Bel Air Impoundment Breach Analysis Report

MARYLAND AMERICAN WATER

April 2016

Gannett Fleming

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Bel Air Impoundment Breach Analysis Report

Harford County, Maryland

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Maryland American Water Company

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Appendices

1.0 Introduction

This report presents the results of the hydrologic and hydraulic analyses required to prepare the dam breach inundation mapping for the proposed Bel Air Impoundment. The report summarizes the modeling inputs, methodologies, and assumptions related to hydrology, dam breach formation, and flood routing analyses. The modeling was completed in adherence with current Maryland Department of Environment (MDE) requirements for dams.

2.0 Project Description

The Bel Air Impoundment will be located approximately 1.7 miles southwest of downtown Bel Air in Harford County, Maryland. The reservoir will be owned and operated by Maryland American Water Company (MAWC) and be used for water supply purposes.

The primary water supply for the Bel Air water system (operated by MAWC) is Winters Run, which is permitted for a 1.4 MGD annual average withdrawal. However, during periods of low stream flow, the primary raw water supply to the system is either restricted or prohibited. The Bel Air Impoundment, an off-stream raw water storage reservoir, has been proposed to address this concern and to provide a raw water supply when water cannot be withdrawn from the stream.

The proposed reservoir adjoins the water treatment plant property along its respective northern edge adjacent to Winters Run. The proposed dam embankment has a maximum height of 51 feet, a 20-foot-wide crest, 3H:1V downstream slope, and a 2.5H:1V upstream slope. Based on the current geotechnical investigations, the embankment and impoundment bottom will require a liner system to control seepage. It is anticipated that the liner system will be exposed on the upstream slope of the embankment. At the normal pool elevation of 256 feet (NAVD 88) the reservoir will impound approximately 90 million gallons (276 acre-feet). A preliminary plan and rendering of the proposed impoundment is included in Appendix A.

Since the reservoir does not have any contributing drainage area, the reservoir will be filled by pumping water from Winters Run into the impoundment. A concrete riser structure spillway with overflow weir will serve as a safeguard against over-filling the reservoir by pumping or during extreme precipitation events. The spillway design will allow passage of the Probable Maximum Precipitation (PMP) event with more than one foot of freeboard. An outlet conduit will convey water from the bottom of the intake structure through the embankment to the downstream toe of the embankment. The outlet conduit and raw water transmission pipelines will run parallel through the dam embankment and will be supported on a concrete cradle. At the toe of the dam embankment, the raw water transmission pipe diverts away from the outlet conduit towards the pumping station and water treatment plant. The outlet conduit will discharge into a plunge pool located downstream beyond the toe of the dam embankment, where an excavated channel lined with riprap will connect the plunge pool to Winters Run.

3.0 Hydrology

Since the Bel Air Impoundment is an upland type reservoir, no hydrologic model was developed for the watershed of the impoundment. The surface area of the impoundment (approximately 15 acres) is the only contributing drainage area to the reservoir. The only hydrologic data analyzed in this study were precipitation and flood frequency data for the adjacent Winters Run, which were used as input into the hydraulic analysis described in the following sections of this report.

3.1 Probable Maximum Precipitation/Probable Maximum Storm

PMP estimates in the vicinity of the Bel Air Impoundment were obtained from Hydrometeorological Report No. 51 (HMR 51) for the entire range of possible storm sizes and durations. These estimates are plotted in Figure 1. Since the surface area of the reservoir is only 15 acres, the smallest (and most intense) storm size of 10 square miles was considered in the analysis. The PMP value for a 6-hour, 10-square mile storm was recommended by MDE as rainfall input for hydraulic modeling. This corresponds to 27.3 inches of rain occurring in a 6-hour duration. Select PMP maps from HMR 51 are presented in Appendix B-1.

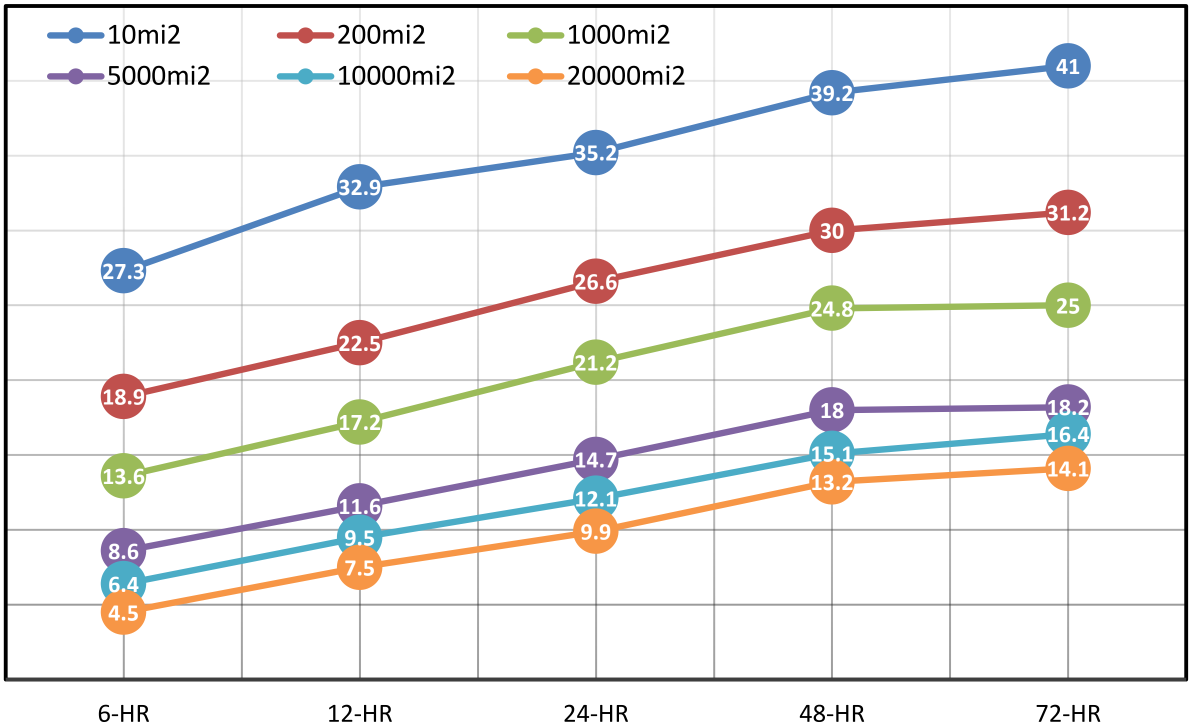

Figure 1 - HMR51 PMP Values in Bel Air, MD (inches)

In a typical dam breach analysis, a runoff hydrograph would be estimated based upon the soil and land use characteristics of the watershed. The hydrograph would be routed through the reservoir and spillway, and a peak water surface elevation would be identified and considered in modeling the dam breach scenario. Since the Bel Air Impoundment is a lined upland reservoir, it is assumed that all the rainfall over the surface of the impoundment reaches the reservoir (no losses). As a conservative assumption, the spillway was not considered in the analysis; rather, the failure elevations for various storm events were identified by adding the normal pool elevation and the rainfall depth for the given storm event. The maximum theoretical pool level in this situation is the sum of normal pool elevation (256 feet) and the PMP depth (27.3 inches) and would result in a pool level of 258.3 feet. For the breach analysis, a conservative "brim-up" failure condition was assumed with the pool level at Elev. 259.0 feet. The brim up failure scenario results in a breach hydrograph with the highest peak flow.

3.2 Stream Flow in Winters Run

For the breach analysis, it is important to identify appropriate flood conditions that could occur within Winters Run coincident with "brim-up" failure of the dam. In coordination with MDE, the 2-year and 100-year peak discharges were selected and analyzed as base flows within Winters Run to represent the range of hydraulic loadings within the downstream floodplain that could occur coincident to a dam failure.

The USGS software program PeakFQ was used for frequency analysis of stream discharge observations retrieved from the USGS gaging station at Winters Run near Benson, MD (Station ID 01581700). As illustrated in Figure 2, this stream gage is located near the Route 1/Bel Air Bypass crossing of Winters Run immediately adjacent to the northern-most portion of the proposed embankment and about 2,000 feet upstream of the existing raw water intake. The stream gage has a continuous record of peak streamflow since 1967, providing 48 years of record for the analysis. The 2-year and 100-year discharges in Winters Run as estimated by the PeakFQ gage analysis are 2,427 and 13,760 cfs, respectively. Analysis results are presented in Appendix B-2.

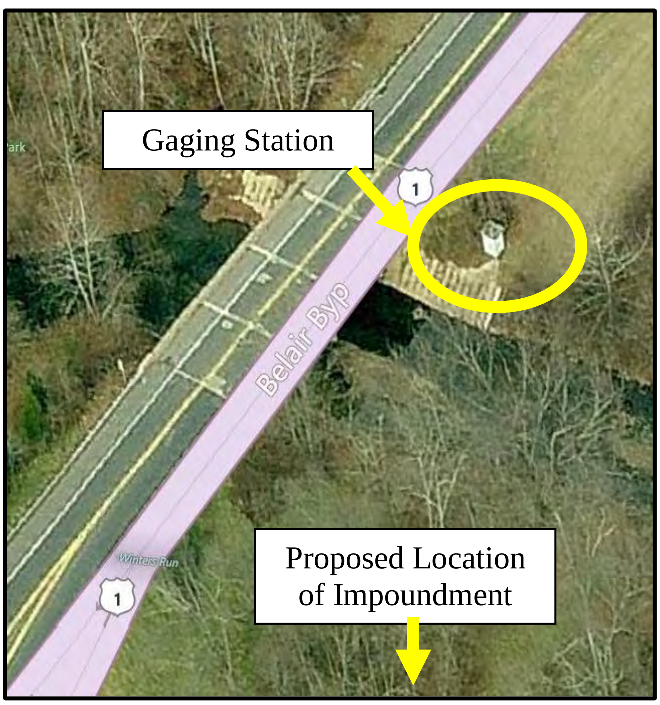

Figure 2 - USGS gaging station at Winters Run near Benson, MD

4.0 Hydraulic Analysis

The Bel Air Impoundment was analyzed for "brim-up" breach scenarios associated with embankment failure during the 2-year flood (referred to as "Sunny Day Failure" scenario) and the 100-year flood (referred to as "100-year Failure) flood events on Winters Run. The two-dimensional hydraulic model HEC-RAS (Version 5.0) was used to model the breach condition and to assess the complex flow conditions that exist downstream of the Bel Air Impoundment.

The inputs to the two-dimensional hydraulic model include a digital terrain data of the study area, Manning's roughness coefficients for the study area, boundary conditions, and a user-defined two-dimensional (2-D) flow area.

4.1 Terrain Processing and 2-D Area Defining

LiDAR terrain data with a resolution of 4 feet by 4 feet in the vicinity of the impoundment and Winters Run was obtained from MDE and is depicted in Figure 3. Additionally, a detailed flood study model (one-dimensional HEC-RAS) of Winters Run was obtained from FEMA. This model included surveyed cross sections of the channel along the entire reach of interest, and was used to burn the channel geometry of Winters Run into the LiDAR terrain data to better represent the stream geometry of the project area (See Appendix C-1).

The reservoir was modeled as a storage area with the anticipated stage-storage relationship of the Bel Air Impoundment. This relationship is summarized in Table 1. The area downstream of the reservoir was defined as a full 2-D flow area with a calculation grid size of 12 feet by 12 feet resulting in a grid of approximately 920,000 cells. A detailed elevation-volume curve is calculated for each of the cells to preserve all sub-grid terrain information. Detailed elevation versus area, wetted perimeter, and roughness curves are developed for each face of each grid. Figure 3 shows the 2-D flow area on the LiDAR terrain data.

4.2 Manning's Roughness

Manning's roughness values for the 2-D flow grid were assigned using both the land cover type defined by the 2011 National Land Cover Data (NLCD) and additional information gathered from high resolution orthoimagery. Manning's roughness values used in the model are listed in Table 2. Refer to Appendix C-2 for more information about spatially-varied roughness layers.

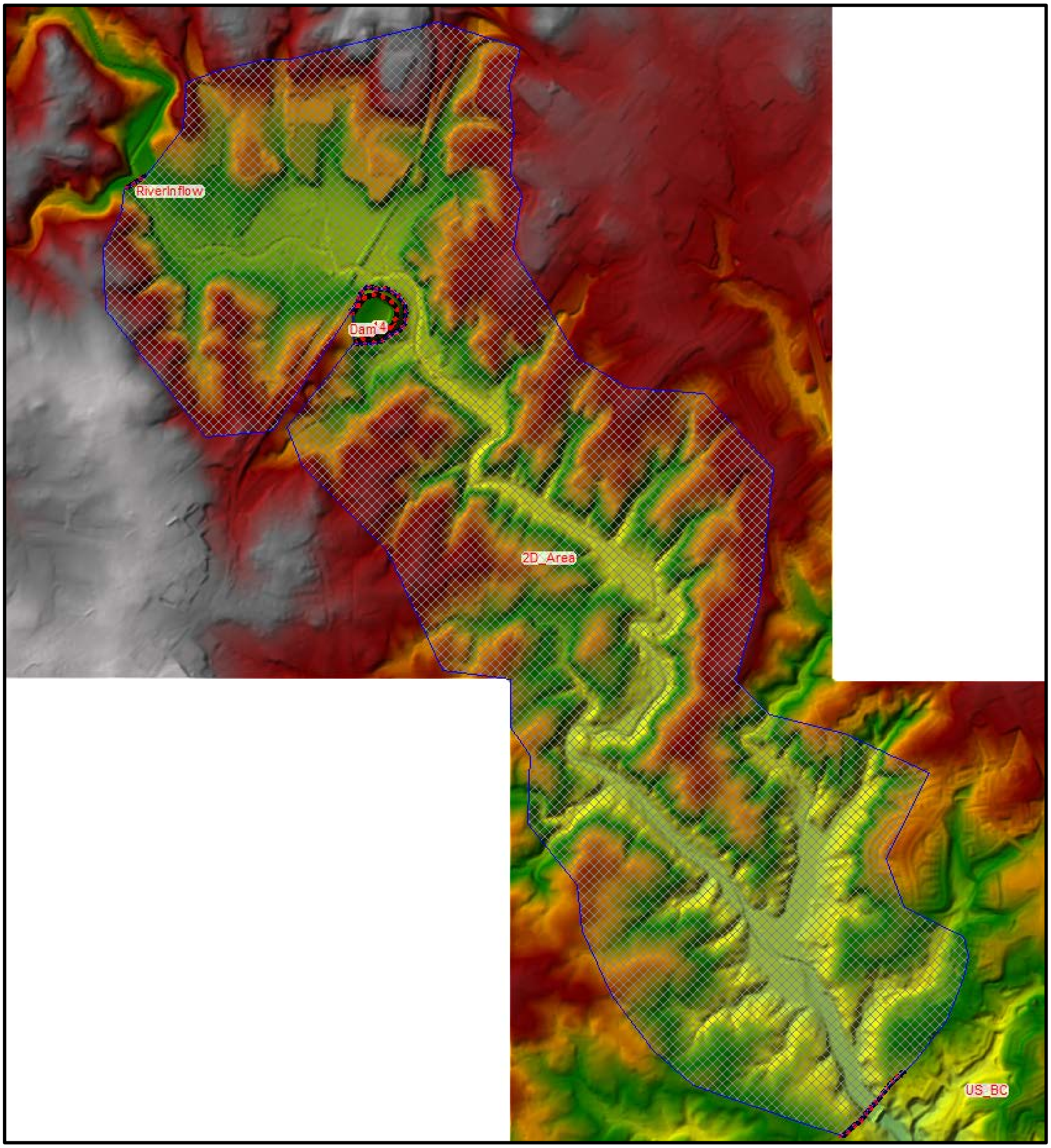

Figure 3 - Two-dimensional Hydraulic Analysis Area Shown on a Terrain Grid

Table 1 - Stage-Storage for the Bel Air Impoundment

Stage (feet NAVD88)	Storage (acre-feet)
209	0.0
214	1.2
219	7.1
224	19.7
229	40.6
234	71.9
239	112.2
244	157.7
249	207.4
254	261.1
259	316.5

Table 2 - Manning's roughness values

NLCD /User-defined Land Cover Type and Number	Manning's n Value
Open Water (11)	0.03
Developed, Open Space (21)	0.035
Developed, Low Intensity (22)	0.06
Developed, Medium Intensity (23)	0.10
Developed High Intensity (24)	0.20
Deciduous Forest (41)	0.12
Evergreen Forest (42)	0.12
Mixed Forest (43)	0.12
Shrub/Scrub (52)	0.06
Grassland/Herbaceous (71)	0.06
Pasture/Hay (82)	0.06
Woody Wetlands (90)	0.08
Emergent Herbaceous Wetlands (95)	0.03
Detailed Houses (1)	0.50
Detailed Roads (2)	0.025
Detailed River (3)	0.055

4.3 Boundary Conditions

The upstream boundary condition was defined as a constant inflow at the upstream end of Winters Run within the defined 2-D analysis area. The 2-year and 100-year flow rates were used for the Sunny Day Failure and the 100-year Failure scenarios, respectively as described in Section 3.2.

