



Lake Shenandoah Watershed Master Plan

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Submitted To:
Rockingham County Department of Public Works

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Executive Summary

In recent years, residents have contacted Rockingham County with complaints of localized flooding along Congers Creek, a major tributary to Lake Shenandoah. Timmons Group was retained by Rockingham County to determine and analyze alternative solutions for improving drainage and reducing flooding within the residential neighborhoods that border the headwaters of Congers Creek. Timmons Group modeled watershed hydrology and channel/culvert hydraulics to confirm areas of existing drainage problems and to determine anticipated future conditions associated with development within the upper watershed. Based on the results of this evaluation, various engineering and land-use alternatives were identified and presented within three strategies to improve drainage along Conger's Creek and throughout the greater watershed of Lake Shenandoah.

Timmons Group used TR-55 methodology and US Army Corps of Engineers HEC-HMS software to model watershed hydrology and determine peak flows for the 2, 5, 10, 25, and 100-year recurrence, 24-hour storm events for existing land use conditions and anticipated future land use conditions. Timmons Group subsequently conducted a topographic survey of Congers Creek and developed a HEC-RAS model to estimate peak water surface elevations for the 2, 5, 10, 25, and 100-year recurrence, 24-hour flood events. Model results suggest that anticipated land use will result in a modest increase in water surface elevations, with the greatest change in the vicinity of Baybrook Drive.

Timmons Group used the hydrologic and hydraulic models to evaluate two strategies to reduce flooding impacts within the Project Reach. The first strategy generally consists of increasing the conveyance capacity of road culverts and the channel to reduce water surface elevations and provide a level of flood protection that exceeds a 10-year storm event. The second strategy considers impacts of potential new stormwater best management practices (BMPs) and retrofits of existing BMPs to detain the 10-yr storm event and reduce water surface elevations. A third strategy, which was not evaluated within the modeling framework, consists of making changes to County policies and procedures for stormwater management that will affect future watershed land-use.

Estimated costs and impacts are presented for strategies to increase channel conveyance and improve stormwater management in the Congers Creek watershed. Model results suggest that a combination of four projects to increase channel conveyance could provide 10-yr flood protection to 15 homes at a cost of \$1.45 million, or \$96,667 per home benefited. Alternatively, model results suggest that four different potential BMP projects could provide 10-yr flood protection for up to three homes at an estimated cost ranging from \$86,667 to \$690,000 per home benefited.

Timmons Group evaluated the three strategies to reduce flooding impacts along Congers Creek and provided a set of recommendations to the County. Final recommendations are to 1) revise 100-year floodplain mapping along Congers Creek; 2) establish a flooding district requiring 25-year detention; 3) retrofit an existing detention basin along Kentshire Drive; 4) retrofit an existing detention basin within the Taylor Springs neighborhood; and 5) coordinate with VDOT to explore road crossing upgrades.

Introduction

Scope of Work

Timmons Group was retained by Rockingham County to determine and analyze alternative solutions for improving drainage and reducing flooding within the residential neighborhoods that border the headwaters of Congers Creek, a major tributary to Lake Shenandoah. The Project Reach (**Figure 1**) consists of approximately 5,600 linear feet of open channel and road culverts between Baybrook Drive and Lake Shenandoah. Timmons Group modeled watershed hydrology and channel/culvert hydraulics to confirm areas of existing drainage problems and determine anticipated future conditions associated with development within the upper watershed. Based on the results of this evaluation, various engineering and land-use alternatives were identified and presented within three strategies to improve drainage along Conger's Creek and throughout the greater watershed of Lake Shenandoah.

Project Background

In recent years, residents living along Congers Creek have contacted Rockingham County with complaints and concerns of localized flooding affecting their homes, properties, and neighborhood roadways. The County does not own or maintain drainage easements within the Project Reach, and all roads are considered secondary roadways and maintained by VDOT.

The built-out portions of the watershed consist of primarily residential single family homes. Most of the homes along Congers Creek that currently experience drainage issues are relatively new, built in the 2000's. Similarly, most of the roads appear to be new and in good condition. However, there is limited stormwater management within the watershed and recent storm events have created flooding problems for many of the residents (many of these homes have basements). Proposed developments within the upper watershed bring further concern to downstream residents.

The County has hired Timmons Group to assess the extent of current drainage issues and evaluate options for improving drainage and reducing flooding. The goal of this analysis is to better inform the County of the opportunities and constraints that exist for the Project Reach and its watershed.

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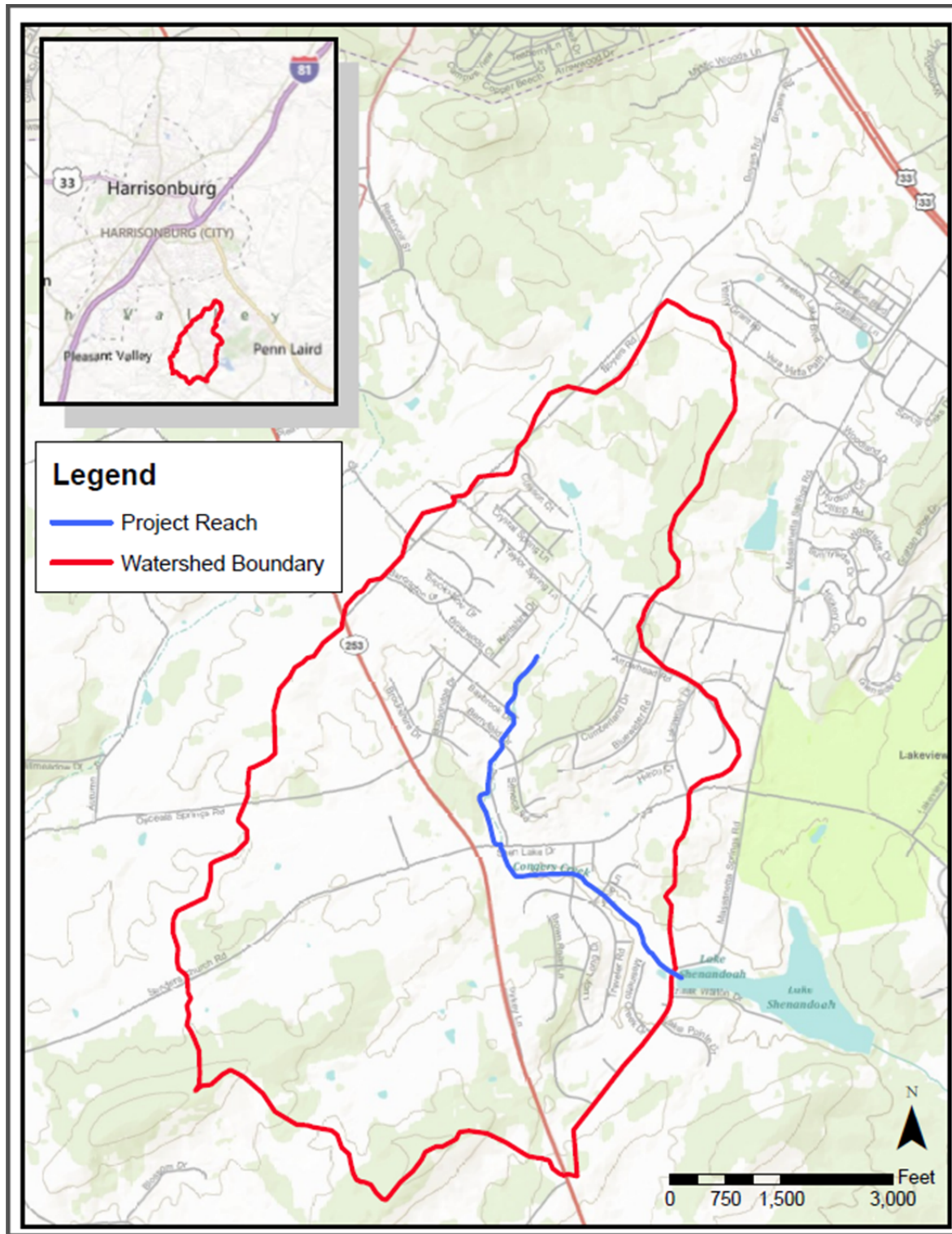


Figure I: Project Map

Existing Conditions Assessment

Timmons Group developed hydrologic and hydraulic models to determine existing flow capacities within the channel and culverts of the Project Reach for the 2, 10, 25, and 100-year recurrence flood events. Corresponding outputs for flood elevations were compared to elevations of adjacent homes and roadways to provide a baseline level of flooding and determine specific problem areas.

Hydrologic Assessment

Watershed Characteristics

The Project Reach lies within a 1.9 square-mile watershed that drains to the western arm of Lake Shenandoah (**Figure 1**). The watershed contains 95% type B soils based on the most recent NRCS soil survey data, and it has an average slope of 5-6%. Existing land use is divided within the watershed with mostly residential development to the east of Port Republic Road and pasture/agriculture to the west.

Methodology

Timmons Group used TR-55 methodology and US Army Corps of Engineers HEC-HMS software to model watershed hydrology and determine peak flows for the 2, 10, 25, and 100-year recurrence flood events. TR-55 methodology utilizes soil type, land cover type, and time of concentration parameters and is a widely used method for determining peak flows in large watersheds.

The watershed boundary was delineated using County-provided 5-foot contours and verified in the field, where accessible by vehicle. Sub-watersheds were delineated for each culvert and/or road crossing to more accurately evaluate the capacity of the drainage network. **Figure 2** shows the watershed and sub-watershed boundaries and drainage areas (DA).

Precipitation data was obtained from the NOAA Atlas 14 Rainfall Data for Rockingham County. The following rainfall amounts for a 24-hour storm were used in the model:

2-Year	2.73 inches
5-Year	3.43 inches
10-Year	4.03 inches
25-Year	4.91 inches
100-Year	6.49 inches

The curve numbers used in our study were based on the Runoff Curve Number tables provided in the NRCS TR-55 manual using a combination of the most recent NRCS soil survey data depicting hydrologic soil groups (A, B, C, and D) and the land use classifications. Weighted curve numbers for sub-watersheds generally ranged between 64-85 for existing conditions.

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There are no large stormwater detention facilities within the watershed. Although a few smaller facilities exist within the watershed, they were assumed to have little effect on overall watershed hydrology and were not included as part of the existing conditions hydrologic analysis.

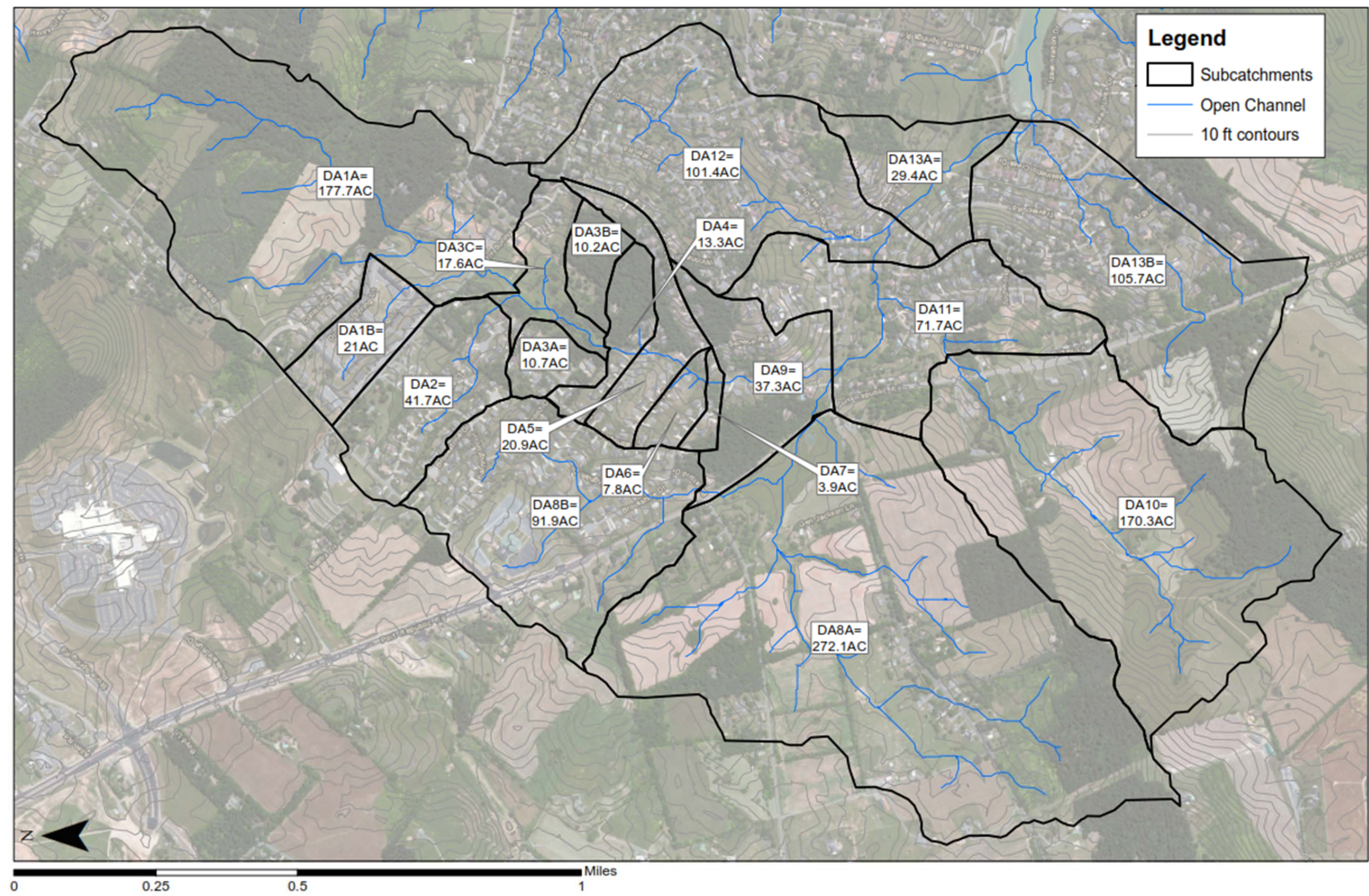


Figure 2: Drainage Area Map

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Limitations

TR-55 methodology is best used to determine watershed-scale hydrology. The ultimate design of alternatives presented in this report may require more site-specific analyses to accurately size road crossings and channel improvements. Furthermore, karst geology may exist within the watershed; potentially affecting hydrologic conditions. An evaluation of karst geology was not included as part of this assessment.

