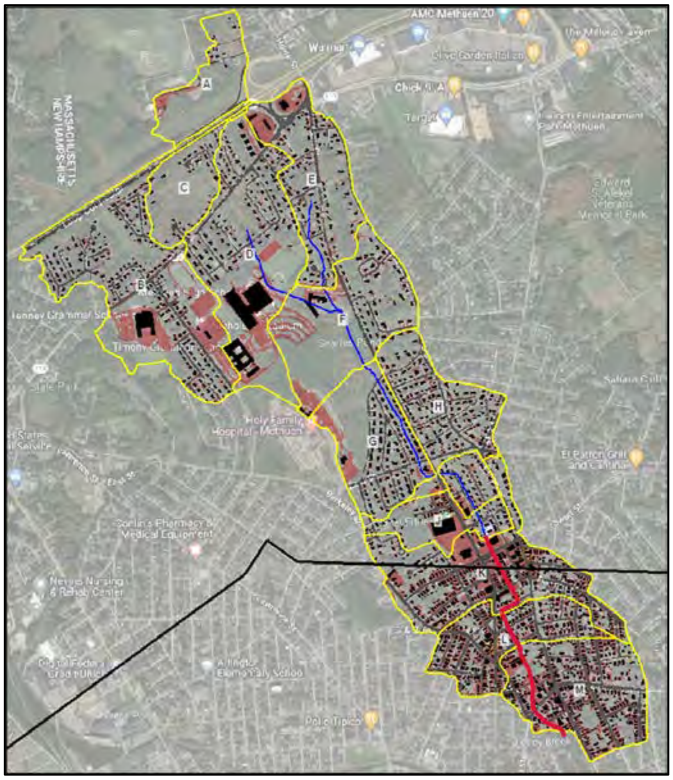
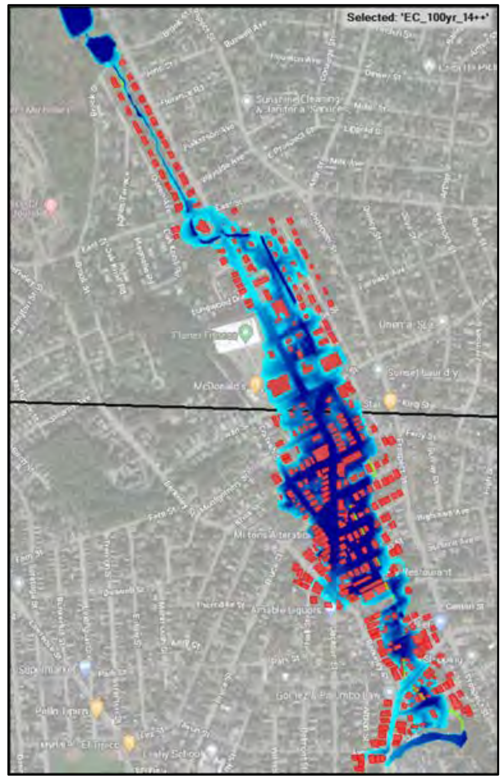
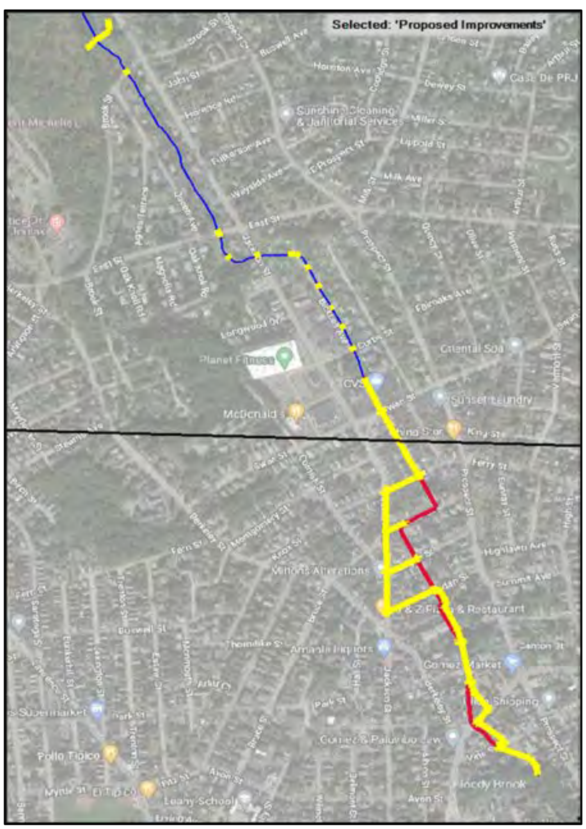
PREPARED FOR: CITY OF METHUEN

