Technical Documentation

High-Water Mark (HWM) Field Identification and Survey Manual

Prepared for the Pennsylvania Emergency Management Agency (PEMA)

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Introduction: The Value of High-Water Marks

The "Missing Link" in Flood Assessment

Flooding is the most destructive natural hazard on Earth. According to the Joint Economic Committee (JEC), flooding costs the U.S. between $179.8 and $496.0 billion each year.[1] While a network of stream-gages is maintained across the country, these gages cannot provide sufficient data for all fluvial (i.e., riverine) and pluvial (i.e., surface) flood assessments, especially for ungaged streams and communities. High-Water Marks (HWMs) serve as fragile, physical evidence that allows for accurate indirect streamflow measurement when gaging stations are destroyed, overwhelmed, or nonexistent.

Capturing these peak flood elevations empowers local communities to directly assist the Federal Emergency Management Agency (FEMA) in updating both regulatory and non-regulatory Digital Flood Insurance Rate Maps (DFIRMs). Furthermore, raw HWM data provides critical insights for local hazard mitigation, resilience, and recovery planning efforts. For example, historical flood photos like Figure 1 from the U.S. Army Corps of Engineers (USACE) recorded that many bridges across the Cedar River in Cedar Rapids, IA were either submerged or damaged by the 2008 flood.[2] Because those bridges were built decades prior, if historical HWMs had been available during their initial design phases—allowing for accurate hazard mitigation and resilience planning—the infrastructure outcomes could have been vastly different.

Figure 1: Flooding in Cedar Rapids, IA (Source: USACE)

Severe floods can cause catastrophic damage to structures, leaving distinct physical scars on buildings. These scars serve as crucial evidence indicating exactly how high the floodwaters reached during extreme events.

The before-and-after photos in Figure 2 illustrate this impact, clearly demonstrating how flood destruction originates at the base of the structure and extends upward. In this specific example, the water damage reached the roofline, establishing a peak flood elevation of more than 10 feet above the surrounding ground.

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[1] JEC, 2024.
[2] USACE, 2018.

Figure 2: Example Unelevated Structure Destroyed by Flood Impact from Hurricane Ian (Source: Cotality)

Over the past 50 years, many communities have implemented flood mitigation policies—such as requiring Base Flood Elevations (BFEs) plus freeboard—for effective floodplain management. However, when flood elevations from severe storm events exceed these federal and local standards, catastrophic structural damage can still occur. Therefore, accurate HWM data is critical for informing future flood mitigation strategies and guiding associated policy decisions.

Figure 3: Example Before and After Flood Impacts on an Elevated Structure (Source: Cotality)

In addition to structural damage, floodwaters carry various substances and debris from the natural environment, leaving deposits on buildings, manmade objects (e.g., fences and bridges), and natural features (e.g., trees and the ground surface). Furthermore, high-velocity floodwaters can erode topsoil, leaving distinct physical scars. These deposits and erosion patterns allow field surveyors to accurately identify peak water levels. The following taxonomy organizes the methods used to identify these various types of high-water marks in the field.

Figure 4: Example of HWM Evidence from Storm Events (Source: USGS)

Event Triggers and Timing

Flooding is a highly dynamic process; floodwaters rise and recede rapidly. Because peak flows and their associated flood elevations are the standard metrics used for flood mapping and damage assessment, the primary objective of HWM collection is to accurately capture these peak elevations or depths.

However, HWM collection is a race against time and the elements. Physical evidence is highly perishable, and successive storm events (such as the two-week gap between Hurricanes Helene and Milton in 2024) can mix or wash away evidence, making event-specific HWM collection extremely difficult.

- **Triggers**: HWM collection should be initiated when flood severity reaches a level that inundates communities, or during any event resulting in a State Disaster Declaration. The table below highlights named storm events that have driven significant National Flood Insurance Program (NFIP) losses in Pennsylvania since 1996, serving as prime examples of the types of severe events that warrant immediate HWM collection. These are excellent examples of types of storm events that HWM collections should be carried out.

EVENT_YEAR	EVENT_NAME	NFIP LOSS COUNT	NFIP_DAMAGE (2024$)	NFIP_CLAIMS (2024$)
1996	Flooding	8,829	$307,931,840	$242,877,504
1999	Hurricane Floyd	1,604	$115,980,777	$101,948,193
2001	Tropical Storm Allison	491	$49,943,981	$44,287,158
2003	Hurricane Isabel	22	$264,518	$235,878
2004	Tropical Storm Ivan	7,641	$359,631,090	$301,133,141
2005	Torrential rain	257	$15,342,854	$13,928,083
2010	March 2010 Nor'easter	68	$642,706	$541,500
2011	Hurricane Irene	1,295	$63,124,199	$54,972,149
2011	Tropical Storm Lee	7,355	$481,798,057	$412,800,615
2012	Hurricane Sandy	129	$2,865,757	$2,527,226
2014	Mid-spring storms	321	$15,952,350	$14,195,864
2015	Tropical Storm Bill	17	$412,581	$364,356
2020	Hurricane Isaias	954	$50,749,262	$46,383,718
2021	Hurricane Elsa	3	$32,466	$39,242
2021	Hurricane Ida	1,631	$138,973,551	$123,220,996
2021	Tropical Storm Fred	21	$2,067,742	$1,815,628
2021	Tropical Storm Henri	24	$1,843,292	$1,644,156
2023	December Nor'easter	19	$193,037	$144,024
2024	Hurricane Debby	143	$5,523,241	$4,830,367

Figure 5: Named Storm Events in PA Since 1996 (Source: Cotality)

While data from all storm events are technically useful for flood model calibration and validation, the time, effort, and cost associated with HWM collection must be carefully weighed during field survey planning. For severe flood events with low frequencies, flood evidence could be obvious and stand up in comparison with the surrounding environment. However, low-intensity flood events occur frequently; physical evidence from these smaller, successive storms can overlap and obscure one another, making it more difficult to isolate the marks of one specific event from evidence that may be polluted by multiple events. Therefore, special techniques and preparation efforts need to be applied to help flood evidence detection on smaller flood events.

One effective strategy for managing resources is to initially auto-populate elevation values using high-resolution Digital Elevation Models (DEMs), including 1-meter or sub-meter DEMs, and then gradually update those records with highly accurate, survey-grade elevations as field teams complete their work.