Results

Table 1 shows the existing conditions results of the hydrologic model. Peak flows are displayed for each drainage area (Refer to Figure 2) with combined peaks show at each road crossing.

Table 1: Existing Conditions Peak Flows

Area	Existing Flows (cfs)				
	2-yr	5-yr	10-yr	25-yr	100-yr
DA1A	32	76	125	207	375
DA1B	34	49	62	81	117
DA2	20	38	55	82	137
DA3A	7	13	18	27	44
DA3B	1	4	7	13	24
DA3C	6	13	20	31	53
DA4	4	9	14	22	40
Baybrook Drive	89	176	267	417	717
DA5	10	20	28	43	70
Berryfield Drive	99	195	295	459	787
DA6	4	8	12	18	30
DA7	2	3	5	7	12
DA8A	59	120	183	287	494
DA8B	37	70	101	154	260
DA9	9	20	32	50	88
Shen Lake Drive	175	357	544	850	1472
DA10	41	87	133	209	366
DA11	25	50	77	119	204
Lucy Long Drive	237	489	747	1169	2013
DA12	41	76	111	167	276
Janie Lane	278	566	858	1336	2288
DA13A	38	74	109	166	278
DA13B	12	23	34	52	87
Lake Shenandoah	327	662	1000	1551	2647

*Refer to Appendix A for complete HEC-HMS model outputs.

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Hydraulics Assessment

Channel Characteristics

The Project Reach consists primarily of natural bottom open channels with culverts at road crossings and within residential yards. The upper portion of the channel between from Baybrook Drive to Shen Lake Drive is poorly defined, mostly grass-lined, and has an average slope of approximately 2%. There is a 42" plastic culvert at Baybrook Drive, a 42" concrete culvert at Berryfield Drive, and 42" corrugated metal pipe adjacent to Cumberland Drive. At Shen Lake Drive there are four 24" corrugated metal pipes. From Shen Lake Drive to Lake Shenandoah, the channel flattens slightly with an average slope of 0.5%. The channel is more defined here with slightly more riparian vegetation. There are three 4'x6' box culverts at Lucy Long Drive, two 4'x6' box culverts at Janie Lane, and a single 30" corrugated metal pipe at Massanetta Springs Road.

Methodology

Timmons Group developed a HEC-RAS model to determine water surface elevations at peak flows for the 2, 10, 25, and 100-year recurrence flood events, as determined by the hydrologic model. Flow changes were made at each sub-watershed (Refer to Figure 2 and Table 2). The upper boundary condition was based on channel slope and the lower boundary condition was set at normal lake elevation at the lower end.

Timmons Group conducted a topographic survey including spot elevations and measurements on all drainage structures and channel cross sections set at specified locations. Cross section survey points included top of bank, toe of bank, flow path, and spot elevations on the floodplain. The cross sections were then extended using 10-foot contour data provided by the County. The Mannings coefficients for roughness (n) was 0.03 – 0.035 for most of the channel and floodplain, and 0.07 - 0.1 for limited areas of brush/trees. Houses were not included as "blocked obstructions" in the cross sections. **Figure 3** shows the locations of cross sections used in the model.

The following road crossings were included in the model:

- Massanetta Springs Road
- Janie Lane
- Lucy Long Drive
- Shen Lake Drive
- Berryfield Drive
- Baybrook Drive

In addition, 3 in-line culverts within residential yards were surveyed and included in the model.

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Limitations

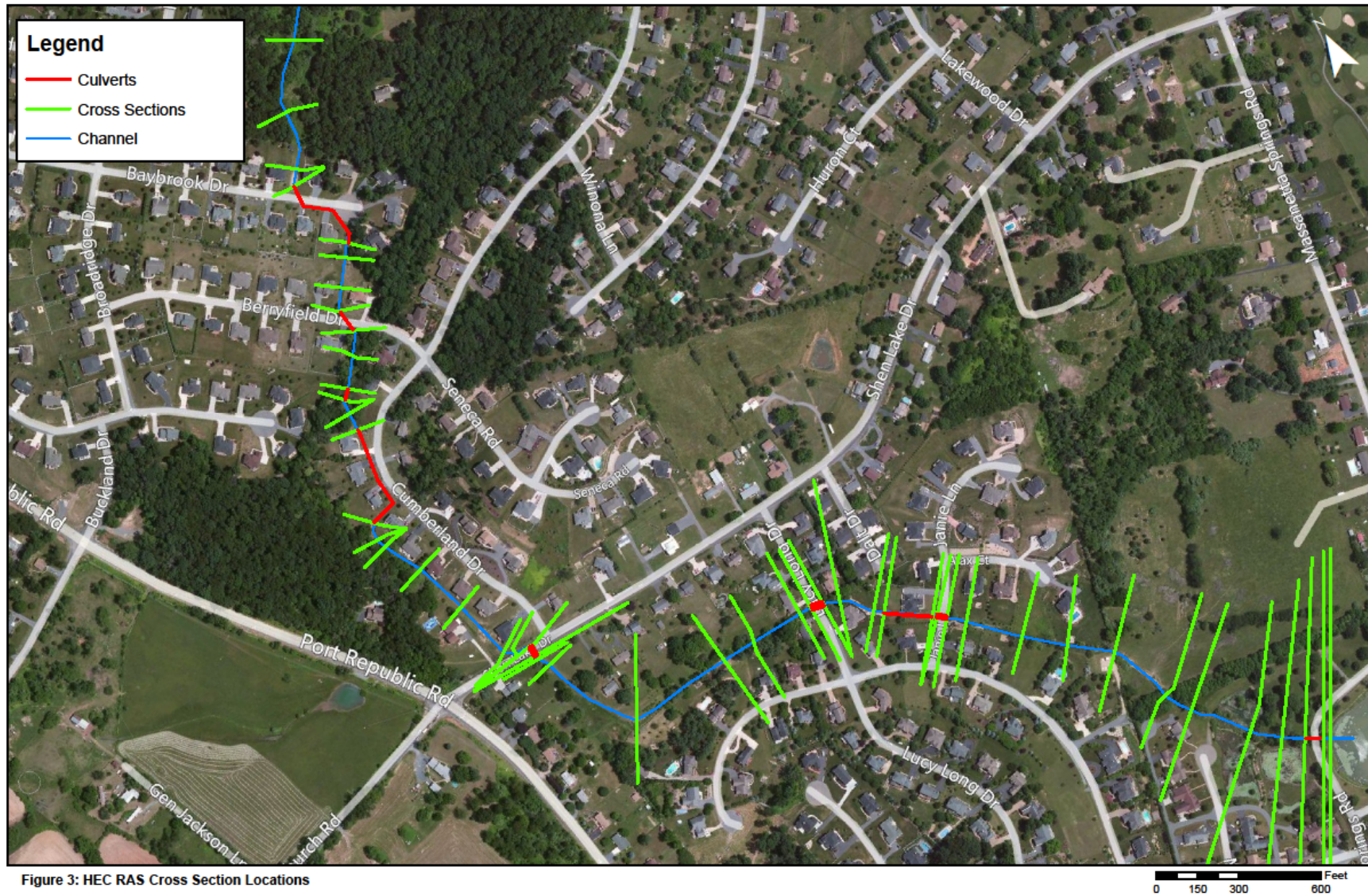
The accuracy of HEC-RAS models increases with additional cross sections. Given the scope and budget of this project, the number of cross sections was optimized to provide necessary model input while minimizing survey costs. Likewise, the use of 10-foot contour data to extend cross sections may result in a loss of accuracy. The ultimate design of alternatives presented in this report will require more site-specific hydraulic analyses to accurately size road crossings and channel improvements.

Results

Figure 4 displays HEC-RAS outputs of water surface profiles for the 2, 5, 10, 25, and 100-year storm events. As illustrated by the profile, road crossings can create significant backwater impacts upstream during larger storm events. Berryfield Drive, Shen Lake Drive, and Massenetta Springs Road overtop during a 2-year event. All road crossings are predicted to overtop during a 10-yr event.

Refer to Appendix B for complete HEC-RAS model results.

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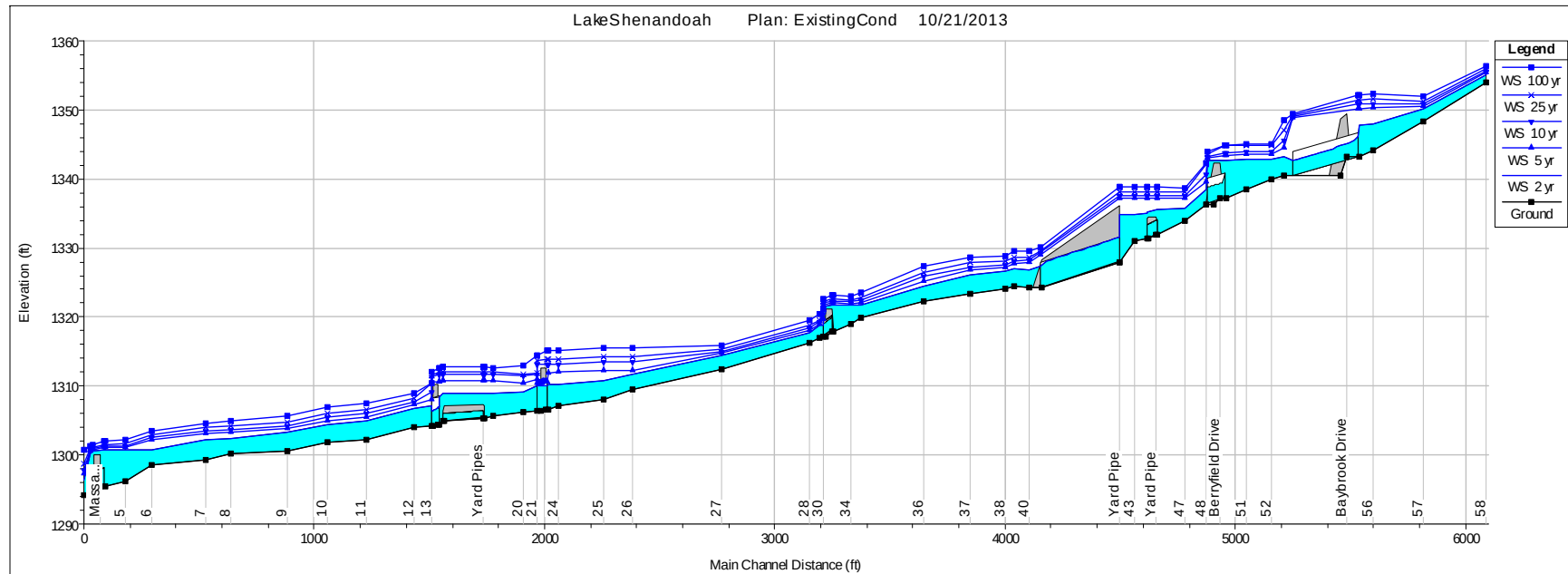


Figure 4: Existing Conditions Water Surface Profiles

Problem Areas

Timmons Group surveyed lowest floor elevations for the homes adjacent to the Project Reach. By analyzing these elevations relative to the results of the hydraulic models, Timmons Group was able to identify problem areas where flooding issues were likely to occur and potentially threaten homes.

Figure 5 displays the homes potentially at risk of flooding during a 10-year storm event.

Table 2 lists the addresses of homes within the 10-year flood inundation area.

Table 2: Addresses of Potential Flooding of Structures

Address		
3280 BAYBROOK DR	3280 BERRYFIELD DR	1801 JANIE LN
3297 BAYBROOK DR	1855 CUMBERLAND DR	1831 JANIE LN
3277 BAYBROOK DR	1875 CUMBERLAND DR	4060 LUCY LONG DR
3300 BAYBROOK DR	1835 CUMBERLAND DR	4065 LUCY LONG DR
3260 BERRYFIELD DR	1789 CUMBERLAND DR	4045 LUCY LONG DR

Disclaimer: This list is based on results of the hydrologic and hydraulic models; additional homes may experience drainage/flooding issues.

The following four problem areas were identified, as shown in **Figure 5**.

Problem Area 1: Janie Lane to Lucy Long Drive

Two hydraulic constrictions exist within this problem area. There are two 4' x 6' concrete box culverts at Janie Lane as seen in **Figure 6**. The HEC-RAS model suggests that these culverts are undersized, causing a backwater effect and overtopping of the road at a 5-year storm event (Refer to Figure 4). The backwater effect from Janie Lane extends to Lucy Long Drive, where there are three 4'x6' concrete box culverts, as seen in **Figure 7**. The HEC-RAS model suggests a second backwater effect and overtopping of the road at a 10-year storm event (Refer to Figure 4). The channel in this area is narrow with numerous homes along its floodplain. Many of the homes are located close to the channel and at an elevation relatively low to the road crossings. **Figure 5** shows five homes in this problem area potentially at risk of flooding during 10-year storm events.

