to discharge (Figure 25).

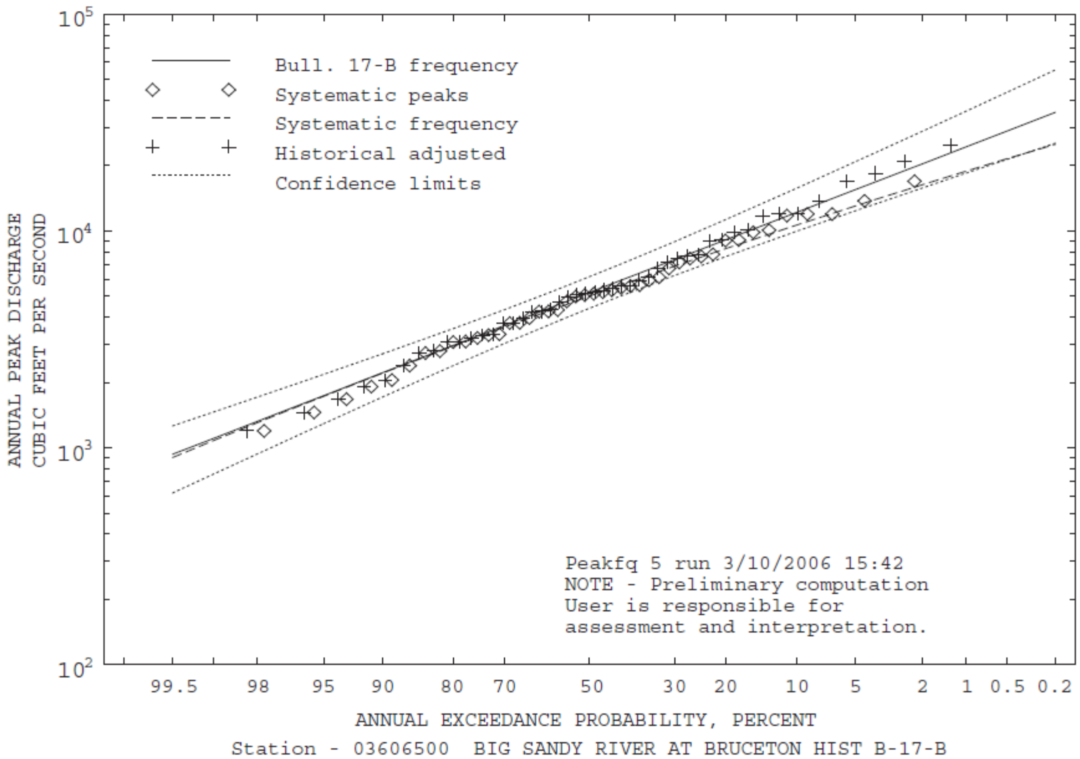


Figure 25- PeakFQ flood frequency curve output. (Flynn et al., 2006)

For HWMs on ungaged stream reaches, the specific location of a HWM with respect to the state, hydrologic region, and watershed in which it lies are important to know for the use of the USGS StreamStats application. StreamStats is intuitive and relies on an input location from which estimates of peak flow statistics are made. The HWM location is identified on a map in StreamStats and the tributary watershed will be delineated in purple from this user-selected point—shown as a dark blue circle with a red cross behind it in the upper right corner in Figure 26. A streamgage is indicated by a red diamond, while dams are blue pentagons.

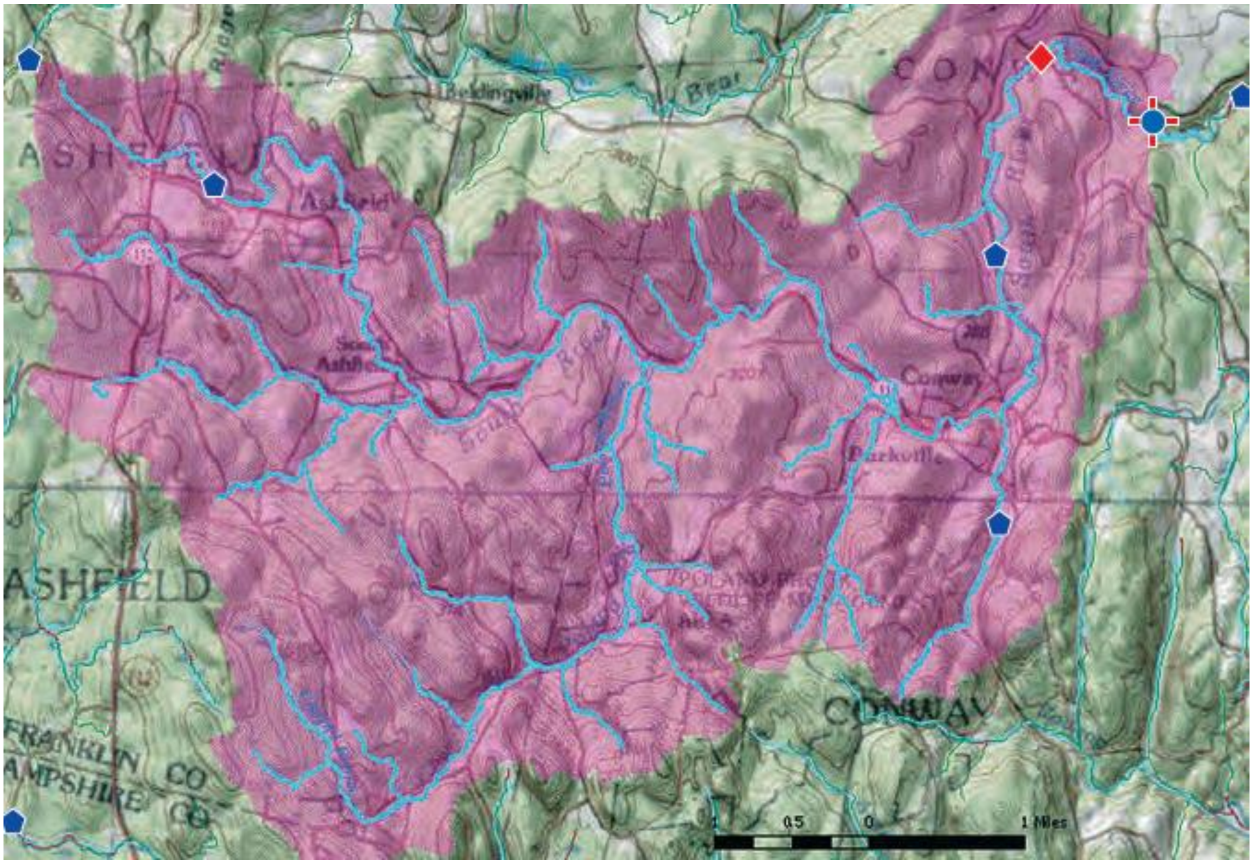


Figure 26- Example of USGS StreamStats watershed delineation. (Ries et al., 2008)

StreamStats then provides the necessary basin characteristics for use in regression equations (Figure 27). The application then solves the regression equations appropriate for the area to estimate peak flow statistics.

