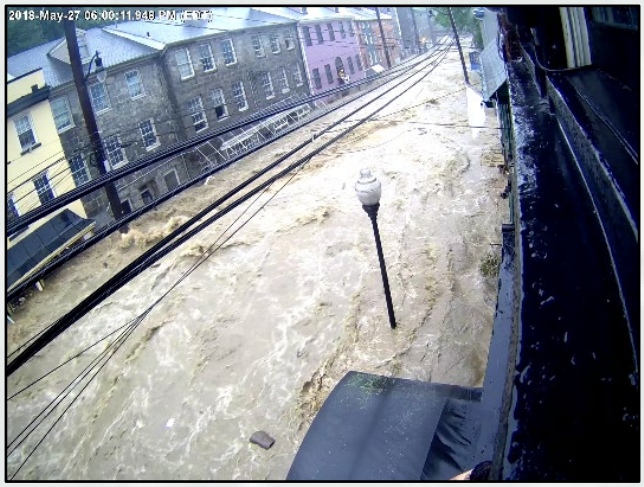
EVALUATION OF ELLICOTT CITY FLOOD RISK MANAGEMENT ALTERNATIVES HOWARD COUNTY, MARYLAND



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FINAL
DECEMBER 2019

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EXECUTIVE SUMMARY

Ellicott City, in Howard County, Maryland, was founded in 1772 and soon after became one of the largest mill towns in the Eastern United States. It contains the first terminus of the initial B. & O. Railroad located at Ellicott City Station. Built in 1830, this historic station now houses the B. & O. Railroad Museum. The downtown historic district, often referred to as "Historic Ellicott City" is located in the valley of the upper Western Branch of the Patapsco River. Multiple sources of flooding impact Ellicott City. The Tiber Branch, Hudson Branch, Autumn Hill Branch, and New Cut Branch all converge within the vicinity of downtown Ellicott City, just upstream of the Patapsco River confluence. Historically, Ellicott City has experienced both "top-down" flooding originating from upstream within its watershed and "bottom-up" flooding originating from the Patapsco River.

Ellicott City experienced two severe storms on July 30, 2016 and May 27, 2018 which resulted in the loss of life and significant property damage. Both of these storms deposited significant rainfall within the watershed in a short period of time, which resulted in top-down flash-flood events. Since 2016, Howard County has funded multiple efforts to investigate flood risk management alternatives that could make the area more resilient to this type of flash-flooding, including the acquisition of properties on Main Street. The County requested that the U.S. Army Corps of Engineers (USACE) coordinate a review of the conducted flood studies and evaluate the County's proposed alternatives in order to help inform future decision-making. Additionally, the team was asked to identify potential new Flood Risk Management (FRM) measures or strategies for the County's consideration.

Under the Floodplain Management Services Program, USACE Baltimore District organized a team of USACE FRM experts from around the country to conduct this evaluation. These experts spanned multiple disciplines and were specifically recruited from outside of Baltimore District to allow for a more independent review process. The disciplines of the review team included: Community Planner, Civil Engineer, Cultural Resource Specialist, Geotechnical Engineer, Hydraulic Engineer and a National Nonstructural Committee member. The Baltimore District was responsible for the project management and preparation of presentations and this report.

The independent team reviewed documents provided by the County, including hydrologic studies, master planning documents, USGS data collected from flood events, and modeled outputs from hydraulic modelling. This review focused on general integrated design approaches, the hydraulic modeling results, and conceptual formulations of FRM alternatives. No comprehensive detailed engineering designs of Howard County's proposed FRM measures had been developed at the time of this USACE review.

Howard County's goal for Ellicott City is to reduce the risk to loss of life and damage to property through the reduction of flood depths and velocities associated with a July 2016 storm event, combined with the implementation of non-structural flood proofing by property owners. This goal included reducing roadway flooding depths down to approximately 3 feet (or below) and roadway flood velocities down to 5 feet/second (or below). These targets were selected as they represent the approximate upper effective limits for non-structural flood proofing (USACE 2019). As such, the County's planning process was focused on measures meant to address top-down flash-flood events similar to those experienced on July 30, 2016 and May 27, 2018.

The scope of this review was therefore defined by the County's measures which would mitigate an equivalent top-down flash-flood event. The measures evaluated here were not specifically intended to address Patapsco River flooding, although some of the County's proposed measures (e.g. removal of structures, flood proofing of buildings) as well as some USACE proposed measures (e.g. vertical evacuation plans, elevated egress walkways) could result in reduced flood risk associated with a Patapsco River flood.

This USACE evaluation was at the planning level and was not intended to produce detailed designs leading to construction. No designs or modeling were developed or completed by USACE. Howard County conducted all studies, including the hydrologic and hydraulic modeling and provided those data and reports to USACE for review.

The USACE evaluation team reviewed all sixty hydraulically modeled alternatives provided by the County. Of these sixty alternatives, only eight reduced flooding to acceptable levels. These eight alternatives were comprised of fourteen unique FRM measures, two of which were in late-design or construction phase. The remaining twelve FRM measures were assessed by the USACE team utilizing seven team-derived criteria.

The criteria used by the team for the evaluation of the FRM measures were: Prevention of Loss of Life, Preservation of Historical and Cultural Resources/Community Cohesion, Reduction of Flooding, Economic Impacts, Operations and Maintenance, Initial Construction Costs, Implementation Duration, and Environmental Impacts. Each criteria was assigned a weight (value of 1-3) and each measure was assigned an impact rating (value of 0-3) based on the team's judgment, which allowed for a weighted-sum calculation for each evaluated measure. In addition to that evaluation method, the team provided information for each measure for the County to consider for future decision making.

To leverage the expertise of a wide audience of flood experts, the USACE also held two meetings/webinars with other subject matter experts to solicit their input. A presentation was made to the Maryland Silver Jackets team (August 27, 2019), which is comprised of Federal, State, academia, and nonprofit entities involved in FRM. A second webinar (October 10, 2019) was offered to a national USACE FRM audience. During the national USACE FRM webinar, experts from 20 Districts and 7 different areas of expertise (planning, hydraulics/hydrology, civil engineering, geotechnical engineering, environmental, economics, and emergency management) participated in the discussion.

At both events, the audience members were given the opportunity to learn about the flooding issues, the measures being considered, and provide feedback that would be valuable for the County to consider. All comments, suggestions and feedback received at the above two meetings have been integrated into this report.

Overall, the USACE review team found that the County is following a sound process and that the FRM measures being considered are typical of the measures considered for USACE FRM projects. The current County-selected alternative (known as 3G.7.0) can significantly reduce flood risk to downtown Ellicott City.

The County expects there to be residual flood risk even after the construction of the measures proposed in alternative 3G.7.0 (Howard County 2019). To help further reduce flood risk, the USACE team identified additional FRM measures and strategies, both structural and nonstructural, which the County can consider. These include:

- An aggressive debris management plan to clear debris along stream reaches, together with potential flood plain zoning ordinances that specifically restrict objects or ancillary structures which may be damaged and become flood debris during large events.
- Although the County is already pursuing several property buyouts, the USACE team, as well as a number of FRM experts from various fields stressed this potentially be pursued further, as it is a proven method to reduce the risk of loss of life and damages to property. Any future property buyout decisions will have to be balanced with the public desire to maintain a cohesive and historic downtown Ellicott City. Further pursuit of this measure could also provide flood risk reduction associated with Patapsco River flooding.

- The County could consider a network of elevated egress walkways (located behind certain buildings) designed to allow pedestrians and building occupants to exit to high ground. This measure could also provide flood risk reduction associated with Patapsco River flooding.
- The County could consider mandating that individual businesses and property owners in the lower Main St. section develop and post vertical evacuation plans, and that tenants, owners, and employees be trained in their execution. This measure could also provide flood risk reduction associated with Patapsco River flooding.
- Parking restrictions, which are already being considered by the County, are a valuable tool for reducing risk of loss of life as they reduce the number of people in vehicles during flood events and prevent vehicles from becoming flow-constricting debris. Additionally, continue to consider removing as much parking as feasible from the highest-risk areas and replacing it with parking at higher elevations (with potential shuttle services to connect to downtown).
- Bollards or similar structures may be included along channel reaches and terraced floodplains throughout the lower sections of downtown to prevent vehicles and large debris from entering channels.
- As feasible, the County should continue to collaborate with other agencies (National Weather Service) to improve flood warning forecasts and flood warning systems/sirens.
- With significant work expected to occur in and around channels, the opportunity for environmental improvements to in-stream and riparian habitats exists.
- The team identified two potential structural FRM measures for the County's consideration. One is a dry flood storage structure located on the New Cut Branch, which if sized appropriately, could significantly reduce flood flows originating from the New Cut watershed (a major source of floodwaters during both the 2016 and 2018 storm events, based on USGS calculations). This proposed measure, however, includes significant challenges including property acquisition, removal of the New Cut Road, and the permitting required for a structure that would likely be classified as a high-hazard dam. Two, the team suggests the County consider improving the conveyance capacity of the downtown channelized reaches via channel widening, deepening, and/or the potential addition of parapet flood walls.
- The County has initiated a funding program to encourage property owners to flood proof their buildings, and as feasible this effort should continue and be expanded to mitigate residual risk in the most significant inundation areas. On lower Main St., the flood proofing of structures would also provide flood risk mitigation during future Patapsco River flood events.
- Whenever feasible, the construction of flood conveyance improvement measures should be sequenced downstream to upstream to avoid increasing flood levels downstream before capacity improvements are made at the lower end of the project.
- The owner of the FRM system typically should acquire permanent real estate interest for the comprehensive footprint of the project for operations and maintenance purposes. USACE minimum footprints normally extend a minimum of 15 feet beyond the physical FRM features (such as floodwalls and channel walls).
- Implement an inspection program of the system once construction is complete. Periodic inspections of the entire system should be scheduled to ensure integrity, operations, and design capacity are not compromised over time. Unscheduled inspections should also occur after the recession of each significant flood event.
- The County may consider initiating flood map revisions with the Federal Emergency Management Agency (FEMA) once FRM project improvements have been completed.

- A Patapsco River flood event (a bottom-up flood event for Ellicott City) is a different type of flood event than those experienced in 2016 and 2018. Comparatively, a Patapsco River flood would typically have much lower velocities, significantly longer warning time, and would mainly impact just the lower Main St. area. Currently, some of the measures proposed by the County (e.g. removal of structures, flood proofing of buildings) as well as some USACE proposed measures (e.g. vertical evacuation plans, elevated egress walkways) would help reduce risk associated with a bottom-up Patapsco flood event. However, the County may consider undertaking additional studies to define measures which could directly mitigate flood risk associated with Patapsco River flood events.

Although the County is undertaking the planning and construction of FRM measures, this USACE evaluation also identified components of the USACE FRM project processes that the County could consider. These include the following:

- USACE is required to perform an economic analysis in the form of benefit cost ratios (BCRs) to identify the most cost effective solutions, and would typically formulate an array of measures based on benefits. The County may consider a similar strategy for decision making.
- USACE would typically conduct an incremental modeling analysis to evaluate each potential FRM measure. That is, each measure would be modeled separately such that the hydraulic impacts and benefits could be individually quantified and then the measures incrementally combined to form sets of alternatives. The County could consider this approach to help determine the individual contribution of each potential measure in a systematic fashion.
- Some USACE projects include the consideration of impacts to the FEMA Flood Insurance Rate Map (FIRM) as a part of incremental modeling and a systematic design. The current FIRM map for Howard County, enacted in 2013, shows all buildings and properties lining lower Main Street as being within the 1% annual chance (100-year) floodplain. Properties above the confluence of New Cut Branch are mostly in the 0.2% annual chance (500-year) flood zone. If the County's future goals include reducing the 1% annual chance floodplain, this strategy could help inform and define the necessary engineering and sizing of individual measures.
- The USACE approach for modelling storm events would typically include the modeling of an array of different storm scenarios, as a diversity of modeled storms would better inform the selection of measures. For example, under different storm scenarios, more significant rainfall may impact one sub-watershed versus another which could affect the decision making for measure and alternative selection.
- A USACE FRM project of this scope would entail multi-agency collaboration (FEMA, US Fish and Wildlife, etc.). Although the County has certainly collaborated with a number of State and Federal agencies, they may consider expanding these efforts as feasible.
- USACE FRM projects incorporate natural and nature-based FRM measures whenever feasible; the County could consider utilizing natural or nature-based measures within the watershed (e.g. opening space for the river, green roofs, decentralized rainwater management, etc.). These types of measures may not reduce flooding from severe storms but may be beneficial during smaller rain events.
- USACE FRM project formulation process also includes broad public engagement (which the County has engaged in), as well as formal identification of objectives, opportunities and constraints, and comparison to the USACE Planning Guidance Notebook evaluation criteria. Furthermore, USACE has begun adopting and documenting risk considerations in decision making.

ELLICOTT CITY EVALUATION OF FLOOD RISK MANAGEMENT ALTERNATIVES

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Appendix A: US Army Corps Ellicott City FRM Evaluation Matrix

Appendix B: Ellicott City Flood Mitigation Alternatives Matrix; McCormick Taylor

ACRONYMS

BCR	Benefit Cost Ratio
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FRM	Flood Risk Management
LERRDS	Land, Easement, Right of Way, Relocations and Disposal
O&M	Operations and Maintenance
USACE	United States Army Corps of Engineers

1 INTRODUCTION

1.1 BACKGROUND

Situated in upper Western Branch of the Patapsco River valley, Ellicott City, Howard County, Maryland, was founded in 1772 and soon after became one of the largest mill towns in the Eastern United States. It contains the first terminus of the initial B. & O. Railroad located at Ellicott City Station. Built in 1830, this historic station now houses the B. & O. Railroad Museum. The downtown historic district, often referred to as "Historic Ellicott City" is located at the confluence of multiple streams which includes the Tiber Branch, the Hudson Branch, the Autumn Hill Branch, and the New Cut Branch.

In the summer of 2016 and late spring of 2018, two major floods occurred in historic downtown Ellicott City which resulted in loss of life and significant property damage. Since 2016, Howard County, Maryland (Howard County or County) has funded a number of efforts to investigate flood risk management (FRM) alternatives which could reduce future flood risk in Ellicott City. Some examples include hydrologic studies, hydraulic modeling, and watershed master planning. The FRM alternatives studied by the County each consisted of some combination of unique FRM measures. Examples of the FRM measures studied by the County included (but are not limited to): flood diversion tunnels, culvert additions and/or improvements, upstream storage and detention structures, floodplain terracing/modification, building acquisitions and flood proofing of structures.

Under authority granted by Section 206 of the Flood Control Act of 1960, as amended (33 U.S. Code § 709a), the County requested that the U.S. Army Corps of Engineers (USACE) coordinate an independent review of the completed flood-related studies and evaluate proposed alternatives in order to help inform future decision making. At the time of this evaluation, the County had developed 60 FRM alternatives.

The USACE review focused on general design approaches, hydraulic modeling results, and conceptual formulations of flood risk management alternatives. No detailed engineering designs of Ellicott City's proposed FRM measures had been developed at the time of the USACE review.

No designs or modeling were developed or completed by USACE and USACE is not expected to be a partner during the design or construction of projects. Howard County conducted all studies, including the hydrologic and hydraulic modeling and provided those data and reports to USACE for review.

1.2 STUDY AREA

The study area is comprised of the area incorporated by the boundaries of the hydrologic and hydraulic model developed to study Ellicott City flooding (Figure 1). The streams which flow to downtown Ellicott City are situated within a 3.7 square mile watershed, which forms the hydrologic model boundary. The County's hydraulic modelling is bounded by U.S. Route 29 and the Patapsco River and is in the vicinity of MD Route 144 (Main Street).