BLOODY BROOK WATERSHED PLANNING STUDY
Methuen, Massachusetts







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1.0 BLOODY BROOK CORRIDOR – AN OVERVIEW

The Bloody Brook Corridor is a section of stream channel located in and through the cities of Methuen and Lawrence that extends from near the MA-213/MA-113 Interchange at its upstream reaches to its discharge location at the Spicket River located just downstream of Vine Street in Lawrence. The corridor is comprised of three primary reaches as defined below. Photographs of the various components of each reach are included as an attachment to this memorandum.

1.1 Reach 1 – Upstream of Searles Pond Dam

The first reach, which is the reach that is furthest upstream (north), is a 1-mile stretch of stream channel that extends from MA-113 to Searles Pond Dam that has a contributing drainage area of 0.65 square miles. The watershed is comprised primarily of developed land including residential neighborhoods of medium to high intensity development and several school sites including Methuen High School. Surrounding the developed land is woodlands and wooded wetlands.

The primary hydraulic structure within the watershed and focus of the scope of work for this Section is Searles Pond Dam. The dam was constructed in 1979 by the City of Methuen with its primary purpose being flood control for the downstream communities surrounding Bloody Brook. The dam is an 8-foot high earthen embankment dam with a 2-foot diameter low level outlet pipe, a 3-foot diameter spillway pipe, and an impoundment storage capacity of 30 acre-feet.

Based upon review of available information, there has not been any flooding concerns within this portion of the watershed/corridor and there has been no known history of dam overtopping or significantly elevated pool levels within the impoundment.

1.2 Reach 2 – Searles Pond Dam to Swan Street

The second/middle reach is a 0.6-mile stretch of stream channel that extends from Searles Pond Dam to the Bloody Brook Culvert just upstream (north) of the CVS parking Lot off and north of Swan Street. The direct contributing drainage area of this reach is 0.18 square miles and is primarily storm drainage systems and overland flow within a residential and commercial area of relatively high intensity development.

The corridor along this reach is comprised of variable lengths of man-made open channel spanning between 9 culvert sections, as broken down below:

Section	Features	Notes
1. Open Channel from SPD to Brook Street	Natural stream channel through wooded wetlands	Generally, no issues identified
2. Brook Street Culvert	2’x3’ stone box culvert	The stones of the culvert are partially dislodged, further reducing its already limited hydraulic capacity
3. Open Channel from Brook Street to East Street	Man-made / man-modified channel through a wooded area and residential development.	The channel has several sections that are debris prone, overgrown, have limited hydraulic capacity, and/or are subject to stream bank erosion and sedimentation.

4. East Street Culvert	Twin 3’ RCP’s	There is limited hydraulic capacity as well as sedimentation and debris issues within the upstream and downstream approaches as well as at the culvert itself
5. Channel and Culvert through Jehovah’s Witness Property	Man-made / man-modified channel through a paved parking lot with a 3’ CMP culvert at mid-length.	The channel is debris prone, overgrown, has limited hydraulic capacity, and is subject to stream bank erosion and sedimentation.
6. Jackson Street Culvert	8-foot CMP arch; height is only 1-2 feet.	There is sedimentation and debris issues within the upstream and downstream approaches as well as at the culvert itself.
7. Channel and Culverted Sections along Bicknell Ave from Jackson Street to Curtis Street	Man-made / man-modified channel through residential development with five (5) 3.5’ CMP driveway culvert crossings.	The channel has limited hydraulic capacity and sedimentation and stream bank erosion issues along its entire length.
8. Channel from Curtis Street to the Inlet of the Bloody Brook Culvert	Man-made / man-modified channel through a wooded area.	The channel is overgrown and has sedimentation and stream bank erosion issues along its entire length.