Regression Equations

The USGS has developed equations to estimate peak-flow frequency statistics, such as the 100-year flood, for ungaged sites in every state. Regression equations also have been developed to estimate other types of streamflow statistics for many states. As an example, the equation for estimating the 100-year flood for ungaged sites in part of northern Idaho is:

$$Q_{100} = 5.39\ DA^{0.874}(E/1{,}000)^{-1.13}\ P^{1.18}$$

where

- **Q_{100}** is the peak flow that occurs, on average, once in 100 years (1-percent chance of occurrence in any year), in cubic feet per second;
- **DA** is the drainage area, in square miles;
- **E** is the mean basin elevation, in feet; and
- **P** is the mean annual precipitation, in inches.

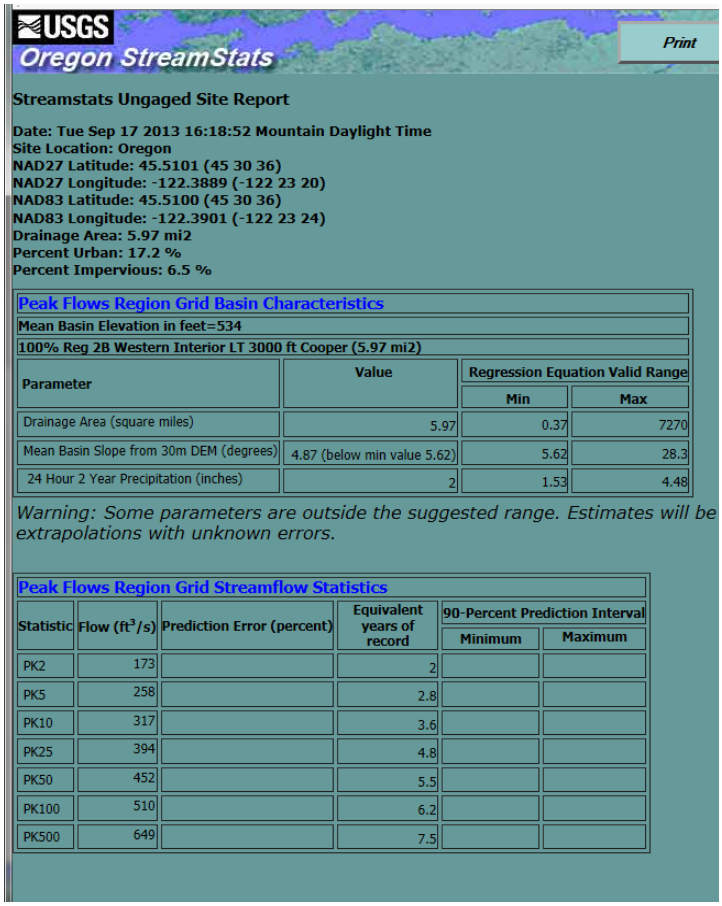
Reference

Berenbrock, Charles, 2002, *Estimating the magnitude of peak flows at selected recurrence intervals for streams in Idaho: U.S. Geological Survey Water-Resources Investigations Report 02–4170, 59 p.*

Figure 27- Description of regression equations for streamflow statistics.

The regression equation shown in figure 27 was developed for Idaho using the streamgages and land cover data in that region of the state. By comparing the regression equation results at streamgage locations with real historic gage numbers the degree of uncertainty associated with the results can be determined. As an example, for the state of Idaho, the average errors of prediction for the regression equations developed for the regions in the state range from +143 percent to 58.8 percent (Berenbrock, 2002). While this amount of uncertainty is significant, it is less uncertain than flood flow estimates where no historic documented flood flows are available to quantify the amount of uncertainty. It is important to document the uncertainty associated with the flood frequency estimate for the flood event that created the HWM. This information can then be appropriately compared with the uncertainties associated with other methods used to estimate the flood frequency of the flood event.

StreamStats can generate a range of peak flow statistics from the 2-year (PK2) (50% AEP) flood event to the 500-year (PK500) (0.2% AEP) flood event (Figure 28). These tabular values can be plotted as a flood frequency curve for the ungaged location of the HWM.


USGS
Oregon StreamStats
Print

Streamstats Ungaged Site Report

Date: Tue Sep 17 2013 16:18:52 Mountain Daylight Time
Site Location: Oregon
NAD27 Latitude: 45.5101 (45 30 36)
NAD27 Longitude: -122.3889 (-122 23 20)
NAD83 Latitude: 45.5100 (45 30 36)
NAD83 Longitude: -122.3901 (-122 23 24)
Drainage Area: 5.97 mi2
Percent Urban: 17.2 %
Percent Impervious: 6.5 %

Peak Flows Region Grid Basin Characteristics

Mean Basin Elevation in feet=534

100% Reg 2B Western Interior LT 3000 ft Cooper (5.97 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	5.97	0.37	7270
Mean Basin Slope from 30m DEM (degrees)	4.87 (below min value 5.62)	5.62	28.3
24 Hour 2 Year Precipitation (inches)	2	1.53	4.48

Warning: Some parameters are outside the suggested range. Estimates will be extrapolations with unknown errors.

Peak Flows Region Grid Streamflow Statistics

Statistic	Flow (ft^3/s)	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
PK2	173		2		
PK5	258		2.8		
PK10	317		3.6		
PK25	394		4.8		
PK50	452		5.5		
PK100	510		6.2		
PK500	649		7.5		

Figure 28- Example of USGS StreamStats peak flow statistics.

Basin Comparison Analysis

A basin comparison analysis is often conducted to reduce the uncertainty associated with USGS regression equation and StreamStats results. The basin comparison process involves comparing the results for a basin with no gage to streamgage data in basins that have similar shapes, drainage areas, slopes and land cover characteristics. This helps increase the confidence that the results are adequate to for input into hydraulic engineering models used to develop flood inundation maps.

Estimate a Flood Frequency for the HWM Discharge

For high water marks associated with either gaged or ungaged locations, once both the discharge and the respective flood frequency curve have been estimated, assigning a flood frequency for that discharge is relatively simple. The discharge associated with the HWM can be entered on the y-axis of a flood frequency plot and intersected with the curve to estimate the AEP, on the x-axis, of the flood event documented by the HWM (Figure 28).