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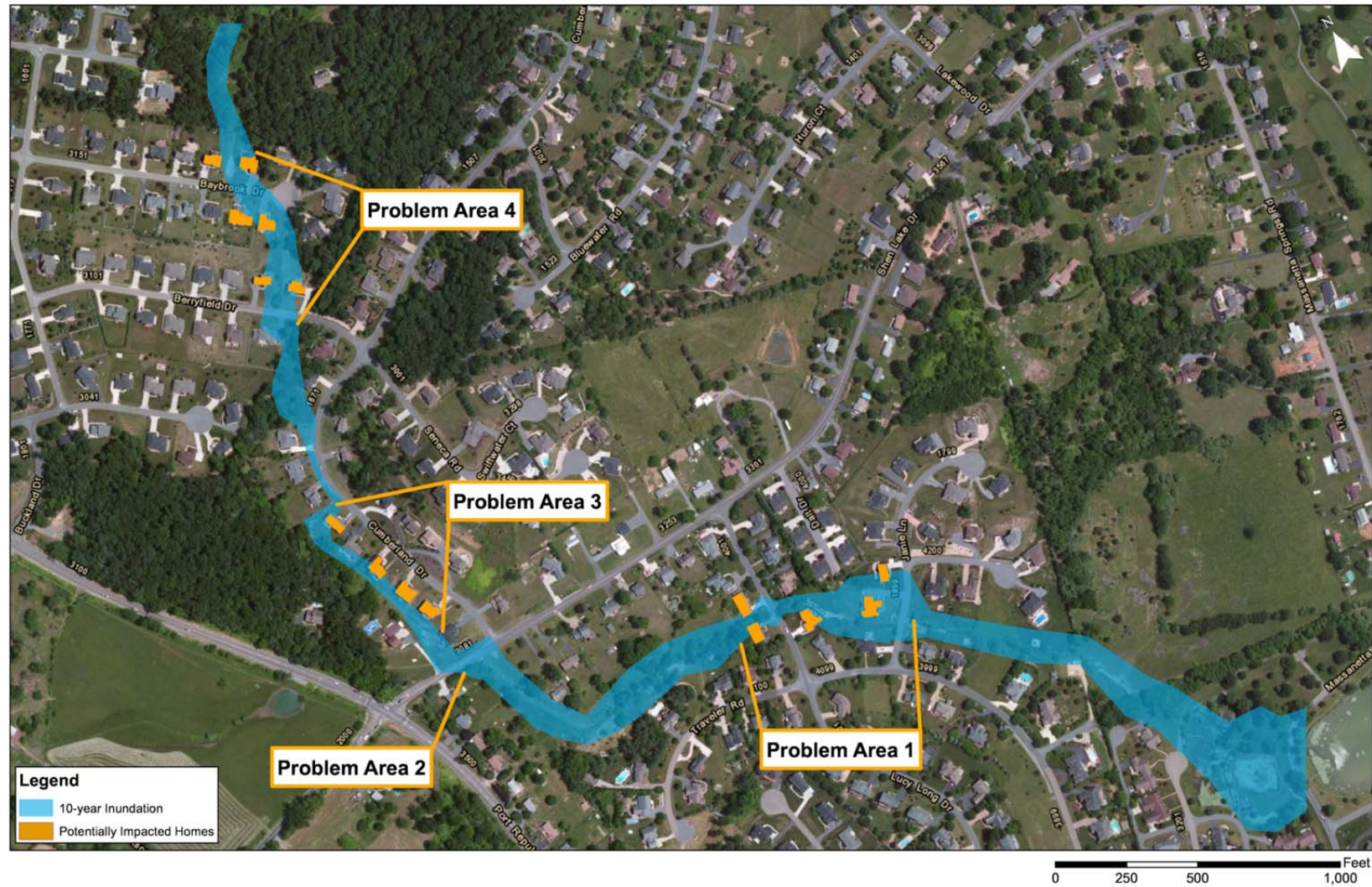


Figure 5: Inundation Map



Figure 6: Janie Lane Crossing (looking DS)



Figure 7: Lucy Long Drive Crossing (looking US)

Problem Area 2: Shen Lake Drive

Shen Lake Drive lies directly downstream of the confluence of a major drainage area west of Port Republic Road (DA8 A/B, Figure 2). There are four 24" corrugated metal pipe culverts at the crossing, as seen in **Figure 8**. The channel makes an abrupt right angle and is poorly defined upstream of the crossing. The HEC-RAS model suggests that this crossing is undersized, overtopping the road at a 2-year storm event (Refer to Figure 4). The low elevation of the road relative to the upstream grade results in little backwater effect, with no direct impacts to upstream homes. However, this problem area does create potential transportation impacts to Shen Lake Drive.



Figure 8: Shen Lake Drive Crossing (looking DS)

Problem Area 3: Cumberland Drive

The channel upstream of Shen Lake Drive runs parallel to Cumberland Drive and behind numerous houses with walk-out basements. The channel is poorly defined and grassed-lined, as seen in **Figure 9**. The channel cross section is constricted by a steep slope along its western side, resulting in potential flooding of four homes on the eastern side of the channel (Refer to Figure 5).



Figure 9: Channel behind homes along Cumberland Drive (looking US)

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Problem Area 4: Berryfield Drive to Baybrook Drive

The road crossings at Berryfield Drive and Baybrook Drive each consist of a single 42" culvert (concrete and HDPE, respectively). The channel upstream and downstream of Baybrook is poorly defined and grass-lined as seen in **Figure 10**. The channel upstream and downstream of Berryfield is slightly more defined and partially wooded, as seen in **Figure 11**. The HEC-RAS model suggests that both crossings are undersized, creating backwater effects and overtopping Berryfield Drive at a 2-year storm event and Baybrook Drive at a 5-year storm event (Refer to Figure 4). Six homes in the vicinity of the crossings are potentially at risk of flooding in 10-year (or less) storm event.



Figure 10: Upstream extent of Project Reach – Baybrook Drive inlet (looking US)

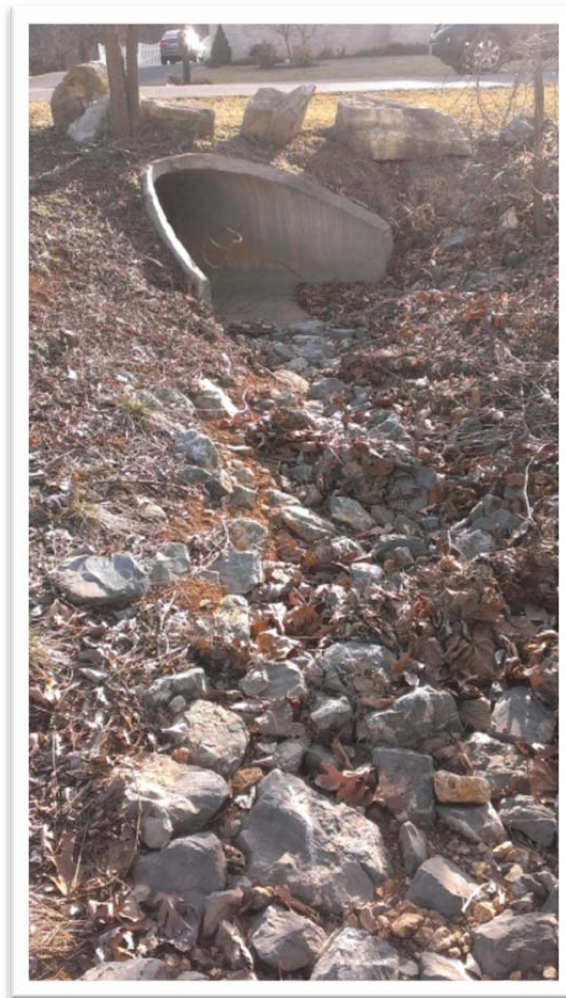


Figure 11: Berryfield Road Crossing (looking DS)



Anticipated Future Watershed Conditions

Timmons Group also assessed watershed hydrology and hydraulics for anticipated future conditions in the watershed. The hydrologic and hydraulic models were re-run to include these anticipated conditions and the corresponding impacts to problem areas were evaluated.

Hydrologic Assessment

There are four areas zoned for proposed development in the upper watershed of the Project Reach (DA 1A, DA 3A, DA 3B, DA 3C, and DA 4; Figure 2). For these areas, a curve number of 75 (1/4 acre residential, B soils) was used to update the hydrologic model. Anticipated stormwater management facilities were not included in the model, as explained above. **Table 3** shows the results of the HEC-HMS model for anticipated future peak flows; as compared the existing conditions peak flows shown in Table I above.

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Table 3: Anticipated Future Peak Flows compared to Existing Conditions

Area	Existing Flows (cfs)					Future Flows (cfs)				
	2-yr	5-yr	10-yr	25-yr	100-yr	2-yr	5-yr	10-yr	25-yr	100-yr
DA1A	32	76	125	207	375	105	176	242	346	543
DA1B	34	49	62	81	117	34	49	62	81	117
DA2	20	38	55	82	137	20	38	55	82	137
DA3A	7	13	18	27	44	10	16	22	32	50
DA3B	1	4	7	13	24	8	14	19	27	43
DA3C	6	13	20	31	53	13	22	31	43	67
DA4	4	9	14	22	40	11	18	25	36	57
Baybrook Drive	89	176	267	417	717	179	300	414	592	931
DA5	10	20	28	43	70	10	20	28	43	70
Berryfield Drive	99	195	295	459	787	189	320	443	635	1001
DA6	4	8	12	18	30	4	8	12	18	30
DA7	2	3	5	7	12	2	3	5	7	12
DA8A	59	120	183	287	494	59	120	183	287	494
DA8B	37	70	101	154	260	37	70	101	154	260
DA9	9	20	32	50	88	9	20	32	50	88
Shen Lake Drive	175	357	544	850	1472	264	476	684	1023	1686
DA10	41	87	133	209	366	41	87	133	209	366
DA11	25	50	77	119	204	25	50	77	119	204
Lucy Long Drive	237	489	747	1169	2013	326	608	886	1333	2210
DA12	41	76	111	167	276	41	76	111	167	276
Janie Lane	278	566	858	1336	2288	366	684	997	1500	2486
DA13A	38	74	109	166	278	38	74	109	166	278
DA13B	12	23	34	52	87	12	23	34	52	87
Lake Shenandoah	327	662	1000	1551	2647	416	780	1139	1715	2844

*Refer to Appendix A for complete HEC-RAS model outputs.

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Hydraulics Assessment

A second HEC-RAS model was run using anticipated future peak flows to assess increases in water surface elevations. Slight increases in water surface elevation are anticipated based on development in the upper watershed, with the greatest increase expected to occur in the vicinity of Baybrook Drive during the 2-year event. Results suggest that the 42" culvert under Baybrook Drive can convey the existing 2-year event but will overtop during anticipated 2-year flows. **Figures 12 & 13** display a comparison of the 2 & 25-year water surface profiles for the project reach.

Impacts to Existing Problem Areas

Anticipated future flows increase water surface profiles throughout, adding to the drainage/flooding issues at the existing problem areas identified above. However, these increases are relatively minor and do not create any significant new problem areas.