The downstream boundary condition was defined as a rating curve at the Atkisson Reservoir Dam approximately 4.4 miles downstream of the Bel Air Impoundment. The spillway rating curve was obtained from documentation of a Dam Breach Analysis of Atkisson Dam (1985) that was provided by MDE. This rating curve is summarized in Table 3.

Table 3 - Atkisson Dam Spillway Rating Curve

Stage (feet NAVD29)	Stage (feet NAVD88)	Discharge (cfs)
120	119.173	0
122	121.173	1,960
124	123.173	5,830
126	125.173	11,049
128	127.173	17,582
130	129.173	25,102
132	131.173	33,696
134	133.173	43,342
136	135.173	55,963
138	137.173	71,225

4.4 Dam Failure Analyses

For inline dams in typical valley terrain, the embankment surrounds only one side or face of the reservoir. Most of the reservoir is impounded by the surrounding natural ground. As described in Section 2, the Bel Air Impoundment is an upland reservoir with a configuration which is significantly different from that of typical embankment dams. Because of this unique configuration, multiple breach locations were considered in order to identify all potential impacts of failure of the impoundment.

Two breach locations were selected for the analysis that allow identification of maximum flooding extents both upstream and downstream of the proposed Bel Air Impoundment along Winters Run. Figure 4 illustrates these locations. Location 1 is situated near the maximum section of the impoundment along the proposed spillway conduit. A breach at this location would deplete the entire reservoir storage and direct the flood wave directly into the downstream reach of Winters Run, thereby producing the greatest flooding extent in downstream reaches. A breach at Location 2 would release the majority of storage and direct outflow into the upstream reaches of Winters Run. This scenario would produce the greatest flooding extent in upstream reaches.

Table 4 presents the breach parameters that were applied to both breach locations. The breach parameters were estimated using MDE recommended methodology as well as several other commonly applied regression methods. All parameters were carefully selected to be sufficiently conservative in the analysis. A summary of the methods used as well as detailed calculations of the breach parameters can be found in Appendix C-3.

In total, four dam breach scenarios were analyzed using the 2-D HEC-RAS model. These scenarios encompass the variations in both breach location and hydrological conditions in Winters Run as follows:

1. Sunny Day Failure (2-year Flood) – Breach Location 1
2. Sunny Day Failure (2-year Flood) – Breach Location 2
3. 100-year Failure – Breach Location 1
4. 100-year Failure – Breach Location 2

Using the output of the 2-D dam breach model, the inundation limits for the 100-year Failure and Sunny Day Failure events were digitally mapped with GIS software. Breach inundation mapping was developed to represent the maximum flooding extent based on the composite inundation extent of both breach locations. These composite extents were developed for both the 100-year Failure and the Sunny Day Failure scenarios and are presented in Appendix D.

Table 4 - Dam Embankment Breach Parameters

Parameter	100-yr Failure	Sunny Day Failure
Breach Formation Time (minutes)	15	15
Breach Width (feet)	100	100
Breach Side Slopes	0.9V:1H	0.9V:1H

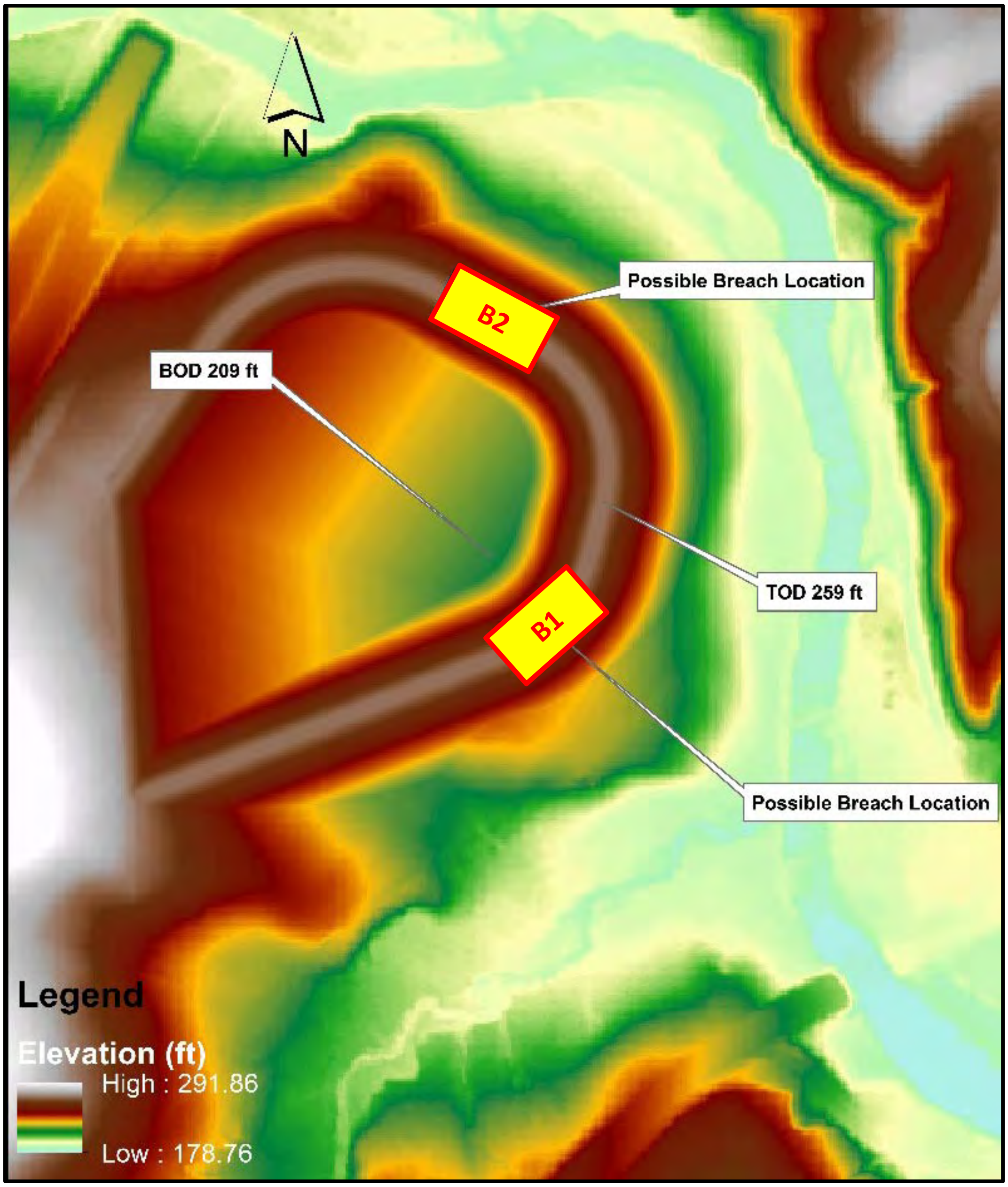

Figure 4 - Breach locations used in 2015 Gannett Fleming analysis

5.0 Dam Breach Hazard Assessment and Classification

Based upon the dam breach analyses for the Bel Air Impoundment, a consequence analysis was conducted utilizing the Bureau of Reclamation's ACER Technical Memorandum No.11, *Downstream Hazard Classification Guidelines* (ACER 11). Dr. Yan Wang of Gannett Fleming conducted a field reconnaissance visit on January 30, 2016 to identify potential hazards within the estimated breach inundation extent. To supplement this effort, a detailed review of available orthophotos was also completed. The consequence/hazard analysis was carried out for all structures and roads that were identified within the inundation boundary.

5.1 Consequence Analyses for Structures

Twenty-four structures that are located both upstream and downstream of the proposed impoundment are impacted in one or more breach analysis scenarios. Of these 24 structures, there are 6 residential houses, 7 buildings associated with the Bel Air WTP facilities, and 11 unoccupied structures (e.g. sheds, garages, or barns). For organizational purposes, the structures were geographically combined into three groups for detailed analysis as depicted in Figure 5 with more detailed views of each individual group in Figures 6 through 8. The maximum flooding extents of the Sunny Day Failure and 100-year Failure scenarios at both breach locations are also depicted on Figures 5 through 8.

The first group of structures (depicted in Figure 6) consists of two storage sheds (Structures 1 and 2), one single-story residential house (Structure 3), and one garage (Structure 4). Therefore, the only potential hazard to life in this group of structures was assumed to be to Structure 3, the residential house. This house would be impacted in the scenario when a breach occurs at Location 2 during a 100-year flood on Winters Run (100-year Failure – Breach Location 2 Scenario). During this scenario, the model analysis indicates that this house would be partially flooded by 1.6 feet of water with 0.2 feet per second (fps) velocity. Based on the ACER 11 hazard analysis for residential houses, the flooding that occurs at Structure 3 is within the low danger zone.