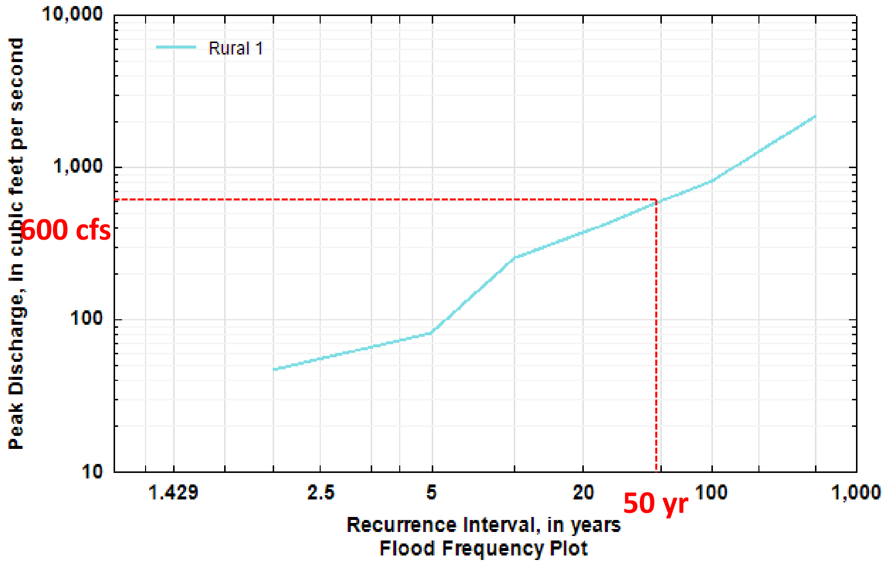


Figure 29- Example of a flood frequencyplot.

Perform an Independent Check

It is always a good practice to perform an independent check on the high water mark annual exceedance probability estimated by the methods described above. Data sources for an independent check will vary widely depending on the geographic location, flood history, and other factors associated with the HWM. A good starting point would be other federal, state, or local agencies with water resources and flood management responsibilities.

Pertinent data from state and federal agencies is summarized as follows:

- Federal Emergency Management Agency (FEMA) – For the most populated areas of the U.S., FEMA has prepared maps depicting one-percent AEP floodplains (the "regulatory" floodplain) and in some areas 0.2% AEP floodplains, while associated flood insurance study reports and computer models typically have profiles and tabular data for the 10%, 2%, 1%, and 0.2% AEPs along stream reaches that have been studied. These maps have been approved and adopted by the community and are the basis of land use management decisions in the community.

  FEMA flood information has been made available as geospatial datasets in recent years with the development of the National Flood Hazard Layer (NFHL), which can be accessed through the FEMA Map Service Center (MSC) website. Once the location and elevation of a HWM has been established, FEMA supporting data can be referenced to determine if it falls within a 1% or 0.2% AEP mapped floodplain and a refined estimate of the HWM AEP can be obtained.

  It is important to review the flood insurance study associated with flood information obtained from the NFHL. The flood insurance study will contain information on the data used in the hydrologic analysis and state whether the modeling was calibrated using historic HWMs. If the modeling was not calibrated, the FEMA flood hazard mapping cannot be used as an independent check. It is important to note the age of hydrologic data in the flood insurance study because the hydrologic data used in flood frequency analyses may be significantly older than the effective date on the published flood map and flood insurance study report.

- U.S. Army Corps of Engineers (USACE) – The USACE may have data that supplements FEMA data. One example is the post-flood reports the agency prepares after significant flood events in the U.S. These reports may have information that can be used to check HWM AEP estimates in the USACE reports against the FEMA data.

- Natural Resources Conservation Service (NRCS) – The NRCS compiles and publishes soils data for the U.S. This data may include estimates of flood frequency classes for mapped soil units in the vicinity of a water body where a HWM was documented. NRCS flood frequency classes include: *Very Rare* (0.2% to 1% AEP), *Rare* (1% to 5% AEP), *Occasional* (5% to 50% AEP), and *Frequent* (more than 50% AEP) (Figure 30). The location of a HWM and the lateral projection of the flood stage it identifies may coincide with soils units having a designated flood frequency class, which can then be compared to the AEP previously estimated for the HWM. As stated in Section 4, the use of soils data for floodplain mapping purposes remains a novel approach and should be applied with diligence; however, several applications have been made in recent years (Coulton, 2013; Merwade and Sangwan, 2012). Merwade and Sangwan performed a detailed analysis comparing floodplain maps derived from NRCS Soil Survey Geographic (SSURGO) soil data with FEMA-derived FIRMs in relation to some recently observed flood events in Indiana, Washington, Minnesota and Wisconsin. Sangwan found that many of the SSURGO-derived floodplain maps correspond to a flood with a recurrence interval between 75 and 100 years. In addition, there is a 75-80% overlap between SSURGO floodplain maps and FEMA Flood Insurance Rate Maps (FIRMs) in the study areas.