- **Beyond the SFHA:** It is critical to collect HWMs for severe events (e.g., 200-year, 500-year, and 1,000+ year floods) that extend beyond the Special Flood Hazard Area (SFHA), particularly in cases of pluvial (i.e., surface) flooding. For example, in May 2025, a severe storm event caused flash flooding that reached the second floor of Westernport Elementary School. Because the school was located in a FEMA Zone X (i.e., an area of minimal flood hazard), capturing HWMs for this type of extreme, out-of-bounds flash flooding is incredibly important for accurate future mapping and risk assessment.

Figure 6: Case Study of Extreme Flash Flood Inundation at Westernport Elementary (Sources: Cotality, Washington Post)

- **Deployment:** HWMs can be collected during or immediately after peak flood inundation has occurred. Teams should flag HWM locations and perform measurements as soon as weather conditions safely allow for field data collection. It is important to note that severe storm events often impact vast geographical areas. For example, the map in Figure 7 illustrates the widespread community impacts across Pennsylvania from Hurricane Ida in 2021. Therefore, rapidly informing and coordinating local HWM teams across the state must be a core component of the HWM planning process. Because flood intensities are distributed unevenly across these large areas, HWM survey efforts should be strategically prioritized to focus on the communities most significantly affected by the storm event.

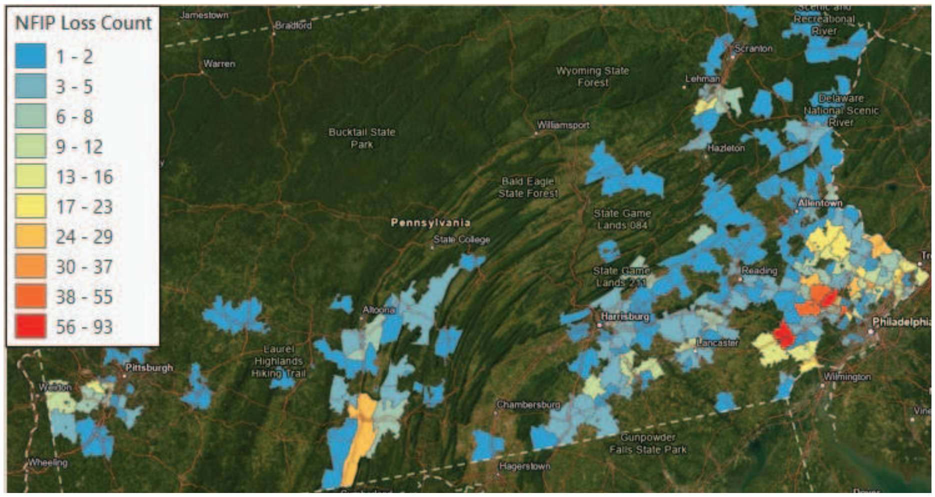

Figure 7: NFIP Flood Loss Count from Hurricane Ida by ZIP Code (Source: Cotality)

It has to be acknowledged that enhancing water observations and collecting HWMs are a national effort. Some flood events may only affect small areas of PA, but the HWMs collection effort in those areas could help flood mapping efforts in adjacent states too, Therefore, HWM collection planning needs to consider watershed approach rather than political boundary-based approach.

Standardized HWM Survey Methodology

Because PEMA will provide survey-grade equipment to HWM field survey teams, the primary method for HWM collection across Pennsylvania will be land elevation surveys utilizing Real-Time Kinematic Global Navigation Satellite Systems (RT-GNSS).[3] For detailed technical specifications and operational instructions regarding specific RT-GNSS devices, surveyors should refer to the respective manufacturer's product manuals.

Accuracy and Compliance

When utilizing professional land survey equipment and trained personnel, the strict USGS standard for accuracy must be maintained. Field surveyors must evaluate the vertical uncertainty of every mark and assign a shorthand rating based on the USGS HWM standard.[4]

Table 1: Shorthand Rating Table

Vertical Uncertainty	Shorthand	Interpretation
Within ±0.05 foot	Excellent (E)	Sharp, well-defined evidence.
Within ±0.10 foot	Good (G)	Clearly visible indicator.
Within ±0.20 foot	Fair (F)	Wide or slightly blurred line.
Within ±0.40 foot	Poor (P)	Vague or variable evidence.
More than ±0.40 foot	Very Poor (V)	Heavily smeared/unreliable evidence.
Minimum Height	ALTH	At Least This High: Peak may have been higher.

[3] Real-Time Kinematic (RTK) typically provides 1.5-3 cm (approximately 0.05-0.1 ft) under ideal conditions, using base stations to correct signals.
[4] USGS, 2017.

Generally, the USGS HWM standard represents a high standard of land-survey-grade accuracy. Historically, obtaining NFIP policies required Elevation Certificates (ECs) to determine the lowest adjacent grade and floor elevations, which demanded a similarly strict vertical accuracy standard.

However, from a flood modeling and mapping perspective, the results generated by flood analytical tools can rarely match the exact precision of a physical land survey. Inherent uncertainties stemming from various hydrologic and hydraulic (H&H) variables—such as terrain conditions, rainfall totals, land use, surface roughness, soil infiltration, and imperviousness—can all impact the final accuracy of H&H modeling. Furthermore, modernizing flood risk assessment to account for both fluvial (i.e., riverine) and pluvial (i.e., surface) flooding requires 2D hydraulic computation based on high-resolution DEMs. Running depth computations across billions of grid cells could inherently reach limitations on computational cost and performance.

- **FEMA Standard Comparison:** Research conducted by the National Research Council concluded that the vertical accuracy standard for FEMA flood mapping is 1.2 feet in relatively flat areas and 2.4 feet in hilly areas.[5] Because the FEMA mapping standard is broader than the strict USGS HWM standard, it allows for some practical tolerance and flexibility during field data collection. Therefore, while field teams should strive to meet the rigorous USGS HWM accuracy standards whenever possible, all collected data must, at an absolute minimum, comply with the FEMA mapping standard.
- **Required Datums:** To ensure database compatibility, all key measurements must adhere to a strict standard: World Geodetic System 1984 (WGS84) for the horizontal datum, North American Vertical Datum 1988 (NAVD88) for the vertical datum, and feet (i.e., ft.) for all elevation and height measurements. Maintaining this consistency is crucial for streamlining HWM data collection and maximizing the efficiency of backend data processing.

Location Pinning (Best Practice)

HWMs must be precisely defined in both their horizontal coordinates and vertical elevations. Hydrologically, water surface elevations within a small, localized area (e.g., within a few meters) remain relatively stable and uniform. Additionally, RT-GNSS equipment has the capability to accurately pinpoint flagged HWM locations, effectively minimizing vertical measurement errors.