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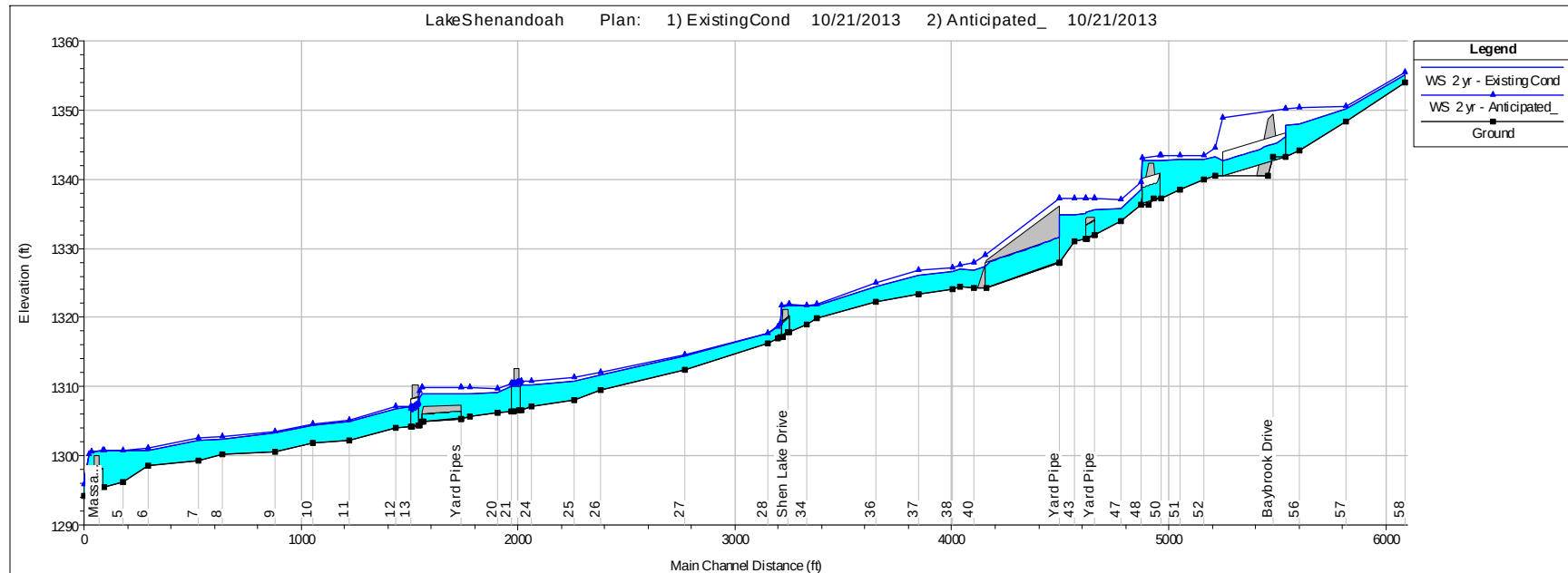


Figure 12: 2-year Water Surface Comparison



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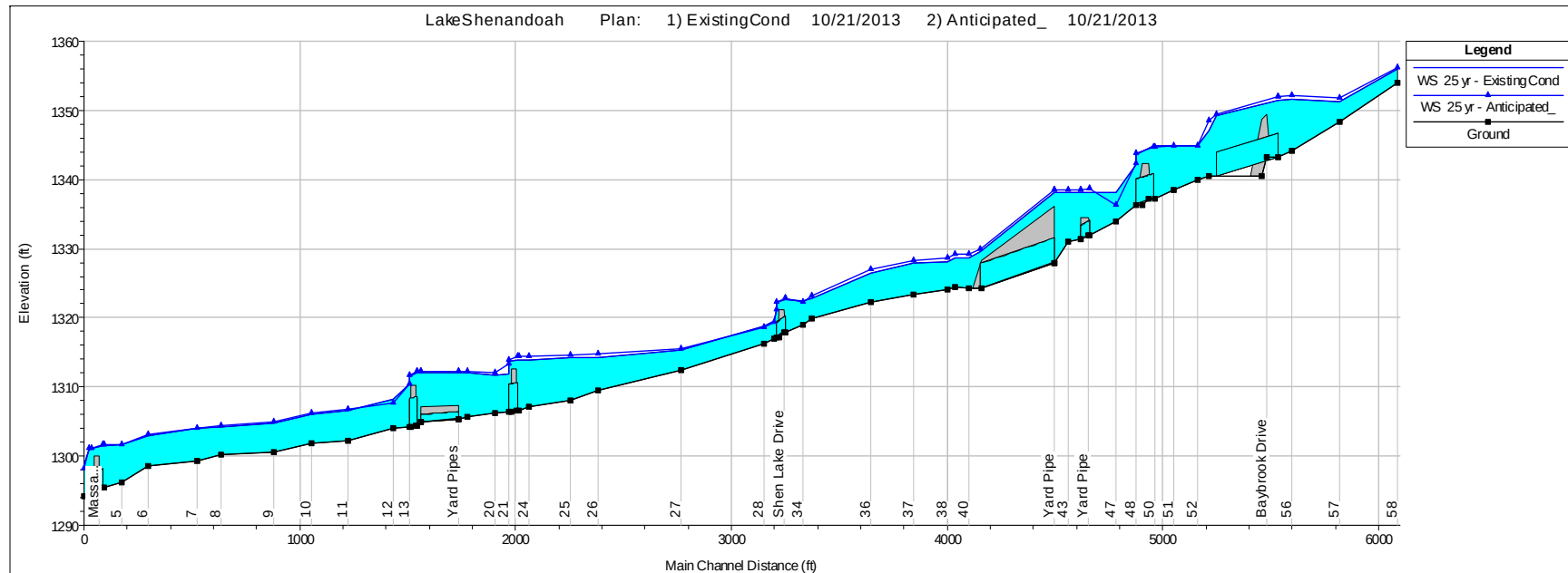


Figure 13: 25-year Water Surface Comparison

Drainage Improvement Strategies

Timmons Group evaluated several solutions to reduce drainage and flooding issues within the Project Reach. These solutions were grouped under three strategies for the County to consider. The first strategy focuses on evaluating engineering solutions to improve conveyance and address specific existing drainage problems within the Conger's Creek watershed. The second strategy includes a larger-scale watershed evaluation of existing and possible new stormwater best management practices (BMPs). The third strategy looks at making changes to County policies and procedures for stormwater management that affect future watershed land-use including proposed/anticipated future development.

Strategy I: Increase Conveyance Capacity

The primary goal of this strategy is to increase flood protection and improve drainage for the homes along the Project Reach. Strategy I generally consists of increasing the conveyance capacity of road culverts and the drainage channel to reduce water surface elevations and provide a level of flood protection that exceeds a 10-year storm event.

Given that numerous homes lie within the 10-year inundation areas of this channel, Timmons Group recommends a phased approach to this strategy; working from downstream to upstream. This approach will ensure that the downstream-most homes receive conveyance improvements prior to removing any hydraulic constrictions upstream, which could slightly increase downstream peak flows.

Environmental permits may be required for projects within the channel. The channel generally appears to be intermittent and mostly grass-lined from Baybrook Drive to Shen Lake Drive, and then transitions to more of a perennial stream between Shen Lake Drive and Lucy Long Drive, with mostly managed vegetation/grass within the channel and on floodplains. Improvements along the project reach will likely to require a permit from the US Army Corps of Engineers and/or the Department of Environmental Quality.

Summary tables of opportunities and constraints (Tables 4 – 7) are provided for each phase, and planning-level cost estimates are provided for project implementation. The opportunities, constraints, and costs provided below are based on the following assumptions/disclaimers:

- Utilities were not located as part of this analysis
- Streams/Wetlands were not classified/delineated
- Costs assume no purchase for easements
- Construction costs provided as order of magnitude estimates

Note: The 30" culvert at Massanetta Springs Road directly upstream of Lake Shenandoah was not included in assessment. Elimination of road flooding at this location would require additional studies with respect to the entire Lake Shenandoah watershed and the dam/outlet configuration. However, this particular crossing does not appear to create any hydraulic impacts to upstream homes.

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Table 4 - Strategy I, Phase 1 Improvements

ID	Project Description	LF of Channel	Benefit to Homes	Constraints			Implementation Costs			
			Homes No Longer within 10-yr Floodplain due to Improvements ¹	Easements	Environmental	Other	Design	Construction	Total Cost	Cost per Home Benefited
1	Add (2) box culverts to Janie Lane , lower/regrade channel downstream and between Janie Lane and Lucy Long Drive	760	3	10 + VDOT	yes	-utilities likely -residential yards	\$50,000	\$400,000	\$450,000	\$150,000
2	Add (1) box culvert at Lucy Long Drive, lower/regrade channel 200 feet upstream	240	2	4-5 + VDOT	yes	-utilities likely -residential yards	\$25,000	\$200,000	\$225,000	\$112,500
Phase Totals		1,000	5	14-15			\$75,000	\$600,000	\$675,000	\$135,000

Table 5 - Strategy I, Phase 2 Improvements

ID	Project Description	LF of Channel	Benefit to Homes	Constraints			Implementation Costs			
			Homes No Longer within 10-yr Floodplain due to Improvements ¹	Easements	Environmental	Other	Design	Construction	Total Cost	Cost per Home Benefited
3	Raise road and construct low bridge crossing	40	N/A	VDOT	possible	-sharp bend in alignment -utilities likely	\$100,000	\$750,000	\$850,000	\$850,000

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Table 6- Strategy I, Phase 3 Improvements

ID	Project Description	LF of Channel	Benefit to Homes	Constraints			Implementation Costs			
			Homes No Longer within 10-yr Floodplain due to Improvements ¹	Easements	Environmental	Other	Design	Construction	Total Cost	Cost per Home Benefited
4	Lower/regrade channel	720	4	6	no	-utilities likely -residential yards	\$20,000	\$150,000	\$170,000	\$42,500

Table 7 - Strategy I, Phase 4 Improvements

ID	Project Description	LF of Channel	Benefit to Homes	Constraints			Implementation Costs			
			Homes No Longer within 10-yr Floodplain due to Improvements ¹	Easements	Environmental	Other	Design	Construction	Total Cost	Cost per Home Benefited
5	Upsize to double box culverts at Berryfield Drive	80	3	3-4 & VDOT	no	-utilities likely	\$25,000	\$250,000	\$450,000	\$150,000
6	Upsize to larger culvert(s) at Baybrook Drive	285	3	5 & VDOT	no	-sharp bend in alignment -utilities likely	\$30,000	\$300,000	\$225,000	\$75,000
Phase Totals		365	6	8-9	-	-	\$55,000	\$550,000	\$675,000	\$112,500

I. Based on County records and Conger's Creek HEC RAS model (Timmons Group, 2013).



Phase I – Improvements at Janie Lane and Lucy Long Drive (Problem Area I)

Phase I improvements will address a series of hydraulic constrictions created by undersized culverts at Janie Lane and Lucy Long Drive, and a narrow channel and floodplain restricted by a cluster of houses. Proposed projects would increase conveyance in this area by lowering the channel grade and increasing the size/number of the road crossing culverts. The relatively flat channel slope in this area will require channel grading to extend downstream approximately 300 feet in order to maintain a positive grade.

A large number of easements and close proximity to existing houses present implementation constraints. Some homes have invested in stone lining of the channel, small bridges, and low-flow pipes. It is also likely that work within this portion of the channel will require environmental permitting. Design of channel improvements will need to consider maintaining or improving riparian habitat; mitigation may be required.

Improvements to Problem Area I will consist of the following major components:

- Install two new box culverts (estimated 6'x6', 40-feet) at Janie Lane with inverts set 2 feet lower than existing (4'x6') culverts.
- Install one new box culvert (estimated 6'x6', 40-feet) at Lucy Long Drive, invert set 2 feet lower than existing (4'x6') culverts.
- Lower channel approximately 2 feet for a distance of approximately 300 linear feet downstream of Janie Lane.
- Lower channel approximately 2 feet for distance of approximately 420 linear feet between Janie Lane and Lucy Long Drive.
- Lower channel approximately 2 feet, transitioning to existing grade over a distance of approximately 200 linear feet upstream of Lucy Long Drive.



Phase 2 – Improvements to Shen Lake Drive Crossing (Problem Area 2)

Improvements to the Shen Lake Drive crossing include raising the road as much as 4 feet to allow for a large enough conveyance opening to pass the flows without creating a backwater effect. Currently, the road acts as a weir during storm events, and therefore does not backwater the houses along Cumberland Drive. Preliminary estimates, using the HEC-RAS model, suggest that a low bridge may be a feasible solution at this location. Given that Shen Lake Drive sees significantly more traffic than the other crossings within the Project Reach, the County should consider up-front coordination with VDOT to assess partnering opportunities to improve current conditions.

Phase 3 – Channel Improvements along Cumberland Drive (Problem Area 3)

The channel adjacent to homes along Cumberland Drive can be improved by grading a more defined channel with increased capacity. Unlike Problem Area 1, it is not anticipated that there will be any environmental constraints for this portion of the channel, which will drastically reduce costs per linear foot. Preliminary analysis suggests that lowering the existing channel approximately two feet will increase flood protection for the adjacent homes to approximately a 10-year event level. Upstream of the channel, there is a 42" culvert that bypasses three homes. Although the hydraulic model suggests that this culvert is undersized, the effects of the hydraulic constriction do not appear to impact any adjacent homes.

Phase 4 – Improvements at Berryfield Drive and Baybrook Drive (Problem Area 4)

The crossings at Berryfield Drive and Baybrook Drive can be improved by up-sizing the existing culverts. For Berryfield Drive, this can be achieved with two new box culverts (estimated 4'x6'). Baybrook Drive, however, has a very sharp bend in the channel alignment and will likely require a pipe/manhole system to make the nearly right angle bend.



Strategy 2: Increase Watershed Stormwater Management

The goal of Strategy 2 is to improve stormwater management within the greater watershed by reducing the peak flows and associated impacts to the existing problem areas, while also providing water quality benefits to Lake Shenandoah. Strategy 2 aims to improve stormwater management throughout the watershed through one or more of the following three objectives:

1. Retrofit existing stormwater management facilities to improve their performance.
2. Create regional stormwater management facilities to provide water quality and quantity treatment.
3. Incorporate stormwater management policies that encourage/require reduced runoff volume.

For the analysis of Strategy 2, the study area was increased to include areas of the larger Lake Shenandoah Watershed that lie within the County's designated urban growth boundary. **Figure 14** shows the expanded study area. Within the study area, Timmons Group cataloged and ranked locations suitable for the installation or retrofit of stormwater management facilities. Ranks were based on potential improvements to flooding at downstream homes. Timmons Group then modified the HEC-HMS model in order to estimate the impacts that detention basins would have on peak flow rates, if installed at the highest ranking locations. Surface area and depth for each basin were determined based on topographic and parcel boundary constraints. Basins were initially modeled with a single 18" diameter outlet pipe, but, for basins that were predicted to overtop during a 10-yr event, surface area and pipe diameter were increased within site constraints until the basin was no longer predicted to overtop during a 10-year event. Peak flow estimates predicted by HEC-HMS were subsequently used as inputs into the HEC-RAS to predict changes in water surface elevations as a result of BMP installation / retrofit. For each BMP modeled, flooding improvements were analyzed by comparing the predicted 10-year water surface elevation to the finished floor elevation of flood-prone homes.