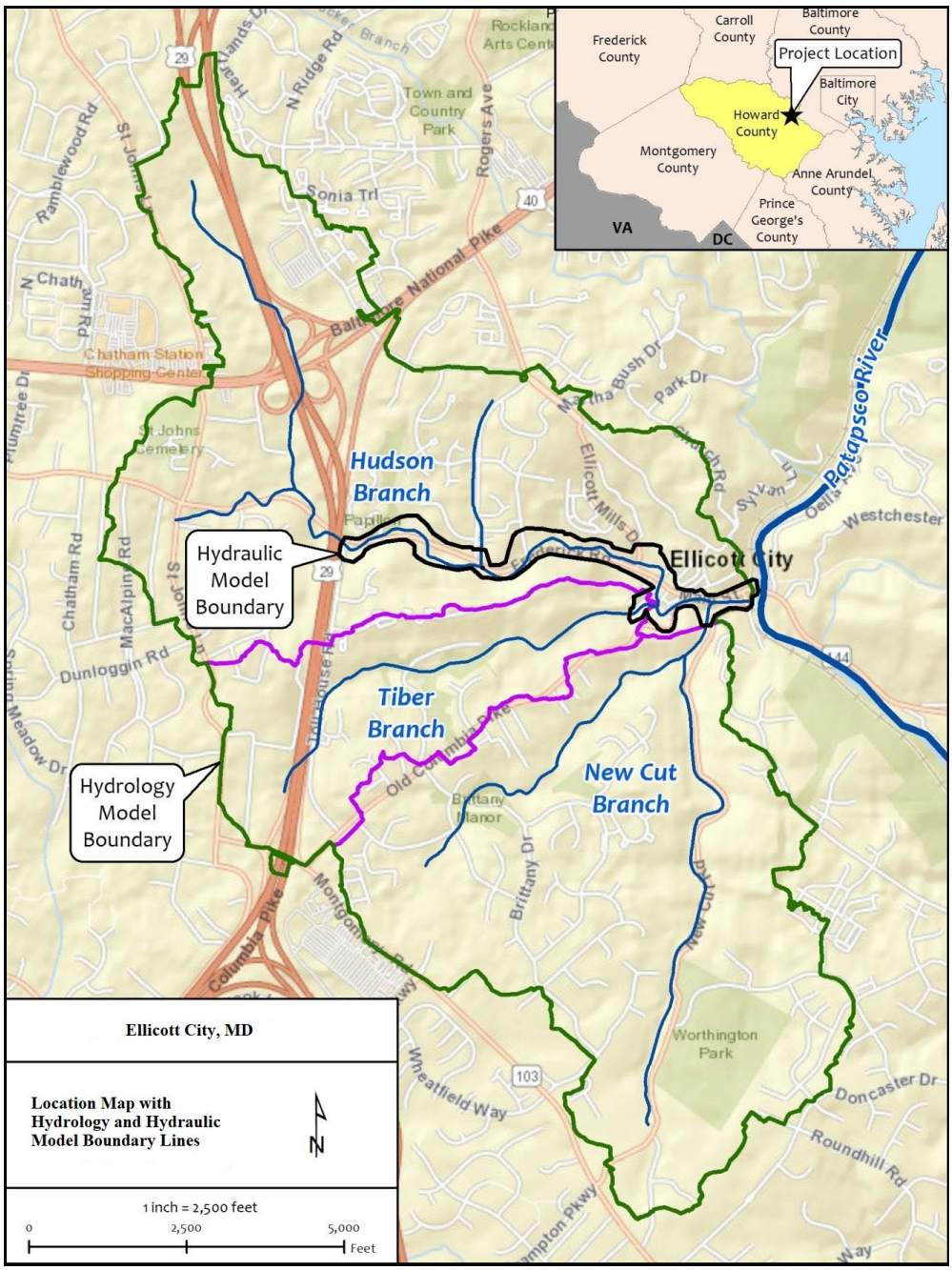

Figure 1. Ellicott City Project Location Map with Hydrologic and Hydraulic Model Boundary Lines (modified from McCormick Taylor 2017)

1.3 PURPOSE AND GOALS

Utilizing a national cadre of USACE multi-disciplined FRM experts, the purpose of this evaluation was to review the recent flooding problems and completed flood studies (including modeling results) commissioned by the County, evaluate the County's proposed FRM measures, and generate any new potential strategies/measures for the County's consideration. As a part of this evaluation, the team produced an evaluation matrix to aid in its assessment process and to serve as a tool to assist the County with future decision making.

Additionally, this evaluation leveraged the expertise of a wider audience of flood experts via two meetings/webinars with other FRM subject matter experts to solicit their input. A presentation was made to Maryland Silver Jackets team (which is comprised of Federal, State, academia, and nonprofit entities involved in flood risk management) and a webinar was presented to a national USACE Flood Risk Management audience. During the national USACE FRM webinar, experts from 20 Districts and 7 different areas of expertise (planning, hydraulics/hydrology, civil engineering, geotechnical engineering, environmental, economics, and emergency management) participated in the discussion. At both events, the audience members were given the opportunity to learn about the recent flooding issues, the measures being considered, and provide any feedback that would be valuable for the County to consider. All comments, suggestions and feedback received at the above two meetings have been integrated into this report.

The County's goal for Ellicott City is to reduce the risk to loss of life and damage to property through the reduction of flood depths and velocities associated with a July 2016 or May 2018 magnitude storm event. This goal included reducing roadway flooding depths down to approximately 3 feet (or below) and roadway flood velocities down to 5 feet/second (or below). These targets were selected as they represent the approximate upper effective limits for non-structural flood proofing (USACE 2019).

The current effort by the County is focused on mitigating flash flooding similar to that experienced in July 2016 and May 2018. This evaluation, therefore, was of FRM measures and alternatives which could address these types of storm event. The current set of measures and alternatives being considered by the County and evaluated in this report are not specifically intended to address potential Patapsco River flooding. Some FRM measures and strategies being considered by the County, however, would likely reduce flood risk associated with a future Patapsco River flood event (e.g. removal of structures, flood proofing of buildings, vertical evacuation plans, elevated egress walkways).

This review focused on general design approaches, hydraulic modeling results, and conceptual formulations of flood risk management alternatives. No detailed engineering designs of Ellicott City's proposed FRM measures had been developed at the time of the USACE review. No designs were developed or engineering analysis were performed by the USACE review team.

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2 EVALUATION METHODOLOGY

2.1 Evaluation Kick-Off

USACE's Baltimore District coordinated and facilitated a kick-off meeting with Howard County, during which time the County briefed USACE on the two most recent floods, past commissioned work and the current status of Ellicott City flood resilience planning activities. The County's goals and constraints were also confirmed during this meeting, including the need for potential FRM measures which minimize operations and maintenance (O&M), relocations, change to community structure or infrastructure, and that consider a range of historical preservation methods.

Coordinated by Baltimore District, a national team of USACE FRM subject matter experts were then recruited to conduct the evaluation. These USACE FRM experts were recruited from outside of the Baltimore District in order to establish an independent review team and included a range of disciplines. The team was comprised of members with the following disciplines: Planner, Civil Engineer, Cultural Resource Specialist, Geotechnical Engineer, Hydraulic Engineer, and a National Nonstructural Committee member.

2.2 Documents Reviewed

The team began with a review of documents, modeling results, and data provided by the County. These documents and data reviewed included, but was not limited to the following:

- 2016 Ellicott City Hydrology/Hydraulic Study and Concept Mitigation Analysis (McCormick Taylor, 2017)
- The Ellicott City Flood Mitigation Plan (Howard County, 2018)
- Ellicott City Watershed Master Plan Public Meeting (March, October, September 2018)
- Ellicott City Watershed Master Plan – Online Input / Survey Summary (October 2018)
- Nonstructural Flood Proofing Study for Ellicott City (USACE, 2018)
- To-date tunnel bore/geotechnical information
- Ellicott Mills Drive Culvert Boring Location Plan (RK&K, 2018)
- Ellicott Mills Drive Channel Extension Boring Location Plan (RK&K, 2018)
- Case Study: Ellicott City Flood Event (Smith Planning and Design, LLC, 2017)
- Ellicott City Flood Recovery Community Advisory Group: Final Report (2017)
- The Economic Impact of the 2016 Ellicott City Flood (Richard Clinch, 2016)
- 2-D hydraulic modeling outputs for FRM alternatives (Howard County, 2019)
- Video footage of 27 May 2018 flooding

The review focused on general design approaches, modeling results, and conceptual formulations of flood risk management alternatives. A detailed technical review of these documents was not conducted. No detailed engineering designs of any specific alternatives were available for the team's review.

2.3 First Team Meeting: Development of Criteria and Evaluation Matrix

After each USACE team-member reviewed all pertinent documents, modeling results, and data, the team then convened for its first meeting, which was conducted through webinar. The team decided that the best way to evaluate and compare the County's alternatives was to establish a set of criteria and develop a matrix (Appendix A).

The development of the criteria, the criteria weighting, and the impact ratings (all discussed below) was informed by the review of the County's documents and drew heavily on the independent review team members' best professional judgment.

Quantification (weighting) of the evaluation criteria and impact ratings was intentionally broad (e.g. the criteria weights were placed on a 1-3 scale; impact ratings on a 0-3 scale) as this was a high-level review, and not a detailed technical analysis. The team was not able to review engineering designs/drawings, as they did not exist at the time of the review.

Although the summed weighted score did produce a numerical value associated with each FRM measure (Appendix A), the purpose of this evaluation matrix was not to establish a definitive "rank" or "grade" for each. Instead, it was intended as a method which would allow the team to perform a high-level and semi-quantitative comparison of each measure relative to the other measures, based on the team's best professional judgment and the review of the conceptual-level FRM measures.

The other main purpose of the evaluation matrix was to generate descriptive "Advantages," "Challenges," and "Considerations" for each of the most effective FRM measures. These Advantages, Challenges and Considerations (Sections 3 and 4; Appendix A) are intended to aid in the County's decision making process. Furthermore, the evaluation matrix can be adapted by the County, or any interested entity or individual, as a tool for performing their own evaluations. For example, criteria could be added or subtracted, existing criteria modified, weighting and rating scheme altered, etc. based on the users' preference.

2.3.1 Evaluation Criteria

A key component of this evaluation was the development of the set of criteria by which each FRM measure could be gauged. The development of these criteria, as well as the associated weighting scheme and ratings of specific measures relied heavily upon the best professional judgment of the independent review team, based on the review of the body of documents and modeling outputs provided by Howard County.

After brainstorming a number of potential criteria, the team reduced the list of criteria down to seven. Those seven criteria and their description are presented below. Note that this list is not in order of relative significance.

<u>Prevention of Loss of Life</u>
Criteria Description: To what degree does the measure impact prevention of loss of life in a July 2016-type flood event based on one or more of the following: lower flood velocities, lower flood depths, allow for more effective evacuation by car or by foot. Additionally, building acquisitions that remove people from hazardous flood zones has been considered in this criteria.

<u>Preservation of Historical and Cultural Resources/Community Cohesion</u>
Criteria Description: To what extent does the measure impact: historic preservation, integrity of cultural/historic aspects of buildings, historic setting, recreation/walkability, changes to look and feel of community.

Reduction of Flooding
Criteria Description: To what degree does the measure result in reduction to flood depths and velocities associated with a July 2016-type flood event.

Economic Impacts
Criteria Description: To what degree would the measure results in economic impacts via one or more of the following: reductions of flood damages (based on a July 2016-type flood event), removal of businesses, potentially lost opportunities to businesses, loss of employment opportunities, potential increased business opportunities from draw to downtown parks/recreational opportunities along streams/increased sense of safety.

Operations and Maintenance
Criteria Description: Significance of O&M costs associated with measure, including considerations for manpower and frequency of O&M efforts.

Initial Construction Costs
Criteria Description: Significance of initial constructions costs, including costs associated with real estate acquisition, construction, permitting, and Land, Easement, Right of Way, Relocations and Disposal (LERRDS).

Implementation Duration
Criteria Description: Years to benefits realized (duration to implement project; to include planning, design and construction).

Environmental Impacts
Criteria Description: Significance of impacts to one or more of the following: habitat (riverine and riparian), aquatic species, water quality, groundwater impacts (includes consideration of these possible effects along adjacent reaches of the Patapsco River).

2.3.2 Criteria Weights and Impact Rating Scales

The team then established a "weight" (scale of 1-3) and an "impact rating" (scale of 0-3) for each criteria (impact rating scale details are discussed below). The purpose of the weight and impact rating is so that each measure can receive a weighted score (criteria weight X impact rating) for each criteria, and those weighted scores could then be summed across all the criteria for that particular measure. This allowed the team to assess the evaluated FRM measures relative to one another.

Criteria Weights
Based on best professional judgment and a review of the County's documents, the team established a weight for each criteria (scale of 1-3). The most critical criteria (e.g. prevention of loss of life, reduction in flooding) received the maximum weighting value of 3. Criteria which was of lesser consequence (e.g. implementation duration) received a weight of 1.

Impact Rating Scales
The review team developed an impact rating for each criteria so that each measure's impact could be rated for each of the above described criteria.

Each criteria was assigned a positive (+), negative (-), or a combination (+/-) symbol within the matrix. This indicates the directionality of the impact rating scale itself; examples are provided below for clarity. The directionality of the impact rating scale for each criteria are:

- Prevention of Loss of Life (+)
- Preservation of Historical and Cultural Resources/Community Cohesion (+/-)
- Reduction of Flooding (+)
- Economic Impacts (+/-)
- Operations and Maintenance (-)
- Initial Construction Cost (-)
- Implementation Duration (-)
- Environmental Impacts (+/-)

Three impact rating scale descriptions are provided below, one from each directionality group. The remainder of the impact rating descriptions are included within the evaluation matrix (Appendix A). Note that while the initial impact rating scale was developed during the first team meeting, this was an iterative process that included refinement in later team meetings.

Example 1: Impact Rating Description for Prevention of Loss of Life (+)

For each FRM measure evaluated by the review team, a value of 0-3 was assigned for the "Prevention of Loss of Life" criteria based on the following scale:

- 0 = No beneficial impact towards prevention of loss of life
- 1 = Minimal impacts towards prevention of loss of life
- 2 = Moderate impacts towards prevention of loss of life
- 3 = Maximum impacts towards the prevention of loss of life

Note that this scale has a positive (+) directionality; that is, a higher score represents a larger or more positive impact.

*Example 2: Impact Rating Description for Preservation of Historical and Cultural Resources/Community Cohesion **(+/-)***

For each FRM measure evaluated by the review team, a value of 0-3 was assigned for the "Preservation of Historical and Cultural Resources/Community Cohesion" criteria based on the following scale:

- 0 = Negative impact to preservation of historical and cultural resources and/or to community cohesion/recreation
- 1 = Minor negative impacts to preservation of historical and cultural resources and/or to community cohesion/recreation
- 2 = Neutral/somewhat positive impact to preservation of historical and cultural resources and/or to community cohesion/recreation
- 3 = Strongly positive impacts to preservation of historical and cultural resources and/or to community cohesion/recreation

Note that this scale spans both a negative and positive (+/-) directionality; that is, the lower scores (0-1) represent negative impacts, while the higher scores (2-3) represent neutral to positive impacts.

Example 3: Impact Rating Description for Initial Construction Cost (-)

For each FRM measure evaluated by the review team, a value of 0-3 was assigned for the "Initial Construction Cost" criteria based on the following scale:

- 0 = Very significant initial construction costs
- 1 = Significant initial construction costs
- 2 = Moderate initial construction costs
- 3 = Minimal initial construction costs

Note that this scale has a negative (-) directionality; that is, a higher score represents a lesser or more minimal impact.

2.4 Depth and Velocity Screening Criteria: Reducing the Number of Measures for Further Evaluation

Each USACE evaluation team member began by reviewing all the proposed FRM alternatives for which the County had conducted hydrologic and hydraulic modeling. This initial review encompassed sixty modeled alternatives, each comprised of two to seventeen individual FRM measures (Appendix B). To conduct a more detailed evaluation using the developed evaluation matrix, the team was required to first reduce the number of alternatives/measures to a more feasible quantity for further evaluation.

The method employed to reduce the total number of alternatives to a smaller sub-set was via a screening of all alternatives based on how much they reduced the flood depth and velocity at four locations along the Main St. road surface (Figure 2). Alternatives which resulted in a reduction of the modeled July 2016 storm flows down to or below a depth of 3.5 feet and a velocity 5 feet/second at those four locations were included for further evaluation. Those alternatives which did not meet this criteria were eliminated from further evaluation, as the main purpose of each alternative is flood risk reduction.

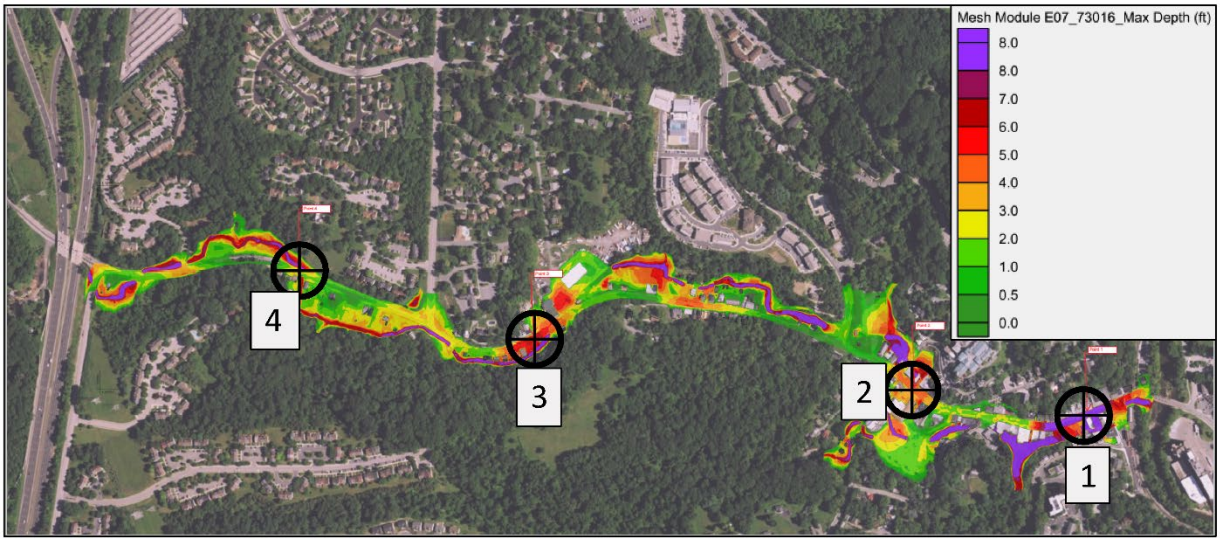

Figure 2. Modeled depth outputs from Howard County's 2-D hydraulic model for 30 July 2016 storm event with the four locations used for depth screening. This screening process was repeated at the same four locations using the modeled velocity outputs.

The four particular locations were selected due to the flooding issues experienced at those locations during the 2016 and 2018 storm events. The 3.5 foot depth and 5 feet/second velocity thresholds were selected as these represent the upper limits of effectiveness for non-structural flood proofing of buildings (USACE 2019). The County has targeted a reduction goal of 3 feet (or below) for roadway flood depths from a July 2016 storm, which is slightly below this maximum effective limit of nonstructural flood proofing.

The result of this depth/velocity screening was twofold. One, it removed from consideration any of the proposed alternatives which did not achieve the primary goal of reducing depths and velocities to the desired level, which ensured that the USACE team's evaluation would only focus on the most effective (from a strictly flood risk reduction perspective) alternatives. Two, it reduced the number of alternatives from sixty down to eight. Those remaining eight alternatives were comprised of fourteen unique FRM measures which ultimately became the focus for of the team's detailed evaluation – a more feasible array for review. A list of the fourteen County FRM measures which resulted from this depth/velocity screening is provided below.