However, the terrain surrounding a structure is rarely perfectly flat, and ground elevations can vary significantly along a building's footprint. For example, a structure built with a walk-out basement typically sits on a steep slope. If the recorded horizontal coordinate does not exactly match the physical location where the flood elevation was measured, it creates significant discrepancies that degrade the usability of the HWM data.

The charts below illustrate a real-world example of this issue from the USGS HWM Viewer. As shown, the recorded latitude and longitude place the HWM point in the center of the structure—likely an auto-generated coordinate from a mobile device's GPS. However, the physical flag was actually placed at the corner of the building. Because the ground elevations at these two distinct points differ, applying the same peak flood elevation would result in two entirely different calculated water depths, severely skewing subsequent flood models.

[5] NRC, 2003.

Figure 8: Example of Discrepancy Between GPS Location and Physical HWM Flag (Sources: Cotality and USGS)

Today, mobile devices (e.g., smartphones) are equipped with high-resolution aerial imagery within mapping applications, allowing users to visually define locations with high accuracy. It is a strict best practice for field surveyors to manually place a location pin precisely at the physical corner of the building using their mobile application, rather than relying on auto-generated points from GPS. This ensures the land elevation is accurately attached to the exact point of measurement. By confirming this exact coordinate, the resulting elevation measurement can be confidently utilized for hydraulic model calibration and validation.

Inside vs. Outside Measurement Calculations

For standard HWM collection, the recorded water height must represent the depth of the water above the immediate ground surface.

- **Outside Measurements:** If the water height is measured on the exterior of a structure (designated as H1 in the example in Figure 9), the height above ground and the surveyed ground elevation can be directly recorded and utilized without adjustment.
- **Inside Measurements:** If the water height is measured inside a structure as a height above the floor (designated as H2 in the example in Figure 9), the elevation of that specific floor relative to the ground must also be measured or surveyed using RT-GNSS. In this scenario, the final HWM elevation is calculated by adding the interior water depth (i.e., H2) to the surveyed first-floor elevation.

  For structures sitting on a slab foundation, the calculation is straightforward: **HWM elevation = Tape Measurement + Surveyed Slab Elevation**. It is extremely important to provide the accurate horizontal coordinates (i.e., latitude and longitude) of the exact location where the HWM height was measured to ensure the elevation matches the terrain perfectly.

Figure 9: Concept Charts for Inside vs. Outside Tape Measurements (Source: Cotality)

Floods cause extensive damage not only to building structures but also to their interior contents. As illustrated in the photos below, debris piles on the streets—such as discarded mattresses and large furniture—serve as clear secondary indicators of interior inundation. When items like mattresses are destroyed and discarded, it strongly suggests that floodwaters inside the structure reached multiple feet in depth, at minimum exceeding the height of a standard bed.

Figure 10: Flood Debris on the Street (Source: Cotality)

HWM Evidence Taxonomy and Identification

A primary educational focus for field surveyors is the accurate identification of the specific types of water marks created by a flood event.

Damage Lines

Severe floods, particularly high-velocity coastal events, often cause direct structural damage. Because damage lines are defined by distinct physical scars on a building, they offer a unique advantage: these marks usually remain visible much longer than other highly perishable types of HWMs, typically lasting until the structure undergoes repair or reconstruction.

- **Identification:** Damage lines are identified by locating the highest position of structural scarring. These marks can be found anywhere on the structure, from the main body of the building to the roofline. Damage lines can be found on the damaged structures below.

Figure 11: Damage Line Examples (Source: Cotality)

- **Wind vs. Flood:** The distinction between wind versus flood damage is a frequently asked question in hazard loss analysis and is critically important for HWM identification. Strong winds can break roofs, allowing rainfall to enter and damage both the structure and its contents. For site-specific cases resulting purely from roof or wind damage, no HWM should be collected. As shown in the photos below, these structures show no signs of flood damage at the bottom of the buildings, but obvious wind damage can be found on their roofs.

Figure 12: Wind Damage Examples (Source: Cotality)

Seed Lines

Floodwaters often carry seeds and other fine organic materials, depositing them as a distinct line on objects above the ground (e.g., buildings, trees, and fences) as the water recedes.[6] However, seed lines possess a significant weakness: they are highly perishable. Exposure to natural elements like sun, wind, and rain can quickly degrade or completely remove these fine materials within a matter of hours or days.

- **Collection:** To accurately document a seed line, place colored marking tape along the deposit line on manmade structures or use a wire marker flag and nail for natural objects (such as tree trunks). Take clear photographs of the marked line, ensuring the ground is visible in the frame for perspective. Finally, use a measuring tape to record the exact height of the seed line above the ground. For severe flood events with low frequencies, natural forces (e.g., sun, wind and rain) should be able to remove seeds from previous events. It is still very important to start HWM data collection as soon as weather conditions allow when flood evidence is still fresh and obvious. For capturing HWMs from insignificant but frequent flood events, conducting preparation work (e.g., cleanup of any seeds from previous events) prior to incoming storm events and making targeted sites or objects (such as the tree example in Figure 13) ready for catching fresh seed lines for the next flood events can be very useful. Take photos on the targeted sites before incoming storm impacts, so that those pre-event photos can be used for "before and after" event comparison. Previously determined HWM sites can be

[6] USGS, 2017.

used as targeted sites since floods can be repetitive at those HWM sites, particularly natural sites near streams. Furthermore, multiple types of flood evidence could be found if structural damage occurred. For example, in the center and right photos in Figure 13, there should be water stains from flood inundation on interior walls inside those structures. This technique can be applied to some other types of flood evidence described in the following sections.

Figure 13: Seed Lines (Sources, left to right: USGS, USGS, Cotality)

Mud Lines

A mud line is formed by sediment staining or general discoloration resulting from direct water contact on objects above the ground (e.g., trees, bridge piers, and buildings).[7] Mud lines are considered a relatively reliable type of HWM because they create a distinct, obvious visual contrast between the flooded and unflooded portions of manmade or natural objects. However, like seed lines, they remain vulnerable to the elements and can be easily washed away by subsequent rainfall.

- **Collection:** Place wooden stakes, wire flags, or colored marking tape directly on the mud line. Take clear photographs of the marked line, ensuring the ground and surrounding context are visible for perspective.
- **Exception (Basements):** It is critical that field surveyors exclude mud lines found inside basements. Because basements are below grade, a mud line in this space only indicates that the basement filled with water; it does not accurately represent the true ground inundation or peak water surface elevation. Some preparation on targeted locations (e.g., utility poles) of prior storm events as described in a previous section could be helpful.

Figure 14: Mud Lines (Source: USGS)

[7] USGS, 2017.