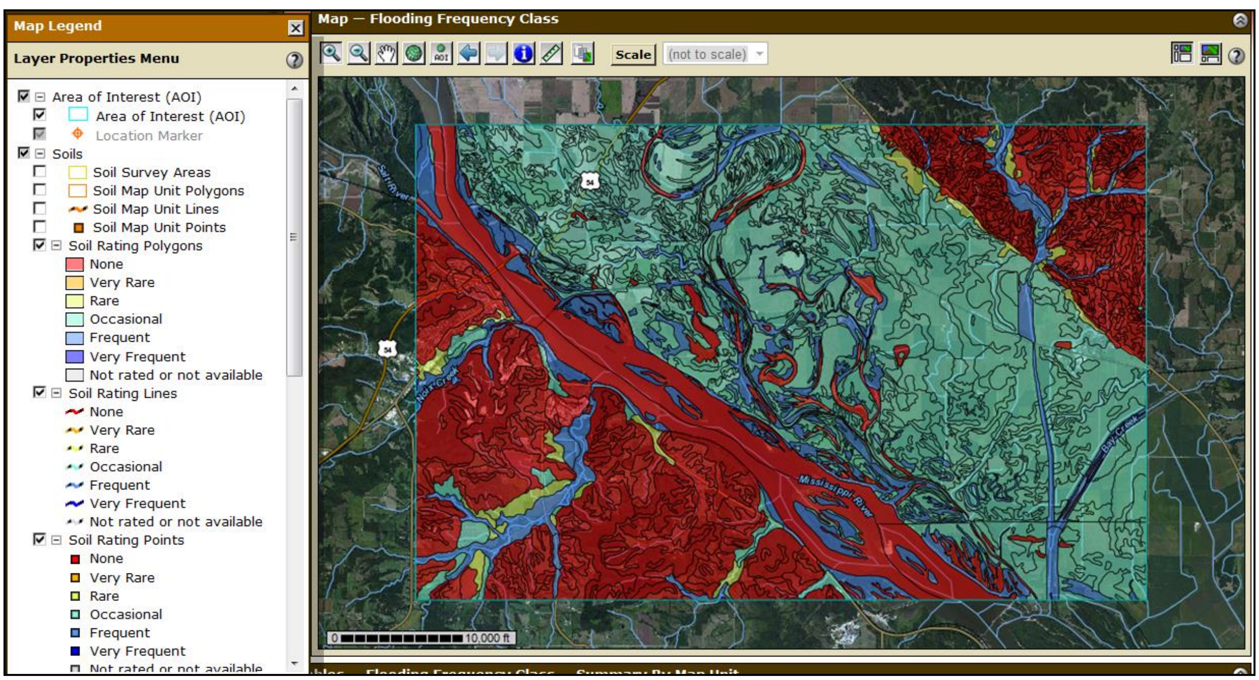


Figure 30- Example of NRCS soil map showing flood frequency. (Hoover, 2013)

- States and authorities/basin commissions - States and authorities/basin commissions have a long history of generating data on flood elevations. Many routinely collect high water marks and have regulatory processes in place for the review and approval of flood discharge frequency determinations.

Historic flood inundation maps

Historic flood inundation maps developed from aerial photography or satellite imagery can also be useful if the frequency of the flood event can be established. An example is shown in figure 31.

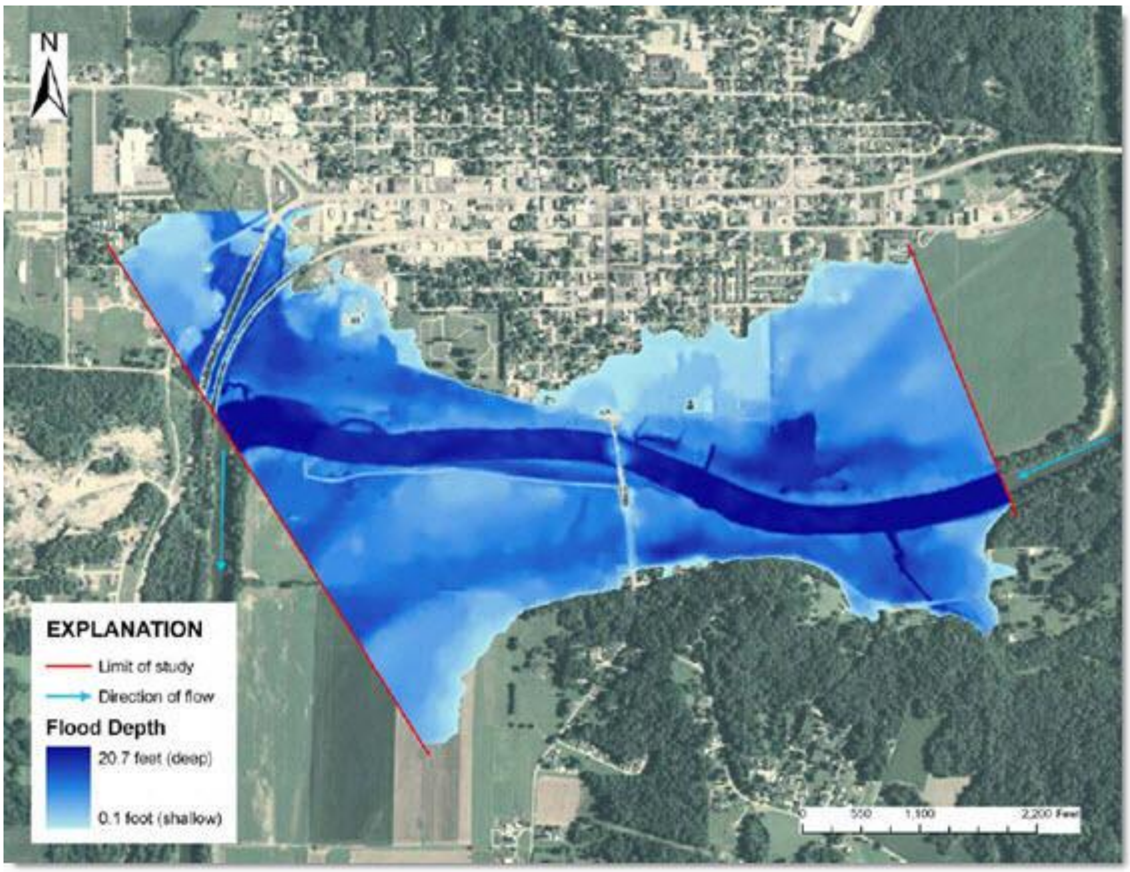


Figure 31 - Inundation map flooding of June 2008 for the White River at Spencer, Indiana (Source:USGS)

As stated previously, it is important to know the date of the flood event and associated HWM. If the age of the data being used for an independent check coincides with the historic flood of interest or otherwise falls within the same time period, then these data should be considered as a primary reference for estimating the HWM AEP.

Document the Process

As a final step, the process used to estimate a flood frequency for a high water mark should be documented so that the data, assumptions, limitations and uncertainty associated with the estimate can be clearly expressed to others. It is recognized that the specific method used may vary significantly in different situations, thus a prescriptive documentation procedure is not warranted here. However, the generalized and detailed approaches presented in this report (Figures 24 and 32) should be considered as an outline for reporting, as applicable.