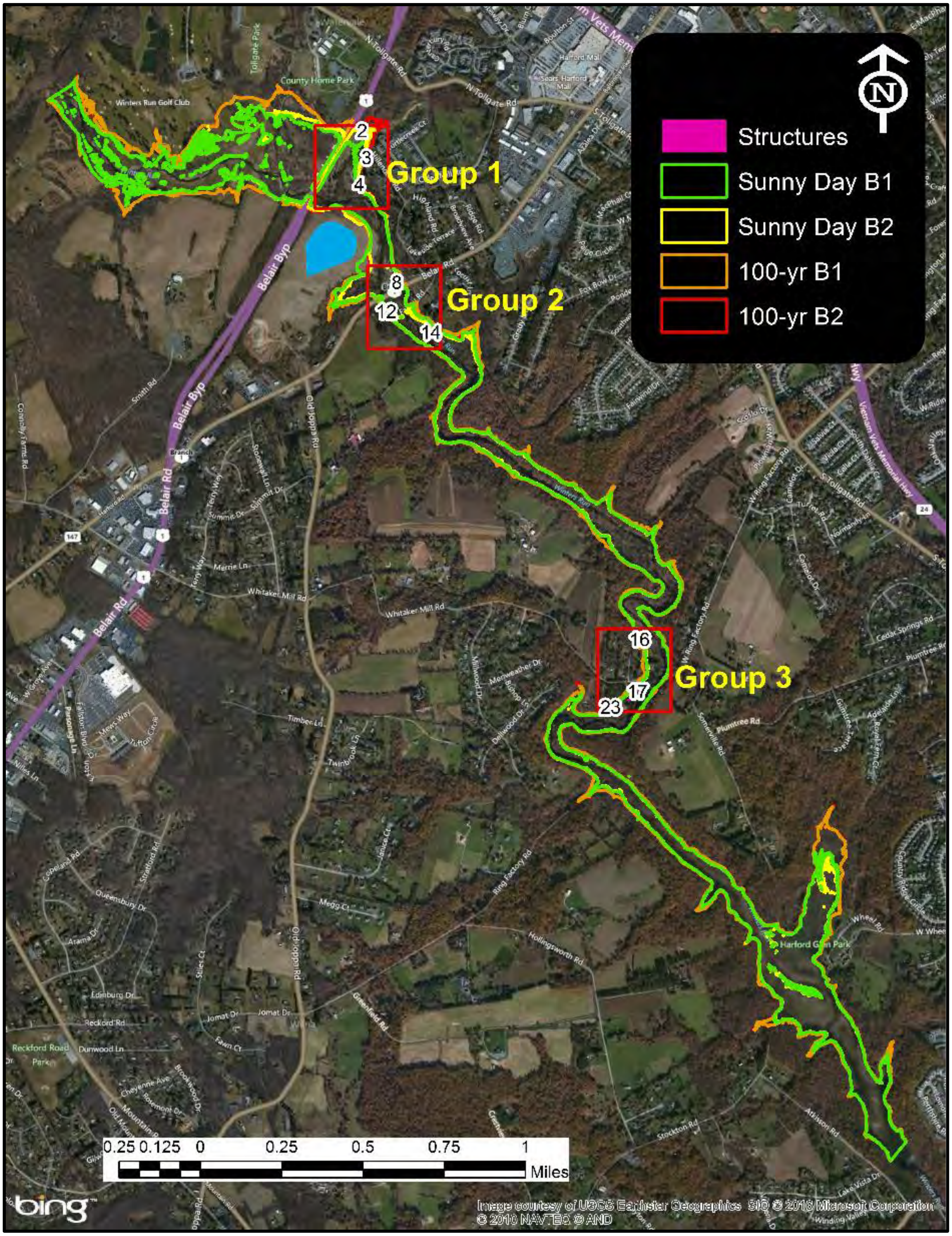

Figure 5 - Overview of Impacted Structures

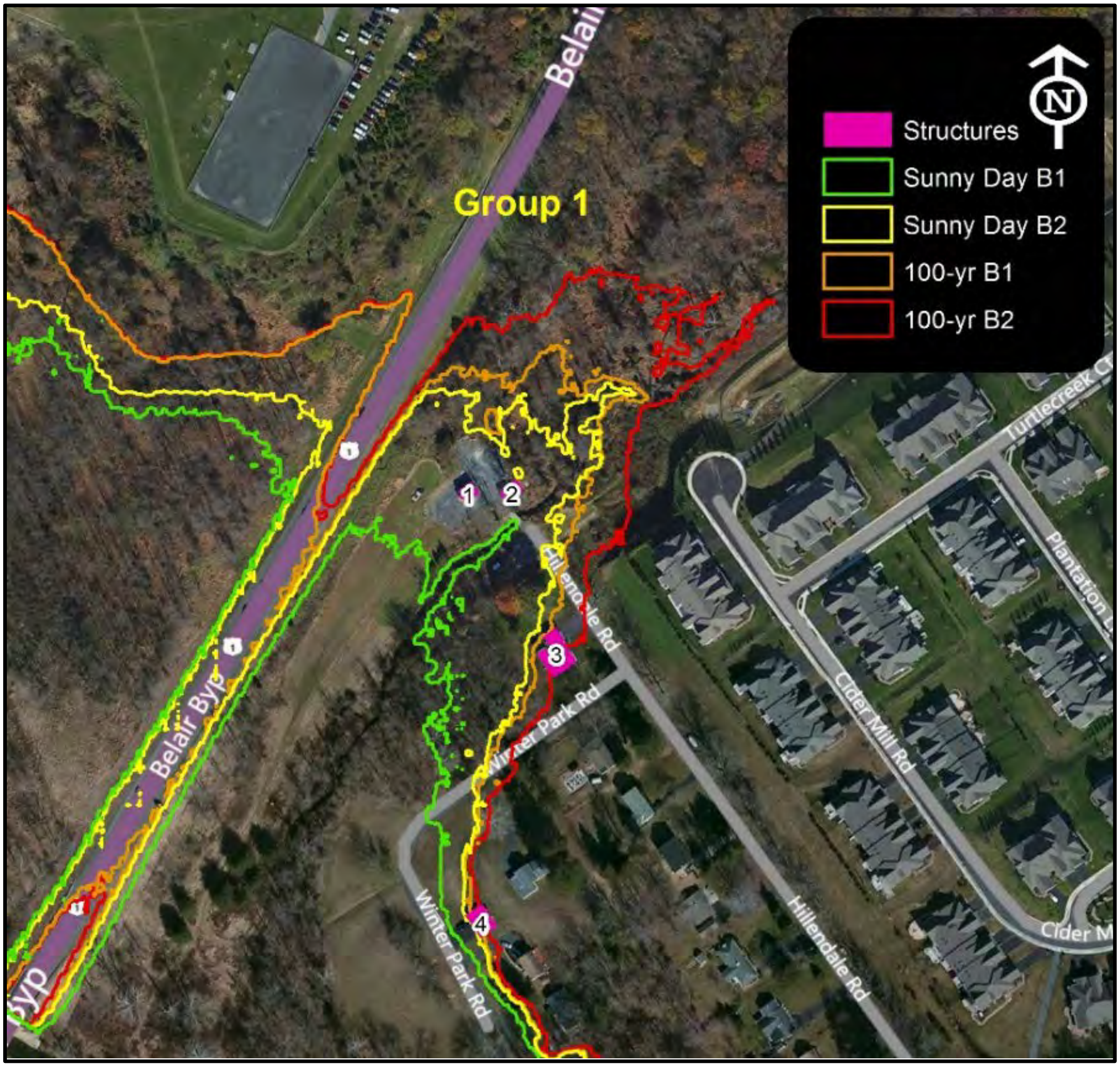

Figure 6 - Dam Breach Impacts on Group 1 Structures

The second group of structures (depicted in Figure 7) consists of the seven buildings at the Bel Air WTP (Structures 5-11), a two-story residential house (Structure 12), a storage shed (Structure 13), and an abandoned barn (Structure 14). Of the seven structures at the WTP, there are three storage sheds (Structures 5-7), three water tanks (Structures 8-10), and one main office (Structure 11). The primary hazard in this group (Structure 12) would be flooded by 2.5 feet of water with a velocity of 2.0 fps during the Sunny Day Failure scenario, and 6.0 feet of water with a velocity of 3.0 fps during the 100-year Failure Scenario. This house is within the FEMA 100-

year Floodplain. In a 100-year flood without failure of the impoundment, this structure would experience 0.5 feet of flooding with a velocity of 0.5 fps. Based on the ACER 11 hazard analysis for residential houses, Structure 12 is within the low danger zone during a Sunny Day Failure and a high danger zone during the 100-year Failure scenario.

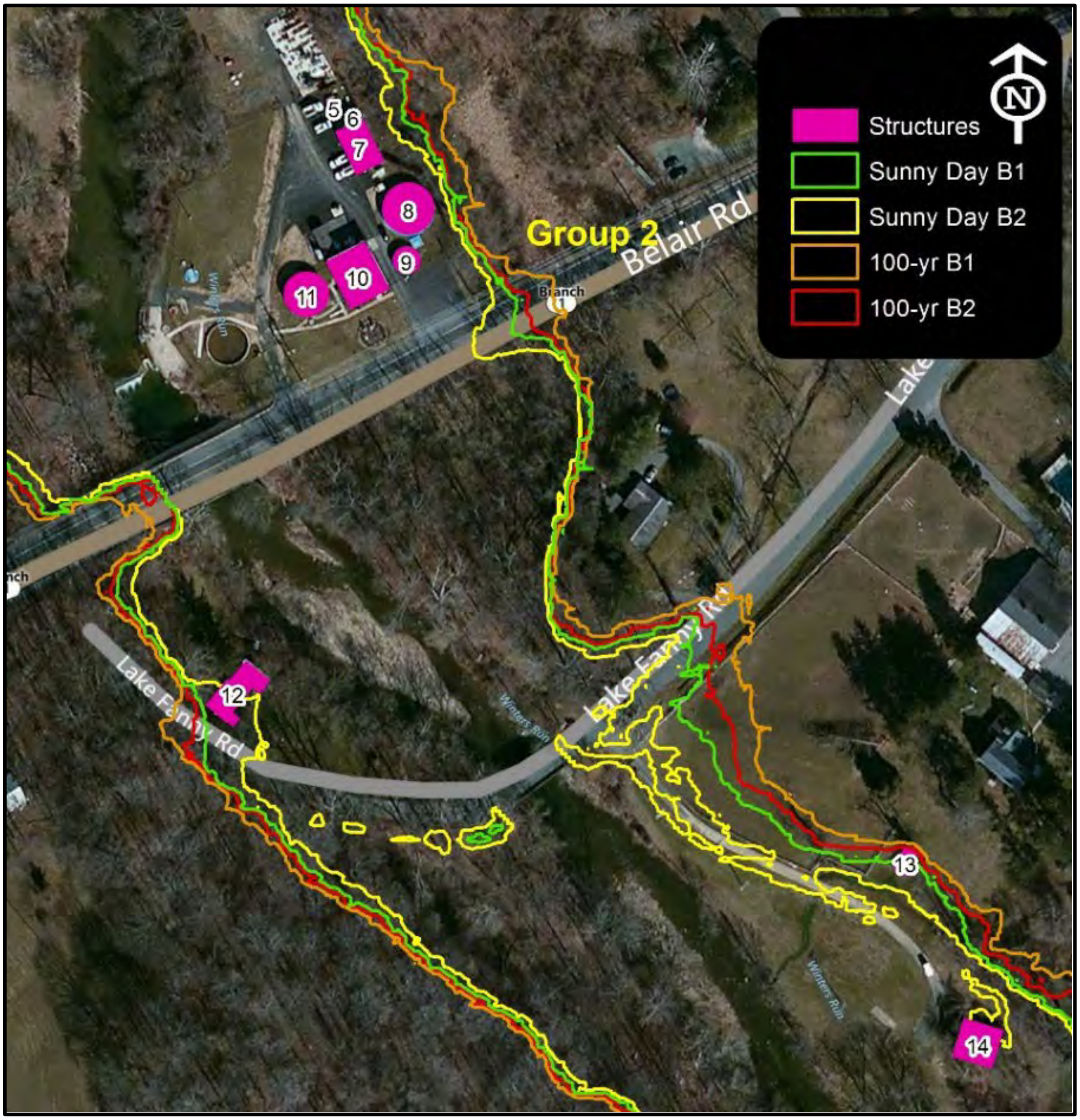

Figure 7 - Dam Breach Impacts on Group 2 Structures

The third group of structures (depicted in Figure 8) consists of six storage sheds (Structures 15, 20-24), two single-story residential houses (Structures 16 & 18), and two multi-story residential houses (Structures 17 & 19). Structures 16 and 18 would be partially impacted by the 100-year Failure with flooding depths of less than 1.0 feet and velocities under 1.0 fps. Structure 17 would

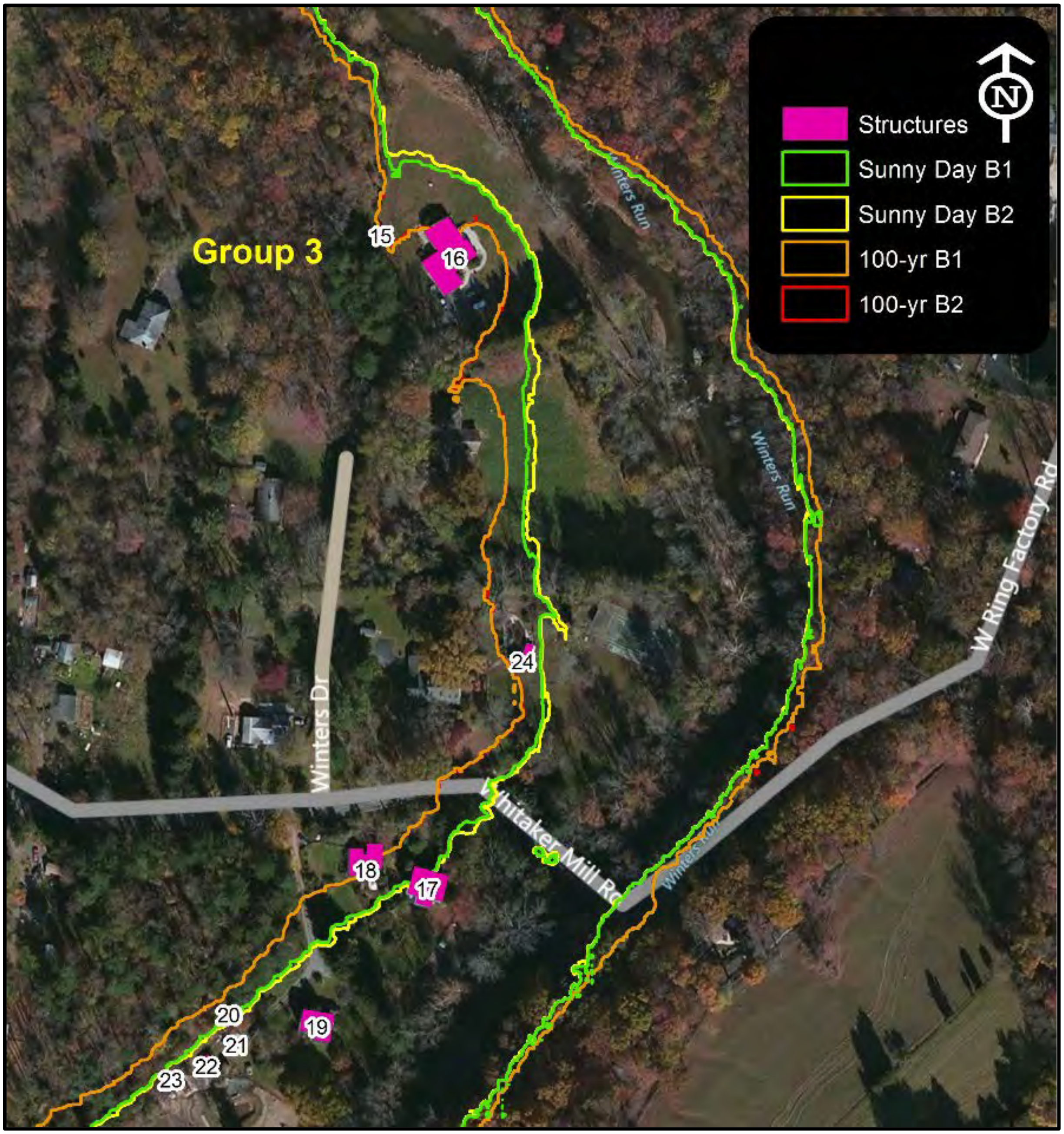

Figure 8 - Dam Breach Impacts on Group 3 Structures

be impacted by a maximum depth of 2.6 feet and a velocity of 1.0 fps during the Sunny Day Failure, and a depth of 9.0 feet with a velocity of 3.0 fps during the 100-year failure. Structure 19 would be impacted by a depth of 2.5 feet and a velocity of 2.5 fps during the Sunny Day Failure, and a depth of 9.2 feet with a maximum velocity of 3.5 fps during the 100-year Failure. Structures 17 and 19 are both within the regulatory FEMA 100-year Floodplain and would be flooded by 6.5 feet of water at a velocity of 3.0 fps during a 100-year flood event without failure of the Bel Air Impoundment.

Based on the ACER 11 hazard analysis for residential houses, Structures 16 and 18 are within the low danger zone even during the 100-year Failure scenario. Structures 17 and 19 are in the low danger zone during a Sunny Day Failure. During a 100-year flood, both of these structures would be in the high danger zone with or without failure of the impoundment.

For additional information regarding estimated depths and velocities at each structure in the four dam breach analysis scenarios, please refer to Appendix E-1. Non-breach analysis results are also presented for comparison.

5.2 Consequence Analyses for Stream Crossings

Five stream crossings located both upstream and downstream of the impoundment were identified that would be impacted in one or more of the analyzed breach scenarios. Among them, there are three major roads, one access road, and one pedestrian bridge.

Bel Air Bypass (Route 1), which is upstream of the reservoir would be overtopped by about 1.7 feet of water with a velocity of 5.0 fps during the 100-year Failure scenario. Based on this amount of flooding, the road remains in low danger zone of the ACER 11 assessment for passenger vehicles.

Bel Air Road (Baltimore Pike) is located immediately downstream of the proposed impoundment and would be impacted by a flooding depth of 4.9 feet and a velocity of 8.5 fps during a Sunny Day Failure, and 8.4 feet and 8.5 fps during the 100-year Failure. All breach scenarios would result in high danger conditions to passenger vehicles at the crossing according to ACER 11.

Lake Fanny Road is also located immediately downstream of the Bel Air Impoundment and provides access to one residential house (Structure 12). The stream crossing is the only means of vehicular access to this structure. The road would be impacted by 0.8 feet of flooding with a velocity of approximately 7.0 fps during a Sunny Day Failure, and 5.2 feet with a velocity of 8.5 fps during a 100-year Failure. Failure of the impoundment would cause low danger conditions during the Sunny Day Failure and a high danger conditions during the 100-year Failure per ACER 11 criteria.

Whitaker Mill Road and Ring Factory Road are located more than two miles downstream of the proposed impoundment. Whitaker Mill Road would be impacted by a flooding depth of 1.6 feet and a velocity of 6.0 fps during a Sunny Day Failure, and 7.1 feet with a velocity of 7.0 fps during a 100-year Failure. The stream crossing would experience potentially high danger conditions for passenger vehicles during a dam failure event. Ring Factory Road is a pedestrian bridge, and flooding of this structure due to failure of the impoundment is not anticipated to jeopardize human life.

For additional information regarding estimated depths and velocities at each stream crossing in the four dam breach analysis scenarios, please refer to Appendix E-2. Non-breach analysis results are also presented for comparison.

5.3 Hazard Classification

Code of Maryland Regulations stipulate that all dams be classified based on the downstream damage that would result if the dam were to fail. The three classifications of dams are as follows:

1. High Hazard Dam – *Failure would likely result in loss of human life, extensive property damage to homes and other structures, or cause flooding of major highways such as state roads or interstates.*

2. Significant Hazard Dam – *Failure could possibly result in loss of life or increase flood risks to roads and buildings, with no more than two houses impacted and less than six lives in jeopardy.*

3. Low Hazard Dam – *Failure is unlikely to result in loss of life and only minor inceases to existing flood levels at roads and buildings is expected.*

Based upon the analysis results presented in this report and in consultation with MDE Dam Safety representatives, it is recommended that the Bel Air Impoundment be classified as a Significant Hazard Dam. Failure of the proposed impoundment could result in loss of life by increasing risks to a few roads and buildings, including significant increases in flooding levels to one residential house (Structure 12).

6.0 References

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U.S. Geological Survey (2015). PeakFQ Version 7.1. Retrieved from USGS website (http://water.usgs.gov/software/PeakFQ).

Appendix A – Preliminary Design Drawings

MARYLAND AMERICAN WATER
HARFORD COUNTY, MARYLAND

BEL AIR RESERVOIR FEASIBILITY STUDY

PROPOSED SITE B RENDERING

Gannett Fleming	DATE: SEPT 2014	SCALE: AS SHOWN
	EXHIBIT 5	

S:\DIV-4\059267 - MAWC Reservoir Study\05 Working\CADD\Design Set\Sections.dwg
Plot Date: 9/23/2014 4:30 PM, Plotted By: Hoover, Chad T.