Debris Lines (i.e., Drift Lines)

Debris lines, also referred to as drift lines, are composed of sticks, trash, and other coarse organic or manmade materials deposited on the ground at the maximum extent of the floodwater.[8]

- **Collection Dynamics:** Historical data shows that terrain slopes in affected areas are often significant. Because a minor shift in horizontal location on a slope can result in a substantially different vertical elevation, achieving high horizontal precision is just as critical as the vertical measurement itself.
- **Verification:** Floods could carry various types of debris. The debris line examples on the left and right in Figure 15 represent where inundation ended and where peak water surface boundaries were located for specific flood events. However, similar materials to debris could already exist in the natural environment, that may create uncertainties in HWM location determination. As presented in the following examples, multiple HWM data points along different debris lines can be collected in nearby areas, that can be used for cross-validation during post-survey processing, so that HWM anomalies can be removed.

Figure 15: Debris Line Examples (Source: USGS)

Debris snags are another critical indicator used to define debris line elevations. A snag occurs when floating material (e.g., grass, plastic, or woody debris) is caught and held by stationary objects like fences, utility poles, or vegetation as the water levels peak. Figure 16 shows examples of debris snags.

Figure 16: Debris Snag Examples (Source: USGS)

In cases of extreme inundation, debris may also be deposited well above ground level, appearing on rooftops or within tree canopies. These elevated snags serve as clear markers of significant flood depths and represent important data points that should be captured during the field survey to help verify the full extent of the event.

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[8] USGS, 2017.

Figure 17: Rooftop Debris Line Example (Source: Cotality)

Wash Lines

A **wash line** occurs when high-velocity floodwaters strip away loose organic material and topsoil from the ground surface, revealing underlying bare rock or creating a "cleaned" appearance that contrasts sharply with adjacent, non-flooded soil.[9]

- **Identification:** Wash lines are primary indicators of flash floods characterized by high flow velocities. In recent years, extreme weather events (e.g., 1,000-year storms) have occurred with increasing frequency across the country. The intense, concentrated rainfall from these events can generate violent flash flooding capable of significant topsoil erosion and the creation of prominent wash lines.

Figure 18: Wash Line Examples (Source: USGS)

Cut Lines

A **cut line** is a specific category of flood erosion found along riverbanks. These lines are created when high-velocity water scours the stream bank, leaving a distinct horizontal "cut" at the peak water surface elevation.[10]

- **Safety Warning:** Personnel safety is the absolute top priority of any HWM field survey. Areas featuring cut lines and wash lines often present inherently unstable and dangerous ground conditions with steep slopes.

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[9] USGS, 2017.
[10] USGS, 2017.

Only experienced and well-trained survey teams should be assigned to conduct HWM hunting and surveying in these high-risk areas.

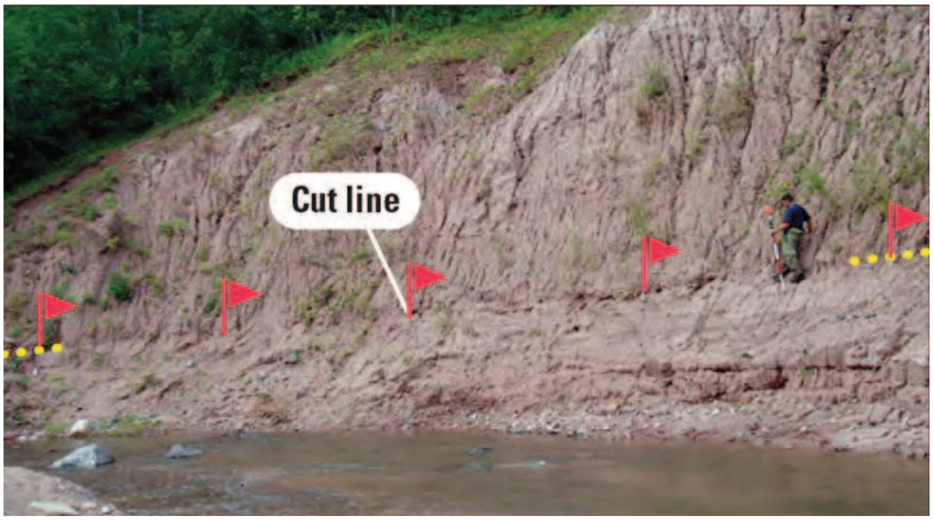


Figure 19: Cut Line Example (Source: USGS)

Water Edge (Edge of Flood Inundation)

While not a traditional physical mark left behind after a storm, the active edge of flood inundation captured during the event serves as a different and effective way to obtain valuable HWMs.

- **Real-Time Documentation:** First responders are often tasked with establishing road closures and managing public safety when severe floods inundate roadways. Because they are on-site during the event, these personnel have unique opportunities to observe and document the maximum extent of floodwaters near the peak time of inundation.
- **Submission Workflow:** If responders capture a photograph of the water's edge and forward the image—along with the GPS location (i.e., latitude and longitude)—to Local Mission Assignment, a HWM can be automatically generated. The Local Mission Assignment utilizes the photo's metadata, timestamp, and sender information to create a verified data point for the flood record.

Figure 20: Water Edge Examples (Sources, left to right): WSYX, ABC7 News, Weather Damage)

Water Surface

The active water surface and its elevation represent the primary objectives of HWM collection efforts. With modern technology, these elevations can now be accurately derived in real-time while a flood is still in progress.

- **Collection via Street Gages (i.e., Virtual Sensing):** By leveraging existing infrastructure (e.g., traffic, security, or "smart city" cameras), the active water surface can be monitored and documented remotely. In this "virtual gage" approach, the flood elevation is calculated by identifying a surveyed object with a known elevation within the camera's field of view (e.g., a specific bolt on a signpost or a crosswalk indicator). The water surface elevation is then determined using the following calculation:

$$Elevation_{Water} = Elevation_{Reference} - \Delta Height_{to\_Surface}$$

Figure 21: Water Surface Examples (Sources, left to right: Libby Solomon (The Baltimore Sun), Erin Fluharty (The Star Democrat), USA Today)

Exception Handling: Inland vs. Coastal Considerations

It is important to note that the clues and methods described above cannot be applied to all areas equally. Many types of evidence used for inland floods are not applicable to coastal regions. During severe coastal events, storm surges and waves can push sand and debris across large areas, making it difficult to identify clear patterns on a building's exterior.

As shown in the photo below from Hurricane Helene, a street was fully covered by sand pushed inland by the surge. In these cases, the most reliable method is to inspect the interiors of flooded buildings. HWM collection teams should first identify the primary flood source, whether riverine, coastal, or flash flood—to determine the best approach for data collection.