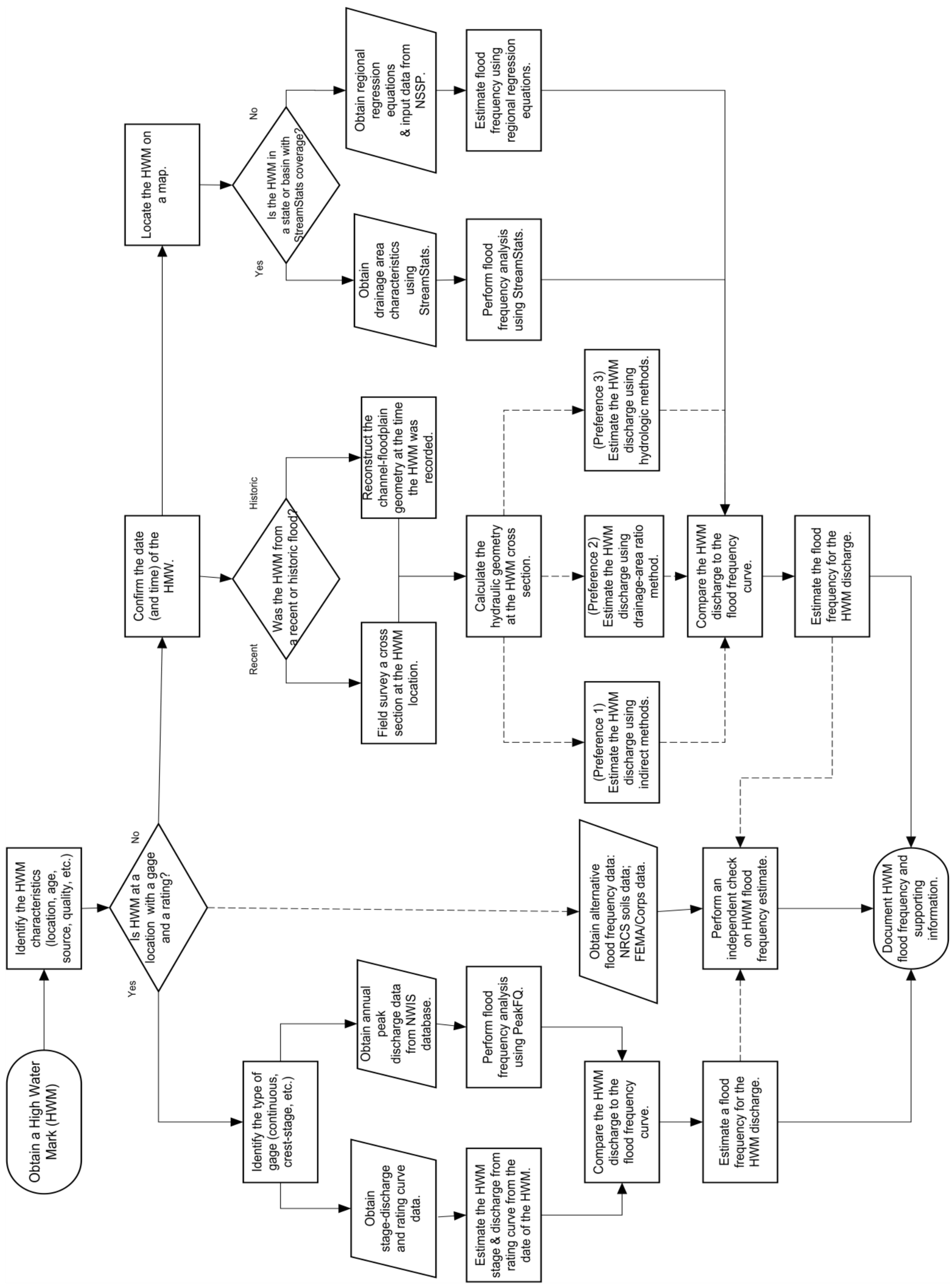


Figure 32- Detailed approach for estimating flood frequency of a HWM

7.0 RECOMMENDATIONS

The interviews of personnel at agencies responsible for collecting high water mark (HWM) data across the country identified several recommended best practices for computing or estimating flood frequencies associated with documented flood events on gaged and ungaged streams. These best practices facilitate the most effective collection of information to be used in conveying flood risk to a given community. The recommendations gathered can also help communities to understand the uncertainties inherent in streamflow estimation. Other detailed recommendations for the acquisition, assessment, and documentation of HWMs are provided throughout this report, while Section 6 provides a recommended approach for using HWMs to assign a flood frequency for a flood event documented by a HWM.

From a larger perspective, several broad recommendations are provided to improve the understanding and acquisition of HWMs and their use in strategies to estimate the frequency of flood events in the absence of streamgage data. The recommendations are as follows:

1. A nationwide geospatial database for archiving high water mark data and making it available to the public should be developed. This may be a single steward for a state (such as USGS) or a state effort (such as the Texas Natural Resources Information System) working with local and regional partners. When possible HWM data collected by a state or local partner should be incorporated into the national system (similar to data furnished by partners that is incorporated into the National Water Information System). For optimal accessibility, these geospatial HWM data should include referencing links to the U.S. Geologic Survey (USGS) National Hydrologic Dataset[2]. If a flood frequency has been established for a documented HWM archived in the system, the flood frequency should be stored as an attribute of the HWM.
2. Guidance materials on methods to estimate the flood frequency for high water marks at a given site should be made available with any High Water Mark database developed. This guidance should include standard templates for documenting methods used to estimate the flood frequency for HWMs at a given site. This information should be available to system users.
3. Training associated with collecting high water mark data should be provided to federal, state and local entities that are collecting or are interested in collecting high water marks. This training should provide information on the standard workflows and attributes that have been developed by the USGS and state agencies responsible for collection of HWMs. The training should include a workflow for delivery of the HWM data to appropriate state or federal agencies maintaining high water mark data so that it can be appropriately integrated.
4. Training should be provided to state and local officials to foster understanding of generalized approaches to estimating and understanding uncertainty in flood frequency estimates and how HWMs can be used to reduce this uncertainty. This training should include information on the importance of maintaining and enhancing the nation's streamgage network to enable the assignment of flood frequencies to HWMs.

[2] The National Hydrologic Dataset is a geospatial framework provides a comprehensive inventory of water surface features with a data structure that enables flow analysis and a continuous maintenance process through stewardship that allows geospatial datasets associated with surface water to be integrated and cross referenced.

REFERENCES

Bedient, P. B. and Huber W. C. 1992. "Hydrology and Floodplain Analysis", 4th Ed. Prentice-Hall ... Publishing Co., Inc., Lancaster, PA *1992*, 188 pp.

Benson, M.A. and T. Dalrymple. 1984. General Field and Office Procedures for Indirect Discharge Measurements, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3: Applications of Hydraulics. U.S. Government Printing Office, Washington, D.C. 30 pages.

Berenbrock, C. 2002, Estimating the magnitude of peak flows at selected recurrence intervals for streams in Idaho: U.S. Geological Survey Water-Resources Investigation Report Report 02-4170, 59 p.

Bodhaine, G.L. 1968. Measurement of peak discharge at culverts by indirect methods, U.S. Geological Survey. 60 pages.

Bürger, K., Dostal, P., Seidel, J., Imbery, F., Barriendos, M., Mayer, H., et al. 2006. Hydrometeorological reconstruction of the 1824 flood event in the Neckar River basin (southwest Germany). *Hydrological Sciences Journal* 51(5): 864–877. Taylor & Francis, London.

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Company, New York.

Cleaves, E. T. and Doheny, E. J. 2000. *A Strategy for a Stream-Gaging Network in Maryland.* Maryland Geologic Survey, Annapolis, Maryland.