Potential Conveyance Improvement Measures

1) North Tunnel
2) South Tunnel
3) Maryland Avenue Culvert(s)
4) Lot D Channel Expansion
5) Terraced Floodplain – Lower Main St.
6) West End Floodplain & Conveyance
7) Ellicott Mills Drive Culvert (excluded from further evaluation; see below)

Potential Flood Storage Improvements

1) T-1 Pond
2) NC-3 Pond
3) H-7 Pond
4) Robert's Property (H4) Pond

5) H1-UG1 & H8-UG1 Lot F/Old Roger Carter Community Center
6) H1-UG2 (West End)
7) Quaker Mill Pond (excluded from further evaluation; see below)

The team decided that projects which the County had already initiated (and which were in a late-planning or early construction phase) would not be included for further evaluation within the matrix. Specifically, the Quaker Mill Pond improvement and Ellicott Mills Culvert improvement were removed from further consideration at this stage, as Quaker Mill Pond was in a late-development phase and the Ellicott Mills Culvert was already under construction at the time of this evaluation. As such, the above list was reduced down to a total of twelve FRM measures.

The reasoning for this decision was that the purpose of the team's evaluation was to assist the County with future decision making related to FRM alternatives and measures.

The detailed descriptions of each measure and the results of the team's evaluation for each measure can be found in Section 3 and Appendix A.

2.5 Second Team Meeting: Site Visit and In-Person Workgroup

On May 30, 2019, the USACE review team convened in Baltimore for its second meeting. This included a half-day site-visit to downtown Ellicott City with walking tours of the major flood-prone areas along lower Main St., Upper Main St. and the West End where many of the proposed FRM measures could be located.

After the site visit, the team conducted a number of tasks during its follow-on workgroup meeting:

- Using the team-developed matrix, the team conducted an evaluation of the twelve County FRM measures which resulted from the depth/velocity screening exercise by the assignment of an impact rating score for each measure, for each criteria. The team provided written explanations within the body of the matrix as to why a particular impact rating was assigned, and included Advantages, Challenges and Considerations for each measure. The results of the evaluation, including the Advantages, Challenges and Considerations are included in Section 3 and Appendix A.
- The team conducted an exercise to better define any new potential FRM measures for the County's consideration. Two new potential measures were developed and evaluated in the matrix along with the County's twelve FRM measures. The new potential measures were titled "Downtown Targeted Conveyance Increases" and "New Cut Branch Dry Flood Mitigation Structure." A detailed description of these two newly proposed measures and the results of the team's evaluation of them is included in Section 4.
- Another exercise was conducted where the team envisioned the Ellicott City FRM project as if it were a USACE FRM project. The goal was to compare and contrast the County's strategies and processes with the USACE FRM project process. The results of this exercise is located in Section 5.

2.6 Third Team Meeting: Finalization of Evaluation Matrix

Following the team's in-person meeting and site visit, the team then reviewed and added additional information and clarifying details the evaluation matrix, as needed. The team then convened for a third meeting (via webinar) to finalize the evaluation matrix, mainly through additional refinement of the Advantages, Challenges and Considerations sections.

2.7 Presentation to FRM Experts

To leverage the expertise of a wider audience of flood experts, USACE also held two meetings/webinars with other subject matter experts to solicit their input. A presentation was made to Maryland Silver Jackets team (on August 27, 2019), which is comprised of Federal, State, academia, and nonprofit entities involved in flood risk management. Following that, a webinar (on October 10, 2019) was presented to the nationwide USACE Flood Risk Management audience. During this October webinar, roughly 60 experts from 20 Districts and 7 different areas of expertise (planning, hydraulics/hydrology, civil engineering, geotechnical engineering, environmental, economics, and emergency management) participated in the discussion.

At both events, the audience members were given the opportunity to learn about the flooding issues, the measures being considered, and provide feedback that would be valuable for the County to consider. Comments, suggestions and feedback received at the above two meetings have been integrated into this report.

3 FLOOD RISK MANAGEMENT MEASURES EVALUATED

Listed below is the outcome of the USACE team's matrix evaluation of the twelve FRM measures which resulted from the depth/velocity screening described in Section 2.4. The matrix can be found in Appendix A. The FRM measures are grouped by sub-category ("Conveyance Improvement Measures" and "Flood Storage Improvements"). Section 4 includes the results of the matrix evaluation of the USACE-developed potential FRM measures. Section 6 contains additional FRM strategies which the County may consider for Ellicott City.

One result of the evaluation matrix was a weighted-sum for each measure. Based on this weighted-sum value, each measure is assigned to one of three tiers. Those measures which fell within the top third of the weighted-sums were assigned to the "highest tier", those in the middle third were assigned to the "middle tier", and those in the lower third were assigned to the "lower tier". The significance of each measure's individual weighted-sum score was not emphasized in this report for the following reasons. One, the main purposes of the matrix was to qualitatively evaluate the most effective FRM measures based on the criteria and generate descriptive "Advantages," "Challenges," and "Considerations" for each to aid in the County's decision making process. Two, the measures evaluated in the matrix, because of the depth/velocity screening performed previously (Section 2.4), were the most effective at reducing flood depths and velocities for Ellicott City and would each successfully contribute to reduce flood risk if implemented. Three, to accommodate the inherent level of uncertainty associated with a review of conceptual level designs, the evaluation scoring was intentionally left at three tiers.

Also, note that building removal or modification was evaluated by the team only in the cases where measures specifically required it. For instance, the "Terraced Floodplain" and "Lot D Channel Expansion" as proposed, required a number of buildings to be removed or modified. The team took this into consideration when evaluating those measures. For example, the team attempted to account for the fact the removal of structures in the "Terraced Floodplain" option contributes to the prevention of loss of life (as individuals under that scenario are ultimately removed from a high risk area) while detrimentally impacting historical/cultural resources and community cohesion (by removing historic structures). However, each permutation of building removal or modification was not evaluated on its own, as the modeled outputs did not show substantial hydraulic impacts associated with individual building removals or modifications.

3.1 Conveyance Improvement Measures Evaluated

The matrix evaluation results for each reviewed measure are presented here. Note that the evaluation of each measure was based on the County's hydraulic and hydrologic modeling configuration at the time of USACE review process (Spring 2019). The descriptions of specific measures presented below reflect how those measures were modeled. Any subsequent changes to these measures or models that the County may have since pursued are therefore not included. All the measures were modeled by the County using the July 30, 2016 storm event, and hydrologic or hydraulic conditions referenced are related to that particular storm event. See Figure 3 for a location map of the conveyance improvement measures.

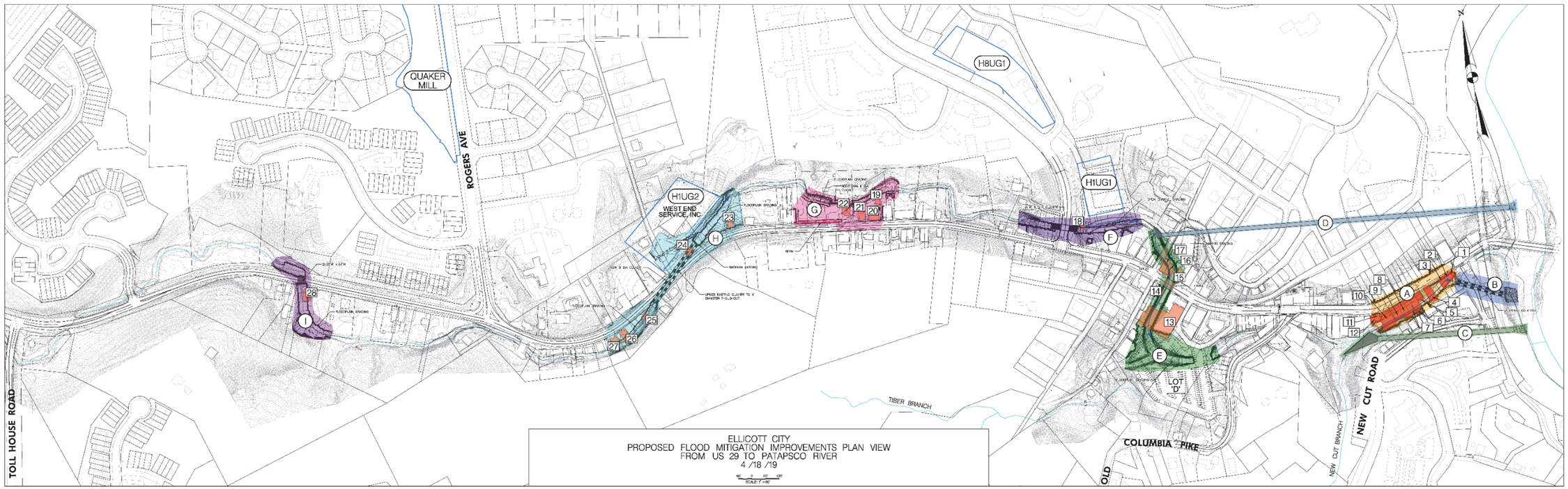

Figure 3. Ellicott City proposed flood mitigation improvements from US 29 to Patapsco River

3.1.1 North Tunnel

Description: Area D in Figure 3. This proposed tunnel intercepts Hudson Branch flows near Court Ave. and outfalls to the Patapsco River upstream of Main St. The measure includes minor stream grading and weir structure across the stream to facilitate high flow diversions into the tunnel, while allowing some flow through existing channel. Potential tailwater effects from Patapsco River flooding are not expected to result in backwater flooding through the tunnel and the tunnel is anticipated to include sufficient inlet control conditions due to significant elevation differences between inlet and outlet. Due to the steep slope of the tunnel and expected higher energy discharge flows, appropriate sizing of dissipation structures/stabilization methods will be required at the outlet. This has the potential to significantly reduce flood depths along Main St. from Court Ave. downstream. Both bore sizes (12' and 15') as evaluated have a headwater depth to discharge relationship that conveys roughly 80-90% of 2016 storm flow without affecting upstream water surface elevations, based on stated inflow invert assumptions.

Weighted-Sum Outcome: Highest tier.

Advantages: Construction of this measure would have little to no impact on any historic structures, it does not impact community cohesion and it minimizes or avoids utility relocations. As modeled, this measure as a stand-alone produces the most significant reduction to flood depths and velocities downtown.

Challenges: The most expensive option, tunneling may pose significant engineering challenges including constructability and construction duration. The complexities in the proposed alignment (passes under active railway embankment and may require easements on private property) add potential significant growth risk to cost and construction duration for implementation of this measure. There would be a potential for debris to block the intake or upstream channel and reduce the effectiveness of the bypass. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: This is the most costly option, and there may be less costly options that achieve similar extents of flood reduction (e.g. Lot D Floodplain Expansion) but which would require more extensive changes to the downtown area. Although requiring a longer construction duration relative to other measures, the tunnel operation would largely avoid impacts to businesses and existing infrastructure during construction. From an environmental standpoint, the impact to known resources and stream flows may elevate the level of documentation under the National Environmental Policy Act to an Environmental Impact Statement, if implemented. The County could also consider a program to control obvious upstream debris sources (e.g. vehicles) which could significantly impact effectiveness during high storm flows. Outlet structure design should include components to minimize potential erosion and scouring of Patapsco River bed and banks. Additionally, this measure captures flows from the Hudson Branch but would not impact flows originating in the Tiber/New Cut/Autumn Hill watershed. Conversations with CSX Transportation would be required for final alignment evaluations. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.1.2 South Tunnel

Description: Area C in Figure 3. This proposed tunnel captures flows just upstream of buildings spanning over the stream along lower Main Street (Bldg. 10 in Figure 3) and outfalls in Patapsco River downstream of the Main Street Bridge. Various tunnel diameters were modeled, including a 10', 15', 20', and a 2 x 5'. This measure would include a weir and concrete flume to allow low flows to bypass the tunnel entrance while improving entrance hydraulics for high flows. This measure has the potential to significantly reduce depths on lower Main Street. When the South Tunnel outlet approximately 85% submerged from Patapsco

River flows, the hydraulic capacity is significantly impacted by the minimal slope of the bore. Otherwise the hydraulic capacity is controlled by tunnel characteristics.

Weighted-Sum Outcome: Highest tier.

Advantages: Very similar to North Tunnel. Construction of this measure would have little to no impact on historic structures, it does not impact community cohesion and it minimizes or avoids utility relocations. Modeling of the South Tunnel defined an approximate 1 foot reduction in flood depths within downtown Main Street.

Challenges: Similar to the North Tunnel, although shorter length of tunnel. The complexities in construction (passes under active railway) add potential significant growth risk to cost and duration to implementation of the measure. There is still a potential for debris to block the intake or upstream channel and reduce the effectiveness of the bypass. Any excavation activities present potential to impact archaeological resources. Modeling showed that entrance hydraulics and minimal slope resulted in this measure being less effective when compared to the North Tunnel.

Additional Considerations: Similar to the North Tunnel, including the outlet structure design considerations. Although longer construction duration relative to other measures would be required, the measure would largely avoid impacts to businesses and existing infrastructure during and subsequent to construction. The tunnel effectiveness could be improved with additional hydraulic head on the intake via a weir structure. Additionally, the South Tunnel entrance alignment should be oriented such that it ensures maximum efficiency for capturing flows downstream of the Tiber-Hudson/New Cut confluence. Conversations with CSX Transportation would be required for determination of final tunnel alignment. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.1.3 Maryland Avenue Culvert

Description: Area B in Figure 3. The Maryland Ave Culvert(s) connect the Terraced Floodplain measure upstream of Maryland Ave. to the Patapsco River providing additional conveyance capacity. This measure significantly reduces flood depths on Maryland Ave. and on lower Main St.

Weighted-Sum Outcome: Highest tier.

Advantages: The model outputs show significant reductions to flood depths and velocities on Maryland Ave. and lower Main St. as a result of this measure.

Challenges: These culvert(s) would be installed under the CSX railroad as well as in the immediate proximity of two historic railway buildings which may result in increased cost and complexity during construction. Any excavation activities present potential to impact archaeological resources. This measure would require the removal of at least some of the buildings on the southwest corner of Maryland Ave. and Main St.

Additional Considerations: The outlet structure (similar to Tunnel options) should be designed to address erosion of Patapsco River bed and banks. Conversations with CSX Transportation would be required to advance evaluations of alignment alternatives. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.1.4 Lot D Channel Expansion

Description: Area E in Figure 3. The Lot D Channel Expansion measure includes channel grading to lower the elevation of the channel and remove constrictions between Court Ave. and Parking Lot D. Model outputs show significant reductions in flow constrictions and backwatering of flow onto Main Street at Lot E and upstream of Court Ave.

Weighted-Sum Outcome: Highest tier.

Advantages: This expansion greatly reduces flood depths and velocities on lower Main Street to a level that competes with the North Tunnel in a one-one-one comparison. This option, however, should be much less costly than the North (or South) Tunnel option. The channelized stream reach through the Hudson Bend and Lot D area currently has poor in-stream habitat and little to no riparian habitat present. This measure, if implemented, would allow the opportunity to create both types of habitat.

Challenges: The channel and floodplain expansion would include removal, relocation or modification of some historic buildings. Additionally, this measure would impact the utility corridor at the Main St./Court Ave. area. There is the potential for loss of parking depending on Lot D's final configuration. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: If implemented, the County could consider a parking structure or adding parking elsewhere. Similar to the Terraced Floodplain measure, this area could be a highly walkable space for visitors. Additionally, there is potential for environmental improvements via the introduction of in-stream and riparian habitat. Evaluation of any historic structures would be required.

3.1.5 Terraced Floodplain (Lower Main St.)

Description: Area A in Figure 3. This measure includes floodplain grading and channel widening along lower Main Street. It removes flow constrictions upstream of Maryland Ave. and reduces flow escaping the channel and pushing out onto Main Street. There were multiple building removal scenarios modeled and considered by County. The County's most recently proposed plan calls for removal of buildings 1-4 and partial removal or modification of buildings 5-10.

Weighted-Sum Outcome: Middle tier.

Advantages: Increased conveyance decreases flooding along lower Main Street although modeling results show only a minimal impact from this measure. The removal of structures reduces risk of loss of life associated with upstream flash flood events and the removal of the rear portions of structures which span the stream would increase conveyance. Additionally, the building removal component on lower Main St. has the coincident benefit of mitigating risk related to property damage and loss of life from future Patapsco River flood events. Many recreational opportunities exist (including terraced park space could allow for events/amphitheater type shows), and the area may be a tourist attraction. The channelized stream reach currently present has poor in-stream and little to no riparian habitat present; this measure, if implemented, would allow for the opportunity to develop both types of habitat.

Challenges: Although real estate acquisitions may be finalized prior to this review's completion, this step will likely be the most significant challenge. Sediment and debris management will be required to prevent channel blockages. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: The County might consider incorporating parapet walls (either permanent or automated) along the Terraced Floodplain downtown area. Bollards placed along lower Main St. could be

considered to help reduce vehicles and other large debris from entering the channel along this reach during floods. The final design for this measure should include consideration of potential backwater effects from bottom-up Patapsco River flood events.

3.1.6 West End Floodplain & Conveyance

Description: Areas G, H and I in Figure 3. This measure includes multiple improvements in conveyance extending from Ellicott Mills Drive upstream. The measure generally doubles capacity of roadway culverts below the Main St. and Frederick Rd. intersection and includes stream grading. Modeling results show a reduction in residential and roadway flood depths, but the measure is more effective for storm events smaller than the 7/30/16 event.

Weighted-Sum Outcome: Lower tier.