- **Saltwater Effects:** In coastal flooding events, saltwater can create additional, distinct damage to both buildings and their interior contents. Surveyors must consider the primary flood source (e.g., riverine, coastal, or flash flood) before beginning their assessment to know which specific clues to look for.

Figure 22: Example Inundated Area by Coastal Flood (Source: Cotality)

HWM Data Quality Assurance (QA)/Quality Control (QC)

As discussed in the previous sections, various types of water marks have been described and evaluated. In actual field assessments, each type may present variations, mixtures, and uncertainties that require HWM teams to exercise their professional judgment and adjustments.

A standard approach for quality control is to take multiple HWM point measurements and validate them against each other, USGS stream gages, or new technology used for flood monitoring on street networks. Figure 23 provides a conceptual chart of a flood profile along a river to assist in this validation.

- **Downstream Gradient:** In theory, the water surface elevation should decrease smoothly and gradually in the downstream (i.e., downhill) direction.
- **Outlier Identification:** If an HWM elevation shows a significant jump or drop compared to nearby points, it may be invalid and should be removed from the dataset.
- **Gage Comparison:** When a gaged point is nearby, upstream points should consistently have higher elevations, and downstream points should have lower elevations relative to the gaged peak elevation for that specific event.
- **Aerial photos and flood footprint photos**: In recent years, drones were widely used by first responders, news and media, and private companies to observe flood impacts in sizable flooded areas. Photos on flood footprints in close ranges from news and media or the public can provide physical facts on flood inundation. Those can be very useful for validating HWM data collected from fields. For example, if a photo on water inundation presented a water depth on object is higher than height reported at a HWM data point, it could indicate that an error may occur during the HWM data collection process.

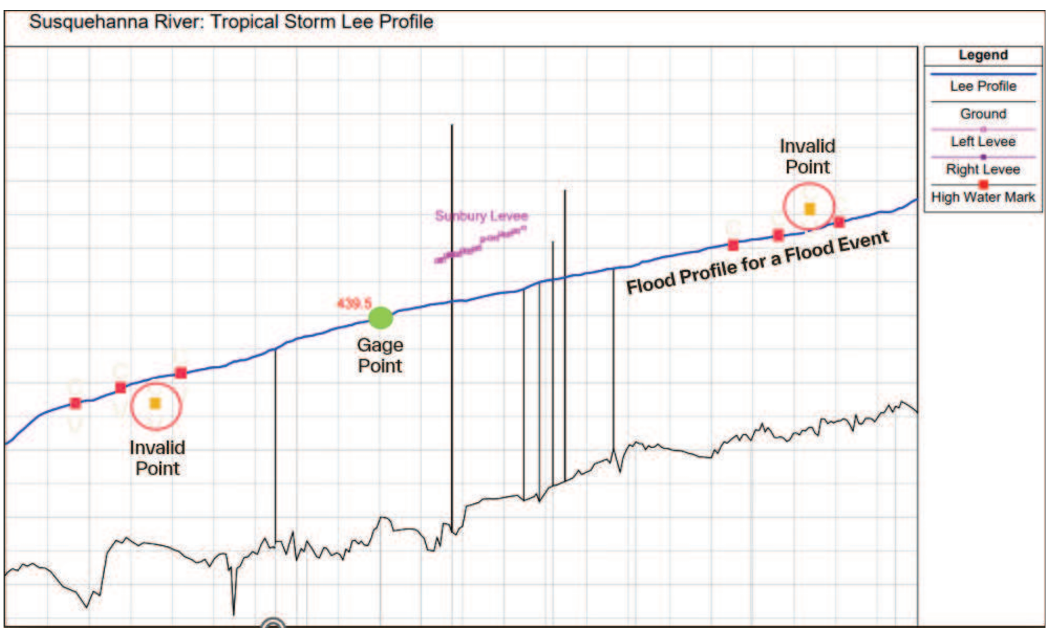


Figure 23: Conceptual Flood Profile for QA/QC Validation (Source: FEMA Flood Insurance Study and Cotality)

- **DEM Cross-Validation:** If the difference between a surveyed elevation and a tape measurement of the height above ground is significantly different from a referenced Digital Elevation Model (DEM) value as an independent elevation data, additional validation may be needed.
- **Post-Survey Processing:** Invalid HWM points identified during the QA/QC check should be removed from the event collection during post-survey processing to ensure the final dataset is accurate.

Streaming HWM Data Collection Process and Workflow

To maximize the efficiency of field teams, Pennsylvania's HWM collection workflow integrates both traditional land survey methods and advanced technological solutions. The workflow is designed to reduce the administrative burden on surveyors by automating the back-end data processing.

By leveraging this streaming process, **80% to 90%** of the data fields specified by the standard USGS HWM data form can be auto-filled. This significantly increases the efficiency of HWM collection and streamlines the entire data lifecycle from the field to the final database.