Coulton, K.G. 2013. Mapping "Natural" Floodplains: An Engineering Perspective. Wetland Mapping Consortium, Association of State Wetland Managers, September 17, 2013. Retrieved November 23, 2013 from Association of State Wetland Managers: http://www.aswm.org/pdf_lib/mapping_webinar/coulton_nffa_natural_floodplain_091713_1.pdf

Dalrymple, Tateand M.A. Benson. 1967. Measurement of peak discharge by the slope-area method.Techniques of Water Resources Investigations. Book 3, Chapter A2 US Geological Survey

Davidian, Jacob. 1984. "Computation of Water-Surface Profiles in Open Channels," Book 3, Chapter A15, Techniques of Water-Resources Investigations of the U.S. Geological Survey, USGS, Alexandria, Virginia.

Federal Emergency Management Agency. 2001. "Modernizing FEMAs flood hazard mapping program – A progress report."

Federal Emergency Management Agency. 2013. *Hurricane Isaac in Lousiana: Building Performance Observations, Recommendations, and Technical Guidance.*

Fenske, J. 2003. *Application of Paleohydrology to Corps Flood Frequency Analysis.* Davis, California: U.S. Army Corps of Engineers.

Flynn, K.M., Kirby, W.H., and Hummel, P.R. 2006. User's Manual for Program PeakFQ Annual Flood-Frequency Analysis Using Bulletin 17B Guidelines, U.S. Geological Survey Techniques and Methods, Book 4 Chapter B4. 42 pages. Retrieved November 21, 2013 from U.S. Geological Survey: http://pubs.usgs.gov/tm/2006/tm4b4/tm4b4.pdf

Ford, D., Pingel, N., and DeVries, J.J. 2008. Hydrologic Modeling System HEC-HMS Applications Guide. U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, California. 116 pages. March 2008.

Hester, G., Carsell, K., and Ford, D. 2006. Users and Uses of USGS Streamflow Data. Report of the National Hydrologic Warning Council. 17 pages.

Hester, G., Ford, D., Carsell, K., Vertucci, C., and Stallings, E. 2006. Flood Management Benefits of USGS Streamgaging Program. Report of the National Hydrologic Warning Council. 48 pages.

Hodgkins, G.A., Dudley, R.W., Aichele, S.S., 2007. Historical changes in precipitation and streamflow in the US Great Lakes basin, 1915–2004. Scientific Investigations Report 2007-5118. US Geological Survey, Reston, VA, pp. 37

Interagency Advisory Committee on Water Data. 1982. Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee. U.S. Geological Survey, Reston, Virginia. 194 pages.

Holmes, Jr., R.R. and Dinicola, Karen. 2010. 100-Year Flood—It's All About Chance, U.S. Geological Survey General Information Product 106, 4 p. http:// http://pubs.usgs.gov/gip/106/

Jones, K.L, O'Connor, J.E., Keith, M.K., Mangano, J.F., and Wallick, J.R. 2012. Preliminary assessment of channel stability and bed-material transport in the Coquille River basin, southwestern Oregon, U.S. Geological Survey Open-File Report 2012–1064. 84 pages. Retrieved September 21, 2013 from U.S. Geological Survey: http://pubs.usgs.gov/of/2012/1064/

Kennedy, E.J. 1984. Discharge Ratings at Gaging Stations, Chapter A10, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3: Applications of Hydraulics. U.S. Government Printing Office, Washington, D.C. 71 pages. Retrieved November 21, 2013 from U.S. Geological Survey: http://pubs.usgs.gov/twri/twri3-a10

Klingeman, P.C. 1973. Indications of streambed degradation in the Willamette Valley, Water Resources Research Institute Report WRRI–21. Oregon State University Department of Civil Engineering, Corvallis, Oregon. 99 pages.

Koenig, T. 2013. Personal telephone communication with Kevin Coulton. USGS Office of Surface Water, Rolla, Missouri, September 17, 2013.

Leopold, L. 1994. *A View of the River*. Cambridge, MA: Harvard University Press. 298 pages.

Lumia, R., Burke, P. M., and Johnston, W. H. 1987. Flooding of December 29, 1984 Through January 2, 1985 in Northern New York State, with Flood Profiles of the Black and Salmon Rivers. U.S. Geological Survey, Albany, New York.

Mann, M.P., Rizzardo, Julé, and Satkowski, Richard, 2004, Evaluation of methods used for estimating selected streamflow statistics, and flood frequency and magnitude, for small basins in north coastal California: U.S. Geological Survey Scientific Investigations Report 2004-5068, 92 p.

Mastin, M. C., Gendaszek, A. S., and Barnas, C. R. 2010. Magnitude and Extent of Flooding at Selected River Reaches in Western Washington, January 2009. U.S. Geological Survey, Reston, Virginia.

Matthai, H.F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A15, 48p.

Matthai, H.F. 1969. Floods of June 1965 in South Platte River Basin, Colorado, Geological Survey Water-Supply Paper 1850-B. U.S. Government Printing Office, Washington, D.C.

McTigue, N. E. and Symons, J. M. (eds.). 2010. *The Water Dictionary: A Comprehensive Reference of Water Terminology*, 2nd ed. Denver, CO: American Water Works Association.

Merwade, V. and N. Sangwan. 2012. Delineating floodprone areas in Indiana using SSURGO and DEM. Indiana Association for Floodplain and Stormwater Management Annual Conference, Nashville, IN, September 2012.

Morlock, S. E., C. D.Menke, D. V. Arvin, and M. H.Kim. 2008. "Flood of June 7–9, 2008, in central and southern Indiana." U.S. Geological Survey Open File Report 2008–1322, 15 pp., 3 app.

National Research Council. (2009). *Mapping the Zone: Improving Flood Map Accuracy.* Washington DC: National Academies Press.

Parham, J. 2013. Personal email communication with Kevin Coulton. USGS Oregon Water Science Center, Portland, Oregon, September 17, 2013.

Rantz, S.E. and others. 1982. Measurement and Computation of Streamflow:Volume 2. Computation of Discharge, Geological Survey Water-Supply Paper 2175.