Advantages: If all the improvements associated with this measure are implemented, they would reduce flood risk from smaller storm events such as the one experienced on 31 October, 2019. Also, due to the extents of proposed modifications of stream reaches, this measure presents significant potential aquatic habitat restoration opportunities.

Challenges: The large number of real estate acquisitions would be likely be the largest challenge. Also, construction will include crossing utility corridors and disruption to traffic flows.

Additional Considerations: This measure includes the potential for significant improvements for in-stream and riparian habitat and could include bio-engineering/nature-based FRM measures.

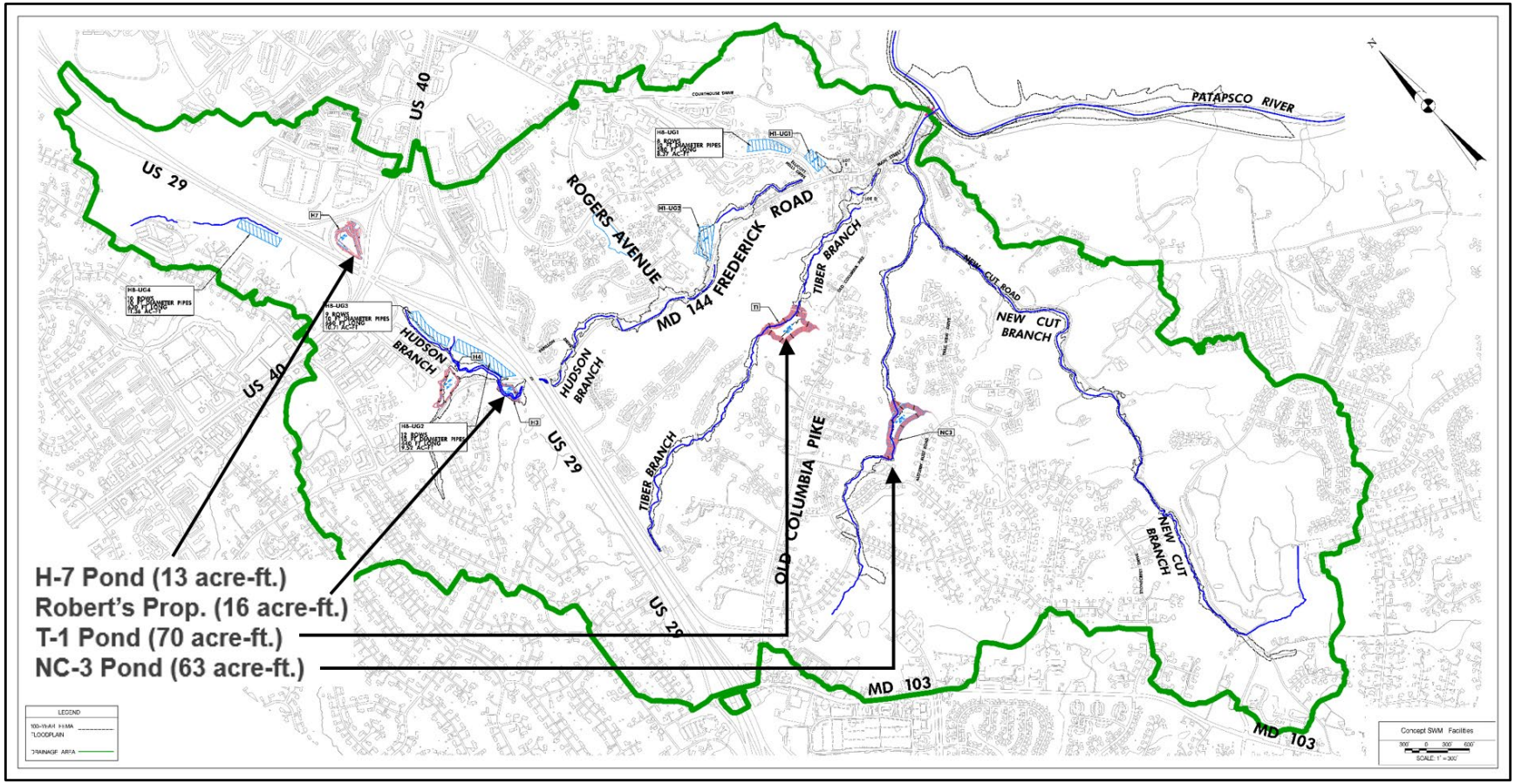

Figure 4. Watershed boundary for Ellicott City showing potential site locations for conceptual above and below ground flood storage improvement structures. The arrows indicate storage improvement structures included in the County's currently selected FRM alternative (Option 3G.7.0).

3.2 Flood Storage Improvements

Figure 4 shows potential site locations for above and below ground flood storage improvement structures.

3.2.1 T-1 Pond

Description: The T-1 pond has 70 acre/feet of storage. The pond is located along the Tiber Branch. Coordinates are 39°15'56.13"N, 76°48'22.80"W.

Weighted-Sum Outcome: Highest tier.

Advantages: Low cost storage and flood reduction option.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources. Property acquisitions are required.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider archaeological investigations early-on in the process to ensure site suitability.

3.2.2 NC-3 Pond

Description: The NC-3 Pond has 63 acre/feet of storage. It is located along the Autumn-Hill Branch, which is a tributary to the New Cut Branch. Coordinates are 39°15'34.57"N, 76°48'18.47"W.

Weighted-Sum Outcome: Highest tier.

Advantages: Low cost storage and flood reduction option.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources. Property acquisitions are required.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider archaeological investigations early-on in the process to ensure site suitability.

3.2.3 H-7 Pond

Description: The H-7 pond has 13 acre/feet of storage. It is located along the intersection of US 40 and US 29. Coordinates are 39°16'44.12"N, 76°49'13.67"W.

Weighted-Sum Outcome: Middle tier.

Advantages: Low cost storage and flood reduction option. This would be placed in an otherwise unused and already ecologically disturbed area and the sediment retention provided would benefit the downstream water quality.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.2.4 Roberts Property (H4) Pond

Description: Roberts Property is a pond with 16 acre/feet of storage. It is located along the Hudson Branch. Coordinates are 39°16'18.22"N, 76°49'8.74"W.

Weighted-Sum Outcome: Lower tier.

Advantages: Low cost storage and flood reduction option. Sediment retention would improve the downstream water quality.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. Removal of forested area represents a loss of habitat. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.2.5 H1-UG1 & H8-UG1 Lot F / Old Roger Carter Community Center

Description: H1-UG1 & H8-UG1 are two underground storage facilities with a combined storage of 33 acre/feet. They are located along Ellicott Mills Drive off of MD 144. Coordinates are 39°16'9.78"N, 76°48'2.07"W (H1) and 39°16'14.13"N, 76°48'5.92"W (H8).

Weighted-Sum Outcome: Lower tier.

Advantages: Water quality benefits from capture of sediments; after construction is complete, little to no negative impacts to local economy or historic feel of downtown.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. More costly than aboveground storage structures of similar capacity. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

3.2.6 H1-UG2 (West End)

Description: H1-UG2 is an underground facility with a storage of 30 ac/ft. It is located off of MD 144 along the Hudson Branch. Coordinates are 39°16'11.56"N, 76°48'25.26"W.

Weighted-Sum Outcome: Lower tier.

Advantages: Water quality benefits from capture of sediments; after construction is complete, little to no negative impacts to local economy or historic feel of downtown.

Challenges: Once storage structure fills, there are no further benefits to flood reduction. More costly than aboveground storage structures of similar capacity. Any excavation activities present potential to impact archaeological resources.

Additional Considerations: The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

4 ADDITIONAL MEASURES AND STRATEGIES FOR COUNTY'S CONSIDERATION

As a part of this evaluation process, the USACE team identified two additional FRM measures for Howard County to consider. The potential new measures were included in the evaluation matrix, and thus compared with the County's existing FRM measures in the evaluation process. A description of these potential measures and results of the team's evaluation of these measures is included below, followed by a list of additional strategies for the County's consideration.

4.1 New FRM Measures Identified by Team

These measures are preliminary concepts. The team did not perform any hydraulic modelling or calculations with regards to these measures, so any specific impacts to flood depths or velocities could not be established. Instead, preliminary hydrologic calculations and best professional judgment were relied upon to perform an evaluation of these two measures.

4.1.1 Targeted Conveyance Increases

Description: Due to the relatively constricted and sometimes winding channel configuration in the lower reaches of the Ellicott City stream system, it was the team's determination that there are significant opportunities to enhance conveyance capacity to these channelized sections. This potential new measure would consist of a number of modifications to the channelized reaches to increase conveyance capacity by means of channel widening, stream-bed lowering (bedrock excavation), and increased channel cross-sectional area by the addition of parapet walls. The parapet wall was generally considered by the team to be a 2-3 foot high flood wall along the channelized sections; it would be structurally reinforced and could include a setting-appropriate façade to merge with the historic setting.

Weighted-Sum Outcome: Highest tier.

Advantages: One of the County's goals is to achieve reductions in flood depths on lower Main St. from a 2016 type storm event down to approximately 3 feet. The team assumed that if such measures were implemented to achieve this 3 foot goal, then this new "Targeted Conveyance Increases" measure could allow for the conveyance of most or all of the remaining July 2016 storm flows within the channel.

Because the downstream reaches are already 100% channelized, this proposed measure to increase the channel capacities would not significantly alter the overall downtown setting. The bedrock channel bed is significant as channel lowering is possible with minimal risk of substantial erosion.

Challenges: Geotechnical investigations would be required for any channel modifications (widening and/or lowering), most significantly in those reaches adjacent to building foundations. Additional structural reinforcement of these structures may be required, as this action may result in significantly higher-energy flows in some areas. Any excavation activities present potential to impact archaeological resources and additional permitting would be required for any dredging activities.

A parapet wall system for the downtown channelized reaches of Ellicott City would also require geotechnical investigations, although this could be a part of the investigative effort to assess adjacent areas for channel modifications. Anywhere a parapet wall would be constructed proximate to buildings and foundations, those structures may require structural evaluation/reinforcement as well. Extensive addition of parapet walls may adversely impact the look and feel of downtown.

Additional Considerations: The 2-D hydraulic model could be used to identify regions of lowest conveyance (most hydraulically constricted) in the system and this could be included as a modeling priority for the County. Should every hydraulic constriction not be addressed, the County could undertake conveyance improvement projects over a number of years, prioritizing channel reaches with the highest cost-effectiveness. As with any conveyance increases in a system, any projects undertaken should begin at the downstream channel confluence and proceed upstream. From a historical perspective, the channel walls themselves may be considered historic structures and would need to be evaluated.

The potential parapet wall could vary in nature by reach. For instance, sections of the parapet wall could include such options as automatic flood barriers or impact-resistant structural glass sections sited for aesthetic purposes.

Any channel modification projects could include low hydraulic head in-stream habitat structures to improve aquatic habitat.

4.1.2 New Cut Dry Flood Mitigation Structure

Description:
This potential dry flood storage structure could be located on the New Cut Branch upstream of Tiber-Hudson/New Cut Branch confluence, far enough upstream to be outside of view from downtown. Approximate embankment location of 39°15'55.3"N, 76°47'53.7"W (Figure 5). As a dry storage structure, it could remain forested and would only be inundated during large storm events. The outlet could be designed at stream elevation and maintain approximate normal low-flow conditions to minimize adverse environmental impacts. Based on preliminary calculations, the approximate storage capacity could range from 135-350 acre-feet with an embankment height of 40 to 60 feet. The ponding area behind the structure would vary with structure embankment height and rainfall event.

Weighted-Sum Outcome: Lower tier.

Advantages: If appropriately sized, the structure could significantly reduce peak flows from the New Cut Branch watershed. The construction of an embankment/reservoir would also retain rock, wood and other debris which would otherwise be deposited in the lower, already constricted channel reaches.

Challenges: Depending on storage capacity and embankment location, this structure would require the relocation or closure of the New Cut Road as well as the residential structures located along New Cut Road in the vicinity of the coordinates provided, and would therefore require acquisition of property. This structure would likely be classified as a high hazard dam requiring permitting, as it would be located immediately upstream of the developed downtown area. Any excavation activities present the potential to impact archaeological resources.

Additional Considerations: Due to the challenges associated with property acquisition, currently the County is only considering one storage measure on the New Cut/Autumn Hill Branches (T-1 Pond located on the Autumn Hill Branch). During both the 2016 and 2018 storm events, the New Cut Branch was a major source of floodwaters based on USGS calculations. This proposed measure could significantly reduce flood risk associated with New Cut Branch flood flows, however there are significant challenges associated with this project including property acquisition and the permitting required for a high-hazard dam.

Embankment construction material would likely be roller compacted concrete. Embankment material could potentially be rock-filled, which would be cheaper due to local material sources. Placement considerations could be prioritized such that the structure would not be not visible from downtown Main St. This measure

may require an Environmental Impact Statement, but more likely an Environmental Assessment would suffice. A dry storage structure could remain in a wooded, natural state and expand opportunities for public recreation space. Permanent real estate interest would need to be acquired for flowage easements for the maximum design flood retention. Some stream mitigation would likely be required for loss of in-stream habitat. Real estate acquisitions would likely be critical path for duration for this project.

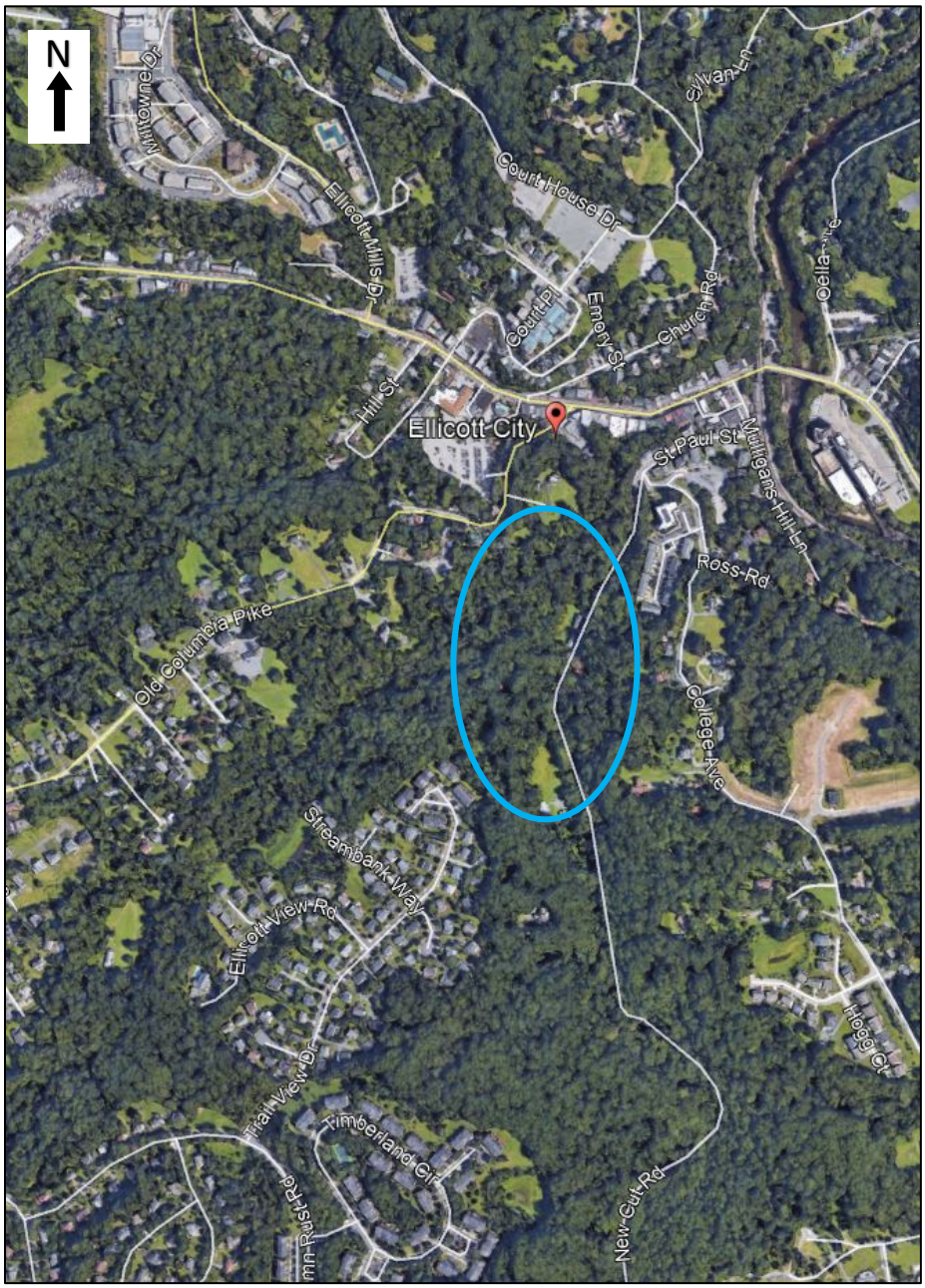

Figure 5. General location of potential New Cut dry flood mitigation structure.

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5 Results of Team Exercise: Comparing and Contrasting Howard County's FRM Approach with the USACE FRM Approach

The team conducted an exercise of evaluating the Ellicott City flooding problems as if it were a USACE FRM project, such that the County's FRM strategies and processes could be compared and contrasted with the USACE process. The goal of this exercise and subsequent comparison was to identify (if any) differences with County's approach that might be re-evaluated. Overall, the team determined that the County followed a sound process and that the FRM measures being considered by the County are similar to those which would be considered for USACE projects and can effectively reduce flooding.

USACE constructed FRM projects have established practices and specific requirements, and as a result there are differences in how an USACE FRM project would be executed. These differences are described below and the County may choose to consider including some of these procedures a part of their process.