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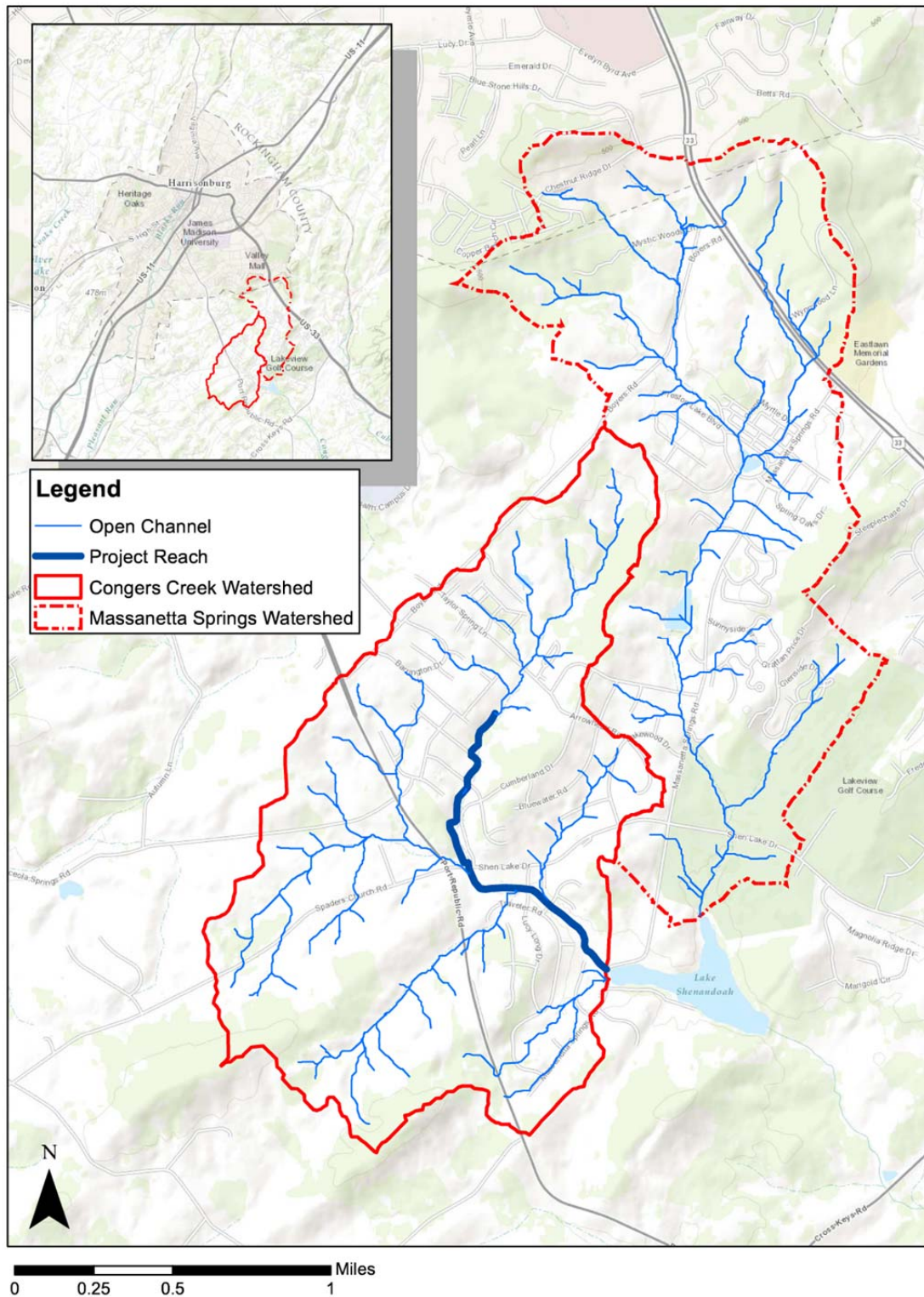


Figure 14. Expanded Study Area

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Retrofit Existing Stormwater Management Facilities

There are many potential opportunities to retrofit existing stormwater management facilities within the Lake Shenandoah watershed. **Figure 15** shows a map of the thirteen locations where there is either an existing stormwater management BMP or a pond which is not designed as stormwater management but still provides water quality and quantity benefits. For the purposes of this study, all ponds will be considered BMPs.

Table 8 provides additional information on BMPs shown in Figure 15 and a ranking of potential benefits that retrofits would offer to downstream homes. Ranks for potential benefits were determined by multiplying three variables: the percentage of the overall watershed (either Congers Creek or Massanetta Springs) which the individual BMP serves, the total number of parcels which are both downstream of that BMP and adjacent to the stream, and the number of homes downstream of that BMP which are known to experience flooding in the 10-year storm. BMP retrofit candidates with the largest treatable drainage areas and the greatest number of downstream homes rank highest in their potential benefit to downstream homes.

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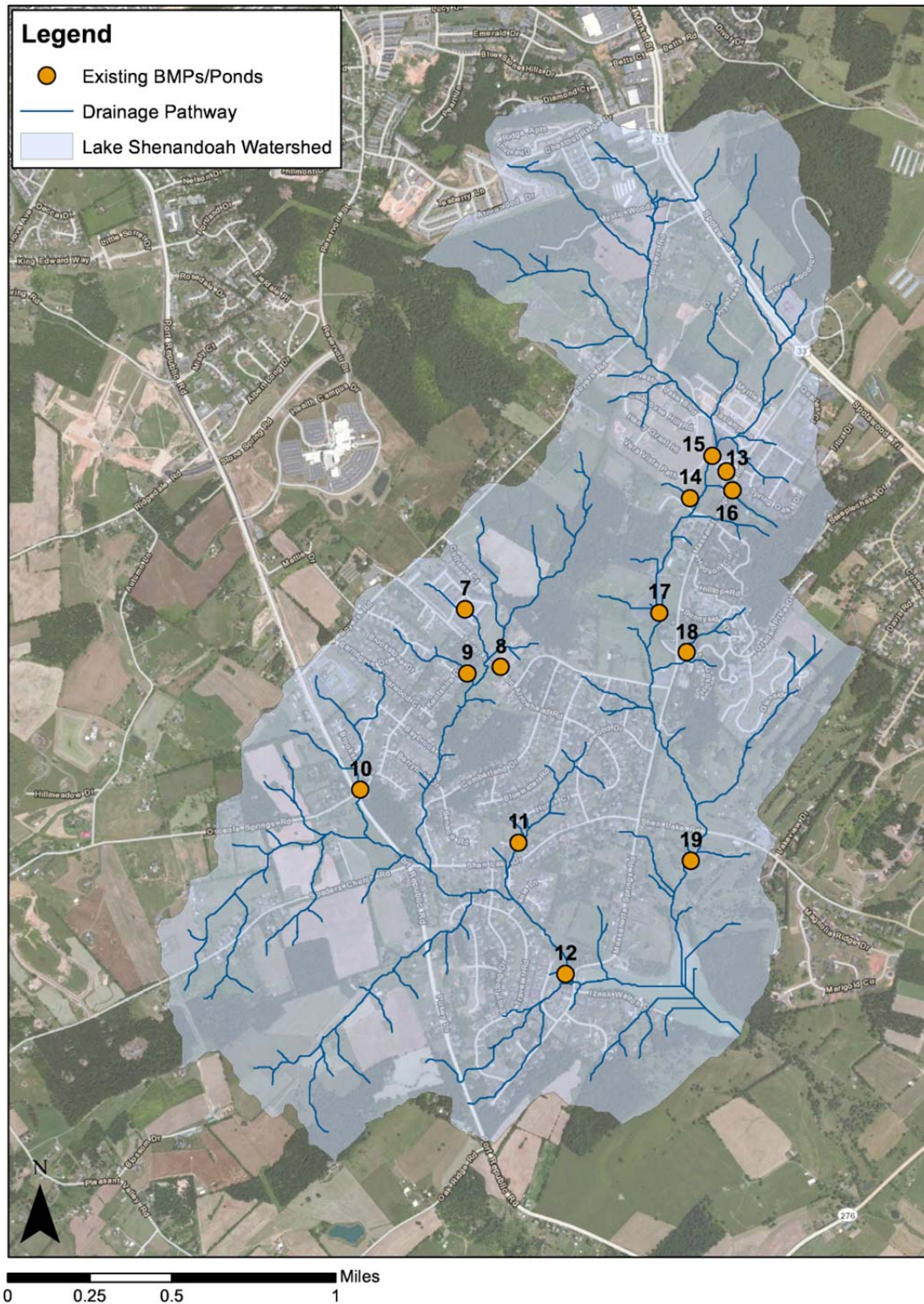


Figure 15. Existing BMPs/Ponds.

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Table 8 – Existing BMPs within the Lake Shenandoah watershed

ID	Name/Location	Type	DA (acres)	DA % of overall watershed ¹ [A]	# of downstream parcels [B]	# of downstream homes flooded in 10-yr storm ² [C]	Potential Benefit to downstream homes ³ [D]
7	Taylor Springs	Detention Basin	21.0	1.7%	61	15	16
8	Taylor Grove	Detention Basin	5.4	0.4%	53	15	3
9	Kentshire Drive	Detention Basin	41.7	3.5%	51	15	27
10	Buckland Drive	Detention Basin	91.9	7.6%	34	5	13
11	Tiller Farm Pond	Wet Pond	87.6	7.3%	23	2	3
12	Lake Pointe Village	Constructed Wetland	6.9	0.6%	1	0	0
13	Preston Lakes Pond	Wet Pond	618.3	53.7%	16	0	0
14	Preston Lakes (E&S-1)	?	12.0	1.0%	15	0	0
15	Preston Lakes (E&S-2)	?	0.7	0.1%	15	0	0
16	Spring Oaks Drive	Detention Basin	1.8	0.2%	16	0	0
17	Massanetta Springs	Wet Pond	769.9	66.9%	11	0	0
18	Sunnyside Drive	Wet Pond	30.4	2.6%	10	0	0
19	Lakeview Golf Course	Wet Pond	1095.0	95.1%	1	0	0

1. Based on respective watersheds for Congers Creek and Massanetta Springs.

2. Based on County records and Conger's Creek HEC-RAS model (Timmons Group, 2013).

3. Relative score based on BMP drainage area and downstream homes/impacts. $[D] = [A] \times [B] \times [C]$



Construct Regional Stormwater Management Facilities

New regional stormwater facilities, or BMPs, can be implemented within as County Capital Improvement Projects. The aim of these BMPs would be to create additional stormwater management within the watershed in addition to required existing and proposed BMPs for developments. **Figure 16** shows five locations where Timmons Group has determined that the construction of new BMPs could help mitigate flooding along Congers Creek.

Table 9 provides additional information and a ranking of potential benefits to downstream homes for each new potential BMP identified in Figure 16. Ranks for potential benefits were determined by multiplying three variables: the percentage of the Congers Creek watershed which drains to that BMP, the total number of parcels which are downstream of that BMP and adjacent to Congers Creek, and the number of downstream homes that are known to experience flooding. Similar to the ranking of BMP retrofit opportunities in Table 8, **Table 9** rewards the highest rank to potential BMPs with the largest treatable drainage areas and the greatest number of downstream homes.

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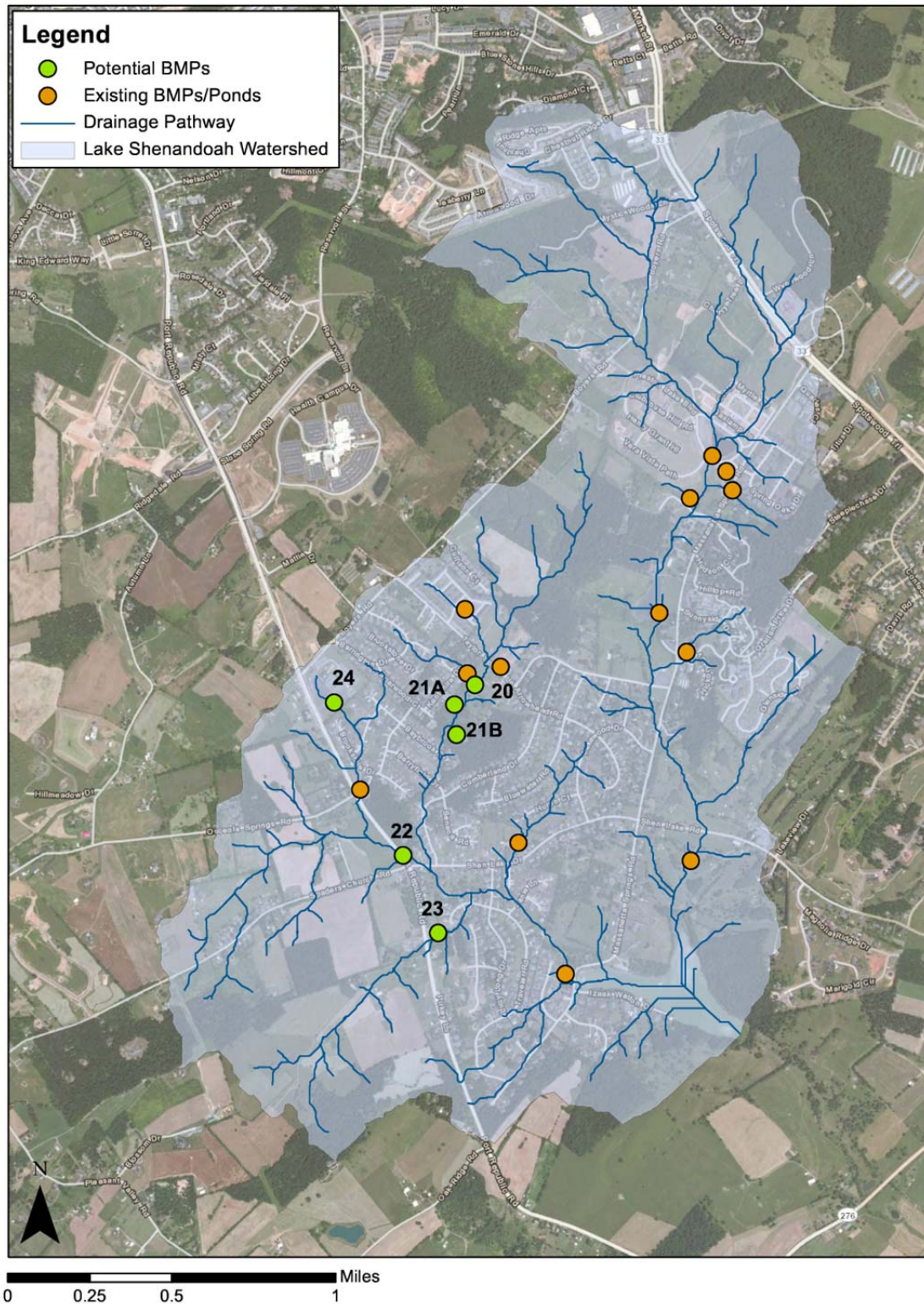


Figure 16. Potential BMPs.