Ries, K.G., Guthrie, J.D., Rea, A.H., Steeves, P.A., and Stewart, D.W. 2008. StreamStats: A Water Resources Web Application, USGS Fact Sheet FS 2008-3067. U.S. Geological Survey West Trenton Publishing Service Center, Trenton, New Jersey. Retrieved November 22, 2013 from U.S. Geological Survey: http://pubs.usgs.gov/fs/2008/3067/

Ries, K.G., Steeves, P.A., Guthrie, J.D., Rea, A.H., and Stewart, D.W. 2009. Stream-Network Navigation in the U.S. Geological Survey StreamStats Web Application, 2009 International Conference on Advanced Geographic Information Systems & Web Services. Retrieved November 23, 2013 from U.S. Geological Survey: http://water.usgs.gov/osw/streamstats/talks.html

Rydlund, P.H., Jr., and Densmore, B.K., 2012, Methods of practice and guidelines for using survey-grade global navigation satellite systems (GNSS) to establish vertical datum in the United States Geological Survey: U.S. Geological Survey Techniques and Methods, book 11, chap. D1, 102 p. with appendixes.

Texas Natural Resources Information System. 2012. *Oldest Documented High-Water Mark in Texas.* Retrieved September 2013 from Texas Natural Resources Information System: http://www.tnris.org/oldest-documented-high-water-mark-in-texas%20

USGS. 2013a. *USGS Definition of "Streamgage"*. Retrieved September 2013 from U.S. Geological Survey National Streamflow Information Program: http://water.usgs.gov/nsip/definition9.html

USGS. 2013b. *USGS Continues Response to Hurricane Sandy*. Retrieved September 2013 from U.S. Geological Survey: http://coastal.er.usgs.gov/hazard-events/sandy/

USGS. 2014. *USGS Threatened and Endangered Stations.* Retrieved June 2014 from U.S. Geological Survey: http://streamstatsags.cr.usgs.gov/ThreatenedGages/ThreatenedGages.html

APPENDICES

Appendix A – Interview Participants
Appendix B – Interview Questionnaire
Appendix C – Reducing Uncertainty Using High Water Marks
Appendix D –High Water Mark Fieldsheet Examples
Appendix E – High Water Mark Profiles

Appendix A. Interview Participants

David B. Knipe, P.E., CFM
Division of Water Engineering Section Manager (Central Basin)
Indiana Department of Natural Resources

Ed Bartels
Assistant County Engineer
Johnson County, Iowa

Brian Huberty
Region 3 Ecological Services
U.S. Fish & Wildlife Service

David Eash
Hydraulic Analysis & Modeling Unit
U.S. Geological Survey Iowa Water Science Center

Marie Peppler
Flood and Hazards Program Coordinator
U.S. Geologic Survey Wisconsin Water Science Center

Robert Holmes
National Flood Specialist
U.S. Geological Survey Office of Surface Water

Richard Pruitt, P.E.
Ch, Hydrology & Hydraulic Design Sec
Louisville District US Army Corps of Engineers

Vincent Brown
Senior Program Specialist, Federal Insurance & Mitigation Administration
Federal Emergency Management Agency

Terry R. Zien, P.E.
Program Manager
St. Paul District US Army Corps of Engineers

Appendix B. Interview Questionnaire

Strategies to Estimate Flood Frequencies Associated with Flood Event High Water Marks on Gaged and Ungaged Streams

The Association of State Floodplain Managers (ASFPM) is leading a study to evaluate ways to estimate flood frequencies associated with documented flood events (i.e., "high water marks") on gaged and ungaged streams.

Through the use of this questionnaire, ASFPM would like to obtain your input on this topic and related input on how your organization collects, uses, and archives high water marks.

Please see the reverse side of this page for more information.

2013 Interview Questionnaire

Interviews conducted by:

John Buechler	*Scott Morlock*	*Kevin Coulton*
Jeff Stone	*Alan Lulloff*	*Shane Hubbard*

One of the limitations associated with HWMs and historic flood inundation maps is that the frequency of the associated events is often unknown. This is because flood frequencies are determined by the magnitude of the volumetric streamflow (discharge) associated with the water level that left a HWM. Obtaining the streamflow associated with a HWM can be done with the greatest confidence at a streamgage that has a documented relation of water level versus discharge (called a "rating"). Confidence decreases on a given "gaged" stream (stream that has a gage on its main stem) with distance upstream or downstream of the gage. For HWMs on streams with no gage at any point on the stream ("ungaged" stream), estimating the discharge and associated flood frequency can be very difficult. This project would evaluate ways to compute or estimate flood frequencies associated with documented flood events on gaged and ungaged streams.

Your assistance is requested to help us review "best practices" in the collection of HWM and estimation of flood frequencies associated with these documented flood events. The ASFPM team would appreciate your cooperation in participating in an interview. Sample questions are shown in the survey below.

1. Does your agency have a program to collect and make available HWMs or historical flood inundation boundaries? If yes, please explain the collection process and storage and dissemination of this information. If no, where do you obtain HWMs or historical flood inundation information?

2. Given the advances in technology (smartphones, social media, etc.), do you have suggestions on a strategy for collection of HWM and historical flood information?

3. Does your organization have guidance or requirements for calibrating or validating flood hazard mapping engineering models?

4. Do you estimate flood frequencies associated with documented flood events? If yes, please explain the process.

5. What, if any, needs do you see to maximize the collection of and benefits from HWM or historic flood inundation boundaries? For example – photographic "field guides" to setting HWMs, training classes/Webinars from experts, state/regional/national databases?

6. Interviewee

Name:	Job Title:
Phone:	Email:

Appendix C. Reducing Uncertainty Using High Water Marks

In a flood study, typical independent variables are the flood discharge *(Q)* and the Manning's n value *(n)*, which are estimated and then used to compute a flood depth *(y)*. In this example, a simplifying assumption of uniform flow of 5,000 cfs is made for a channel having a Manning's n of 0.035, a width of 50 ft, and a bed slope of 0.01-ft/ft, and that an approximate linear relationship can be established between the variation of discharge and Manning's n with depth, $\partial Q/\partial y$ and $\partial n/\partial y$, respectively (Figure 1), by running a computer model multiple times with varying input values of discharge and then Manning's n, while solving for depth.