Appendix B – Hydrology

Appendix B-1 – Hydrology

Bel Air PMP

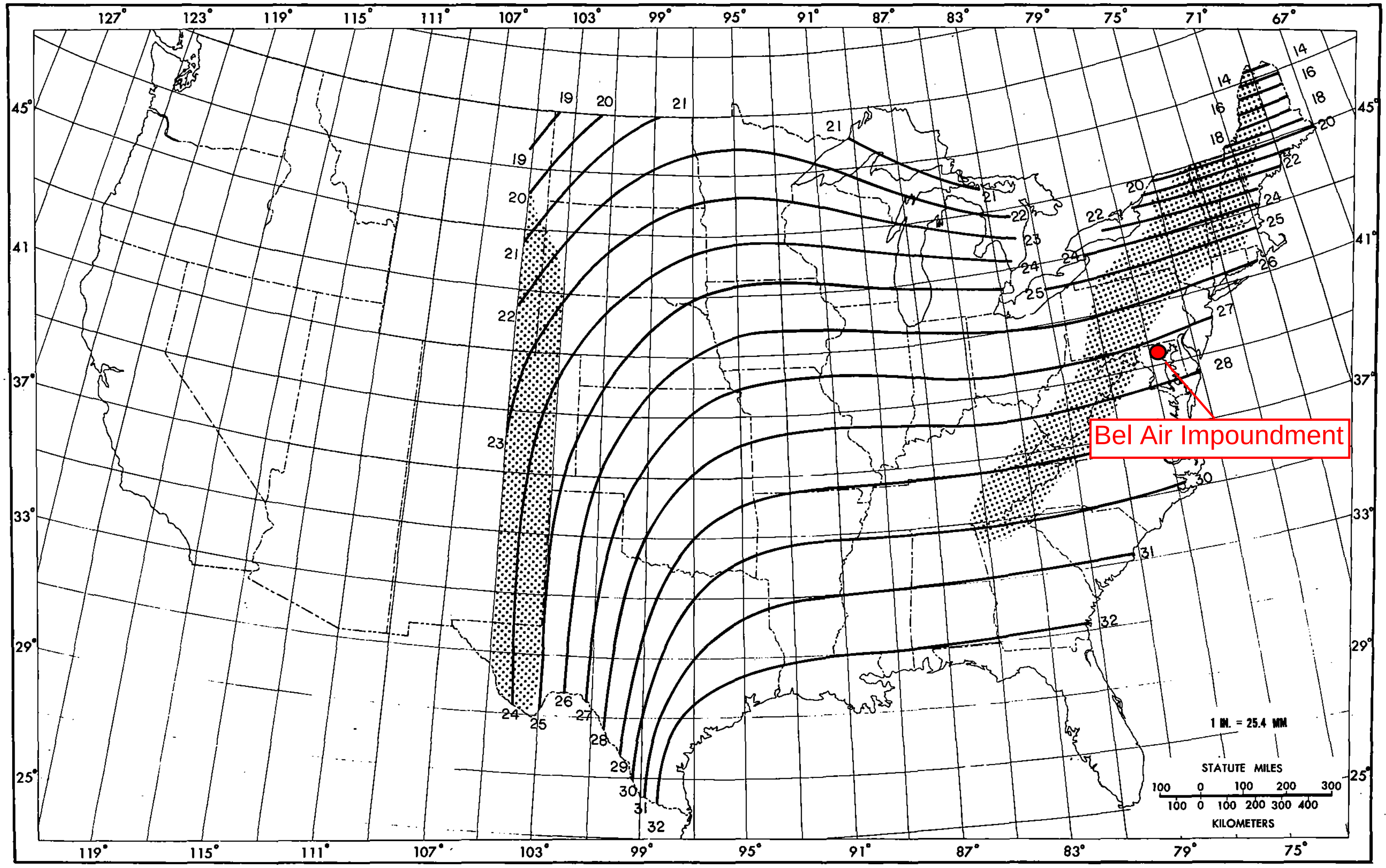

Figure 18.--All-season PMP (in.) for 6 hr 10 mi^2 (26 km^2).

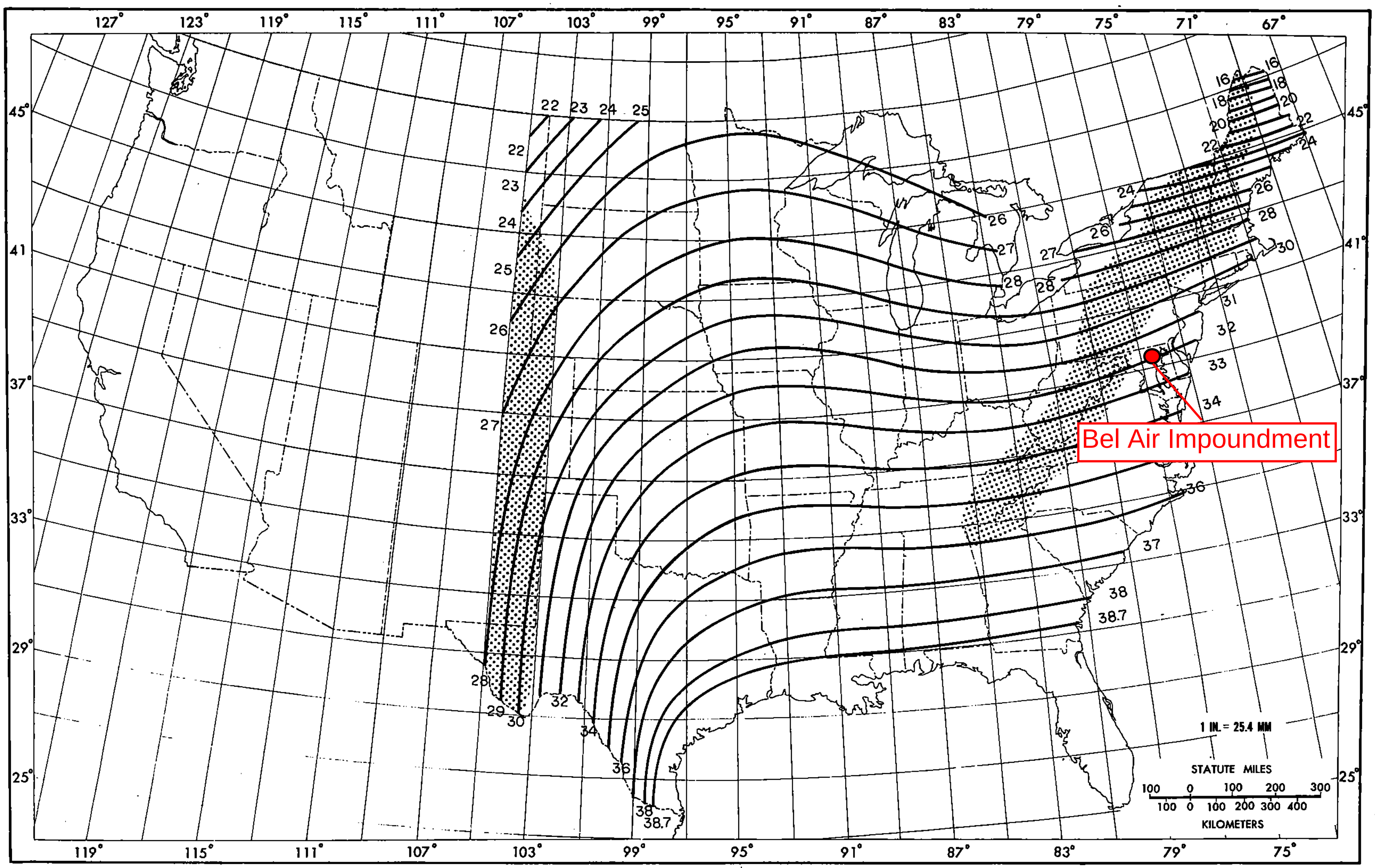

Figure 19.--All-season PMP (in.) for 12 hr 10 mi² (26 km²).

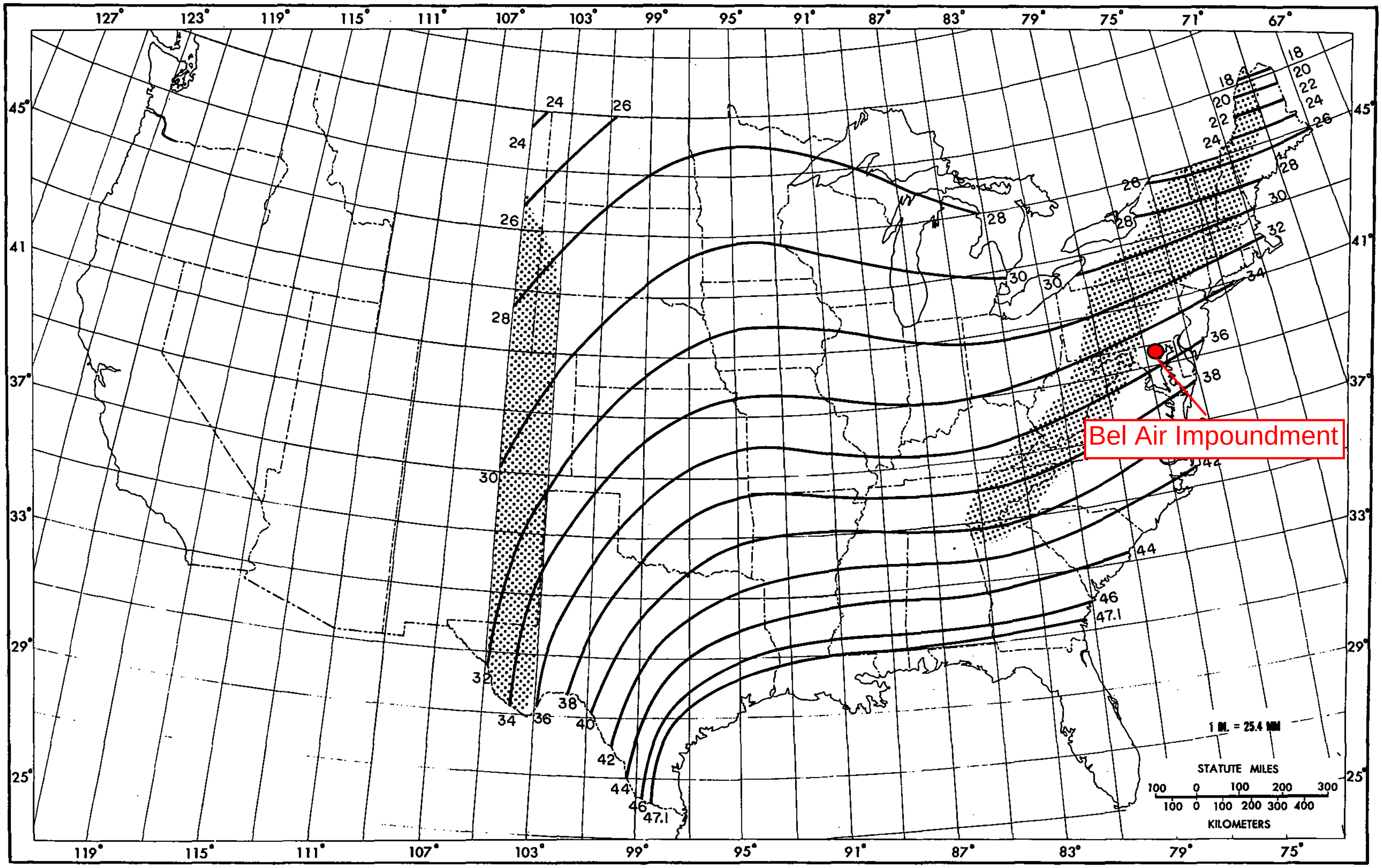

Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

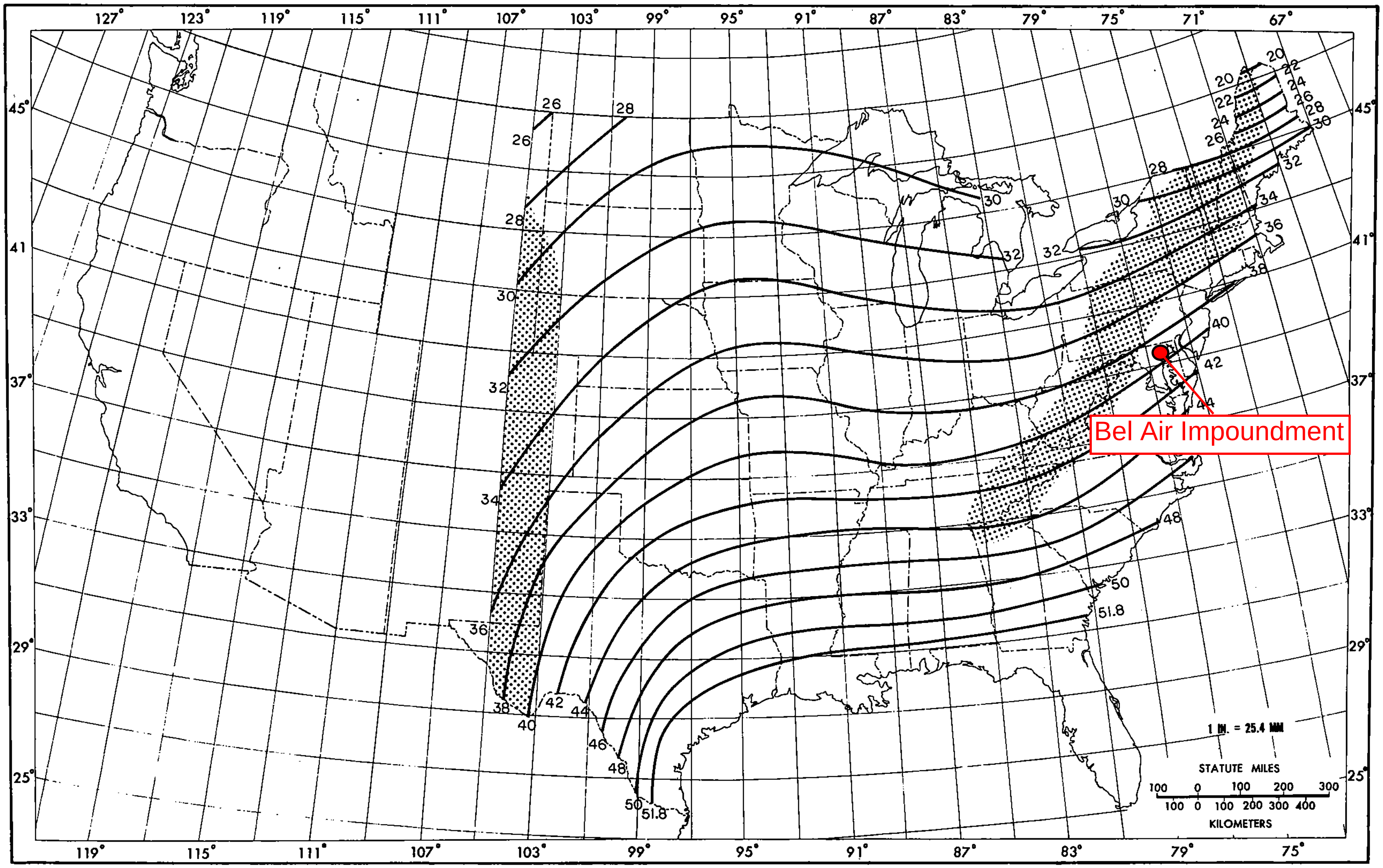

Figure 21.--All-season PMP (in.) for 48 hr 10 mi² (26 km²).