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Table 9 – Potential BMPs within the Lake Shenandoah watershed

ID	Name/Location	DA (acres)	DA % of overall watershed ¹ [A]	# of downstream parcels [B]	# of downstream homes flooded in 10-yr storm ² [C]	Potential Benefit to downstream homes ³ [D]
20	Upper Connemara Site	177.7	14.8%	49	15	109
21A/B	Lower Connemara Site	20.9	1.7%	49	15	12
22	Spaders Church Road – Port Republic Road	364.0	30.2%	32	5	48
23	Upstream of Traveler Road	170.3	14.1%	24	5	17
24	First Church of the Nazarene	16.2	1.3%	46	5	3

1. Based on respective watersheds for Congers Creek and Massanetta Springs.
2. Based on County records and Conger's Creek HEC-RAS model (Timmons Group, 2013).
3. Relative score based on BMP drainage area and downstream homes/impacts. $[D] = [A] \times [B] \times [C]$

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Analysis of Benefits

Three potential BMP retrofit projects and three potential new BMP projects were found to have the highest rank for potential benefit to downstream homes. These potential BMP projects were selected for further modeling to estimate potential benefits to flood elevations during the 10-year event. In order to detain the 10-year event, 36" invert pipes were required for the ponds at Spaders Church Road and upstream of Traveler Road, and a 24" pipe was required for Kentshire Drive. The pond retrofit candidate at Buckland Drive could not be sized large enough to detain the 10-yr storm and was left out of further analysis as a result. The pond characteristics used in final hydrologic and hydraulic modeling are summarized in Table 10.

Table 10 – Potential Stormwater Management Project Modeling Parameters

ID	Project Description	Pond Area (acres)	Depth (ft)	Volume (acre-ft)	Invert Diameter (in)	Invert slope	Floor elevation (ft)
20	Construct extended detention basin on upper Connemara site	2.1	5	9.2	18	1.3%	1365
22	Construct extended detention basin upstream of Port Republic – Spaders Church Road.	4.3	5	19.4	36	1.3%	1329
7	Retrofit basin at Taylor Springs	1.1	5	4.5	18	1.0%	1385
9	Retrofit basin at Kentshire Drive	0.4	6	1.6	24	2.5%	1369
23	Construct extended detention basin upstream of Traveler Road.	1.12	5	4.7	36	1.3%	1325

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Figure 17 shows potential stormwater projects that were selected for modeling to quantify potential improvements to downstream flooding. A variety of HEC-HMS and HEC-RAS model runs were conducted to examine the impacts of these ponds, functioning both individually and in conjunction with one another, on water surface elevations. BMP parameters that were included in the models are shown in Table 10. **Table 11** provides cost estimates and shows the expected impacts of potential stormwater management projects on water surface elevations and home flooding. As shown in **Table 11**, model results suggest that an extended detention basin at the Upper Connemara site is expected to lower water surface elevations by an average of 0.55 feet at flood-prone homes and to eliminate flooding at three homes during the 10-year storm. The combined retrofit of basins at Kentshire Drive and Taylor Springs is also expected to eliminate flooding at three homes during this design storm. Kentshire Drive and Taylor Springs are presented as a single project because their combined impact is significantly greater than the impact of either project by itself. All other projects are recommended individually because flooding was not shown to significantly improve with other combinations of BMPs. Construction of an extended detention basin upstream of Port Republic – Spaders Church Road or upstream of Traveler Road is expected to eliminate flooding during the 10-year storm at only one home.

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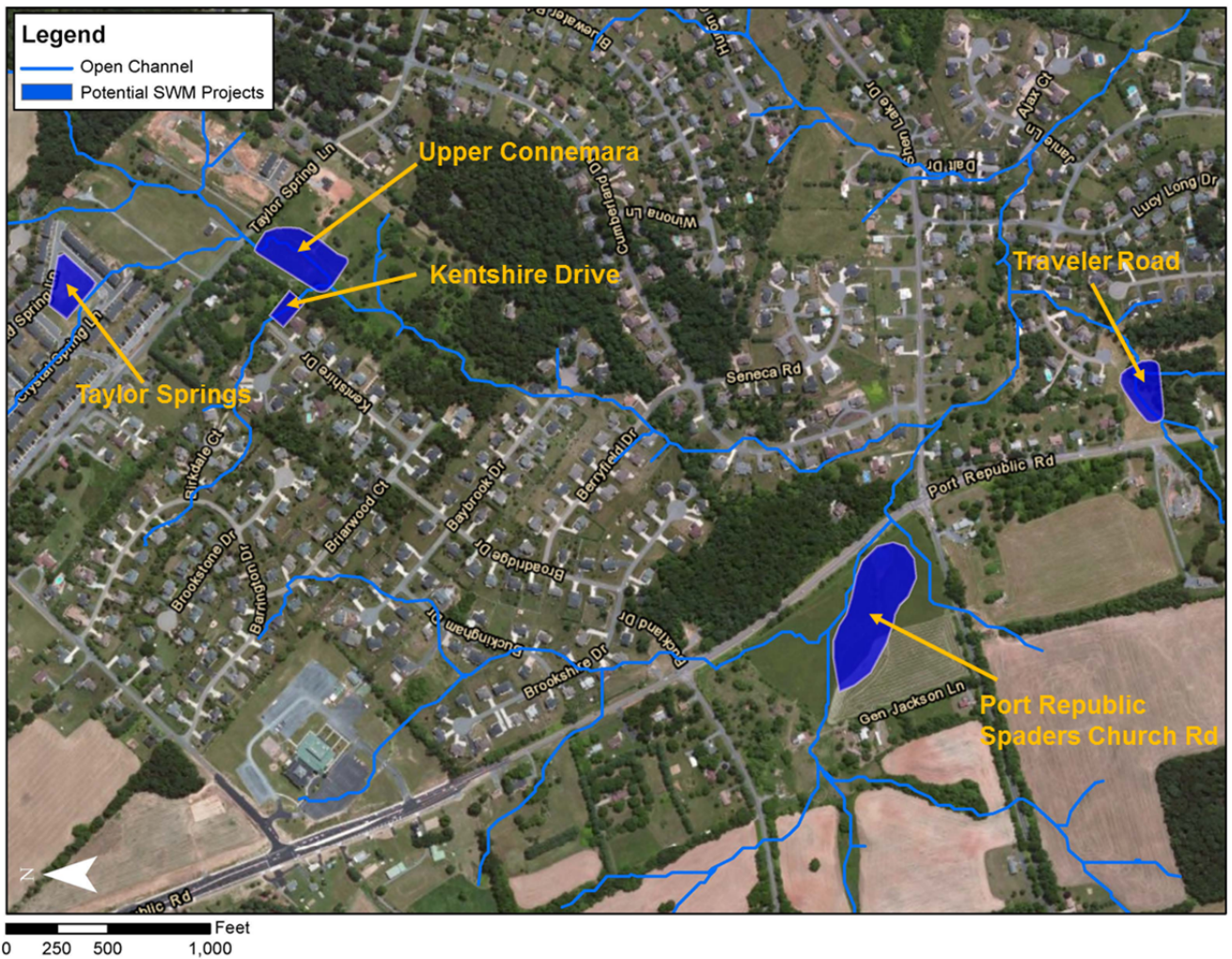


Figure I7: Potential Stormwater Projects Selected for Detailed Modeling



Table 11 – Potential Stormwater Management Projects

ID	Project Description	Benefit to Homes			Constraints			Implementation Costs					
		# of Downstream Homes Flooded in 10-yr Storm ¹	Average Decrease in 10-yr Flood Elevation due to BMP ²	Homes No Longer within 10-yr Floodplain due to BMP ²	Easements	Environmental	Other	Design	Land Acquisition ³	Construction	20-year Maintenance	Total Cost	Cost per Home Benefited ⁴
20	Construct extended detention basin on upper Connemara site	15	0.55 ft	3	1	Not likely	Private Property, Proposed Development	\$20,000	\$65,000	\$160,000	\$95,000	\$340,000	\$113,333
22	Construct extended detention basin upstream of Port Republic – Spaders Church Rd.	5	0.76 ft	1	1	Yes	Private Property	\$35,000	\$55,000	\$375,000	\$225,000	\$690,000	\$690,000
7&9	Retrofit basins at Kentshire Drive and Taylor Springs to provide enhanced detention.	15	0.45 ft	3	2	No	Existing residential areas, Existing infrastructure	\$20,000	\$0	\$150,000	\$90,000	\$260,000	\$86,667
23	Construct extended detention basin upstream of Traveler Road.	5	0.35 ft	1	1	Yes	Traveler Road extension,	\$15,000	\$0	\$110,000	\$65,000	\$190,000	\$190,000

1. Based on County records and Conger’s Creek HEC-RAS model (Timmons Group, 2013).
2. Based on decrease in water surface elevations at home locations as modeled in HEC-RAS (Timmons Group, 2013).
3. Based on average land value per acre as determined from County GIS parcel information.
4. Based on number of homes that no longer flood during 10-year event due to BMP.

Description of Potential Stormwater Projects

Construct extended detention basin on upper Connemara site – ID 20

The Connemara site (Figure 18) is located in the headwaters of the Congers Creek watershed and has forest and pasture as primary land use classifications. Jurisdictional wetlands and streams are believed to exist in the lower site; therefore, any stormwater management facility must be located in the upper portion of the site. The proposed stormwater facility at the upper Connemara site has a drainage area of approximately 180 acres and is located approximately 300ft southwest of the intersection of Taylor Spring Ln and Taylor Grove Lane, as shown in Figure 17. Because this drainage area is in the headwaters of the watershed, stormwater management at Upper Connemara is expected to provide some flood-reduction benefit to all downstream properties. HEC-RAS modeling suggests that construction of a dry detention basin at this site could remove three homes from the 10-yr floodplain, at an estimated cost of \$113,000 per home benefited (Table 10). Despite this site being a good potential candidate for a stormwater management facility, it was eliminated as a recommended project due to the high likelihood of future residential development. If plans for development change, the County should consider this site a high priority for stormwater management.



Figure 18: Upper Connemara Site, looking south from Taylor Spring Ln.

Construct extended detention basin upstream of Port Republic – Spaders Church Rd – ID 22

The Port Republic – Spaders Church Road site is located toward the center of the Congers Creek watershed, approximately 300 ft northeast of the intersection of Port Republic Rd and Spaders Church Road, as shown in Figure 19. The 100+ acre parcel (TMP 125-A-L52) has a drainage area of approximately 272 acres, and it drains the western portion of the watershed. Pasture/agriculture is the primary land use. This parcel, or a portion thereof, would need to be purchased from the owner to

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construct a BMP. Providing extended detention at this location would likely remove 1 home from the 10-yr floodplain at a cost of \$690,000 (Table 10). Timmons Group does not recommend this project due to the high cost per home benefited.



Figure 19: Port Republic – Spaders Church Rd Site, looking west from Port Republic Rd.

Construct extended detention basin upstream of Traveler Road – ID 23

The Traveler Road site is located upstream of Traveler Road, immediately to the east of Port Republic Road in the southeast portion of the Congers Creek watershed, as shown in Figure 20. The site has a drainage area of approximately 170 acres and is located between Traveler Road and Port Republic Rd. Agriculture/pasture is the primary land use within the site drainage area. Model results indicate that construction of an extended detention basin at this site could remove one home from the 10-year floodplain at an estimated cost of \$190,000 (Table 10). Timmons Group does not recommend this project due to the low number of homes benefited.



Figure 20: Traveler Rd Site, looking east from Port Republic Rd.

Retrofit basin at Kentshire Drive – ID 9

The Kentshire Drive site is located in the northern portion of the Congers Creek watershed. The site drains approximately 41 acres of mixed residential development. The site location is pictured below in Figure 21. The proposed pond occupies 97% of the 0.387 acres in parcel number 125H-(11)- L12. There appears to be an existing small basin at this location; however the proposed project would greatly enhance the storage capacity and flood reduction potential over the existing basin.