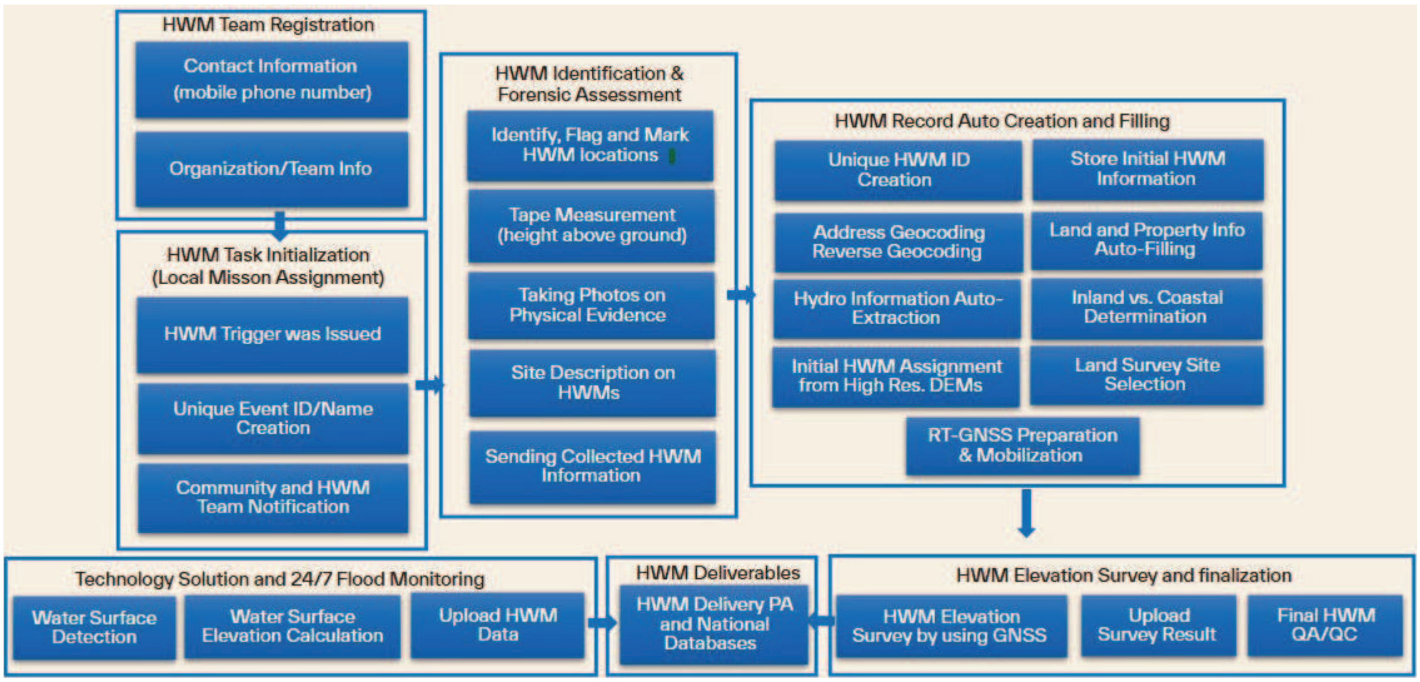


Figure 24: Streaming HWM Data Collection Process and Workflow (Source: Cotality)

Workflow Phases

The streaming HWM collection workflow is a continuous, interconnected process divided into the following phases.

Phase 1: Registration & Initialization: The data management team maintains a dedicated registration site where HWM team members self-register. This system facilitates the assignment of specific forensic and survey tasks and provides a central portal for uploading results.

- **Initialization**: Once a collection effort is triggered, the management team assigns a unique Event ID and Name. National collaboration on event naming for large storm events is necessary. For example, a hurricane event could affect multiple states.
- **Naming Protocol**: It is critical that flood events are assigned unique, descriptive identifiers (e.g., "**1996 January PA Flood**" or "**Hurricane Ida 2021**") to prevent historical confusion. Field teams must use this assigned name consistently across all records.
- **Crowdsourced Data**: If a first responder at a roadway blockade forwards a photo of the water's edge to the HWM data processing team, the system can automatically create an HWM entry using the photo's embedded GPS location and timestamp.

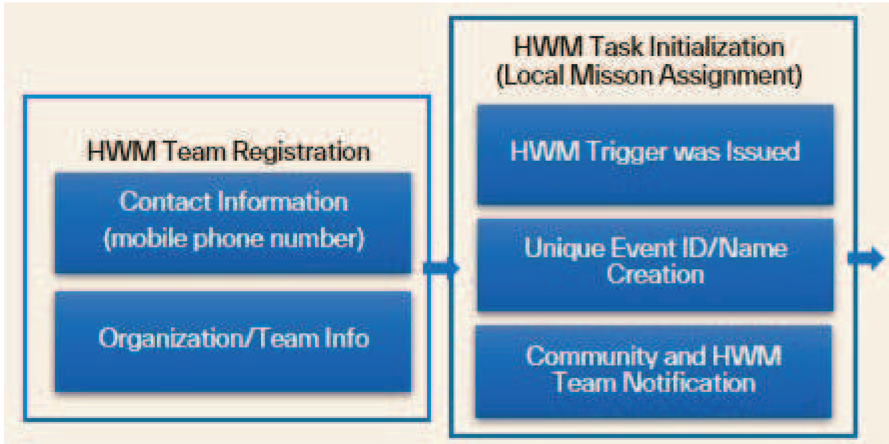


Figure 25: Registration & Initialization

Phase 2: Identification & Forensic Assessment: Field teams deploy to affected areas to search for and detect physical evidence of flooding. During this phase, they:

- Identify, flag, and clearly mark physical HWM locations
- Capture tape measurements of the height above ground
- Take photographs of physical evidence and actual flood facts
- Provide brief HWM site descriptions
- Transmit initial location data and detailed site descriptions to the central database

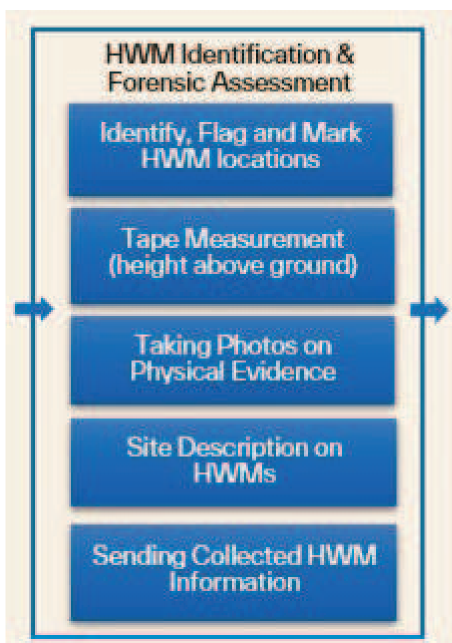


Figure 26: Identification & Forensic Assessment

Phase 3: Record Auto-Creation & Survey Preparation: Each HWM is assigned a Unique HWM ID, linked to the associated Event ID and the identifying team member. A significant portion of the standard USGS HWM data form (see **Appendix A:** Example USGS HWM Form) is automatically populated by the system. This automation includes:

- **Geocoding**: Automated address geocoding and reverse geocoding
- **Data Extraction**: Automated extraction of land and property information, as well as hydrological data to determine Inland vs. Coastal flooding sources
- **Initial Elevation**: Assignment of initial elevations derived from high-resolution (i.e., 1-meter or better) DEMs, that can be replaced by elevation survey results
- **Selection**: Based on this data, the system selects land survey sites and assigns elevation survey tasks to field teams

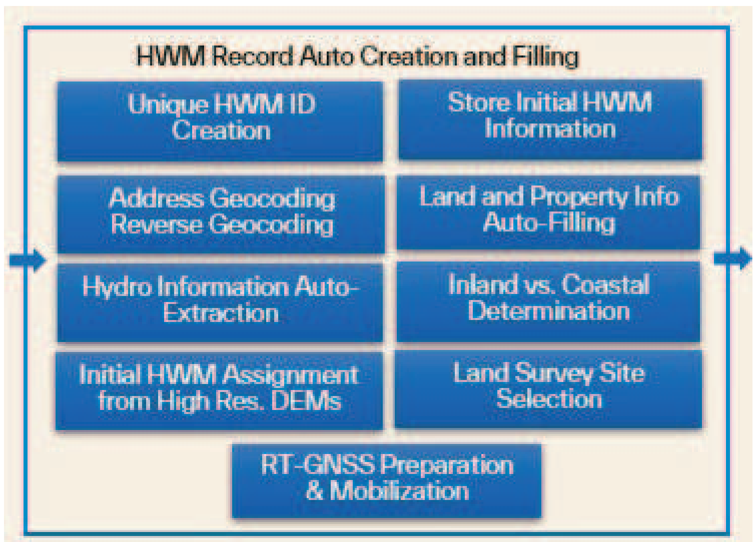


Figure 27: Record Auto-Creation & Survey Preparation

Automating the HWM data fields can reduce time spent in the field and improve the productivity of HWM data collection.