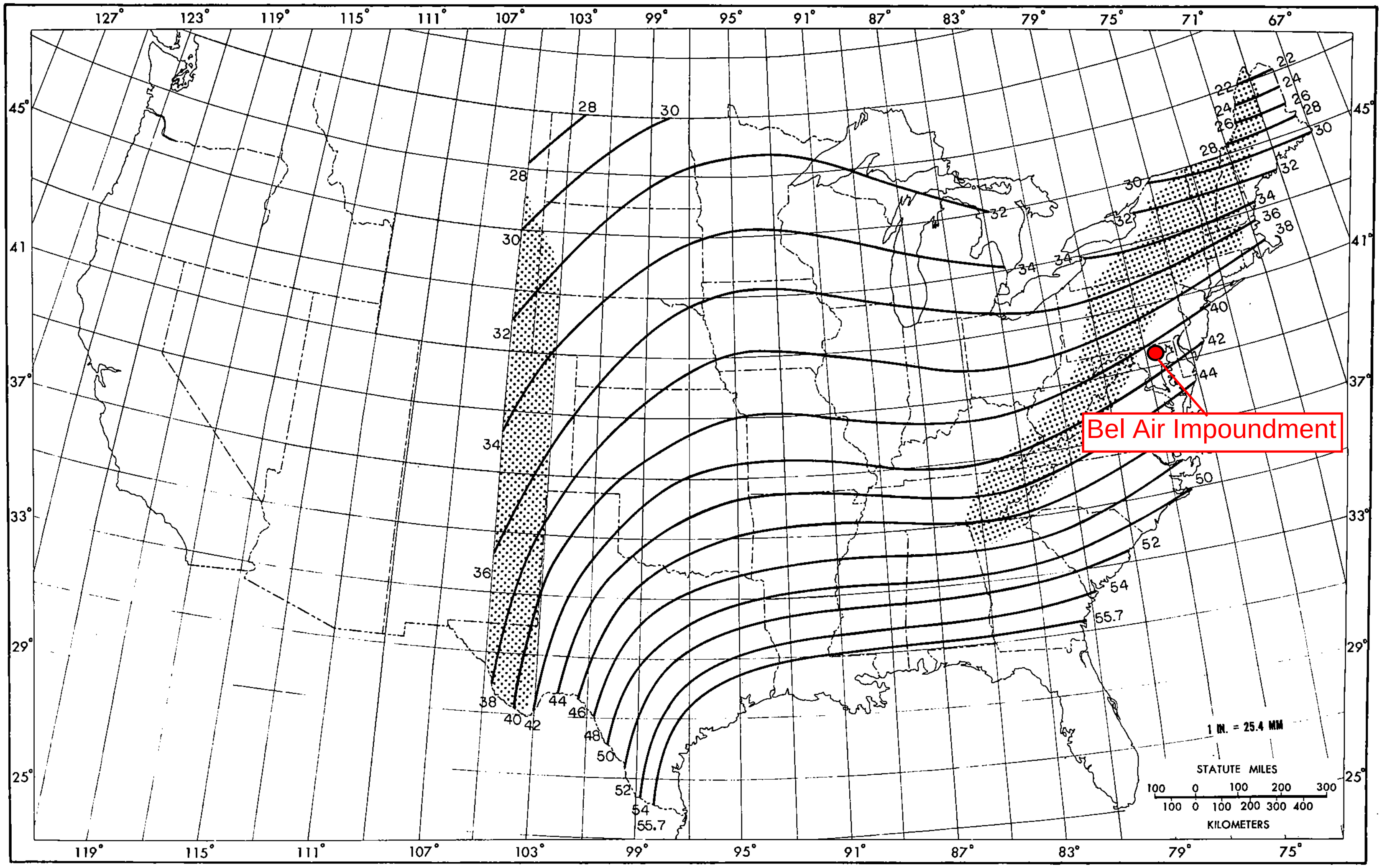

Figure 22.--All-season PMP (in.) for 72 hr 10 mi² (26 km²).

Appendix B-2 – Hydrology
PeakFQ Flood Frequency Analysis

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.000.000
  Ver. 5.2            Annual peak flow frequency analysis      Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines      10/27/2015 16:32

                         --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\USERS\GRICHARDS\DESKTOP\PEAK_BELAIR.INP

                         specifications - PKFQWPSF.TMP

                      Output file(s):
                         main - C:\USERS\GRICHARDS\DESKTOP\PEAK_BELAIR.PRT


1


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  Ver. 5.2            Annual peak flow frequency analysis      Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines      10/27/2015 16:32

                Station - 01581700  WINTERS RUN NEAR BENSON, MD


                     I N P U T   D A T A   S U M M A R Y

                Number of peaks in record            =       48
                Peaks not used in analysis           =        1
                Systematic peaks in analysis         =       47
                Historic peaks in analysis           =        0
                Years of historic record             =        0
                Generalized skew                     =    0.645
                     Standard error                  =    0.550
                     Mean Square error               =    0.303
                Skew option                          =   WEIGHTED
                Gage base discharge                  =      0.0
                User supplied high outlier threshold =   --
                User supplied low outlier criterion  =   --
                Plotting position parameter          =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********

  **WCF109W-PEAKS WITH MINUS-FLAGGED DISCHARGES WERE BYPASSED.       1
  **WCF113W-NUMBER OF SYSTEMATIC PEAKS HAS BEEN REDUCED TO NSYS =   47
    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                    0.0
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.             275.4
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.     20649.0
    WCF002J-CALCS COMPLETED.  RETURN CODE =  2
1
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Ver. 5.2	Annual peak flow frequency analysis	Run Date / Time
11/01/2007	following Bulletin 17-B Guidelines	10/27/2015 16:32

Station - 01581700 WINTERS RUN NEAR BENSON, MD

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.3774	0.3416	-0.512
BULL.17B ESTIMATE	0.0	1.0000	3.3774	0.3416	-0.133

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	285.1	216.2	252.0	175.4	407.4
0.9900	354.4	286.5	322.1	227.0	492.9
0.9500	635.2	589.3	607.9	451.0	825.6
0.9000	861.1	841.7	838.0	641.9	1086.0
0.8000	1237.0	1264.0	1220.0	969.1	1517.0
0.6667	1724.0	1802.0	1714.0	1398.0	2085.0
0.5000	2427.0	2549.0	2427.0	2004.0	2941.0
0.4292	2790.0	2922.0	2796.0	2310.0	3403.0
0.2000	4645.0	4678.0	4704.0	3785.0	5935.0
0.1000	6458.0	6199.0	6617.0	5131.0	8635.0
0.0400	9113.0	8154.0	9511.0	6998.0	12870.0
0.0200	11340.0	9602.0	12030.0	8498.0	16630.0
0.0100	13760.0	11020.0	14870.0	10080.0	20890.0
0.0050	16400.0	12420.0	18080.0	11760.0	25710.0
0.0020	20230.0	14220.0	22960.0	14130.0	32960.0

1

Program PeakFq	U. S. GEOLOGICAL SURVEY	Seq.001.003
Ver. 5.2	Annual peak flow frequency analysis	Run Date / Time
11/01/2007	following Bulletin 17-B Guidelines	10/27/2015 16:32

Station - 01581700 WINTERS RUN NEAR BENSON, MD

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1967	3350.0		1991	-800.0	G
1968	4300.0		1992	873.0	
1969	364.0		1993	1700.0	
1970	1880.0		1994	4910.0	
1971	5350.0		1995	2200.0	
1972	7600.0		1996	5930.0	
1973	1600.0		1997	2090.0	
1974	1440.0		1998	1520.0	

PEAK_BELAIR

1975	3750.0	1999	6340.0
1976	5190.0	2000	1940.0
1977	1760.0	2001	1110.0
1978	4950.0	2002	356.0
1979	5510.0	2003	2680.0
1980	2230.0	2004	2610.0
1981	632.0	2005	1280.0
1982	1230.0	2006	6740.0
1983	1480.0	2007	4950.0
1984	7280.0	2008	1060.0
1985	5230.0	2009	1160.0
1986	595.0	2010	4660.0
1987	5460.0	2011	5400.0
1988	2020.0	2012	2130.0
1989	4730.0	2013	2140.0
1990	2260.0	2014	1500.0

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq | U. S. GEOLOGICAL SURVEY | Seq.001.004
Ver. 5.2 | Annual peak flow frequency analysis | Run Date / Time
11/01/2007 | following Bulletin 17-B Guidelines | 10/27/2015 16:32

Station - 01581700 WINTERS RUN NEAR BENSON, MD

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1972	7600.0	0.0208	0.0208
1984	7280.0	0.0417	0.0417
2006	6740.0	0.0625	0.0625
1999	6340.0	0.0833	0.0833
1996	5930.0	0.1042	0.1042
1979	5510.0	0.1250	0.1250
1987	5460.0	0.1458	0.1458
2011	5400.0	0.1667	0.1667
1971	5350.0	0.1875	0.1875
1985	5230.0	0.2083	0.2083
1976	5190.0	0.2292	0.2292
1978	4950.0	0.2500	0.2500

PEAK_BELAIR

2007	4950.0	0.2708	0.2708
1994	4910.0	0.2917	0.2917
1989	4730.0	0.3125	0.3125
2010	4660.0	0.3333	0.3333
1968	4300.0	0.3542	0.3542
1975	3750.0	0.3750	0.3750
1967	3350.0	0.3958	0.3958
2003	2680.0	0.4167	0.4167
2004	2610.0	0.4375	0.4375
1990	2260.0	0.4583	0.4583
1980	2230.0	0.4792	0.4792
1995	2200.0	0.5000	0.5000
2013	2140.0	0.5208	0.5208
2012	2130.0	0.5417	0.5417
1997	2090.0	0.5625	0.5625
1988	2020.0	0.5833	0.5833
2000	1940.0	0.6042	0.6042
1970	1880.0	0.6250	0.6250
1977	1760.0	0.6458	0.6458
1993	1700.0	0.6667	0.6667
1973	1600.0	0.6875	0.6875
1998	1520.0	0.7083	0.7083
2014	1500.0	0.7292	0.7292
1983	1480.0	0.7500	0.7500
1974	1440.0	0.7708	0.7708
2005	1280.0	0.7917	0.7917
1982	1230.0	0.8125	0.8125
2009	1160.0	0.8333	0.8333
2001	1110.0	0.8542	0.8542
2008	1060.0	0.8750	0.8750
1992	873.0	0.8958	0.8958
1981	632.0	0.9167	0.9167
1986	595.0	0.9375	0.9375
1969	364.0	0.9583	0.9583
2002	356.0	0.9792	0.9792
1991	-800.0	--	--

1

```
 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      48
```

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4, or *.)
(2, 4, and * records are ignored.)

For the station below, the following records were ignored:

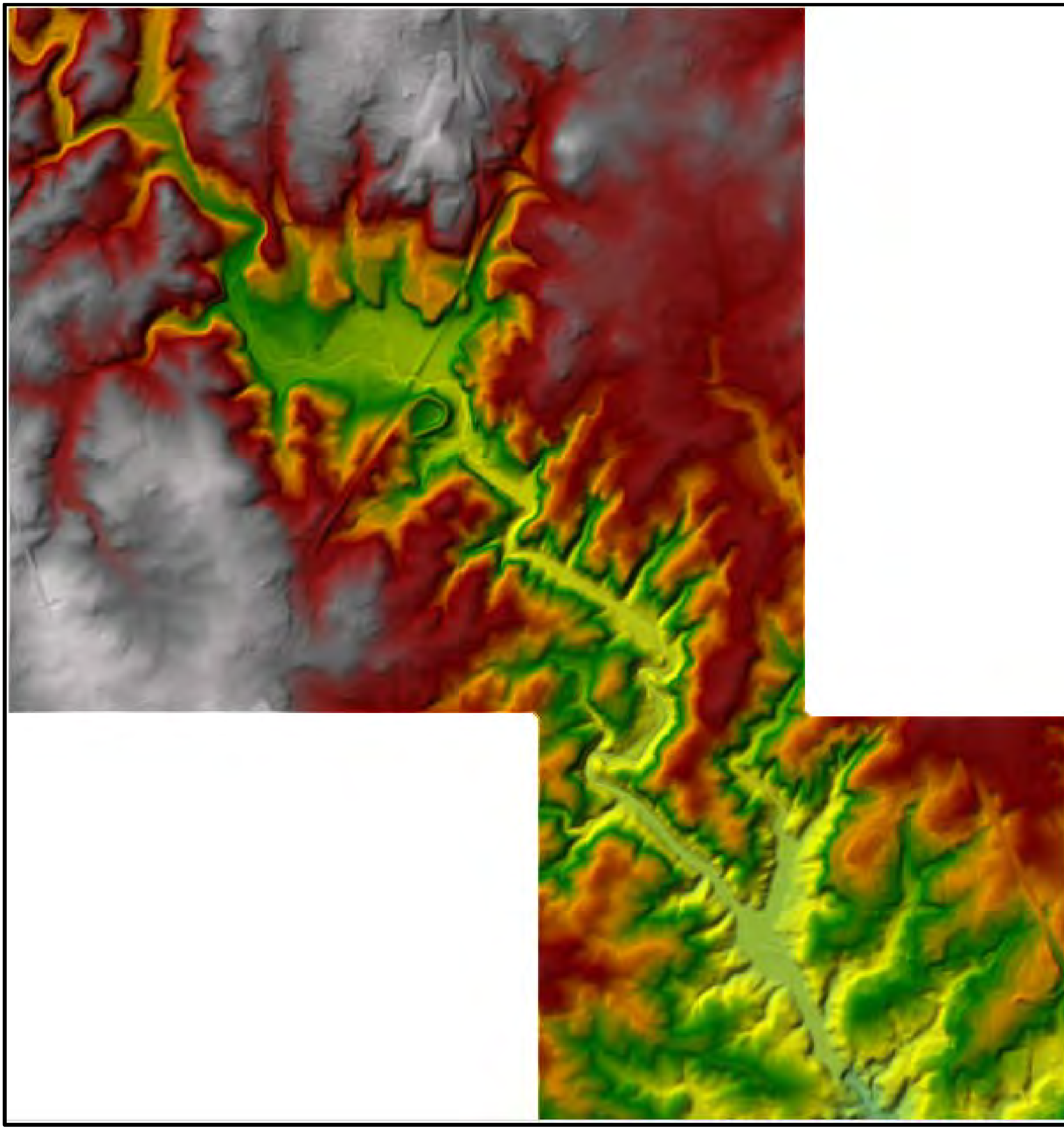
FINISHED PROCESSING STATION: 01581700   USGS WINTERS RUN NEAR BENSON, MD

For the station below, the following records were ignored:

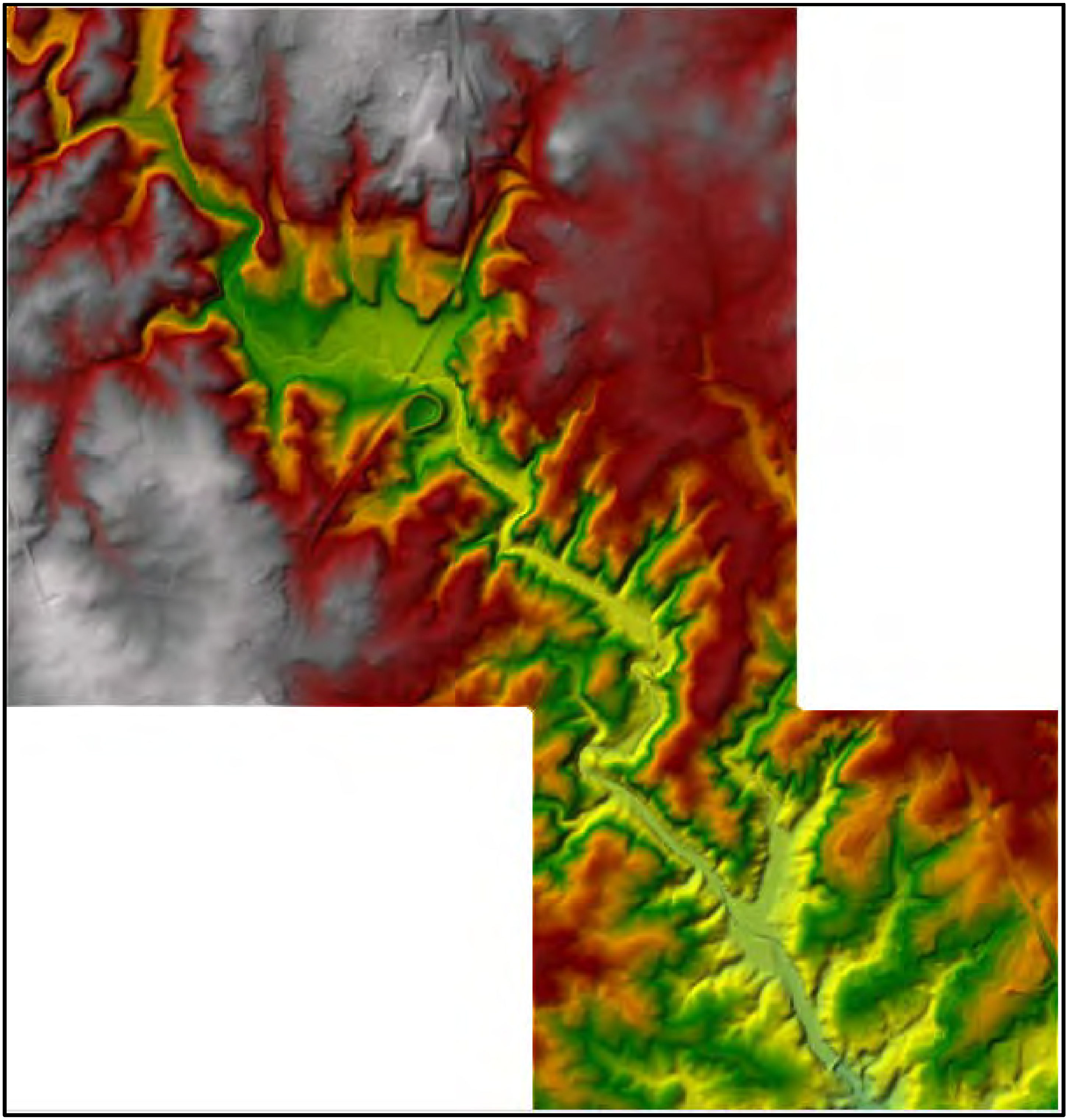
FINISHED PROCESSING STATION:

Appendix C – Hydraulics

Appendix C-1 – Preprocessing of LiDAR Terrain

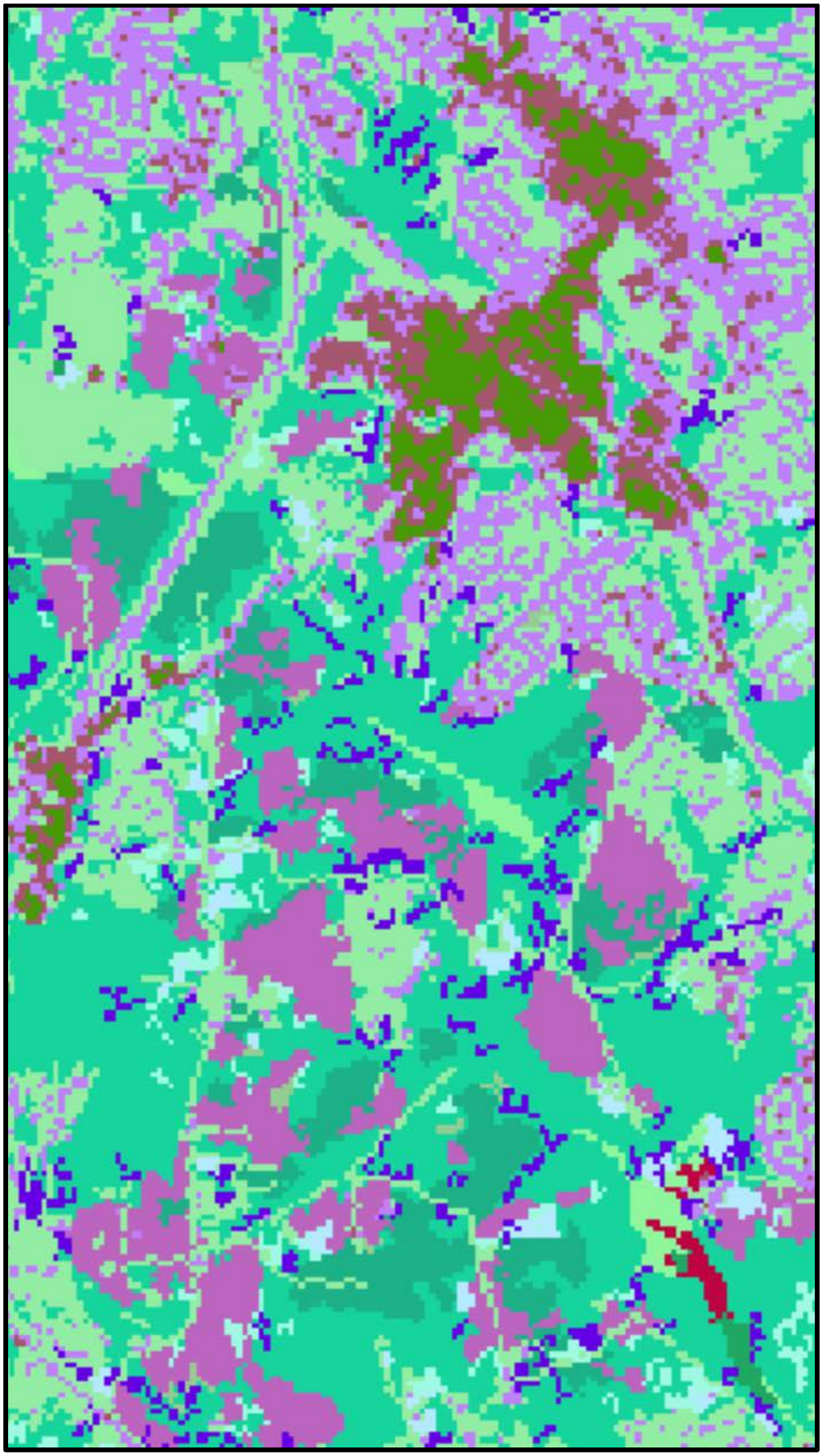


Original 4X4 LiDAR Data

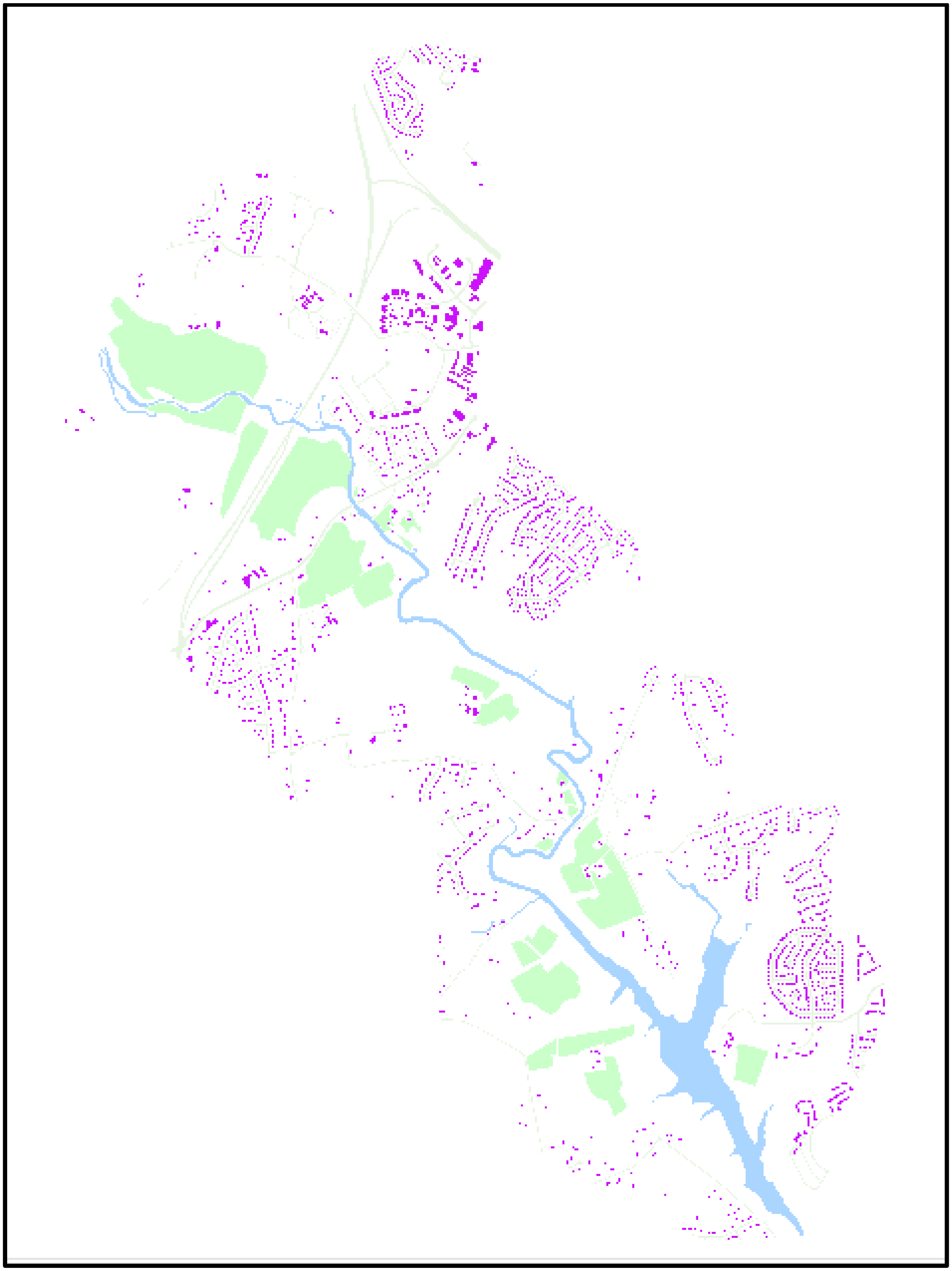


Channel Modified 4X4 LiDAR Data

Appendix C-2 – Manning’s Roughness Coefficients Definition



Base Roughness Layer NLCD



Detailed Roughness Layer Orthoimagery

Appendix C-3 – Dam Breach Parameter Estimation

Embankment:	Bel Air Dam	By:	YW	Date:	10/26/2015
Breach Scenario:	Top of Dam Failure Event	Checked:	GLR	Date:	11/20/2015

Input:

Height of dam (structural) =	50.00	ft	Water surface elev. @ failure=	259.00	ft
Height of water above breach =	50.00	ft	Top of dam elev.=	259.00	ft
Storage =	318.2	AF	Auxiliary spillway crest elev.=	259.00	ft
			Breach invert elev.=	209.00	ft

USACE (1980)

Width of bottom breach =	25	to	150	ft
Time of breach formation =	0.5	to	4	hrs
Side slope =	1	H:1V		

FERC (1987)

Width of bottom breach =	100	to	200	ft	
Time of breach formation =	0.1	to	1	hrs	For Engineered, Compacted Dam
Side slope =	0.25	to	1	H:1V	For Engineered, Compacted Dam

Von Thun and Gillette (1990)

Average Breach Width =	145	ft		
Time of breach formation =	0.555	or	0.725	hrs (erosion resistant)
Time of breach formation =	0.229	or	0.362	hrs (easily eroded)
Side slope =	0.33	to	1.00	H:1V (for cohesive shell material)
Side slope =	1	H:1V (for non-cohesive shell material)		

Reservoir Size	B
<1000 AF	20
1000 to 5000 AF	60
5000 to 10000 AF	140
>10000 AF	180

B = 20

MacDonald (1984)

Select case:	Earthfill				
Average Breach Width =	19.03	ft	Embankment top width=	20	ft
Time of breach formation =	0.37	hrs	Upstream slope=	2.5	H:1V
Side slope =	0.50	H:1V	Downstream slope=	3	H:1V

Froehlich (1995)

Select case:	Piping		ko =	1	
Average Breach Width =	61.20	ft	Vw =	0.392	million m^3
Time of breach formation =	0.202	hrs			
Side slope =	0.9	H:1V			

Froehlich (2008)

Select case:	Piping		ko =	1.0	
Average Breach Width =	60.91	ft	Vw =	0.392	million m^3
Time of breach formation =	0.230	hrs			
Side slope =	0.7	H:1V			

Selected Parameters

Width of bottom breach =	**100**	**ft**
Time of breach formation =	**0.25**	**hrs**
Side slope =	**0.9**	**H:1V**

BREACH PREDICTOR EQUATIONS

Recently some statistically derived predictors for average breach width (b) and time of failure (T_f) have been developed by MacDonald and Langridge-Monopolis (1984) and Froelich (1987, 1995). From Froelich's work in which he used the properties of 63 breaches of dams ranging in height from 12 to 285 feet, with 6 dams greater than 100 feet, the following predictor equations were obtained:

$$T_f = 0.59(V_s^{0.47})/(H^{0.91})$$

$$b = 9.5K_o(V_sH)^{0.25}$$

where,

b = average breach width (ft),
T_f = time of failure (hrs), only includes vertical erosion of dam
K_o = 0.7 for piping and 1.0 for overtopping failure
Vs = storage volume (ac-ft), and
H = height (ft) of water over breach bottom `

BREACH WIDTH & TIME OF FAILURE FOR

Your Small Dam

INPUT VARIABLES:			OUTPUT PARAMETERS:		
H =	50.00	ft	b =	74.7	ft
Vs =	318.2	ac-ft	T_f =	0.25	hrs
Ko =	0.7				

DEVELOPED BY BRUCE HARRINGTON, 9/92, REVISED 10/96

NWS SIMPLE DAM BREAK EQUATION:

Your Small Dam

$$Q_b = Q_o + 3.1B_r(C/(T_f + C/\sqrt{H}))^3$$

WHERE,

Q_b = BREACH FLOW + NON-BREACH FLOW (cfs)
Qo = NON-BREACH FLOW (cfs)
Br = FINAL AVERAGE BREACH WIDTH (ft, APPROX. 1H TO 5H)
C = 23.4*As/Br
As = RESERVOIR SURFACE AREA (ac) AT MAXIMUM POOL LEVEL
H = SELECTED FAILURE DEPTH (ft) ABOVE FINAL BREACH ELEVATION
T_f = TIME TO FAILURE (hrs, USE H/120 OR A MINIMUM OF 10 MIN)

INPUT VARIABLES:

Qo =	**0**	**cfs**
As =	**12.77**	**ac**
H =	**50.0**	**ft**

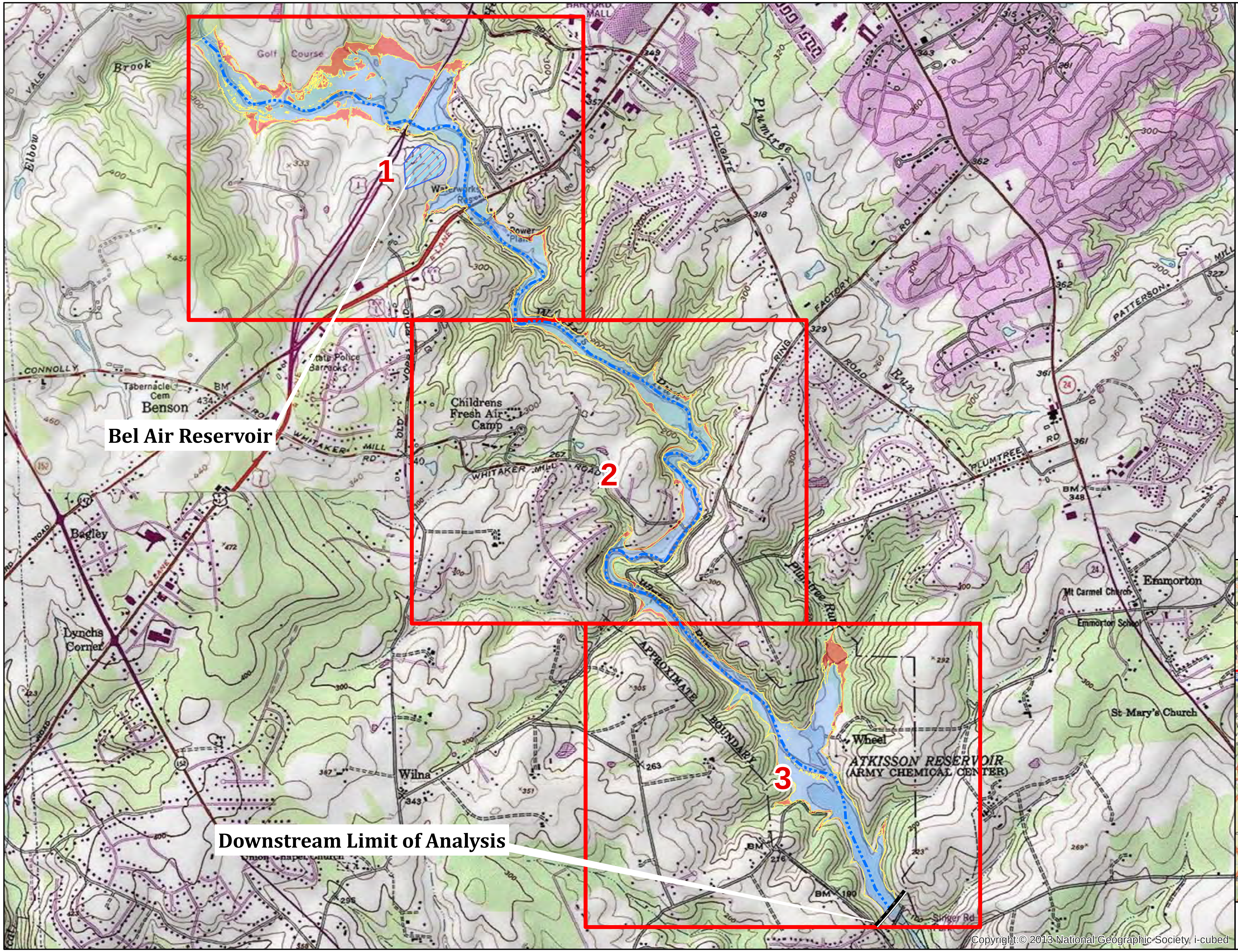
Note: Must enter Data on Brwidth Worksheet as well

OUTPUT VARIABLES:

SELECTED BREACH WIDTHS Br, [ft]		TIME OF FAILURE T_f, [hrs]	COMPUTED C VALUE	MAXIMUM BREACH FLOW Q_b, [cfs]	
50.0	[H]	0.42	5.98	**16467**	
75.0	[1.5H]	0.42	3.98	**15618**	
100.0	[2H]	0.42	2.99	**13992**	
125.0	[2.5H]	0.42	2.39	**12313**	
150.0	[3H]	0.42	1.99	**10792**	
175.0	[3.5H]	0.42	1.71	**9474**	
200.0	[4.0H]	0.42	1.49	**8351**	
250.0	[5.0H]	0.42	1.20	**6587**	<SELECTED FLOW
74.7	Froelich Eq	0.25	4.00	**27129**	
74.7	Froelich Eq	0.42	----	**15291**	= Volume / Failure time

DEVELOPED BY BRUCE HARRINGTON, 9/92, REVISED 10/96

Appendix D – Flood Inundation Mapping



Bel Air Impoundment

Dam Break Inundation Mapping

MAP INDEX PANEL

LEGEND:

- Stream Centerline
- County Boundary
- 100-Year Breach Inundation
- Sunny Day Breach Inundation
- Bel Air Reservoir

Scale (Miles)

0 0.2 0.4 0.8

SOURCE DATA: MICROSOFT BING IMAGERY;
INUNDATION AREAS, ELEVATIONS REFERENCED TO NAVD 1988.

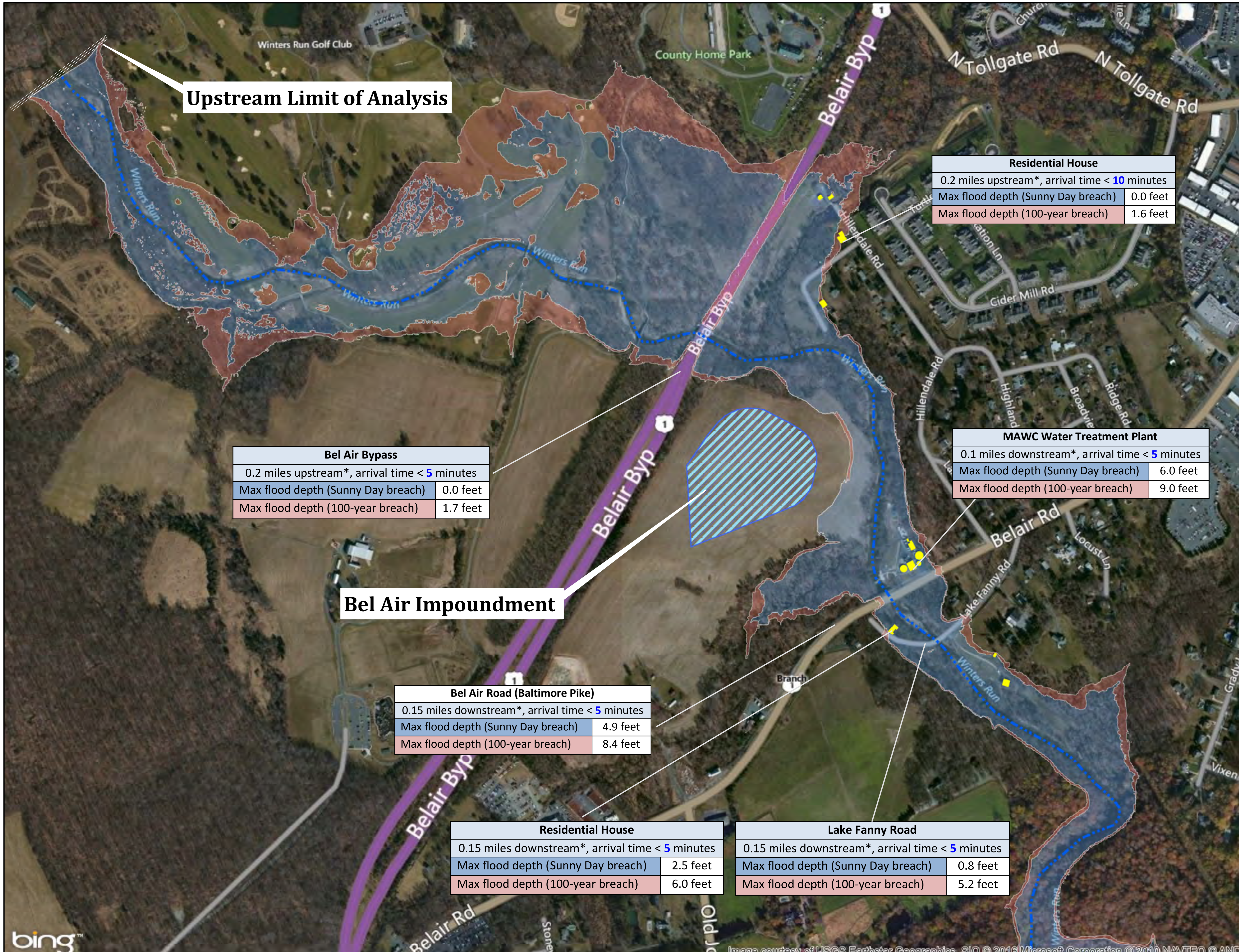
FLOODING LIMITS WERE DETERMINED USING THE HEC-RAS COMPUTER MODEL FOR VARIOUS DAM FAILURE SCENARIOS. THE FAILURE OF A DAM IS A COMPLEX HYDRAULIC OCCURRENCE WHICH CAN RESULT IN UNEXPECTEDLY HIGH DEPTHS OF FLOW. DEBRIS AND THE EFFECT OF ENCROACHMENTS CAN RAISE THE WATER SURFACE SIGNIFICANTLY. THESE LOCAL EFFECTS WERE NOT MODELED IN DETAIL WHEN COMPUTING THE FLOODED AREAS SHOWN ON THE INUNDATION MAPS.

BECAUSE OF THE LIMITATIONS OF THE METHODS AND PROCEDURES USED TO DEVELOP THE FLOODED AREAS, THE USER OF THIS MAP IS ADVISED THAT THE LIMITS OF FLOODING SHOWN ARE APPROXIMATE AND SHOULD BE USED SOLELY AS GUIDELINES FOR THE ESTABLISHMENT OF EVACUATION ZONES.

THE INFORMATION CONTAINED IN THIS MAP IS PREPARED FOR USE IN NOTIFICATION OF DOWNSTREAM PROPERTY OWNERS BY EMERGENCY MANAGEMENT PERSONNEL.

BEL AIR LOCATION MAP:

February 2016 Gannett Fleming



Bel Air Impoundment

Dam Break Inundation Mapping

PANEL 1 OF 3

LEGEND:

- Stream Centerline
- Single Structure
- 100-Year Breach Inundation
- Sunny Day Breach Inundation
- Bel Air Reservoir

* Distance Measured from the Dam

Scale (Miles): 0 — 0.05 — 0.1 — 0.2

SOURCE DATA: MICROSOFT BING IMAGERY;
INUNDATION AREAS, ELEVATIONS REFERENCED TO NAVD 1988.

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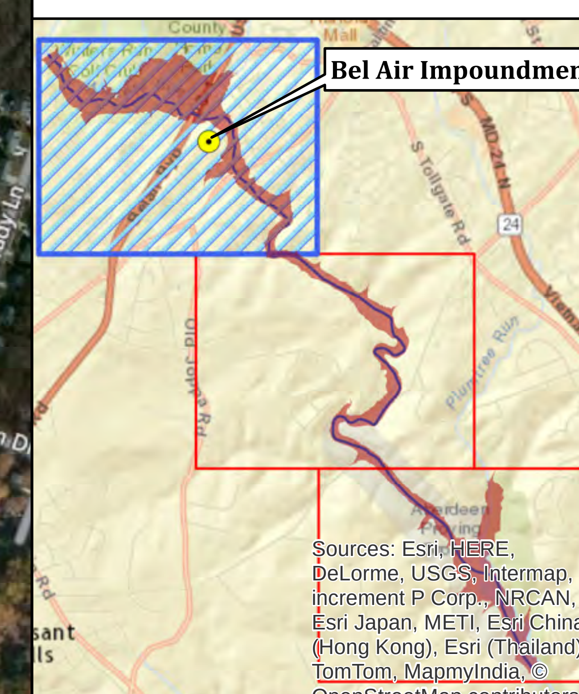
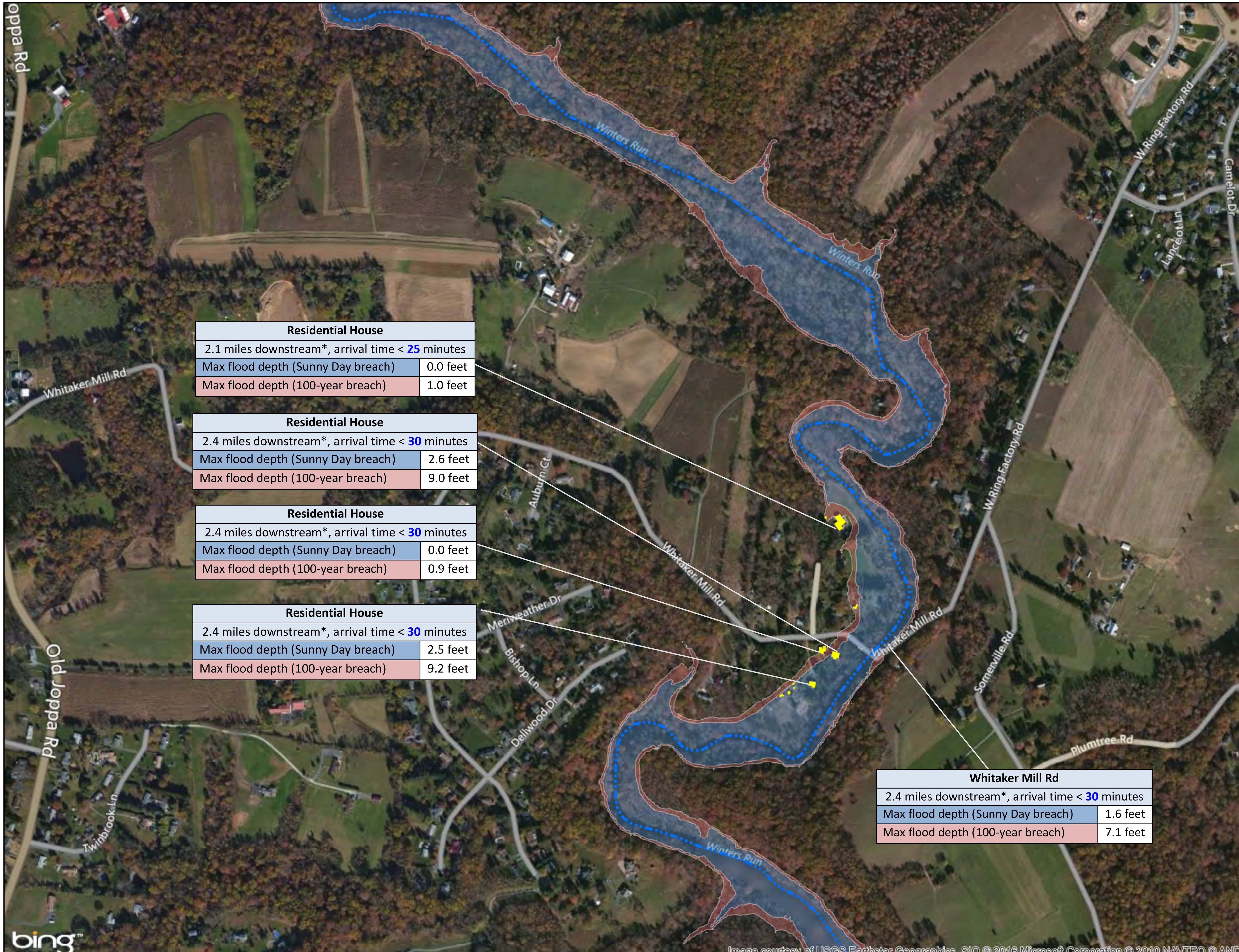
INDEX MAP:



February 2016 Gannett Fleming



Residential House	
2.1 miles downstream*, arrival time < 25 minutes	
Max flood depth (Sunny Day breach)	0.0 feet
Max flood depth (100-year breach)	1.0 feet

Residential House	
2.4 miles downstream*, arrival time < 30 minutes	
Max flood depth (Sunny Day breach)	2.6 feet
Max flood depth (100-year breach)	9.0 feet

Residential House	
2.4 miles downstream*, arrival time < 30 minutes	
Max flood depth (Sunny Day breach)	0.0 feet
Max flood depth (100-year breach)	0.9 feet

Residential House	
2.4 miles downstream*, arrival time < 30 minutes	
Max flood depth (Sunny Day breach)	2.5 feet
Max flood depth (100-year breach)	9.2 feet

Whitaker Mill Rd	
2.4 miles downstream*, arrival time < 30 minutes	
Max flood depth (Sunny Day breach)	1.6 feet
Max flood depth (100-year breach)	7.1 feet

Bel Air Impoundment

Dam Break Inundation Mapping

PANEL 2 OF 3

LEGEND:

- Stream Centerline
- Single Structure
- 100-Year Breach Inundation
- Sunny Day Breach Inundation
- Bel Air Reservoir

* Distance Measured from the Dam

N

Scale (Miles)
0 0.05 0.1 0.2

SOURCE DATA: MICROSOFT BING IMAGERY;
INUNDATION AREAS, ELEVATIONS REFERENCED TO NAVD 1988.