Figure 21: Kentshire Drive Site.

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Retrofit basins at Taylor Springs – ID 7

The Taylor Springs site is located in the eastern portion of the Congers Creek watershed, near the intersection of Taylor Spring Ln and Mountain Spring Ln. It has a drainage area of 21 acres, and it drains a highly impervious residential area (Figure 21). The proposed site is located in parcel number 125H-(23)- LA, in the center of a development of townhouses. An existing basin exists on this site; however, the proposed project would greatly increase storage capacity and improve downstream flood control. Attention to the safety and aesthetics would need to be considered for the proposed project.

Construction of stormwater management facilities at Taylor Springs and Kentshire Drive are recommended as a single combined project, as model results indicate that these combined facilities could remove 3 homes from the 10-year floodplain at a cost estimate of approximately \$87,000 per home benefited.



Figure21: Taylor Springs Site, looking northwest

Strategy 3: Amend Stormwater Management Regulations and Policy

Timmons Group evaluated the County's existing stormwater policies to determine areas where revisions may help alleviate some of the flooding issues on Conger's Creek and along other streams within the County and prevent similar issues from occurring in the future.

Stormwater Ordinance

As Rockingham County makes the transition to administering their own local Virginia Stormwater Management Program (VSMP) by July 1, 2014, regulations for stormwater management will strengthen. The methodologies used to design stormwater management facilities for new development will shift from performance-based methods to runoff volume reduction methods; thus helping to reduce future hydrologic impacts.

The County currently has a land disturbance threshold of 1-acre for requiring stormwater management. This threshold will remain under the new regulations; however the County may choose to reduce the threshold. For reference, the threshold for requiring Erosion and Sediment Control is 10,000 square feet (0.28 acres). Tidewater Localities (localities adjacent to the Chesapeake Bay) require a stormwater management plan for land disturbances exceeding 2,500 square feet.

Flood Districts

The County currently requires minimum elevations for finished floors and basements for all new development within designated Flood Districts. The County's flood districts correspond with delineated FEMA 100-year floodplains. The 100-year floodplain is typically mapped for waterways with a drainage area of 1 square mile or greater. Congers Creek, upstream of Lake Shenandoah (Study Reach), has drainage area of approximately 1.9 squares miles; however, it is not currently mapped on FEMA's flood maps. If the area had been previously mapped, it may have eliminated some of the low finished floor elevations that currently experience frequent flooding. The County should consider mapping the 100-year floodplain in this area such that existing homeowners better understand the flooding hazards associated with their properties and all new development along Congers Creek would be compliant with Flood District regulations. Such mapping is consistent with the National Flood Insurance Program (NFIP) regulations.

Establish Drainage District

The County may choose to create a drainage district wherein stricter water quantity requirements would exist for undeveloped land. For example, detention requirements can be increased to hold back the 25, 50, or 100-year storm flows. Other localities throughout Virginia have implemented similar districts to address pre-existing flooding issues.

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Land disturbance thresholds for requiring stormwater management can also be reduced within a specified district. For example, the existing land disturbance threshold of 1 acre could be reduced to 10,000 square feet (to match the Erosion and Sediment Control threshold) for development within a drainage district. This would increase the amount of stormwater management in the watershed and help reduce further flooding.

At a minimum, any established drainage district should require minimum floor elevations similar to a flood district, as mentioned above.

Strengthening stormwater requirements in select areas, however, may deter development as such requirements will the amount of stormwater management required on a site. The County will need to weigh the benefits of stricter regulations with the economic development goals of the County.



Funding Alternatives

As the County precedes with drainage improvement solutions and continues to develop its stormwater program, it will want to consider alternative funding sources. These sources may include state-funded grants or the creation of fee-based drainage districts and/or stormwater utilities.

Grants

Grants and cost-sharing options are frequently available to fund stormwater initiatives to localities within the Chesapeake Bay watershed. Most of these grants will focus on water quality improvements and, although Strategy 2 focuses primarily on water quantity, detention basins can be designed to incorporate water quality features to improve eligibility for such grants. There are also cost-sharing options with VDOT for projects that exist with state-maintained right-of-ways, such as those outlined in Strategy 1.

Districts

As discussed in Strategy 3, the creation of drainage/flooding district may be warranted to increase stormwater regulations in areas of known problems. These districts may also serve to collect fees from parcel owners to address the specific stormwater issues within the watershed. Often these fees are imposed as one-time costs to new development and not existing homeowners.

Utilities

Many localities across the state are beginning to form stormwater utilities. Unlike a district, a stormwater utility often covers the entire tax base of the locality and allows the locality to use collected revenue for various stormwater costs, including improvement projects or program administration. Many localities base their utility fee on the amount of existing impervious area per parcel. Other localities base their fee on a percentage of the assessed real estate value of a parcel.

Recommendations

Timmons Group recommends the County consider the following actions, presented in order of priority, to address flooding concerns within the Lake Shenandoah Watershed.

1. Map the 100-year floodplain for Congers Creek upstream of Lake Shenandoah

As discussed above, mapping the 100-year floodplain along Conger Creek will allow existing homeowners to better understand the flooding hazards associated with their properties. It should be noted, however, that some mortgage lenders may require homeowners to get flood insurance where they may not have prior to the mapping. Revised mapping will also ensure that all new development would be compliant with the County's existing Flood District regulations.

2. Establish drainage district for the Lake Shenandoah Watershed

A specified drainage district should be established that includes, at a minimum, a detention requirement that the 25-year post-development peak runoff rate is equal to or less than the 25-year pre-development peak runoff rate. The drainage district should also require all new development to set minimum floor (including basements) elevations for all structures; even those outside of a designated Flood District.

The district requirements should be established consistent with Minimum Standard 19 of the Erosion and Sediment Control Regulations (9VAC25-840-40), as well as the proposed Stormwater Management Regulations (9VAC25-870).

3. Retrofit the existing Kentshire Drive basin to maximize detention

As specified in Strategy 2 above, the existing detention basin on Kentshire Drive can be retrofitted to maximize peak flow detention to help minimize downstream impacts. Given the basin's location on a vacant lot and existing drainage patterns, the retrofit should be very feasible to implement – requiring little design and construction cost. The County may want to consider proffering the retrofit of this basin with future development

4. Retrofit the existing Taylor Springs basin to increase detention

As specified in Strategy 2 above, the existing basin at Taylor Springs can be retrofitted to maximize peak flow detention to help minimize downstream impacts. The existing basin is located in a centralized common space and will require coordination with the existing neighborhood and a balance between maximizing detention and maintaining the functional and aesthetic needs of the commons space.



5. Coordinate with VDOT to explore road crossing upgrades

The solutions outlined in Strategy I have a high implementation cost and do not provide any downstream water quality benefits. However, these solutions may be the only option for improving drainage at select residences. The County should coordinate with the Virginia Department of Transportation (VDOT) to explore options for revenue sharing to help offset the high costs of implementation. Partnering with VDOT on these solutions is plausible since undersized culverts and associated roadway flooding contribute, in part, to the residential flooding found along Congers Creek.



Appendix A

HEC-HMS Outputs

Existing Conditions

HEC-HMS Outputs - 2 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	32.3	18	0.36
DA1B	0.03	33.9	0	1.36
HC1	0.31	51.1	6	0.47
DA2	0.07	19.6	6	0.55
HC2	0.38	70.8	6	0.48
DA3A	0.02	7	0	0.61
DA3B	0.02	1.3	6	0.24
DA3C	0.03	6.4	6	0.47
HC3	0.44	84.6	6	0.48
DA4	0.02	4	6	0.38
HC4	0.46	88.6	6	0.47
DA5	0.03	10.4	6	0.56
HC5	0.49	99	6	0.48
DA6	0.01	4.4	0	0.57
HC6	0.50	103.1	6	0.48
DA7	0.01	1.7	6	0.54
HC7	0.51	104.8	6	0.48
DA8A	0.43	58.8	30	0.48
DA8B	0.14	36.9	12	0.55
HC8	0.57	82.3	18	0.5
DA9	0.06	9.1	12	0.41
HC9	0.63	90.7	18	0.49
HC10	1.13	174.9	12	0.48
DA10	0.27	41.2	18	0.45
DA11	0.11	24.8	12	0.49
HC11	1.51	237.2	12	0.48
DA12	0.16	40.5	12	0.57
HC12	1.67	277.7	12	0.49
DA13A	0.17	37.8	12	0.52
DA13B	0.05	11.9	12	0.55
HC13	1.88	327.4	12	0.49

Existing Conditions

HEC-HMS Outputs - 5 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	75.8	12	0.67
DA1B	0.03	48.8	0	1.96
HC1	0.31	101.5	6	0.81
DA2	0.07	37.5	6	0.93
HC2	0.38	139	6	0.83
DA3A	0.02	12.8	0	1.03
DA3B	0.02	4.1	6	0.5
DA3C	0.03	13.3	6	0.83
HC3	0.44	167	6	0.83
DA4	0.02	8.8	6	0.7
HC4	0.46	175.8	6	0.82
DA5	0.03	19.6	6	0.95
HC5	0.49	195.4	6	0.83
DA6	0.01	8.4	0	0.97
HC6	0.50	202.7	6	0.83
DA7	0.01	3.3	6	0.93
HC7	0.51	206	6	0.83
DA8A	0.43	119.9	24	0.84
DA8B	0.14	69.6	12	0.94
HC8	0.57	167.4	18	0.87
DA9	0.06	20.2	12	0.74
HC9	0.63	185	18	0.86
HC10	1.13	357.1	12	0.85
DA10	0.27	86.8	18	0.8
DA11	0.11	50.3	6	0.86
HC11	1.51	489	12	0.84
DA12	0.16	76.4	12	0.97
HC12	1.67	565.5	12	0.85
DA13A	0.17	73.9	12	0.9
DA13B	0.05	23	6	0.94
HC13	1.88	661.7	12	0.86

Existing Conditions

HEC-HMS Outputs - 10 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	124.6	12	0.99
DA1B	0.03	61.9	0	2.48
HC1	0.31	155.9	6	1.15
DA2	0.07	54.8	6	1.31
HC2	0.38	210.7	6	1.18
DA3A	0.02	18.4	0	1.42
DA3B	0.02	7.3	6	0.78
DA3C	0.03	20.1	6	1.18
HC3	0.44	252.9	6	1.17
DA4	0.02	13.6	0	1.03
HC4	0.46	266.5	6	1.17
DA5	0.03	28.4	6	1.34
HC5	0.49	294.9	6	1.18
DA6	0.01	12.3	0	1.35
HC6	0.50	305.3	6	1.18
DA7	0.01	4.9	6	1.31
HC7	0.51	310.2	6	1.18
DA8A	0.43	183.3	24	1.2
DA8B	0.14	101.3	12	1.32
HC8	0.57	253.8	18	1.23
DA9	0.06	31.6	12	1.08
HC9	0.63	280.7	18	1.22
HC10	1.13	543.8	12	1.2
DA10	0.27	132.9	18	1.15
DA11	0.11	76.6	6	1.22
HC11	1.51	746.7	12	1.19
DA12	0.16	111.3	12	1.35
HC12	1.67	858	12	1.21
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.88	999.8	12	1.22

Existing Conditions

HEC-HMS Outputs - 25 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	206.9	12	1.53
DA1B	0.03	81.4	0	3.28
HC1	0.31	247.4	12	1.72
DA2	0.07	82.4	6	1.92
HC2	0.38	329.7	6	1.75
DA3A	0.02	27.2	0	2.06
DA3B	0.02	12.7	6	1.25
DA3C	0.03	31.2	6	1.76
HC3	0.44	395	6	1.75
DA4	0.02	22.4	0	1.57
HC4	0.46	416.5	6	1.74
DA5	0.03	42.5	6	1.95
HC5	0.49	459	6	1.75
DA6	0.01	18.4	0	1.97
HC6	0.50	474.2	6	1.76
DA7	0.01	7.4	6	1.92
HC7	0.51	481.6	6	1.76
DA8A	0.43	287.2	24	1.79
DA8B	0.14	154.2	6	1.94
HC8	0.57	395	18	1.82
DA9	0.06	50.4	12	1.64
HC9	0.63	437	18	1.81
HC10	1.13	850.1	12	1.79
DA10	0.27	208.7	12	1.73
DA11	0.11	119.3	6	1.81
HC11	1.51	1169.1	12	1.78
DA12	0.16	167	12	1.97
HC12	1.67	1336.1	12	1.8
DA13A	0.17	166.3	12	1.87
DA13B	0.05	51.9	6	1.93
HC13	1.88	1551	12	1.8

Existing Conditions

HEC-HMS Outputs - 100 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	375	12	2.63
DA1B	0.03	116.6	0	4.77
HC1	0.31	432.3	6	2.85
DA2	0.07	136.5	6	3.14
HC2	0.38	568.8	6	2.9
DA3C	0.03	53.2	6	2.93
DA3A	0.02	44.2	0	3.31
DA3B	0.02	24.3	0	2.25
HC3	0.44	680	6	2.9
DA4	0.02	40.3	0	2.69
HC4	0.46	717.2	6	2.89
DA5	0.03	70	6	3.18
HC5	0.49	787.2	6	2.91
DA6	0.01	30.4	0	3.2
HC6	0.50	811.7	6	2.91
DA7	0.01	12.3	6	3.13
HC7	0.51	824	6	2.92
DA8A	0.43	494.3	24	2.96
DA8B	0.14	259.5	6	3.16
HC8	0.57	676	18	3.01
DA9	0.06	88	12	2.77
HC9	0.63	749.1	12	2.99
HC10	1.13	1471.9	6	2.96
DA10	0.27	366	12	2.89
DA11	0.11	204	6	2.99
HC11	1.51	2012.6	12	2.95
DA12	0.16	275.8	12	3.2
HC12	1.67	2288.4	12	2.97
DA13A	0.17	278.3	12	3.07
DA13B	0.05	87.1	6	3.15
HC13	1.88	2646.7	12	2.98