- USACE is required to perform an economic analysis in the form of benefit cost ratios (BCRs) to identify the most cost effective solutions; the County may consider a BCR analysis during decision making.
- USACE would typically formulate an array of measures based on benefits, however for this evaluation the team selected measures to evaluate based on engineered outcomes (reduction of flood depths and velocities, which are related to benefits).
- USACE would typically conduct an incremental modeling analysis to evaluate each potential FRM measure. That is, each component would be modeled separately such that the hydraulic impacts and benefits could be quantified and then measures could be incrementally combined to form alternatives. The County could consider this approach to help determine the individual contribution of each potential measure in a systematic fashion. The County's modeling outputs as presented to USACE for this evaluation, typically had multiple combined measures, making the assessment of individual measures somewhat challenging.
- The Corps approach for modelling storm events would typically include the modeling of an array of different storm scenarios, as a diversity of modeled storms can better determine the selection of measures. For example, under different storm scenarios, more significant rainfall may occur in one sub-watershed as compared to another, which could impact the decision making for measure/alternative selection.
- A Corps FRM project of this scope would include multi-agency collaboration (FEMA, US Fish and Wildlife). The County has coordinated with a number of State and Federal agencies to-date, and could consider expanding these efforts when possible.
- USACE FRM projects incorporate natural and nature-based FRM measures whenever feasible; the County could consider utilizing natural or nature-based measures within the watershed (e.g. opening space along the river, green roofs, decentralized rainwater management, etc.). These types of measures may not be effective for severe storms but may be beneficial for smaller rain events.
- USACE FRM project formulation process also includes broad public engagement (which the County has engaged in), as well as formal identification of objectives, opportunities and constraints, and comparison to the USACE Planning Guidance Notebook evaluation criteria. Furthermore, USACE has begun adopting and documenting risk considerations in decision making.

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6 Additional FRM Strategies and Non-Structural Measures for County to Consider

As a part of this evaluation process, the USACE team developed additional FRM strategies and non-structural FRM measures for Howard County to consider. As the concepts are typically non-structural in nature, they did not undergo evaluation via the team's evaluation matrix. A number of these strategies and non-structural FRM measures were proposed by FRM experts in response to the presentations given (Section 2.7). Due to their varied nature, these are not presented in order of importance.

6.1 Non-Structural FRM Measures

- An aggressive debris management plan to clear debris along stream reaches could be considered along with potential flood plain zoning ordinances that specifically restrict objects or ancillary structures which may become flood debris during large events.
- Although the County is already pursuing several property buyouts, the USACE team, as well as a number of FRM experts from various fields stressed this as a proven method to reduce risk to loss of life and damages to property. Any future property buyout decisions will have to be balanced with the public desire to maintain a cohesive and historic downtown Ellicott City.
- The County could consider a network of elevated egress walkways (located behind the buildings in certain areas) designed to allow pedestrians/building occupants to escape to high ground.
- The County could consider mandating that individual businesses and property owners in the lower Main St. section develop and post vertical evacuation plans and that owners, staff and residents be trained in their responsibilities.
- Parking restrictions, which are already being considered by the County, are a valuable tool for reducing risk of loss of life as they limit the number of people in vehicles during flood events and prevent vehicles from becoming flow-constricting debris. Continue to consider removing as much parking as feasible from the highest-risk areas and replacing it with parking at higher elevations (with potential shuttle services to connect to downtown).
- Bollards or similar may be included along channel reaches and terraced floodplains throughout the lower sections of downtown to prevent vehicles and large debris from entering channels.
- As feasible, continue to collaborate with other agencies (National Weather Service) to improve flood warning forecasts and flood warning systems/sirens
- The County has initiated a grant funding program to encourage property owners to flood proof their buildings; this effort should continue and could be expanded to mitigate residual flood risk in the high risk areas. On lower Main St., the flood proofing of structures would also provide the coincident flood risk mitigation benefit for future Patapsco River flood events.

6.2 Modeling Strategies

- As discussed in Section 5, the County could consider modelling an array of different storm scenarios. This would help during decision making, as different storm scenarios could result in higher flows emanating from different sub-watersheds, which can impact the overall effectiveness of specific measures.
- The County could consider modelling each individual measure on its own, such that the relative efficiency of each measure can be assessed (see Section 5). A noted response from the Maryland Silver Jackets participants (Section 2.7) was that this modelling strategy may prove useful for decision making when selecting measures to construct and that being able to show the effectiveness of individual measures may be significant when applying for FEMA grant-funding.

- Impacts to the FEMA Flood Insurance Rate Map (FIRM) could be included as a part of incremental modeling and a systematic design. The current FIRM map for Howard County, enacted in 2013, shows all buildings and properties lining lower Main Street as being within the 1% annual chance (100-year) floodplain. Properties above the confluence of New Cut Branch are mostly in the 0.2% annual chance (500-year) flood zone. If the County's future goals include reducing the 1% annual chance floodplain, this strategy could help inform and define the necessary engineering and sizing of individual measures.
- The County may consider initiating flood map revision with FEMA once FRM project improvements have been completed.

6.3 Other Strategies

- Consider long-term strategies for land-use within this watershed which should aim to balance storm water management best practices with development.
- A USACE FRM expert hailing from a flash-flood prone region in the Southwest United States, strongly stressed that the most effective strategy (both from a flood reduction and cost standpoint) for addressing flash-flooding was the combination of debris management, upstream detention basins, and conveyance improvements.
- Ensure that sequencing of construction of conveyance improvement projects proceed from downstream to upstream to minimize backwatering effects that may exacerbate flooding elsewhere.
- A Benefit Cost Ratio analysis could include social/historical components, evaluating relative impacts between historic assets and life safety/damages. Additionally, a BCR could include information on the income level of the individuals benefiting. This information could be used to determine if there may be a disproportionate benefit to higher vs. lower-income individuals.
- Consider more large-sized flood storage structures wherever possible.
- The responsible entity for the flood risk management system typically should acquire permanent real estate interest for the comprehensive footprint of the project for operations and maintenance purposes. USACE minimum footprints normally extend a minimum of 15 feet beyond the physical FRM features (such as floodwalls and channel walls). Permanent real estate interest will ensure the owner has the access rights to: 1) conduct inspections throughout the entire system; 2) operate and maintain the system to include project repairs, debris and sediment removal; 3) allow necessary vehicle and equipment to access; 4) control and review any future developments under consideration within the footprint of the project along with the authority to remove any unauthorized encroachments.
- Implement an inspection program of the system as phased construction is complete. Periodic inspections of the entire system should be scheduled to ensure functional integrity, operations, and design capacity have not been compromised. Unscheduled inspections should also occur after the recession of each significant flood event.
- The County may consider initiating flood map revision with FEMA once FRM project improvements have been completed.

6.4 Overall Environmental Considerations

- The County has been focused on FRM measures which reduce flood risk as much as possible. Many of these measures present an opportunity for habitat improvements both along (riparian zone) and within the channels (in-stream). Based on a review of the conceptual drawings in October 15th,

2019 Ellicott City Watershed Master Plan Public Meeting, Ellicott City and Howard County planners are considering naturalizing/opening stream channels, tree plantings for shade cover, and in-stream habitat structures. These are the types of habitat improvements that the USACE team had considered, and encourages the County to continue to implement when feasible.

- The County should continue to coordinate with the Maryland State Highway Administration to identify opportunities for mutually beneficial flood related storage structures upstream in the watershed.

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7 LIMITATIONS AND ASSUMPTIONS

This evaluation was intentionally limited in scope. The evaluation was at a planning-level only and was not intended to result in detailed designs for construction. The USACE team performed no modeling or engineering design calculations, as the purpose of this evaluation was an independent review of Howard County's proposed FRM measures and completed modelling. No detailed engineering analyses were performed, and the best professional judgment of the independent review team was relied on.

Assumptions:

The USACE team conducted this evaluation under the following assumptions:

- All modeled alternatives are technically feasible from a construction perspective.
- The team did not review the hydrologic and hydraulic models themselves, but reviewed their graphical outputs. The team assumes that these studies and modeling were sufficiently accurate to properly inform decision making

Limitations

The following are limitations associated with this evaluation

- If this were a USACE FRM project, a more quantitative multi-criteria decision making methodology would be utilized, which would also include a sensitivity analysis. A sensitivity analysis would determine how the rank of a single measure varies when the relative importance (or weight) of the criteria is changed.
- The USACE technical team reviewed modeled alternatives which contained combinations of measures. Therefore, the team was limited in its ability to assess the effectiveness of individual measures.
- The USACE team did not have specific information on the historic significance/value of specific structures; this information may have affected the impact rating for some measures in the evaluation matrix.

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8 CONCLUSIONS

The purpose of this assessment was to provide an independent review of the Ellicott City flooding issues, completed flood studies (including modeling results) and the County's proposed FRM measures. This assessment also included the generation of new potential strategies and measures for the County's consideration. Additionally, the USACE review team produced an evaluation matrix to aid in assessments and to assist the County with ongoing decision making.

Overall, the team determined that the County followed a comprehensive process, that the FRM measures being considered by the County are similar to those utilized during USACE FRM projects, and that the current County-selected alternative can significantly reduce flood risk to downtown Ellicott City.

At the time that this review was conducted, the County-selected FRM alternative (known as Option 3G.7.0. Option 3G.7.0) consisted of the following FMR measures:

1) Terraced Floodplain (Lower Main St.)
2) Maryland Avenue Culvert(s)
3) Ellicott Mills Drive Culvert
4) North Tunnel
5) West End Floodplain & Conveyance
6) Quaker Mill Pond
7) H-7 Pond
8) T-1 Pond
9) NC-3 Pond
10) Robert's Property (H4) Pond

Of the sixty modeled alternatives reviewed, the USACE's team found that eight alternatives met the criteria of reducing roadway flood depths and velocities to the threshold of 3.5 feet/5 feet per second. The County-selected 3G.7.0 was one of the alternatives which met these threshold values (see Section 2.4 for details on the depth and velocity threshold selection and screening methodology).

The eight alternatives which met this threshold criteria were comprised of fourteen FRM measures. The County-selected Option 3G.7.0 contains ten of these fourteen FRM measures. The remaining four measures are the South Tunnel, Lot D Channel Expansion, H1-UG1 & H8-UG1, and H1-UG2 (see Section 3 for detailed description of above measures). Therefore, the County's current plan would implement the majority of the measures associated with the most effective alternatives.

Based on review of the hydraulic model outputs, the County's flood reduction targets (reducing the maximum flood depths from a July 2016 storm event on lower Main Street to approximately three feet) are very likely obtainable with the implementation of the FRM measures outlined in Option 3G.7.0. A reduction of flooding of the July 2016-sized storm to this level means that, although greatly reduced in magnitude, significant flood risk would still remain for lower Main St. predicated on a similar sized storm event. The County should therefore consider continuing to advance other flood risk mitigation measures, including non-structural flood proofing of buildings and improvements to flood-warning systems and evacuation planning. The flood proofing of structures on lower Main St. would also provide the benefit of mitigating flood risk associated with future Patapsco River flood events.

In general, building removal from high risk flood areas is one of the most effective ways to prevent damages and loss of life from flooding. In downtown Ellicott City, the reduction in risk to loss of life from building removal comes with the impact of potential losses to historical and cultural resources, as well as potential adverse impacts to the local economy and community cohesion. The County and City have worked to

engage the community to define an appropriate balance between the loss of historically significant structures and protecting lives, and should continue to do so in making these decisions. The USACE review team and national FRM experts which contributed to this review recognized this, and still noted that the County should continue to develop options for building acquisitions and removal throughout the highest flood risk areas.

During both the 2016 and 2018 storm events, the New Cut Branch was a major source of floodwaters based on USGS calculations. Although there are three proposed FRM measures under the 3G.7.0 alternative which could mitigate some of the flood flows from the New Cut (NC-3 Pond upstream, and Terraced Floodplain and Maryland Ave. Culvert(s) downstream), due to challenges associated mainly with property acquisitions, the County's current plan included just one storage pond in the New Cut / Autumn Hill sub-watershed. Therefore, the team identified a location for a dry flood storage structure for the County's consideration, which could be located on the New Cut just upstream of the Tiber-Hudson Branch confluence (Figure 5). If sized appropriately, this structure could significantly reduce the impacts of flood flows originating from this watershed. This structure could be located such that it would not be visible from downtown. There are however, significant challenges associated with this potential measure, including property acquisition and removal of the New Cut Road. Additional details regarding this potential measure can be found in Section 4.

The USACE review team also found that there are likely significant opportunities to improve conveyance throughout the downtown channelized reaches. These could include channel widening, deepening, and/or the addition of parapet walls (low height structurally reinforced flood walls). The existing 2-D hydraulic model could be used to define reaches with low conveyance (most hydraulically constricted) within the system which the County could then prioritize for improvement projects. Section 4 contains additional details regarding this potential measure.

Although the County is singularly initiating the planning and construction of FRM measures, this USACE evaluation identified components of the USACE FRM project processes that the County could consider. These include the following:

- USACE is required to perform an economic analysis including benefit cost ratios (BCRs) to define the most cost effective solutions, and the formulation of an array of measures based on benefits. The County may consider a similar decision making strategy.
- USACE would typically conduct an incremental modeling analysis to evaluate each potential FRM measure. Each measure would be modeled separately such that the hydraulic impacts and benefits could be individually quantified and the measures would be incrementally combined to form sets of alternatives. The County could consider this approach to more systematically determine the individual contribution of each potential measure.
- Some USACE projects include consideration of impacts to the FEMA Flood Insurance Rate Maps (FIRMs) as a part of incremental modeling and a systematic design. The current FIRM map for Howard County, enacted in 2013, shows all buildings and properties lining lower Main Street as being within the 1% annual chance (100-year) floodplain. Properties above the confluence of New Cut Branch are mostly in the 0.2% annual chance (500-year) flood zone. If the County's goals include removing buildings from the 1% annual chance floodplain, this strategy could better inform and define the necessary engineering and sizing of individual measures.
- The USACE approach for modelling storm events often includes the modeling of an array of different storm scenarios, as a diversity of modeled storms would better define the selection of measures. For example, under different storm scenarios, more significant rainfall may occur in one

sub-watershed versus another which could impact decision making for measure/alternative selection.

- A USACE FRM project of this scope would include multi-agency coordination (FEMA, US Fish and Wildlife, etc.). The County has certainly coordinated with a number of State and Federal agencies and could consider expanding these efforts whenever possible.
- USACE FRM projects incorporate natural and nature-based FRM measures whenever feasible; the County could consider utilizing natural or nature-based measures within the watershed (e.g. increasing space for the river, green roofs, decentralized rainwater management, etc.). These measures may not reduce flooding from severe storms but could be beneficial for smaller rain events.
- USACE FRM project formulation process also includes broad public engagement (which the County has engaged in), as well as formal identification of objectives, opportunities and constraints, and comparison to the USACE Planning Guidance Notebook evaluation criteria. Furthermore, USACE has begun adopting and documenting risk considerations in decision making.

Some additional potential FRM measures and/or strategies which the County might consider are listed below:

- An aggressive debris management plan to clear debris along stream reaches, along with potential flood plain zoning ordinances which specifically restrict objects or ancillary structures which may become flood debris during large events.
- Since the County is already pursuing numerous property buyouts, the USACE team, as well as a number of FRM experts from various fields indicated this as a proven method to reduce risk to loss of life and damages to property and should continue to be considered. Any future property buyout decisions will have to be balanced with the public desire to maintain a cohesive and historic downtown Ellicott City.
- The County could consider a network of elevated egress walkways (located behind the buildings on lower Main Street) designed to allow pedestrians/building occupants to escape to high ground.
- The County could consider mandating that individual businesses/property owners in the lower Main St. section develop and post vertical evacuation plans and that tenants/owners/employees be trained in their execution.
- Parking restrictions, which are already being considered by the County, are a valuable tool for reducing risk of loss of life as they reduce the number of people in vehicles during flood events and prevent vehicles from becoming flow-constricting debris. Consider removing as much parking as feasible from the highest-risk areas and replacing it with parking at higher elevations (with potential shuttle services to connect to downtown).
- Bollards or similar structures may be included along channel reaches and terraced floodplains within the lower sections of downtown to prevent flood displaced vehicles and large debris from entering the channels.
- As feasible, the County should continue to coordinate with other agencies (National Weather Service) to improve flood warning forecasts and flood warning systems/sirens.
- Since significant construction is expected to occur in and around channels, the County could consider this as an opportunity to implement environmental improvements to in-stream and riparian habitats.
- The County has initiated a funding program to encourage property owners to flood proof their buildings, and as feasible this effort should continue and be expanded to mitigate residual risk in

the most significant inundation areas. On lower Main St., the flood proofing of structures would also provide flood risk mitigation during future Patapsco River flood events.

- The construction of flood conveyance improvement measures should be sequenced downstream to upstream to avoid increasing flood levels downstream before discharge capacity improvements are made at the lower extent of the project.
- The responsible entity for the flood risk management system should acquire permanent real estate interest for the comprehensive footprint of the project for operations and maintenance purposes. USACE footprints normally extend a minimum of 15 feet beyond the physical FRM features (such as floodwalls and channel walls).
- The implementation of an inspection program of the system should be required once construction is complete. Periodic inspections of the entire system should be scheduled to ensure functional integrity, operations, and design capacity. Unscheduled inspections should also occur after the recession of each significant flood event.
- The County may consider initiating flood map revision with the Federal Emergency Management Agency (FEMA) once FRM project improvements have been completed.
- A Patapsco River flood event (a bottom-up flood event for Ellicott City) is a different type of flood event than those experienced in 2016 and 2018. Comparatively, a Patapsco River flood would typically have much lower velocities, significantly longer warning time, and would mainly impact just the lower Main St. area. Currently, some of the measures proposed by the County (e.g. removal of structures, flood proofing of buildings) as well as some USACE proposed measures (e.g. vertical evacuation plans, elevated egress walkways) would help reduce risk associated with a bottom-up Patapsco flood event. However, the County may consider additional studies to define measures which would directly mitigate flood risk associated with Patapsco River flood events.