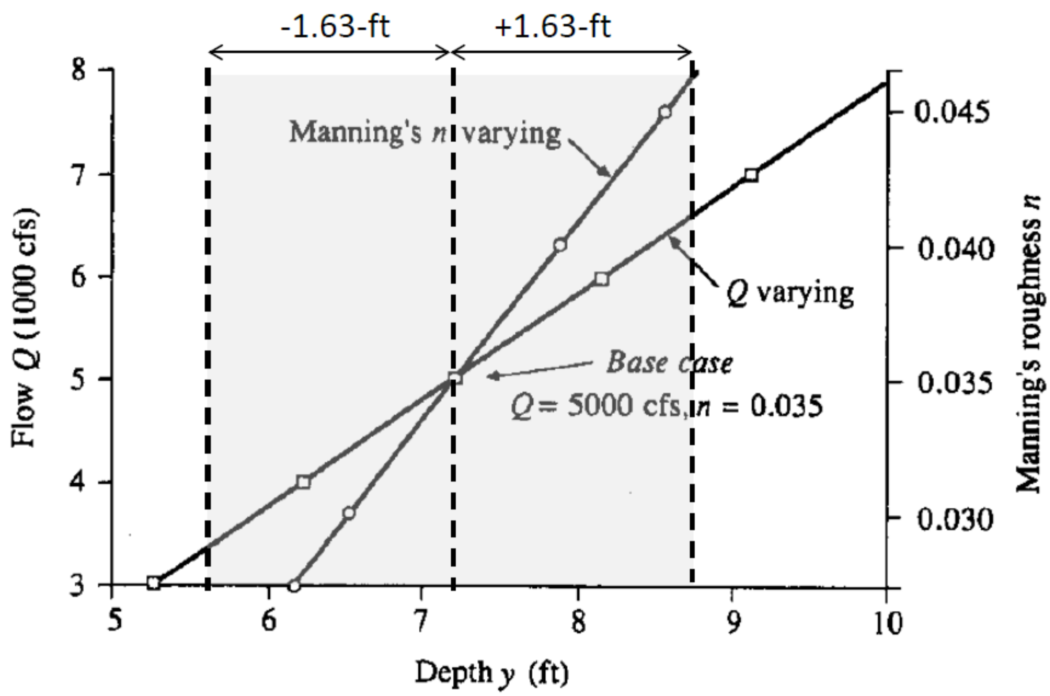


Figure 1. Variation of flow depth with flow rate and Manning's *n* and associated uncertainty. (Chow et al., 1988)

Given these assumptions, a first-order analysis of uncertainty can be applied to quantify the anticipated variability of a dependent variable based on one or more independent variables. The expression for the standard error of the dependent variable, flood depth *(S_y)*, is shown below, where $\partial y/\partial Q$ and $\partial y/\partial n$ is the inverse of the parameters defined above, and S_Q is the inverse of the estimated discharge times the error of that estimate and, similarly, S_n is the inverse of the estimated Manning's n times the error of that estimate.

$$S_y^2 = \left(\frac{\partial y}{\partial Q}\right)^2 S_Q^2 + \left(\frac{\partial y}{\partial n}\right)^2 S_n^2$$

If $\partial Q/\partial y$ and $\partial n/\partial y$ are 1,028 cfs/ft and 0.0072 ft^{-1}, respectively (Figure 1), and the error in the estimate of discharge is assumed to be 30% and the error in the estimate of Manning's n is assumed to be 15%, then $\partial y/\partial Q$ = 1/1028 cfs/ft, $\partial y/\partial n$ = 1/0.0072, S_Q = 1/(5,000 cfs *30%) and S_n = 1/(0.035*15%), resulting in a standard error in depth (S_y) of 1.63 ft (Figure 1).

From this example it can be seen that the availability and quality of high water marks can be used in flood studies to significantly reduce the error of estimate in discharge and Manning's n and, in turn, reduce the error in calculated values of flood flow depth. It should be noted that, quite often in practice, the initial assumptions made in a flood study may not be revisited and adjusted. Meanwhile the computer model is run once, resulting in an answer (the base case in Figure 1) that may be published as, in the case of a FEMA flood insurance study, the Base Flood Elevation (BFE).

Appendix D. High Water Mark Field Sheet Examples

HIGH WATER MARK REPORT		Drainage Basin Stream
High Water Mark No. Stream Mileage	Flood Date	Elevation
Present Water Surface Elevation	Date	Time

Levels Run from B.M.
Location of High Water Mark
Description

Pointed Out By	Address
Observed	Historic

General Impression of Reliability of High Water Mark and Description of Same
Remarks

Mark Investigated	Levels Run By	Closure
Chief of Party	Date	

OVD Form 766
31 July 1959

Hyd.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER
402 W. WASHINGTON ST. ROOM W264
INDIANAPOLIS, INDIANA 46204

PD# ________ Sheet ________
Stream ________
Flood of ________
Date ________
Marks set by ________

HIGH WATER MARKS & STREAM FEATURES

Reach of Stream ________ Quad ________
RP Description: On the ☐ U/S; ☐ D/S; side of the bridge.
_____ ft. _____ of the centerline of the bridge.
_____ ft. _____ of the ☐left; ☐right; end of the bridge. ☐ set, ☐ found

☐ A chiseled "V", ☐ Two filed notches, Other ________
RP Elev ________ Levels by ________ Date / /
Low structure ________ Elev. ________
Crown of Arch ________ Elev. ________
Thalweg ________ Elev. ________
Other ________ Elev. ________
Sec.____, Twp.____, Rge.____,____PM UTM N________
River Mile ________ E________

Field #_____, River Mile________, Crest Date______ Mark #________
Source of info. ☐ P.O., or Other________ Elev.________
Quality of mark ☐ very good, ☐ good, ☐ fair, ☐ poor
Reliability ☐ very good, ☐ good, ☐ fair, ☐ poor
Type of Mark ☐ Mud, ☐Seed, ☐ Drift, Other________
Description: On the ☐ Left Bank; ☐ Right Bank; _____ ft., ☐ U/S; ☐ D/S; of the
☐ bridge; Other________
_____ft. ☐ Landward; ☐ Streamward of________

A ☐ 20d; or_____d nail and ☐ B.C.; ☐ Shiner; ☐ Al. Tag; Other________
On the ☐ U/S; ☐ D/S; ☐ LWD; ☐ SWD side of a _____" dia.________tree
☐ Power Pole; or Other________; _____ft. above ground
A ☐ Chiseled; ☐ Painted crowsfoot________

Field #_____, River Mile________, Crest Date______ Mark #________
Source of info. ☐ P.O., or Other________ Elev.________
Quality of mark ☐ very good, ☐ good, ☐ fair, ☐ poor
Reliability ☐ very good, ☐ good, ☐ fair, ☐ poor
Type of Mark ☐ Mud, ☐Seed, ☐ Drift, Other________
Description: On the ☐ Left Bank; ☐ Right Bank; _____ ft., ☐ U/S; ☐ D/S; of the
☐ bridge; Other________
_____ft. ☐ Landward; ☐ Streamward of________

A ☐ 20d; or_____d nail and ☐ B.C.; ☐ Shiner; ☐ Al. Tag; Other________
On the ☐ U/S; ☐ D/S; ☐ LWD; ☐ SWD side of a _____" dia.________tree
☐ Power Pole; or Other________; _____ft. above ground
A ☐ Chiseled; ☐ Painted crowsfoot________

Appendix E. High Water Mark Profiles