Anticipated Conditions

HEC-HMS Outputs - 2 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	104.5	12	0.79
DA1B	0.03	33.9	0	1.36
HC1	0.31	122.1	12	0.85
DA2	0.07	19.6	6	0.55
HC2	0.38	138.7	12	0.8
DA3C	0.03	13.4	6	0.79
DA3A	0.02	9.8	0	0.79
DA3B	0.02	8.2	6	0.79
HC3	0.44	168	6	0.8
DA4	0.02	10.9	0	0.79
HC4	0.46	178.6	6	0.8
DA5	0.03	10.4	6	0.56
HC5	0.49	189.1	6	0.78
DA6	0.01	4.4	0	0.57
HC6	0.50	193.2	6	0.77
DA7	0.01	1.7	6	0.54
HC7	0.51	194.9	6	0.77
DA8A	0.43	58.8	30	0.48
DA8B	0.14	36.9	12	0.55
HC8	0.57	82.3	18	0.5
DA9	0.06	9.1	12	0.41
HC9	0.63	90.7	18	0.49
HC10	1.13	263.6	12	0.62
DA10	0.27	41.2	18	0.45
DA11	0.11	24.8	12	0.49
HC11	1.51	325.8	12	0.58
DA12	0.16	40.5	12	0.57
HC12	1.67	366.3	12	0.58
DA13A	0.17	37.8	12	0.52
DA13B	0.05	11.9	12	0.55
HC13	1.88	416	12	0.57

Anticipated Conditions

HEC-HMS Outputs - 5 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	175.6	12	1.25
DA1B	0.03	48.8	0	1.96
HC1	0.31	200.5	12	1.33
DA2	0.07	37.5	6	0.93
HC2	0.38	234.3	6	1.26
DA3C	0.03	22.2	6	1.25
DA3A	0.02	16.3	0	1.25
DA3B	0.02	13.7	0	1.25
HC3	0.44	282.9	6	1.26
DA4	0.02	18.4	0	1.25
HC4	0.46	300.2	6	1.26
DA5	0.03	19.6	6	0.95
HC5	0.49	319.8	6	1.24
DA6	0.01	8.4	0	0.97
HC6	0.50	327.1	6	1.23
DA7	0.01	3.3	6	0.93
HC7	0.51	330.4	6	1.23
DA8A	0.43	119.9	24	0.84
DA8B	0.14	69.6	12	0.94
HC8	0.57	167.4	18	0.87
DA9	0.06	20.2	12	0.74
HC9	0.63	185	18	0.86
HC10	1.13	475.7	12	1.02
DA10	0.27	86.8	18	0.8
DA11	0.11	50.3	6	0.86
HC11	1.51	607.6	12	0.97
DA12	0.16	76.4	12	0.97
HC12	1.67	684	12	0.97
DA13A	0.17	73.9	12	0.9
DA13B	0.05	23	6	0.94
HC13	1.88	780.3	12	0.96

Anticipated Conditions

HEC-HMS Outputs - 10 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	242.2	12	1.69
DA1B	0.03	61.9	0	2.48
HC1	0.31	273.4	12	1.77
DA2	0.07	54.8	6	1.31
HC2	0.38	324.5	6	1.69
DA3C	0.03	30.5	6	1.69
DA3A	0.02	22.3	0	1.69
DA3B	0.02	18.9	0	1.69
HC3	0.44	390.7	6	1.69
DA4	0.02	25.4	0	1.69
HC4	0.46	414.1	6	1.69
DA5	0.03	28.4	6	1.34
HC5	0.49	442.5	6	1.67
DA6	0.01	12.3	0	1.35
HC6	0.50	452.9	6	1.66
DA7	0.01	4.9	6	1.31
HC7	0.51	457.8	6	1.66
DA8A	0.43	183.3	24	1.2
DA8B	0.14	101.3	12	1.32
HC8	0.57	253.8	18	1.23
DA9	0.06	31.6	12	1.08
HC9	0.63	280.7	18	1.22
HC10	1.13	684.3	6	1.41
DA10	0.27	132.9	18	1.15
DA11	0.11	76.6	6	1.22
HC11	1.51	885.8	12	1.35
DA12	0.16	111.3	12	1.35
HC12	1.67	997.1	12	1.35
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.88	1138.9	12	1.34

Anticipated Conditions

HEC-HMS Outputs - 25 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	346	12	2.38
DA1B	0.03	81.4	0	3.28
HC1	0.31	386.5	12	2.47
DA2	0.07	82.4	6	1.92
HC2	0.38	465.8	6	2.38
DA3C	0.03	43.3	6	2.38
DA3A	0.02	31.7	0	2.38
DA3B	0.02	27.1	0	2.38
HC3	0.44	559.1	6	2.38
DA4	0.02	36.4	0	2.38
HC4	0.46	592.1	6	2.38
DA5	0.03	42.5	6	1.95
HC5	0.49	634.6	6	2.35
DA6	0.01	18.4	0	1.97
HC6	0.50	649.8	6	2.34
DA7	0.01	7.4	6	1.92
HC7	0.51	657.2	6	2.33
DA8A	0.43	287.2	24	1.79
DA8B	0.14	154.2	6	1.94
HC8	0.57	395	18	1.82
DA9	0.06	50.4	12	1.64
HC9	0.63	437	18	1.81
HC10	1.13	1023.1	6	2.04
DA10	0.27	208.7	12	1.73
DA11	0.11	119.3	6	1.81
HC11	1.51	1333.2	12	1.97
DA12	0.16	167	12	1.97
HC12	1.67	1500.2	12	1.97
DA13A	0.17	166.3	12	1.87
DA13B	0.05	51.9	6	1.93
HC13	1.88	1715.1	12	1.96

Anticipated Conditions

HEC-HMS Outputs - 100 year flood				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	543.3	12	3.7
DA1B	0.03	116.6	0	4.77
HC1	0.31	600.4	12	3.82
DA2	0.07	136.5	6	3.14
HC2	0.38	735.9	6	3.7
DA3C	0.03	67.4	6	3.7
DA3A	0.02	49.5	0	3.7
DA3B	0.02	42.7	0	3.7
HC3	0.44	880.4	6	3.7
DA4	0.02	57.2	0	3.7
HC4	0.46	931.2	6	3.7
DA5	0.03	70	6	3.18
HC5	0.49	1001.2	6	3.66
DA6	0.01	30.4	0	3.2
HC6	0.50	1025.7	6	3.65
DA7	0.01	12.3	6	3.13
HC7	0.51	1038	6	3.65
DA8A	0.43	494.3	24	2.96
DA8B	0.14	259.5	6	3.16
HC8	0.57	676	18	3.01
DA9	0.06	88	12	2.77
HC9	0.63	749.1	12	2.99
HC10	1.13	1685.9	6	3.28
DA10	0.27	366	12	2.89
DA11	0.11	204	6	2.99
HC11	1.51	2210.2	12	3.19
DA12	0.16	275.8	12	3.2
HC12	1.67	2485.9	12	3.19
DA13A	0.17	278.3	12	3.07
DA13B	0.05	87.1	6	3.15
HC13	1.88	2844.2	12	3.18

BMP Scenarios

HEC-HMS Outputs - 10 year flood / BMP 23				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	124.6	12	0.99
DA1B	0.03	61.9	0	2.48
HC1	0.31	155.9	6	1.15
DA2	0.07	54.8	6	1.31
HC2	0.38	210.7	6	1.18
DA3C	0.03	20.1	6	1.18
DA3A	0.02	18.4	0	1.42
DA3B	0.02	7.3	6	0.78
HC3	0.44	252.9	6	1.17
DA4	0.02	13.6	0	1.03
HC4	0.46	266.5	6	1.17
DA5	0.03	28.4	6	1.34
HC5	0.49	294.9	6	1.18
DA6	0.01	12.3	0	1.35
HC6	0.50	305.3	6	1.18
DA7	0.01	4.9	6	1.31
HC7	0.51	310.2	6	1.18
DA8A	0.43	183.3	24	1.2
DA8B	0.14	101.3	12	1.32
HC8	0.57	253.8	18	1.23
DA9	0.06	31.6	12	1.08
HC9	0.63	280.7	18	1.22
HC10	1.13	543.8	12	1.2
DA10	0.27	132.9	18	1.15
BMP10	0.27	52.7	48	1.13
DA11	0.11	76.6	6	1.22
HC11	1.51	637.3	12	1.19
DA12	0.16	111.3	12	1.35
HC12	1.67	748.6	12	1.21
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.8819315	890.4	12	1.21

BMP Scenarios

HEC-HMS Outputs - 10 year flood / BMP 7 and 9				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	124.6	12	0.99
DA1B	0.03	61.9	0	2.48
BMP1B	0.03	6.8	42	2.35
HC1	0.31	131.1	12	1.14
DA2	0.07	54.8	6	1.31
BMP2	0.07	21.8	24	1.3
HC2	0.38	152.2	12	1.17
DA3C	0.03	20.1	6	1.18
DA3A	0.02	18.4	0	1.42
DA3B	0.02	7.3	6	0.78
HC3	0.44	182.1	12	1.16
DA4	0.02	13.6	0	1.03
HC4	0.46	191	12	1.16
DA5	0.03	28.4	6	1.34
HC5	0.49	214.1	6	1.17
DA6	0.01	12.3	0	1.35
HC6	0.50	224.5	6	1.17
DA7	0.01	4.9	6	1.31
HC7	0.51	229.3	6	1.18
DA8A	0.43	183.3	24	1.2
DA8B	0.14	101.3	12	1.32
HC8	0.57	253.8	18	1.23
DA9	0.06	31.6	12	1.08
HC9	0.63	280.7	18	1.22
HC10	1.13	496.9	12	1.2
DA10	0.27	132.9	18	1.15
DA11	0.11	76.6	6	1.22
HC11	1.51	699.7	12	1.19
DA12	0.16	111.3	12	1.35
HC12	1.67	811	12	1.21
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.8819315	952.8	12	1.21

BMP Scenarios

HEC-HMS Outputs - 10 year flood / BMP 22				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	124.6	12	0.99
DA1B	0.03	61.9	0	2.48
HC1	0.31	155.9	6	1.15
DA2	0.07	54.8	6	1.31
HC2	0.38	210.7	6	1.18
DA3C	0.03	20.1	6	1.18
DA3A	0.02	18.4	0	1.42
DA3B	0.02	7.3	6	0.78
HC3	0.44	252.9	6	1.17
DA4	0.02	13.6	0	1.03
HC4	0.46	266.5	6	1.17
DA5	0.03	28.4	6	1.34
HC5	0.49	294.9	6	1.18
DA6	0.01	12.3	0	1.35
HC6	0.50	305.3	6	1.18
DA7	0.01	4.9	6	1.31
HC7	0.51	310.2	6	1.18
DA8A	0.43	183.3	24	1.2
BMP8A	0.43	35.6	114	1.06
DA8B	0.14	101.3	12	1.32
HC8	0.57	102.9	12	1.12
DA9	0.06	31.6	12	1.08
HC9	0.63	134.5	12	1.12
HC10	1.13	441	6	1.15
DA10	0.27	132.9	18	1.15
DA11	0.11	76.6	6	1.22
HC11	1.51	620.5	6	1.15
DA12	0.16	111.3	12	1.35
HC12	1.67	724.7	6	1.17
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.88	863.4	6	1.18

BMP Scenarios

HEC-HMS Outputs - 10 year flood / BMP 20				
Hydrologic Element	Drainage Area (Sq. Mi)	Peak Discharge (CFS)	Time to peak (minutes)	Volume (in)
DA1A	0.28	124.6	12	0.99
BMP1A	0.28	10.4	96	0.86
DA1B	0.03	61.9	0	2.48
HC1	0.31	62.2	0	1.03
DA2	0.07	54.8	6	1.31
HC2	0.38	108.8	6	1.08
DA3C	0.03	20.1	6	1.18
DA3A	0.02	18.4	0	1.42
DA3B	0.02	7.3	6	0.78
HC3	0.44	151	6	1.09
DA4	0.02	13.6	0	1.03
HC4	0.46	164.6	6	1.09
DA5	0.03	28.4	6	1.34
HC5	0.49	193	6	1.1
DA6	0.01	12.3	0	1.35
HC6	0.50	203.4	6	1.11
DA7	0.01	4.9	6	1.31
HC7	0.51	208.3	6	1.11
DA8A	0.43	183.3	24	1.2
DA8B	0.14	101.3	12	1.32
HC8	0.57	253.8	18	1.23
DA9	0.06	31.6	12	1.08
HC9	0.63	280.7	18	1.22
HC10	1.13	434.8	6	1.17
DA10	0.27	132.9	18	1.15
DA11	0.11	76.6	6	1.22
HC11	1.51	626.2	12	1.17
DA12	0.16	111.3	12	1.35
HC12	1.67	737.5	12	1.19
DA13A	0.17	109.3	12	1.27
DA13B	0.05	34.1	6	1.32
HC13	1.88	879.3	12	1.2



Appendix B

HEC-RAS Outputs