References

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US Army Corps of Engineers (USACE). 2019. "Field Guide for Conducting Nonstructural Assessments." <https://www.usace.army.mil/Missions/Civil-Works/Project-Planning/nnc/ > accessed November 13, 2019.

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APPENDIX A

USACE DEVELOPED EVALUATION MATRIX

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Criteria	Criteria #1: Prevention of Loss of Life (+)		Criteria #2: Preservation of Historical and Cultural Resources / Community Cohesion (+/-)		Criteria #3: Reduction to Flooding (+)		Criteria #4: Economic Impacts (+/-)		Criteria #5: Operations and Maintenance (-)		Criteria #6: Initial Construction Cost (-)		Criteria #7: Implementation Duration (-)		Criteria #8: Environmental Impacts (+/-)	
Criteria Description	To what degree does the measure impact prevention of loss of life in a July 2016-type flood event based on one or more of the following: lower flood velocities, lower flood depths, allow for more effective evacuation by car or by foot. Additionally, building acquisitions that remove people from hazardous flood zones has been considered in this criteria.		To what extent does the measure impact: historic preservation, integrity of cultural/historic aspects of buildings, historic setting, recreation / walkability, changes to look and feel of community .		To what degree does the measure result in reduction to flood depths and velocities associated with a July 2016-type flood event.		To what degree would the measure results in economic impacts via one or more of the following: reduction of flood damages (based on a July 2016-type flood event), removal of businesses, potentially lost opportunities to businesses, loss of employment opportunities, potential increased business opportunities from draw to downtown parks / recreational opportunities along streams / increased sense of safety.		Significance of operations and maintenance (O&M) costs associated with measure, including considerations for manpower and frequency of O&M efforts.		Significance of initial constructions costs, including costs associated with real estate acquisition, construction, permitting, and LERRDS (Land, Easement, Right of Way, Relocations and Disposal).		Years to benefits realized (duration to implement to include planning, design and construction).		Significance of impacts to one or more of the following: habitat (riverine and riparian), aquatic species, water quality, groundwater impacts (includes consideration of these possible effects along adjacent reaches of the Patapsco River).	
Criteria Weight (1-3)	3		2		3		3		2		2		1		2	
Impact Rating (0-3) 0 is a negative or neutral impacts 1 is a minor negative or least positively impactful 2 moderately positive impact 3 is a strongly positive impact *Measures were assigned impact ratings relative to one another. For example, an Impact Rating of 3 for Criteria #3: Reduction to Flooding indicates that that the particular measure was the most impactful at reducing flood depths and velocities relative to the other measures evaluated. The meaning of each Impact Rating is unique to that Criteria.*	0 = No beneficial impact towards prevention of loss of life 1 = Minimal impacts towards prevention of loss of life 2 = Moderate impacts towards prevention of loss of life 3 = Maximum impacts towards the prevention of loss of life	Impact Rating Assigned	0 = Negative impact to preservation of historical and cultural resources and/or to community cohesion / recreation 1 = Minor negative impacts to preservation of historical and cultural resources and/or to community cohesion / recreation 2 = Neutral / somewhat positive impact to preservation of historical and cultural resources and/or to community cohesion / recreation 3 = Strongly positive impacts to preservation of historical and cultural resources and/or to community cohesion / recreation	Impact Rating Assigned	0 = No obvious reduction to flood depths 1 = Minimal reduction to flood depths 2 = Moderate reduction to flood depths 3 = Maximum reduction of flood depths	Impact Rating Assigned	0 = Negative economic impacts 1 = Minimal negative economic impacts 2 = Neutral / somewhat positive economic impacts 3 = Strongly positive economic impacts	Impact Rating Assigned	0 = Very significant O&M costs 1 = Significant O&M costs 2 = Moderate O&M costs 3 = Minimal O&M costs	Impact Rating Assigned	0 = Very significant initial construction costs 1 = Significant initial construction costs 2 = Moderate initial construction costs 3 = Minimal initial construction costs	Impact Rating Assigned	0 = 7+ yrs. Very sig. construction duration 1 = 5-7 yrs. Significant construction duration 2 = 3-5 yrs. Moderate initial construction duration 3 = 1-3 years. Minimal initial construction duration	Impact Rating Assigned	0 = Significantly harmful 1 = Neutral or minimal negative impact to environment 2 = Minimal to moderately positive env. impacts 3 = Strongly positive environmental impacts	Impact Rating Assigned			