Phase 4: Elevation Survey, Finalization, & Technology Integration: Field teams conduct final elevation surveys at selected sites utilizing RT-GNSS equipment.

- **Technology Integration (Parallel Track)**: Simultaneously, "Street Gages" and other 24/7 monitoring technologies detect water surfaces and calculate elevations automatically. Leveraging existing infrastructure (e.g., traffic or "smart city" cameras), the active water surface can be monitored remotely. In this "virtual gage" approach, flood elevation is calculated using surveyed objects with known elevations within the camera's view.
- **Real-World Application**: For example, at the intersection of US 22 and Maclay St in Harrisburg, traffic cameras can monitor inundation in real-time. The system can auto-record the process and generate associated HWMs without a manual field visit since camera-mounted elevations were previously determined, which meets the USGS HWM vertical accuracy standard.

Figure 28: Real-World Application Example (Source: Cotality, Live Camera View https://www.511pa.com/)

- **Finalization**: Survey results are uploaded for a final QA/QC review to remove invalid points and integrate the dataset. Finalized records are then delivered to Pennsylvania and National HWM Databases (e.g., database for USGS Event Viewer).

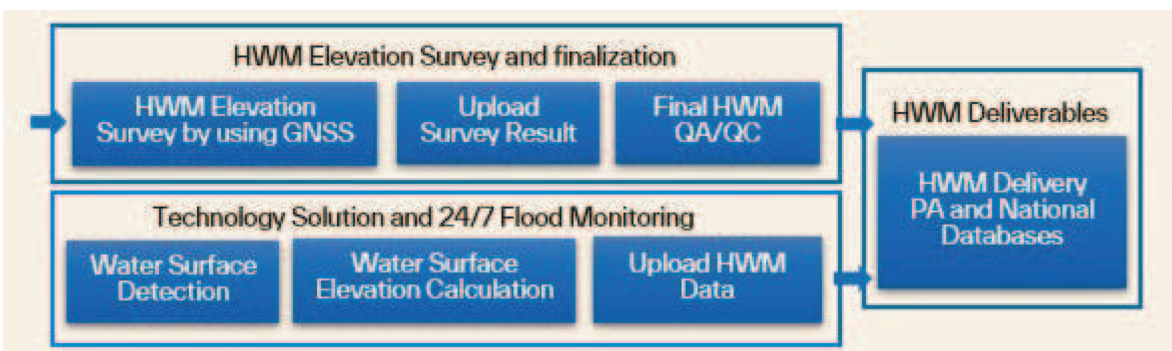


Figure 29: Record Finalization

Required Field Inputs

Because the system auto-fills the majority of fields from the standard form, RT-GNSS field surveyors can focus their time and effort on accurately capturing the following core data points to feed the data engine.

- **Location Information:** Latitude and longitude (WGS84), pinned at the exact corner of the structure
- **Height Above Ground:** Recorded in feet
- **Surveyed Elevation:** Recorded in feet (NAVD88)
- **Vertical Uncertainty Rating:** A rating from "Excellent" to "Very Poor." For this collection process, an alternative vertical rating option could be considered: **FEMA-FMS Compliance**. This rating signifies compliance with

FEMA Flood Mapping Standards, allowing integration of high-resolution (i.e., 1-meter or better) DEMs.

- **Event and Survey Dates:** Accurately capturing the event date is very important since it is necessary for model calibration and validation on flood events.
- **Photographs of Physical Evidence:** Photos of flagged HWM locations are vital for the elevation survey team to quickly relocate them. Additionally, these photos serve as a permanent record of the actual facts of the flood.

Ultimately, all finalized records from both manual RT-GNSS surveys and automated technology solutions are delivered directly to PEMA and National Databases.

Safety Considerations for HWM Collection and Field Work

As described in previous sections, there are many types of HWMs. While some standard USGS documentation focuses on riverine floods, which may require surveys in dangerous conditions like steeply-sloped banks or under bridges, these cases often involve significant field risk.

Personnel safety is the top priority of any HWM field survey. However, valid marks found in inherently dangerous conditions (e.g., cut lines on steeply sloped riverbanks) should still be collected, provided the survey is strictly conducted by a highly trained and experienced surveying or engineering team equipped to handle the field risks.

Figure 30: Safety Consideration Examples (Source: USGS)

Conclusion: Assisting FEMA with DFIRMs and Mitigation

The implementation of survey-grade RT-GNSS equipment by PEMA field teams ensures that Pennsylvania's flood monitoring capabilities remain highly accurate. More importantly, it establishes a direct pipeline for local communities to assist FEMA in accurately modeling flood risk.

The HWM data lifecycle relies on a coordinated workflow.

- **Field Operations:** HWM teams flag locations and perform RT-GNSS measurements as soon as weather conditions allow. Speed is essential, as flood evidence on the ground and on objects can be altered or compromised by human actions and other natural events, particularly subsequent rainfall.
- **State and Federal Flood Mapping Integration:** Finalized HWM records are delivered to State and National Databases. Professionals from both governmental and private entities can utilize these records to validate flood studies and modeling efforts. Improvements to flood models based on HWM data create positive impacts on flood insurance pricing and assist in the creation and revision of future regulatory and non-regulatory Digital Flood Insurance Rate Maps (DFIRMs). Furthermore, HWM collection efforts could not only significantly increase observations on riverine and coastal floods geospatially, but also, very importantly, increase flood hazard observations on land surface flooding inside communities/urban areas, including roadways, that are not primarily covered by USGS stream gages and NOAA coastal gages (i.e., tidal gages).

This training material was designed to provide additional supporting information for HWM data collection. More detailed information on HWM data collections can be found on many USGS HWM documents listed in the Appendix below. In this document, we only referenced some examples from USGS HWM documents. Many other useful examples can be found in USGS HWM documents.