FLOODING LIMITS WERE DETERMINED USING THE HEC-RAS COMPUTER MODEL FOR VARIOUS DAM FAILURE SCENARIOS. THE FAILURE OF A DAM IS A COMPLEX HYDRAULIC OCCURRENCE WHICH CAN RESULT IN UNEXPECTEDLY HIGH DEPTHS OF FLOW. DEBRIS AND THE EFFECT OF ENCROACHMENTS CAN RAISE THE WATER SURFACE SIGNIFICANTLY. THESE LOCAL EFFECTS WERE NOT MODELED IN DETAIL WHEN COMPUTING THE FLOODED AREAS SHOWN ON THE INUNDATION MAPS.

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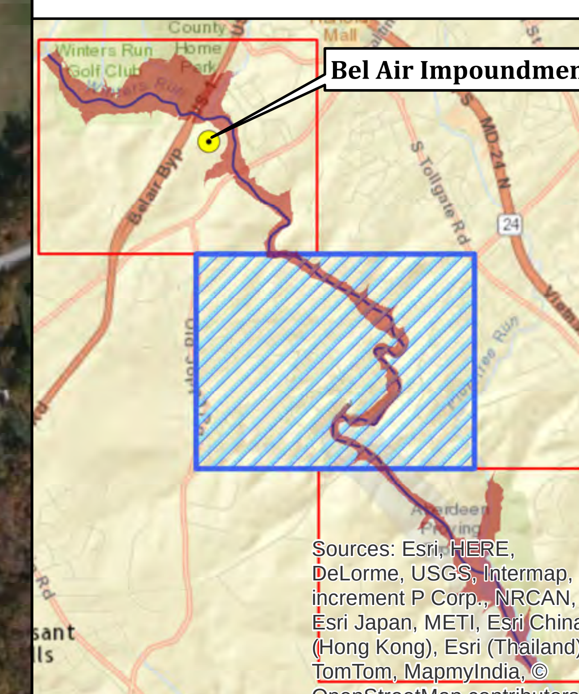
THE INFORMATION CONTAINED IN THIS MAP IS PREPARED FOR USE IN NOTIFICATION OF DOWNSTREAM PROPERTY OWNERS BY EMERGENCY MANAGEMENT PERSONNEL.

INDEX MAP:



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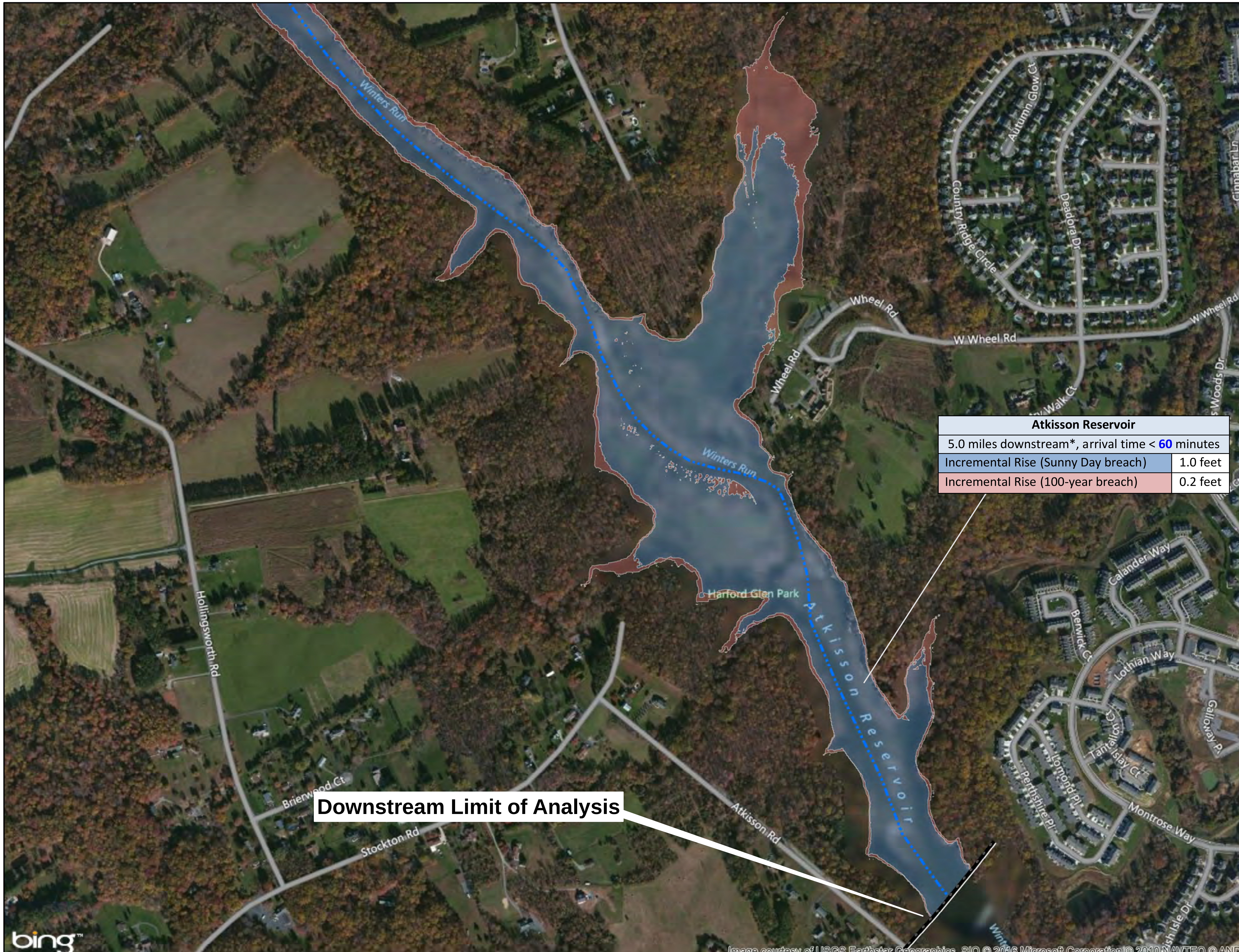
Bel Air Impoundment

Dam Break Inundation Mapping

PANEL 3 OF 3



Atkisson Reservoir	
5.0 miles downstream*, arrival time < 60 minutes	
Incremental Rise (Sunny Day breach)	1.0 feet
Incremental Rise (100-year breach)	0.2 feet

LEGEND:

- Stream Centerline
- Single Structure
- 100-Year Breach Inundation
- Sunny Day Breach Inundation
- Bel Air Reservoir

* Distance Measured from the Dam

Scale (Miles): 0, 0.05, 0.1, 0.2

SOURCE DATA: MICROSOFT BING IMAGERY;
INUNDATION AREAS, ELEVATIONS REFERENCED TO NAVD 1988.

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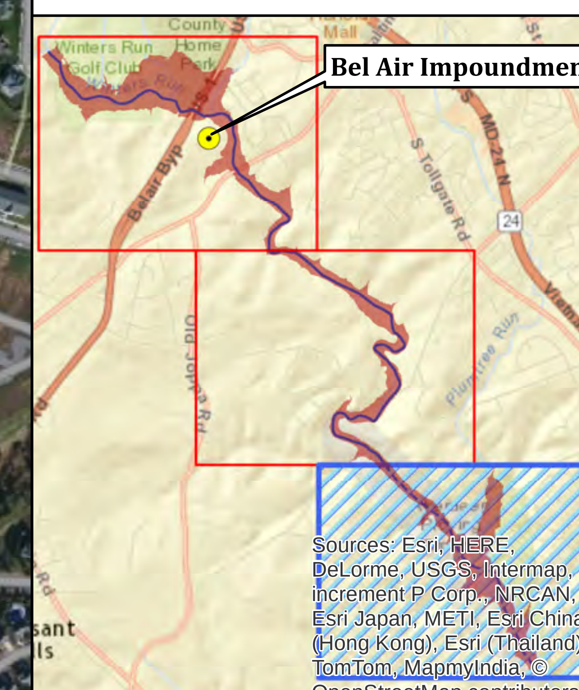
INDEX MAP:



February 2016

Gannett Fleming

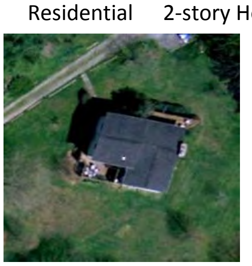
Appendix E – Consequence Analysis

Appendix E-1 – Consequence Analysis for Structures

Structures					Sunny Day (2-yr)		PMF (100-yr)	
No.	Type	Description	Photo	Scenario	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)
1	Commercial	Storage Shed 		Breach 2	2.005	1.352	5.564	1.238
				Breach 1	0.000	0.000	2.895	1.505
				Non-Breach	0.000	0.000	1.066	0.012
2	Commercial	Storage Shed 		Breach 2	0.992	1.505	4.567	1.796
				Breach 1	0.000	0.000	1.897	1.095
				Non-Breach	0.000	0.000	0.066	0.002
3	Residential	1-story House 		Breach 2	0.000	0.000	1.622	0.168
				Breach 1	0.000	0.000	0.000	0.000
				Non-Breach	0.000	0.000	0.000	0.000
4	Residential	Garage 		Breach 2	0.000	0.000	1.959	0.367
				Breach 1	0.000	0.000	0.000	0.000
				Non-Breach	0.000	0.000	0.000	0.000

Structures					Sunny Day (2-yr)		PMF (100-yr)	
No.	Type	Description	Photo	Scenario	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)
5	Commercial	MAWC Storage 		Breach 2	3.131	1.647	6.707	3.129
				Breach 1	5.963	4.306	9.025	5.022
				Non-Breach	0.000	0.000	3.310	2.954
6	Commercial	MAWC Storage 		Breach 2	2.422	1.480	5.997	3.065
				Breach 1	5.209	4.085	8.294	4.807
				Non-Breach	0.000	0.000	2.606	3.049
7	Commercial	MAWC 		Breach 2	2.194	1.782	5.773	2.948
				Breach 1	4.921	4.448	8.062	5.158
				Non-Breach	0.000	0.000	2.380	2.722
8	Commercial	MAWC 		Breach 2	1.719	1.640	5.293	2.601
				Breach 1	4.353	3.587	7.531	4.473
				Non-Breach	0.000	0.000	1.910	2.022
9	Commercial	MAWC 		Breach 2	1.963	2.213	5.539	3.587
				Breach 1	4.517	4.406	7.757	5.431
				Non-Breach	0.000	0.000	2.200	2.095
10	Commercial	MAWC 		Breach 2	2.170	2.390	5.744	4.018
				Breach 1	4.716	4.806	7.951	5.947
				Non-Breach	0.000	0.000	2.382	1.790

11 Commercial MAWC 		Breach 2	2.128	3.282	5.803	4.743
		Breach 1	4.655	5.879	7.956	6.734
		Non-Breach	0.000	0.000	2.429	2.043
12 Residential 2-story House 		Breach 2	0.107	0.127	3.744	2.179
		Breach 1	2.487	2.057	6.006	2.941
		Non-Breach	0.000	0.000	0.576	0.577
13 Residential Shed 		Breach 2	0.000	0.000	2.632	0.237
		Breach 1	0.373	0.160	4.692	0.449
		Non-Breach	0.000	0.000	0.000	0.000
14 Residential Abandoned 		Breach 2	1.109	2.335	6.313	4.547
		Breach 1	3.562	4.481	8.298	5.545
		Non-Breach	0.000	0.000	3.611	3.235

Structures					Sunny Day (2-yr)		PMF (100-yr)	
No.	Type	Description	Photo	Scenario	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)
15	Residential	Shed 						
				Breach 2	0.000	0.000	0.006	0.026
				Breach 1	0.000	0.000	0.159	0.054
				Non-Breach	0.000	0.000	0.000	0.000
16	Residential	1-story House						
				Breach 2	0.000	0.000	0.883	0.488
				Breach 1	0.000	0.000	1.019	0.570
				Non-Breach	0.000	0.000	0.000	0.000
17	Residential	2-story House 						
				Breach 2	1.999	1.044	8.961	3.219
				Breach 1	2.578	1.243	9.026	3.251
				Non-Breach	0.000	0.000	6.652	3.220
18	Residential	2-story House 						
				Breach 2	0.000	0.000	0.803	0.954
				Breach 1	0.000	0.000	0.865	0.977
				Non-Breach	0.000	0.000	0.000	0.000
19	Residential	2-story House 						
				Breach 2	1.904	2.081	9.139	3.531
				Breach 1	2.482	2.344	9.200	3.623
				Non-Breach	0.000	0.000	6.637	3.090
20	Residential	Shed 						
				Breach 2	0.707	0.375	8.124	2.033
				Breach 1	1.321	0.556	8.184	2.038
				Non-Breach	0.000	0.000	5.532	1.941

21 Residential Shed 		Breach 2	3.107	1.036	10.534	2.589
		Breach 1	3.718	1.217	10.594	2.589
		Non-Breach	0.000	0.000	7.921	2.607
22 Residential Shed 		Breach 2	2.745	1.381	10.196	2.719
		Breach 1	3.358	1.549	10.256	2.719
		Non-Breach	0.000	0.000	7.562	2.694
23 Residential Shed 		Breach 2	2.245	0.824	9.734	2.313
		Breach 1	2.862	0.956	9.794	2.313
		Non-Breach	0.000	0.000	7.067	2.333
24 Residential Shed 		Breach 2	0.000	0.000	0.608	0.950
		Breach 1	0.000	0.000	0.681	1.026
		Non-Breach	0.000	0.000	0.000	0.000

Appendix E-2 – Consequence Analysis for Stream Crossings

Roads				Sunny Day (2-yr)		PMF (100-yr)	
No.	Name	Photo	Scenario	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)
1	Bel Air Bypass						
Road Ele	214						
River Bed	190		Breach 2	0.000	0.000	1.672	4.881
	24		Breach 1	0.000	0.000	1.481	4.318
	feet		Non-Breach	0.000	0.000	0.000	0.000
2	Bel Air Rd Baltimore Pike						
Road Ele	197						
River Bed	180		Breach 2	2.249	7.515	6.163	7.531
	17		Breach 1	4.911	8.588	8.402	8.606
	feet		Non-Breach	0.000	0.000	3.047	3.985
3	Lake Fanny Rd						
Road Ele	196						
River Bed	174		Breach 2	0.000	0.000	2.974	7.792
	22		Breach 1	0.809	6.886	5.218	8.504
	feet		Non-Breach	0.000	0.000	0.489	6.400
4	Whitaker Mill Rd						
Road Ele	155						
River Bed	138		Breach 2	1.273	5.249	7.002	7.057
	17		Breach 1	1.644	6.328	7.066	7.228
	feet		Non-Breach	0.000	0.000	4.954	5.539
5	W Ring Factory Rd						
Road Ele	145						
River Bed	129		Breach 2	0.000	0.000	3.658	6.190
	16		Breach 1	0.000	0.000	3.659	6.229
	feet		Non-Breach	0.000	0.000	2.039	3.037

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