Weighted Sum	Measure																			Advantages	Challenges	Considerations for County
40	**North Tunnel** **This proposed tunnel intercepts Hudson Branch flows near Court Ave. and outfalls to the Patapsco River upstream of Main St. The measure includes minor stream grading and weir structure across the stream to facilitate high flow diversions into the tunnel, while allowing some flow through existing channel. Potential tailwater effects from Patapsco River flooding are not expected to result in backwater flooding through the tunnel and the tunnel is anticipated to include sufficient inlet control conditions due to significant elevation differences between inlet and outlet. Due to the steep slope of the tunnel and expected higher energy discharge flows, appropriate sizing of dissipation structures/stabilization methods will be required at the outlet. This has the potential to significantly reduce flood depths along Main St. from Court Ave. downstream. Both bore sizes (12' and 15') as evaluated have a headwater depth to discharge relationship that conveys roughly 80-90% of 2016 storm flow without affecting upstream water surface elevations, based on stated inflow invert assumptions.**	Relative to all other measures, most effective single measure at reducing flood depths and velocities based on model outputs.	3	The bulk of this measure is located underground and as a finished product will be relatively unnoticeable from most of the areas downtown. Furthermore, its placement should not require the relocation or demolition of any buildings. Any excavation activities present potential for below ground artifacts of archeological significance.	3	Very significant reduction in flood depths; most effective single modeled measure relative to all other measures. Model outputs show an approximate 2' reduction to flood depths on Lower Main St.	3	Implementation of measure likely to result in no direct commercial losses; resulting reduction in flooding likely to reduce flood damage and reduced risk could encourage economic development downtown.	3	Debris removal / management after high water events required, but otherwise tunnel will not require significant O&M (annual inspections sufficient). Assumed reinforced concrete lined.	2	Most expensive single measure.	0	Significant (5-7 years); dependent on geology.	1	Low flow maintained in channel. Impacts to stream during duration of construction. Possible changes to flow regime may have impacts to benthic invertebrates / fish. No significant opportunity to improve aquatic habitat.	1	Construction of this measure would have little to no impact on any historic structures, it does not impact community cohesion and it minimizes or avoids utility relocations. As modeled, this measure as a stand-alone produces the most significant reduction to flood depths and velocities downtown.	The most expensive option, tunneling may pose significant engineering challenges including constructability and construction duration. The complexities in the proposed alignment (passes under active railway embankment) add potential significant growth risk to cost and construction duration for implementation of this measure. There would be a potential for debris to block the intake or upstream channel and reduce the effectiveness of the bypass. Any excavation activities present potential to impact archaeological resources.	This is the most costly option, and there may be less costly options that achieve similar extents of flood reduction (e.g. Lot D Floodplain Expansion) but which would require more extensive changes to the downtown area. Although requiring a longer construction duration relative to other measures, the tunnel operation would largely avoid impacts to businesses and existing infrastructure during construction. From an environmental standpoint, the impact to known resources and stream flows may elevate the level of documentation under the National Environmental Policy Act to an Environmental Impact Statement, if implemented. The County could also consider a program to control obvious upstream debris sources (e.g. vehicles) which could significantly impact effectiveness during high storm flows. Outlet structure design should include components to minimize potential erosion and scouring of Patapsco River bed and banks. Additionally, this measure captures flows from the Hudson Branch but would not impact flows originating in the Tiber/New Cut/Autumn Hill watershed. Conversations with CSX Transportation would be required for final alignment evaluations. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability
40	**South Tunnel** **This proposed tunnel captures flows just upstream of buildings spanning over the stream along lower Main Street (Bldg. 10 in Figure 3) and outfalls in Patapsco River downstream of the Main Street Bridge. Various tunnel diameters were modeled, including a 10', 15', 20', and a 2 x 5'. This measure would include a weir and concrete flume to allow low flows to bypass the tunnel entrance while improving entrance hydraulics for high flows. This measure has the potential to significantly reduce depths on lower Main Street. When the South Tunnel outlet approximately 85% submerged from Patapsco River flows, the hydraulic capacity is significantly impacted by the minimal slope of the bore. Otherwise the hydraulic capacity is controlled by tunnel characteristics.**	Model outputs show downtown flood depths reduced by approximately 1', which is highly effective as a standalone measure in improving the prevention of loss of life.	3	Similar to North Tunnel.	3	Reduction of approximately 1' of depth on Lower Main Street; as modeled, S. Tunnel conveys about 900 cfs of flow.	3	Implementation of measure should result in no direct commercial losses; resulting reduction in flooding likely to reduce flood damage and reduced risk could encourage economic development downtown.	3	Debris removal / management after high water events required, but otherwise tunnel will not require significant O&M (annual inspections sufficient). Assumed reinforced concrete lined.	2	Second most expensive measure behind North Tunnel (shorter in length) and significantly more expensive than any other measures evaluated.	0	Significant (5-7 years); dependent on geology.	1	Low flow maintained in channel. Impacts to stream during duration of construction. Possible changes to flow regime may have impacts to benthic invertebrates / fish. No significant opportunity to improve aquatic habitat.	1	Very similar to North Tunnel. Construction of this measure would have little to no impact on historic structures, it does not impact community cohesion and it minimizes or avoids utility relocations. Modeling of the South Tunnel defined an approximate 1 foot reduction in flood depths within downtown Main Street.	Similar to N. Tunnel although shorter length of tunnel. The complexities in construction (passes under active railway) add potential significant growth risk to cost and duration to implementation of the measure. There is still a potential for debris to block the intake or upstream channel and reduce the effectiveness of the bypass. Any excavation activities present potential to impact archaeological resources.	Similar to the North Tunnel, including the outlet structure design considerations. Although longer construction duration relative to other measures would be required, the measure would largely avoid impacts to businesses and existing infrastructure during and subsequent to construction. The tunnel effectiveness could be improved with additional hydraulic head on the intake via a weir structure. Additionally, the South Tunnel entrance alignment should be oriented such that it ensures maximum efficiency for capturing flows downstream of the Tiber-Hudson/New Cut confluence. Conversations with CSX Transportation would be required for determination of final tunnel alignment. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
39	**Team Developed Measure: Targeted Conveyance Increases** **This potential new measure would consist of a number of modifications to the channelized reaches to increase conveyance capacity by means of channel widening, stream-bed lowering (bedrock excavation), and increased channel cross-sectional area by the addition of parapet walls. The parapet wall was generally considered by the team to be a 2-3 foot high flood wall along the channelized sections; it would be structurally reinforced and could include a setting-appropriate façade to merge with the historic setting.**	One of the County's goals is to achieve reductions in flood depths on Lower Main St. down to approximately 3 feet. The team assumed that if such measures were implemented to achieve this goal, then this new "Targeted Conveyance Increases" measure could allow for conveyance of most or all of the July 2016 storm flows within the channel. As such, this new measure could achieve maximum impact of prevention of loss of life.	3	Channel modifications would impact channel walls which may be considered historic structures. Parapet walls, if extensively used, could impact the look and feel of the downtown area though this could be mitigated with appropriate façade materials. Any excavation activities present potential for below ground artifacts of archeological significance.	1	One of the County's goals is to achieve reductions in flood depths on Lower Main St. down to the 2-3 foot range. The team assumed that if such measures were implemented to achieve this goal, then this new "Targeted Conveyance Increases" measure could allow for the conveyance of most or all of the June 2016 storm flows within the channel. This would result in significant reductions to flood depths.	2	Would reduce flood damages as envisioned but potential for impacts to a number of buildings/ businesses via modifications. Overall, expected neutral economic impact.	2	Minimal but some clean up after flooding plus DPW care.	3	Cost of measure dependent on the extent. Significant mechanical excavation required; smaller equipment likely to be used to fit within channel. Reinforcement of foundations and building walls likely.	2	Moderate (3-5 years). Measure would include channel modification at Main St. which would include utility impacts	2	Potential for in-stream improvements compared to current conditions.	2	One of the County's goals is to achieve reductions in flood depths on lower Main St. from a 2016 type storm event down to approximately 3 feet. The team assumed that if such measures were implemented to achieve this 3 foot goal, then this new "Targeted Conveyance Increases" measure could allow for the conveyance of most or all of the remaining July 2016 storm flows within the channel. Because the downstream reaches are already 100% channelized, this proposed measure to increase the channel capacities would not significantly alter the overall downtown setting. The bedrock channel bed is significant as channel lowering is possible with minimal risk of substantial erosion.	Geotechnical investigations would be required for any channel modifications (widening and/or lowering), most significantly in those reaches adjacent to building foundations. Additional structural reinforcement of these structures may be required, as this action may result in significantly higher-energy flows in some areas. Any excavation activities present potential to impact archaeological resources and additional permitting would be required for any dredging activities. A parapet wall system for the downtown channelized reaches of Ellicott City would also require geotechnical investigations, although this could be a part of the investigative effort to assess adjacent areas for channel modifications. Anywhere a parapet wall would be constructed proximate to buildings and foundations, those structures may require structural evaluation/reinforcement as well. Extensive addition of parapet walls may adversely impact the look and feel of downtown.	The 2-D hydraulic model could be used to identify regions of lowest conveyance (most hydraulically constricted) in the system and this could be included as a modeling priority for the County. Should every hydraulic constriction not be addressed, the County could undertake conveyance improvement projects over a number of years, prioritizing channel reaches with the highest cost-effectiveness. As with any conveyance increases in a system, any projects undertaken should begin at the downstream channel confluence and proceed upstream. From a historical perspective, the channel walls themselves may be considered historic structures and would need to be evaluated. The potential parapet wall could vary in nature by reach. For instance, sections of the parapet wall could include such options such as automatic flood barriers or impact-resistant structural glass sections sited for aesthetic purposes. Any channel modification projects could include low hydraulic head in-stream habitat structures to improve aquatic habitat.
37	**Maryland Ave Culvert(s)** **The Maryland Ave Culvert(s) connect the Terraced Floodplain measure upstream of Maryland Ave. to the Patapsco River providing additional conveyance capacity. This measure significantly reduces flood depths on Maryland Ave. and on lower Main St.**	Perform similarly to tunnels; diverts significant quantities of flood waters away from downtown Main Street area thus significantly contributing to the prevention of loss of life.	3	Minor negative impacts to historic preservation as this measure would require the removal of at least some of the buildings on lower Main St. Depending on design, removal of building(s) could allow for recreational space (similar to lower Main St. Terraced Floodplain).	1	Significant reduction to flood depths on Maryland Ave. and Lower Main St., although quite as significant as N. or S. Tunnel	2	Considered neutral/positive economic impacts. Aside from impacts of construction, this option by itself should not result in loss of businesses. Reduction in flooding on lower main likely to reduce flood damages.	2	After high water events will require cleaning,; annual inspections.	3	Passes under CSX rail line; interaction with CSX may result in significant costs; directional boring costs are also significant.	2	Moderate (3-5 years).	2	Effects on in-stream habitat during duration of construction. Possible changes to flow regime (similar to N. and S. Tunnel). Overall likely minimal to neutral environmental impacts.	1	The model outputs show significant reductions to flood depths and velocities on Maryland Ave. and lower Main St. as a result of this measure.	These culvert(s) would be located under the CSX railroad as well as in the immediate proximity of two historic railway buildings which may result in increased cost and complexity during construction. Any excavation activities present potential to impact archaeological resources. This measure would require the removal of at least some of the buildings on lower Main St.	The outlet structure (similar to Tunnel options) should be designed to address erosion of Patapsco River bed and banks. Conversations with CSX Transportation would be required to advance evaluations of alignment alternatives. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
39	**Lot D Channel Expansion** **Area E in Figure 3. The Lot D Channel Expansion measure includes channel grading to lower the elevation of the channel and remove constrictions between Court Ave. and Parking Lot D. Model outputs show significant reductions in flow constrictions and backwatering of flow onto Main Street at Lot E and upstream of Court Ave.**	Based on model outputs, the Lot D Channel Expansion appears to be almost equally effective at reducing flood depths and velocities as the North Tunnel. This measure as modeled includes the removal or modification of four buildings just upstream of Lot D.	3	This measure includes the removal or modification of four buildings on upper Main St. which is a relatively significant change / loss to some historic structures, including the building housing Ellicott City Brewery. Depending on design, may be able to add significant recreational value via park space in the Lot D area (similar to Terraced Floodplain).	1	Significantly reduces flow constrictions and backwatering of flow onto Main Street at Lot E and upstream of Court Ave.	3	Reduction to flood damages likely to be significant, however as proposed there would be somewhat significant loss/modification of commercial structures required. Recreational opportunities could be included (parks along stream) which may benefit nearby businesses. Overall rated as slightly negative economic impacts.	1	Minimal O&M with some clean up after flooding plus DPW care.	3	Demolition of structures is relatively insignificant. Potential real estate costs unknown to team at time of evaluation.	2	Moderate (3-5 years). Measure would include channel modification at Main St. which would include utility impacts.	2	No riparian and poor in-stream habitat present currently; this measure provides significant opportunity to enhance in-stream and riparian habitat	2	This expansion greatly reduces flood depths and velocities on lower Main Street to a level that competes with the North Tunnel in a one-one-one comparison. This option, however, should be much less costly than the North (or South) Tunnel option. The channelized stream reach through the Hudson Bend and Lot D area currently has poor in-stream habitat and little to no riparian habitat present. This measure, if implemented, would allow the opportunity to create both types of habitat.	The channel and floodplain expansion would include removal, relocation or modification of some historic buildings. Additionally, this measure would impact the utility corridor at the Main St./Court Ave. area. There is the potential for loss of parking depending on Lot D's final configuration. Any excavation activities present potential to impact archaeological resources.	If implemented, the County could consider a parking structure or adding parking elsewhere. Similar to the Terraced Floodplain measure, this area could be a highly walkable space for visitors. Additionally, there is the potential for environmental improvements via introduction of in-stream and riparian habitat. Evaluation of any historic structures would be required.
37	**T-1 Pond** **The T-1 pond has 70 acre/feet of storage. The pond is located along the Tiber Branch. Coordinates are 39°15'56.13"N, 76°48'22.80"W.**	Due to moderate reductions to flood depths on Lower Main St., measure considered to have moderate impacts to preventing loss of life	2	Located upstream, no potential impacts to historical downtown structure. Any excavation activities do present potential for below ground artifacts of archeological significance	2	Largest single pond, model outputs show noticeable reductions to flood depths on Lower Main Street.	2	Upstream storage does not impact businesses typically and should serve to reduce some flood damages. Overall somewhat positive economic impacts.	2	O&M would consist of silt removal / mowing. Moderate O&M costs compared to other measures evaluated.	2	Minimal cost to construct.	3	Minimal (1-3 years)	3	Bottom outlet at stream elevation assumed to retain normal low-flow conditions; if deforested, represents a loss of riparian habitat; performs sediment retention function in urbanized area.	1	Low cost storage and flood reduction option.	Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources. Property acquisitions are required.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability
37	**NC-3 Pond** **The NC-3 Pond has 63 acre/feet of storage. It is located along the Autumn-Hill Branch, which is a tributary to the New Cut Branch. Coordinates are 39°15'34.57"N 76°48'18.47"W.**	Second largest proposed pond. NC-3 reduced about 1,000 cfs of flow to downtown during 7/30/2016 event	2	Located upstream, no potential impacts to historical downtown structure. Any excavation activities do present potential for below ground artifacts of archeological significance	2	Model outputs show noticeable reductions to flood depths on Lower Main Street. NC-3 reduced about 1,000 cfs of flow to downtown during 7/30/2016 event.	2	Upstream storage does not impact businesses typically and should serve to reduce some flood damages. Overall somewhat positive economic impacts.	2	O&M would consist of silt removal / mowing. Moderate O&M costs compared to other measures evaluated.	2	Minimal cost to construct.	3	Minimal (1-3 years)	3	Bottom outlet at stream elevation assumed to retain normal low-flow conditions; if deforested, represents a loss of riparian habitat; performs sediment retention function in urbanized area.	1	Low cost storage and flood reduction option.	Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources. Property acquisitions are required.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
35	**H-7 Pond** **The H-7 pond has 13 acre/feet of storage. It is located along the intersection of US 40 and US 29. Coordinates are 39°16'44.12"N 76°49'13.67"W.**	This will likely fill early in rainfall event, before peak flow; on its own, would produce minimal benefit to prevention of loss of life	1	Located within "clover-leaf" of highway interchange; otherwise unused space with no potential impacts to historic structures. Any excavation activities do present potential for below ground artifacts of archeological significance.	2	This will likely fill early in rainfall event, before peak flow; on its own, would produce minimal reductions to flood depths and velocities.	1	Upstream storage does not impact businesses typically and should serve to reduce some flood damages. Overall somewhat positive economic impacts.	2	O&M would consist of silt removal / mowing. Moderate O&M costs compared to other measures evaluated.	2	Minimal cost to construct.	3	Minimal (1-3 years)	3	Sediment retention in urbanized area; an otherwise unused and already ecologically disturbed area could become a benefit for downstream water quality.	3	Low cost storage and flood reduction option. Placed in an otherwise unused and already ecologically disturbed area, the sediment retention provided would benefit downstream water quality.	Once storage structure fills, there are no further benefits to flood reduction. Any excavation activities present potential to impact archaeological resources.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
32	**Team Developed Measure: New Cut Dry Flood Mitigation Structure** **This potential dry flood storage structure could be located on the New Cut Branch upstream of Tiber-Hudson/New Cut Branch confluence, far enough upstream to be outside of view from downtown. Approximate embankment location of 39°15'55.3"N, 76°47'53.7"W. As a dry storage structure, it could remain forested and would only be inundated during large storm events. The outlet could be designed at stream elevation and maintain approximate normal low-flow conditions to minimize adverse environmental impacts. Based on preliminary calculations, the approximate storage capacity could range from 135-350 acre-feet with an embankment height of 40 to 60 feet. The ponding area behind the structure would vary with structure embankment height and rainfall event.**	If sized appropriately, could significantly reduce peak flows from New Cut Branch and reduce dangerous depth/velocities in lower downtown.	3	Potential buyouts required and some change to landscape, including removal of New Cut road. But limited impact to the downtown historic district. Also, as a dry flood structure, the impoundment area behind the structure could be remain as forested area.	1	If sized appropriately, could significantly reduce peak flows from New Cut branch.	3	No commercial business likely impacted but depends on location and sizing, and permanent real-estate interest would be required for flowage easements; roadway relocation likely required. Significant reduction in flood flooding/flood damages associated with New Cut flow. Overall somewhat positive economic impacts.	2	Significant sediment management, inspections, repairs.	1	Significant initial construction cost. Likely fraction of the cost of N. or S. Tunnel, but more expensive than any of the other measures evaluated here.	1	Very significant construction duration (7+ years); real estate acquisition, removal of existing buildings and public debate may all contribute to duration to implementation.	0	Bottom outlet at stream elevation assumed to retain normal low-flow conditions. As dry-storage, could likely remain as forested area thus retaining riparian habitat; loss of in-stream habitat would require mitigation. Nominal retention allows for possibility of perched wetland.	1	If appropriately sized, the structure could significantly reduce peak flows from the New Cut Branch watershed. The construction of an embankment/reservoir would also retain rock, wood and other debris which would otherwise be deposited in the lower, already constricted channel reaches.	Depending on storage capacity and embankment location, this structure would require the relocation or closure of the New Cut Road as well as the residential structures located along New Cut Road in the vicinity of the coordinates provided, and would therefore require acquisition of property. This structure would likely be classified as a high hazard dam requiring permitting, as it would be located immediately upstream of the developed downtown area. Any excavation activities present the potential to impact archaeological resources.	Due to the challenges associated with property acquisition, currently the County is only considering one storage measure on the New Cut/Autumn Hill Branches (T-1 Pond located on the Autumn Hill Branch). During both the 2016 and 2018 storm events, the New Cut Branch was a major source of floodwaters based on USGS calculations. This proposed measure could significantly reduce flood risk associated with New Cut Branch flood flows, however there are significant challenges associated with this project including property acquisition and the permitting required for a high-hazard dam. Embankment construction material would likely be roller compacted concrete. Embankment material could potentially be rock-filled, which would be cheaper due to local material sources. Placement considerations could be prioritized such that the structure would not be not visible from downtown Main St. This measure may require an Environmental Impact Statement, but more likely an Environmental Assessment would suffice. A dry storage structure could remain in a wooded, natural state and expand opportunities for public recreation space. Permanent real estate interest would need to be acquired for flowage easements for the maximum design flood retention. Some stream mitigation would likely be required for loss of in-stream habitat. Real estate acquisitions would likely be critical path for duration for this project.
36	**Terraced Floodplain** **This measure includes floodplain grading and channel widening along lower Main Street. It removes flow constrictions upstream of Maryland Ave. and reduces flow escaping the channel and pushing out onto Main Street. There were multiple building removal scenarios modeled and considered by County. The County's most recently proposed plan calls for removal of buildings 1-4 and partial removal or modification of buildings 5-10.**	Removing buildings eliminates risk to occupants that might otherwise be present during flood flows, in addition to lowering depths / velocities.	3	Elimination of historic structures will change dynamic and feel of Lower Main St.; however, open terraced design could increase walkability and recreational opportunities.	1	Alternative alone has a minimal reduction to flood depths.	1	Loss of structures / business, but creating areas to congregate and significant reduction to flood damages likely. Adjacent business may benefit if terraced park space park is used for gatherings / events. Overall somewhat positive economic impacts.	2	Minimal O&M with some clean up after flooding plus DPW care.	3	Demolition of structures is relatively insignificant. Potential real estate costs unknown to team at time of evaluation.	2	Moderate (3-5 years)	2	No riparian and poor in-stream habitat present currently; this measure provides significant opportunity to enhance in-stream and riparian habitat	2	Increased conveyance decreases flooding along lower Main Street although modeling results show only a minimal impact from this measure. The removal of structures reduces risk of loss of life associated with upstream flash flood events and the removal of the rear portions of structures which span the stream would increase conveyance. Additionally, the building removal component on lower Main St. has the coincident benefit of mitigating risk related to property damage and loss of life from future Patapsco River flood events. Many recreational opportunities exist (including terraced park space could allow for events/amphitheater type shows), and the area may be a tourist attraction. The channelized stream reach currently present has poor in-stream and little to no riparian habitat present; this measure, if implemented, would allow for the opportunity to develop both types of habitat.	Although real estate acquisitions may be finalized prior to this review's completion, this step will likely be the most significant challenge. Sediment and debris management will be required to prevent channel blockages. Any excavation activities present potential to impact archaeological resources.	The County might consider incorporating parapet walls (either permanent or automated) along the Terraced Floodplain downtown area. Bollards placed along lower Main St. could be considered to help reduce vehicles and other large debris from entering the channel along this reach during floods. The final design for this measure should include consideration of potential backwater effects from bottom-up Patapsco River flood events.
31	**Roberts Prop (H4)** **Roberts Property is a pond with 16 acre/feet of storage. It is located along the Hudson Branch. Coordinates are 39°16'18.22"N 76°49'8.74"W**	Storage volume too small for significant reductions to flood depths and velocities; would likely fill early in rainfall event thus minimal impact to improving prevention of loss of life.	1	Located on forested property; no potential for impact to historic structures. Any excavation activities present potential for below ground artifacts of archeological significance.	2	Minor depth reductions observed at West End; overall minimal impact.	1	Property is forested; some flood damage reduction possible. Neutral to somewhat positive economic impacts.	2	O&M would consist of silt removal / mowing. Moderate O&M costs compared to other measures evaluated.	2	Minimal cost to construct	3	Minimal (1-3 years)	3	Loss of forested area and riparian habitat is a negative impact; sediment retention would positively impact downstream water quality	1	Low cost storage and flood reduction option. Sediment retention would improve downstream water quality.	Once storage structure fills, there are no further benefits to flood reduction. Removal of forested area represents a loss of habitat. Any excavation activities present potential to impact archaeological resources.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
32	**WE Floodplain & Conveyance** **Areas G, H and I in Figure 3. This measure includes multiple improvements in conveyance from Ellicott Mills Drive upstream. The measure generally doubles capacity of roadway culverts below the Main St. and Frederick Rd. intersection and includes some stream grading. Modeling results show a reduction in residential and roadway flood depths, but more effective for storm events smaller than the 7/30/16 event.**	Buildings potentially acquired under this measure are mostly residential with second stories and where the flood depths are not as high, therefore not as a significant an increase to prevention of loss of life as building acquisitions on Lower Main St.	1	Any excavation activities present potential for below ground artifacts of archeological significance	1	Some reduction to residential and roadway flood depths, but more effective for smaller storm events	1	No commercial loss expected; reduction to flood damages expected. Overall somewhat positive economic impacts.	2	Minimal O&M with some clean up after flooding plus DPW care.	3	More expensive than Terraced Floodplain but far less than tunnels.	2	Moderate (3-5 years)	2	Potential for significant improvements to in-stream and riparian habitat. Could include bio-engineering / nature-based FRM structures.	3	If all the improvements associated with this measure are implemented, they would reduce flood risk from smaller storm events such as the one experienced on 31 October, 2019. Also, due to the extents of proposed modifications of stream reaches, this measure presents significant potential aquatic habitat restoration opportunities.	The large number of real estate acquisitions would be likely be the largest challenge. Also, construction will include crossing utility corridors and disruption to traffic flows.	This measure includes the potential for significant improvements for in-stream and riparian habitat and could include bio-engineering/nature-based FRM measures.
29	**H1-UG1 & H8-UG1 Lot F Roger Carter** **H1-UG1 & H8-UG1 are two underground storage facilities with a combined storage of 33 acre/feet. They are located along Ellicott Mills Drive off of MD 144. Coordinates are 39°16'9.78"N, 76°48'2.07"W (H1) and 39°16'14.13"N 76°48'5.92"W (H8).**	Storage volume too small to observe reductions; would likely fill early in rainfall event thus minimal impact to improving prevention of loss of life.	1	Any excavation activities present potential for below ground artifacts of archeological significance.	1	Storage volume too small to observe reductions; would likely fill early in rainfall event thus minimal impact to reductions in flood depths.	1	Structure ultimately buried underground; relatively small to reduce flood damages. After construction complete, any economic impacts likely neutral.	2	Regular inspections and cleaning.	2	Underground storage structure would be more costly than above ground storage structures, but far less than diversion tunnels.	2	Minimal (1-3 years)	3	Water quality benefits from sediment capture.	2	Water quality benefits from capture of sediments; after construction is complete, little to no negative impacts to local economy or historic feel of downtown.	Once storage structure fills, there are no further benefits to flood reduction. More costly than aboveground storage structures of similar capacity. Any excavation activities present potential to impact archaeological resources.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.
29	**H1-UG2 (West End) - 30 acre feet** **H1-UG2 is an underground facility with a storage of 30 ac/ft. It is located off of MD 144 along the Hudson Branch. Coordinates are 39°16'11.56"N 76°48'25.26"W.**	Storage volume too small to observe reductions; would likely fill early in rainfall event thus minimal impact to improving prevention of loss of life.	1	Any excavation activities present potential for below ground artifacts of archeological significance.	1	Storage volume too small to observe reductions; would likely fill early in rainfall event thus minimal impact to reductions in flood depths.	1	Structure ultimately buried underground; relatively small to reduce flood damages. After construction complete, any economic impacts likely neutral.	2	Regular inspections and cleaning.	2	Underground storage structure would be more costly than above ground storage structures, but far less than diversion tunnels.	2	Minimal (1-3 years)	3	Water quality benefits from sediment capture.	2	Water quality benefits from capture of sediments; after construction is complete, little to no negative impacts to local economy or historic feel of downtown.	Once storage structure fills, there are no further benefits to flood reduction. More costly than aboveground storage structures of similar capacity. Any excavation activities present potential to impact archaeological resources.	The County could consider sizing outlets of structure to limit storage reductions during initial stages of significant precipitation events. Also, the County could consider beginning any archaeological investigations early-on in the process to ensure site suitability.

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APPENDIX B

Ellicott City Flood Mitigation Alternatives Matrix, McCormick Taylor

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Ellicott City Flood Mitigation - Simplified Scenario Matrix for USACE Reviews