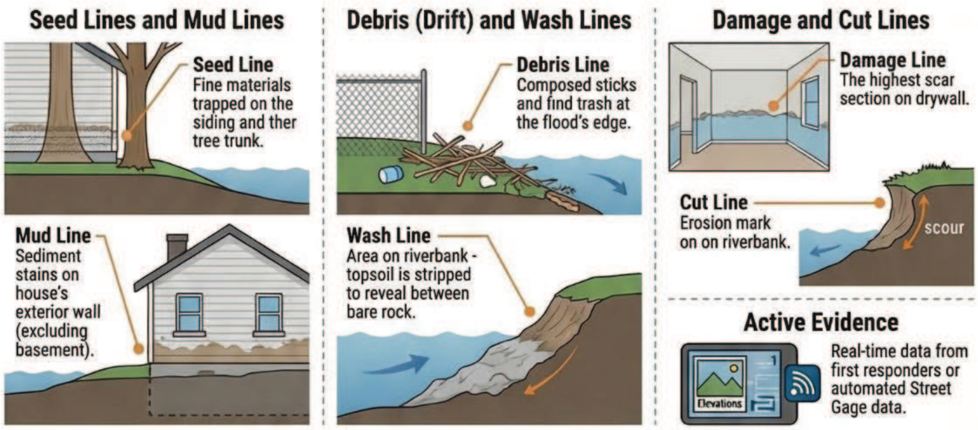
By adhering to the protocols in this manual, surveyors provide the essential raw data required to guide local hazard mitigation, improve community resilience, and ensure that recovery planning is based on the reality of modern, extreme storm events.

PEMA FIELD GUIDE:
Mastering the Mark - High-Water Mark (HWM) Identification & Surveying

Standardizing Flood Data Collection

Standardized identification of physical evidence and measurement protocols ensure consistent, scientifically defensible data for FEMA Rood maps and community resilience. This guide leads from evidence capture to rigorous data submission.

PHASE 1: TAXONOMY OF EVIDENCE (Field Identification)

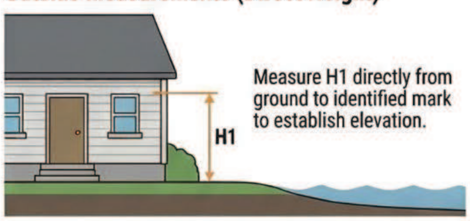


PHASE 2: MEASUREMENT TECHNIQUES & FORMULAS (The "How")

Elevation = H2 + FFE

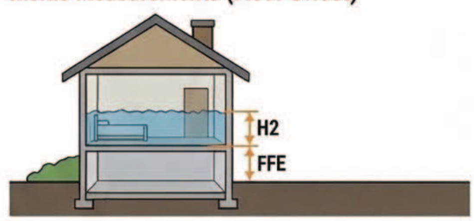
Calculate Elevation using: Water Height above floor (H2) + First Floor Elevation (FFE) above ground level.

Outside Measurements (Direct Height)



Measure H1 directly from ground to identified mark to establish elevation.

Inside Measurements (Floor Offset)



PHASE 3: USGS VERTICAL UNCERTAINTY STANDARDS

Vertical Uncertainty	Shorthand	Interpretation
Within ±0.05 foot	**Excellent (E)**	Sharp, well-defined evidence.
Within ±0.10 foot	**Good (G)**	Clearly visible indicator.
Within ±0.20 foot	**Fair (F)**	Wide or slightly blurred line.
Within ±0.40 foot	**Poor (P)**	Vague or variable evidence.
> 0.40 foot	**Very Poor (V)**	Heavily smeared/unreliable.

Every mark must be assigned a shorthand rating based on visual clarity and vertical uncertainty for data integrity.

PHASE 4: STREAMLINED WORKFLOW

1. Trigger & Initialization
Management issues a unique Exect ID to categorize all incoming data.

2. Forensic Assessment
Field teams identify, Rag evidence, and take precise tape measurements and photographic documentation.

3. Record Auto-Creation
Systems geocode addresses and auto-till 80% to 90% of USGS HWM data form fields.

4. Elevation Survey & QA/QC
Teams conduct final RT-GNSS surveys (WG584 horizontal/ NAVO88 vertical) before PEMA/National Database delivery.

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Appendix A: Example USGS HWM Form

USGS science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey

HIGH WATER MARK FORM

Collection Team: DMM/IBL
Event: Westmoreland20220806
Date: 08/09/22

Site Visit Summary

STATION ID:
STATION NAME: HWM6_E
SITE DESCRIPTION: North side of 1807 Creekside Lane
WATERBODY: Monastary Run
LAND OWNER:
EMAIL:
ADDRESS: 1807 Creekside Lane
COUNTY: Westmoreland
Party: DMM/IBL
Start Time(UTC):
End Time(UTC):
Weather:

Site Visit Tasks

☐ Flagging HWMs only ☑ Retrieving flagged HWMs ☐ Levels Ran ☑ Pictures Taken ☐ Site Sketch

Comments:

Datum

Horizontal datum: WGS 84 (from digital map)
How was it determined: handheld GPS
Vertical datum: NAVD'88
How was it determined: GNSS (RTN)
Type of "on-site" Objective Point used to determine HWM elevation:
Elevation:
Name(If NGSBM): PID DES
Description:

High Water Mark

HWM Elevation: 991.285
(+/-): 0.10
Rated: Excellent
○ Coastal ◉ Riverine
Bank: ○ Left ◉ Right ○ N/A
Type: Seed line
Location (lat/long): 40.302307, -79.395067
How was elevation determined: GNSS (RTN)
Comments:
Marker:
Tranquil/Stillwater HWM: ◉ YES ○ NO
HWM Description: Seed line on north side of 1807 Creekside Lane, owners gave permisson to survey line.
Height above ground: 2.81
Date Flagged:
Date Surveyed: 08/09/22
Comments: Elevation of TBM3: 992.155 ft, Surveyed Elevation of TBM3= 2.619 ft, Height of Instrument: 994.774 ft, Surveyed Elevation of HWM6_E: 3.489 ft.
(Elevation of TBM3 + Surveyed Elevation of TBM3 = Height of Instrument. Height of Instrument - Surveyed Elevation of HWM6_E = HWM Elevation)
992.155 + 2.619 = 994.774 -> 994.774 - 3.489 = 991.285

Source: USGS HWM Event Viewer

About Cotality

Cotality accelerates data, insights and workflows across the property ecosystem to enable industry professionals to surpass their ambitions and impact society. With billions of real-time data signals across the life cycle of a property, we unearth hidden risks and transformative opportunities for agents, lenders, carriers and innovators.

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