	Proposed Improvements																		
	Conveyance Improvements									SWM Improvements									General
	Terraced Floodplain*	Lot D Channel Expansion	Maryland Ave Culvert(s)	Patapsco Tailwater applied for 7/30/16 event?	Ellicott Mills Drive Culvert	WE Floodplain & Conveyance	North Tunnel	South Tunnel		Quaker Mill	H-7 Pond	T-1 Pond	NC-3 Pond	H1-UG1 & H8-UG1 Lot F & Roger Carter	H1-UG2 (West End)	Roberts Prop (H4)	Williamson Prop (H3)	BGE UG (all three)	General Description Including Modifications/Results Summary
	A (shts 1, 3-10)	E (sheet1)	B (shts 1, 3-10)	B (shts 1, 3-10)	F (sheet1)	G thru I (sheet1)	D (shts 1, 11-12)	C (shts 1, 11-12)		See SWM map (Sheet 2)									
Option #	Floodplain Grading and Channel widening along Lower Main Street. Removes flow constrictions upstream of MD Ave. Reduces flow escaping channel and pushing out onto Main Street.	Includes channel grading to lower channel and remove constrictions between Court Ave and Parking Lot D. Significantly reduces flow constrictions and backwatering of flow onto Main Street at Lot E and upstream of Court Ave.	Culvert(s) connecting terraced floodplain upstream of MD Ave. to Patapsco River to provide additional conveyance capacity. Significantly reduces depths on Maryland Ave and on Main St.	Indicator if the tailwater condition (WSE vs. Time) was applied. Adapted from upstream gage and applied across lower model boundary. Does not have significant impact on flows out of current channel or MD Ave. for the 7/30/16 event. (This is not the FEMA 100yr Tailwater elevation =133' as that would already inundate area of focus along Lower Main St.)	Concrete span structure to replace CMP culvert severely damaged during 2018 storm. Includes open channel grading upstream and downstream of culvert. Culvert sized to pass 100yr event with minimal HW above culvert top. Significantly reduces flooding in Lot F and along Main St./ECMills Dr. intersection.	Multiple improvements in conveyance from Ellicott Mills Drive upstream. Generally doubles capacity of roadway culverts below Main St/Frederick Rd. Includes some stream grading. Reduces residential and roadway flood depths, but more effective for smaller storm events than for 7/30/16 event.	Proposed tunnel bore with upstream invert minimum of 10' below stream bottom. Includes minor stream grading and structture across stream to facilitate high flow diversions into the bore, while allowing some flow through existing channel. Captures flow at Court Ave. and outfalls on Patapsco upstream of Main St. Bridge. Tailwater not much impact as slope of bore is steep (would require significnat energy dissiaption along Patapsco). Significantly reduces depths along Main St. from Court Ave. downstream. Both bore sizes evaluated have HW/Q relationship that conveys ~80- 90% of 2016 storm flow without affecting upstream WSEL, based on stated inflow invert assumptions.	Proposed tunnel bore captures flow just upstream of buildings spanning over stream on Lower Main Street (Bldg 10) and outfalls in Patapsco River. Includes a weir and concrete flume structure to allow low flows to bypass, while improving entrance hydraulics for high flows. Has potential to significantly reduce depths on Lower Main Street. Tailwater not significant until pipe outfall is nearly (>85%) submerged (slope of bore is fairly shallow).	All Bldgs Removed or Modified (#'s correspond with mapping) **									
Existing																			Existing conditions; significant flooding throughout modeled corridor for both 100yr and 7/30/16 events. 7/30/16 event slightly larger floodplain extent and magnitude of flooding.
1	x								9-12										Includes only modifications to open up a portion of the channel along Lower Main St. Upstream building removed to evaluate the effect of allowing water to flow back and forth between Main St. and channel, without going through building, as occurred during both observed storm events. This improvement alone had minimal impact on depths and flooding magnitude along Lower Main St.
2	x								elevated 1-12										Buildings along Lower Main assumed elevated above flows (8' -10'). Reduces depths along Lower Main Street, but still significant hazard down Main Street, and still substantial overtopping at MD Ave. Also, concern for debris catching in piers and creating additional flow obstructions.
3	x								halved 1-10										Buildings along Lower Main "halved" so that the portions of the buidlings overtop the stream in existing conditions is removed, allowing open channel flow and minor channel regrading. This reduced depths but is still subject to backwatering against the remaining facades (which get hit with flow from Main Street and from the Channel). Depths along Main Street remain high as overtopping of MD Ave culvert restricts flow at Lower End of open channel section.
4	x								1-12										Buildings along Lower Main removed, and channel terracing to provide additional conveyance capaicty of channel and flow between Main St and open channel. This further reduced depths in Main Street, but depths along Main Street remain high as overtopping of MD Ave culvert restricts flow at Lower End of open channel section.
5	x				x				1-12,18	x	x								Lower 4 scenario with buidling removal at Lower Main St. combined with Ellicott Mills Drive Culvert Expansion. Culvert expansion significantly reduced flow onto Main Street at the Ellicott Mills/Main St. intersection, resulting in less flow down Main St. all the way through Lower Main. Depths of flow reduced in Parking Lot E, Parking Lot D and appx 1' along the Lower Main St. corridor.
5A	x				x				1-3;6-12; halved 4-5,18	x	x								
5B	x				x				1-10,18	x	x								
6	x	x			x				1-12; 13-17,18	x	x								
7	x	x			x				1-12; 13-17,18	x	x		x						
8	x	x			x				1-12; 13-17,18	x	x	x							
9	x	x			x				1-12; 13-17,18	x	x	x	x						
10	x	x	single 10' Dia		x				1-12; 13-17,18										
10A	x	x	(2 pipes - 8' Dia)		x				1-12; 13-17,18										
10-TW	x	x	single 10' Dia	x	x				1-12; 13-17,18										
10-TW2	x	x	(2 pipes- 10'Dia)	x	x				1-12; 13-17,18										
10-TW3	x	x	(2 pipes- 10'Dia)	x	x				1-12; 13-17,18	x	x								
11	x	x	(2 pipes - 8' Dia)		x				1-12; 13-17,18	x	x	x	x						
12	x	x	(2 pipes - 8' Dia)		x				1-3;6-12;halved 4-5; 13-17,18										
13	x	x	(2 pipes - 8' Dia)		x				1-3;6-12; halved 4-5; 13-17,18	x	x	x	x						
14	x	x	(2 pipes - 8' Dia)	x	x				1-3;6-12;halved 4-5; 13-17,18	x	x	x	x						
MP 08a									1-12										
15	x	x	(2 pipes- 10'Dia)	x	x	x			1-3;6-12; halved 4-5; 13-,18-22; 23-27; 28	x	x								
16	x	x	(2 pipes- 10'Dia)	x	x	x			1-12; 13-17;18-22; 23-27; 28	x	x								
16B	x	x	(2 pipes- 10'Dia)	x	x	x			1-11; 13-17; 18-22; 23-27; 28	x	x								
16C	x	x	(2 pipes- 10'Dia)	x	x	x			1-10;13-17;18-22; 23-27; 28	x	x								Lower 4 scenario with buidling removal at Lower Main St. combined with Ellicott Mills Drive Culvert Expansion. Culvert expansion significantly reduced flow onto Main Street at the Ellicott Mills/Main St. intersection, resulting in less flow down Main St. all the way through Lower Main. Depths of flow reduced in Parking Lot E, Parking Lot D and appx 1' along the Lower Main St. corridor.
16D	x	x	(2 pipes- 10'Dia)	x	x	x			1-10;13-17;18-22; 23-27; 28	x	x	x							
17		x		x	x	x		(20' Dia)	13-17;18-22; 23-27; 28	x	x								Includes conveyance improvements through west end and Lot D, but does not include terraced floodplain along Lower Main. 20' dia. South Tunnel at New Cut confluence is included. Depths of flow reduced throughout; south tunnel significant impact on WSEL at Lower Main St.
17A		x		x	x	x		(20' Dia)	13-17;18-22; 23-27; 28	x	x								Same as Scenario 17, but includes minor adjustments to South Tunnel pipe variables. Depths of flow reduced throughout; south tunnel significant impact on WSEL at Lower Main St - WSEL on Lower Main slightly higher than in Scenario 17.
17B		x		x	x	x		(15' Dia)	13-17;18-22; 23-27; 28	x	x								Same as Scenario 17A, but South Tunnel was shrunk down 15' diameter, while holding other variables the same as 17A. Depths of flow reduced throughout; south tunnel reduces WSEL on Lower Main, however Lower Main WSEL approx. 3' higher than 17A (which has a 20' Dia tunnel)
18A	x	x	(2 pipes- 10'Dia)	x	x	x		(15' Dia)	1-10;13-17;18-22; 23-27; 28	x	x								Same as scenario 17B except 2- 10' dia MD Ave culverts included at lower end of Main Street. Weir at front face of culverts not breached, therefore minimal flow entering the South Tunnel. Depths on Main Street significantly reduced from existing, but not as low as 17A.
18C (no 18B)	x	x	(2 pipes- 10'Dia)	x	x	x		(2 pipes - 5' Dia)	1-10;13-17;18-22; 23-27; 28	x	x								Same as scenario 18A except the south tunnel was spilt into 2 tunnels, each 5' in diameter. Weir at front face of culverts not breached, therefore minimal flow entering the South Tunnel. Depths on Main Street significantly reduced from existing, but not as low as 17A.
3A		x			x	x			halved 1-10;13-17;18-22; 23-27; 28	x	x								Model includes west end conveyance improvements and Lot D conveyance improvement and limited SWM improvements. Depths reduced in west end and Lot E/D, but Lower Main Street depths still high.
3B		x			x	x			halved 1-10;13-17;18-22; 23-27; 28	x	x			x					Same as scenario 3A but adds underground storage at Lot F and Roger Carter Center. Depths reduced in west end and Lot E/D, but Lower Main Street depths still high. Depths in Lot D/E/F lower than scenario 3A.
3C		x			x	x			halved 1-10;13-17;18-22; 23-27; 28	x	x			x	x				Same as scenario 3B but adds underground storage at West End Service. Depths reduced in west end and Lot E/D/F (comparable to 3B); depths in Lower Main Street substantially lowered by several feet throughout.
3D	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x								Same as scenario 3A but adds MD Ave Culverts (and associated bldg removal) to help lower depths in Lower Main St. Depths west of Lot D comparable to Scenario 3A; depths along Lower Main St. lowered substantially (lower than 3C)
3E	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x			x					Same as scenario 3D but adds underground storage at Lot F and Roger Carter Center. Depths west of Lot D comparable to Scenario 3A; depths lowered in Lot D/E/F, comparable depths to 3D along Lower Main St.
3F	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x			x	x				Same as scenario 3E but adds underground storage at West End Service. Reduces depths from West End through Lot D/E/F; depths along Lower Main St. substantially reduced from existing conditions (4' -5' for 7/30/16)
3F.1	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x		x	x	x				Same as scenario 3F but adds SWM in New Cut branch. Depths comparable to scenario 3F throughout except Lower Main. Depths in Lower Main St. substantially reduced (2' - 3' depth for 7/30/16).
3F.2	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x	x		x	x				Same as scenario 3F.1 but removes SWM from New Cut branch and adds SWM in Tiber. Depths comparable to scenario 3F throughout except Lower Main. Depths in Lower Main St. substantially reduced (3' - 4' depth for 7/30/16).
3F.3	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x	x		x	x	x			Same as scenario 3F.2 but adds SWM in Hudson Branch (H4). Depths comparable to scenario 3F.3 throughout; Minor reductions in depth along west end. H4 has minimal impact on depth/flood extent. Depths in Lower Main St. substantially reduced (3' - 4' depth for 7/30/16).
3F.4	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x	x		x	x	x	x		Same as scenario 3F.3 but adds more SWM in Hudson Branch (H3). Depths comparable to scenario 3F.3 and 3.F.4 throughout; Minor reductions in depth along west end. H3 has minimal impact on depth/flood extent. Depths in Lower Main St. substantially reduced (3' - 4' for 7/30/16).
3F.5	x	x	(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;13-17;18-22; 23-27; 28	x	x	x		x	x	x	x	x	Model includes substantial SWM in the Hudson Branch, including flow attentuation and storage from 5 above ground and 6 underground flood attenuation facilities. Includes major conveyance improvements through the west end, open channel between Lot E and Lot D, and channel grading and culverts along Lower Main Street (4 buildings removed along Lower Main; 6 bldgs modified). Significant depth and flow reductions throughout west end, significant reductions in depth and floodplain at ECMills Dr., at Lot F, Lot E, Lot D, and 7/30/16 storm depths along Lower Main St. average less than 3'. Addition of BGE SWM reduces depths in west end apprx. 6".
3G	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x								Model includes limited SWM in Hudson Branch and conveyance improvements throughout west end and Lower Main St. Lower Main is terraced and 6 buildings are removed, along with MD Ave bypass culverts. Depth of flow in Lower Main is ~4' -6' throughout for 7/30/16. 7/30/16 flow overtops onto Main St. for Lot D conveyance improvement.
3G.1	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x	x							Model is same as 3G but includes SWM in Tiber Branch (T1). Lower Main is terraced and 6 buildings are removed, along with MD Ave bypass culverts. Depth of flow in Lower Main is generally ~4' - 5' throughout for 7/30/16; T1 storage reduces depths in Lower Main about 1'.
3G.2	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x	x				x			Model is same as 3G.1 but includes more SWM in Hudson Branch (H4). Lower Main is terraced and 6 buildings are removed, along with MD Ave bypass culverts. Additiona lof H4 lowers depths along West End approximately 1' in most areas; H4 reduces flows through Lot D channel expansion to the point flow from 7/30/16 event does not overtop onto Main St. at that crossing. Depths in Lower Main St. are relatively unchanged from 3G.1.
3G.3	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x	x				x	x		Model is same as 3G.2 but includes more SWM in Hudson Branch (H3). Adding H3 yields very little difference in max flow depths from 3G.2.
3G.4	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x	x				x	x	x	Model is same as 3G.3 but includes more SWM in Hudson Branch (all 3 BGE Underground SWM). Adding BGE undergrounds reduces simulated depths across west end by several inches to 1'; depths in Lower Main are reduced by several inches.
3G.5	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x	x	x						Includes above ground flood attenuation storage in Hudson, New Cut and Tiber Branches. Includes major conveyance improvements through the west end, open channel between Lot E and Lot D, and channel grading and culverts along Lower Main Street (6 buildings removed; 4 bldgs modified along Lower Main). Lower Main St. depths significantly reduced. Reduction in floodplain extent through Lot F, Lot E, Lot D. Depth reductions through west end consistent with 16C.
3G.6	x		(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x						Includes above ground flood attenuation storage in Hudson, New Cut and Tiber Branches. Includes major conveyance improvements through the west end, and channel grading and culverts along Lower Main Street (4 buildings removed; 6 bldgs modified along Lower Main). Lower Main St. depths reduced, flow still escapes onto Main St. at Court Ave. Substantial floodplain remains through Lot F, Lot E, Lot D. 4 bldgs vs. 6 buildings removed, minor difference in depths along lower Main.
3G.6.0	x		(2 pipes- 10'Dia)	x	x	x			1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x			x			Includes above ground flood attenuation storage in Hudson, New Cut and Tiber Branches, includes H4 facility. Includes major conveyance improvements through the west end, and channel grading and culverts along Lower Main Street (4 buildings removed; 6 bldgs modified along Lower Main). Lower Main St. depths reduced, flow still escapes onto Main St. at Court Ave. Substantial floodplain remains through Lot F, Lot E, Lot D. Addition of H4 facility further reduces west end depths 3"-6", below those in 3G.5
3G.6.1	x		(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;18-22; 23-27; 28	x	x	x	x						Model is the same as 3G.6, but includes 6 buildings removed along Lower Main Street. Removal of 2 extra buildings has very minimal impact on flow depths in Lower Main St., ie. depths along Lower Main are nearly identical between 3G.6 and 3G.6.1.
3G.7	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)		1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x						Model is the same as 3G.6, but includes 15' diameter North Tunnel. Addition of the North Tunnel eliminates flooding in Lot E and reduces flooding extent and depth in Lot D approximately 1'. Flood Depths along Lower Main Street are about 2' lower than 3G.6 scenario without the North Tunnel.
3G.7.0	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)		1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x			x			Includes above ground flood attenuation storage in Hudson, New Cut and Tiber Branches, includes H4 facility. Includes major conveyance improvements with **15' dia. North Tunnel Bore**, improvements through the west end, and channel grading and culverts along Lower Main Street (4 buildings removed; 6 bldgs modified along Lower Main along Lower Main). Floodplain remains through Lot F, Lot D with lower depths. Lower Main St. depths substantially reduced (~2' lower than 3G.6.0). West end depths consistent with 3G.6.0
3G.7.0.1	x		(2 pipes- 10'Dia)	x	x	x	(12'Dia)		1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x						Model is the same as 3G.7 but North Tunnel diameter is reduced from 15' down to 12'. Inverts and other tunnel variables remain unchanged. 12' diameter pipe functions the same as 15' diameter for reducing depths, because invert in is sufficiently low that headwater doesnt reach critical elevation given amount of flow being diverted. Depths essentially the same as 3G.7.
3G.7.1	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)		1-6; halved 7-10;18-22; 23-27; 28	x	x	x	x						Model includes same items as 3G.7, but removes 6 buildings along Lower Main Street instead of 4. This model also does not have a berm to force flow into the entrance to the North Tunnel. Without berm, slightly less flow is being diverted through tunnel, which means depths in Lot D and Lower Main are slightly higher than 3G.7. Difficult to independently analyze the impact of 6 vs. 4 buidlings under this specific scenario, however based on results of other scenarios it is anticiapted 6 buildings removed (as modeled in this scenario) has minimal depth reductions compared to 4 buildings removed scenario.
3G.8	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)	(10' Dia)	1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x						Model is the same as 3G.7 , but includes a 10' dia. South Tunnel, just downstream of New Cut confluence with Hudson/Tiber. 10' Dia South Tunnel has no impact on flooding upstream of New Cut. Depths in Lower Main St. are lowered "6" in Lower Main Street with this South Tunnel.
3G.8.0	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)	(10' Dia)	1-4; halved 5-10;18-22; 23-27; 28	x	x	x	x			x			Includes above ground flood attenuation storage in Hudson, New Cut and Tiber Branches, includes H4 facility. Includes major conveyance improvements with **15' dia. North Tunnel Bore, 10' dia South Tunnel Bore**, improvements through the west end, and channel grading and culverts along Lower Main Street (4 buildings removed; 6 bldgs modified along Lower Main along Lower Main). Floodplain remains through Lot F, Lot D with lower depths. Lower Main St. depths substantially reduced. 10' Dia. South Bore further reduces Main St. depths about 6". West end depths consistent with 3G.6.0
3G.8.1	x		(2 pipes- 10'Dia)	x	x	x	(15' Dia)	(10' Dia)	1-6; halved 7-10;18-22; 23-27; 28	x	x	x	x						Model is the same as 3G.8, but 6 buildings removed instead of 4. Removal of extra 2 buildings simulates negligible impact on flood depths along Lower Main St.
3H	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x			x					Includes SWM in Hudson Branch and underground SWM at Lot F/Roger Carter; conveyance improvements throughout west end and at Lot D, Lower Main St. 6 buildings removed along Lower Main St. Depths along West End reduced as consistent with comparable other scenarios; flooding eliminated in Lot F through undergound storage, flooding in Lot D significantly reduced. Flood depths in Lower Main St still 4 - 6' for 7/30/16 event.
3I	x	x	(2 pipes- 10'Dia)	x	x	x			1-6; halved 7-10;13-17;18-22; 23-27; 28	x	x			x	x				Includes same improvements as Scenario 3H, however also includes underground SWM at H1-UG2. Addition of large underground SWM reduces flooding in West End and downstream through Lot D. Flood depths in Lower Main St. are reduced apprx. 1' through the addition of H1UG2 (~3'-5' for 7/30/16 storm).

*Terraced Floodplain limited to area where buildings will be removed; primarily for providing entrance for MD Ave Culverts. See graphics.
** Elevated = on 2'x2'piers at 12' OC spacing, raised to second floor elevation (see sheet 4); Halved = Modifying buildings to remove back half above the stream while keeping the front of the buildings along Main Street.