Based upon reported information, high impact/damage flooding occurs, routinely along this reach of the corridor; the flooding results in damages to both residential and commercial properties as well as stresses to the transportation system including necessary road closures with detours.

1.3 Reach 3 – Bloody Brook Culvert

The third reach is the “Bloody Brook Culvert” that extends underground for 0.7 miles from its inlet just upstream (north) of Swan Street to its outfall location at the Spickett River. Along its length, the culvert passes beneath both residential and commercial properties along Swan Street, Knox Street, Custer Street, Logan Street, Sheridan Street, Howe/Berkley Court, Webster Court, Keighley Court, East Haverill Street, and Vine Street. The direct contributing drainage area to this reach is 0.35 square miles and is entirely storm drainage systems feeding into the culvert.

The culvert itself starts off as two 4-foot pipes (one primary RCP and one high level HDPE) that transitions to a 4.5’wx5.3’h concrete box culvert.

Based upon review of available information, the flooding concerns along this reach are primarily driven by debris and/or capacity limitations at the inlet end as well as out of bank flooding that occurs via overland flows from reach 2 into reach 3 as well as reach 3 alone.

2.0 EXISTING CONDITIONS H&H MODELING

H&H modelling of the existing conditions of the Bloody Brook Corridor was completed as part of this project; the following provides a general overview of the model development and results.

2.1 Model Development

As depicted in Graphic #1, the drainage area was divided into 13 subbasins (A thru M).

- The first 6 (A thru F) are located upstream (and contribute to) the Searles Pond Dam and its impoundment; a total contributing drainage area of 418 acres (0.65 mi^2).
- The last 7 (G thru M) are located downstream of the dam and mainly contribute to storm drainage systems and/or overland flow that eventually discharge into the Bloody Brook.
  - Subbasins G, H, and I contribute to storm drainage systems that feed into the open stretch of brook between East Street and Curtis Street. The total area of these three is 118 acres (0.18 mi^2)
  - Subbasins J thru M contribute to storm drainage systems that discharge into the underground Bloody Brook Culvert (BBC); subbasin J at Curtis Street, subbasin K at Knox Street, subbasin L at Logan Street, and subbasin M at Vine Street. The total area of these four is 221 acres (0.35 mi^2)

Graphic #2 provides a tabulated summary of all 13 subbasins. In addition to the subbasins, 33 hydraulic structures were included within the model, as shown in Graphic #4. These hydraulic structures include the Searles Pond Dam, stream crossings (roadways and unnamed embankments), other storage areas (wetlands and slow-moving reaches), as well certain components of the downstream storm drainage systems that feed into the brook.

The 13 subbasins, along with a total of 33 hydraulic structures within the study area, were combined into a single HydroCAD model of the corridor (See Graphic #4 for the Routing Diagram of the Model). In addition to the HydroCAD model, a supplemental HEC-RAS 2D model was developed to better represent and determine the lateral extent of flooding along the corridor.

The modeling was completed utilizing both current rainfall data (NOAA Atlas 14) as well as climate change informed predicted future (CCIPF) rainfall data (NOAA Atlas 14++). Graphic #3 provides a tabulated summary/comparison of the rainfall depth values of both rainfall data sets. Results of each are presented below.

2.2 Model Results – Current Rainfall Data (NOAA Atlas 14)

A broad overview of the model results for each specific areas along the corridor is provided below.

Area ID	Area Description	Capacity Exceedance	Notes
1	***US of SPD***[1]	Varies	Significant amount of peak flow attenuation in subbasins upstream of dam.
2	***SPD***	50yr – 100yr	Dam overtops by 0.6 feet during 100 yr. and 1.9 feet during 1,000 yr.

			Dam and impoundment offer significant amount of peak flow attenuation.
3	***Brook St.***	10yr – 25yr	Roadway overtops by 0.4 feet during the 25yr and 1.5 feet during the 1,000 yr.
4	***East St.***	5yr – 10yr	Roadway overtops by 0.4 feet during the 10-year and 1.3 feet during the 1,000 yr. *Although road does not begin overtopping from brook flow until the 10yr event, surface flooding occurs during lower storms (1 yr.+) due to the limited capacity of the storm drainage system within Subbasin G. Most overtopping flow flows along East Street and down Jackson Street and ponds at Swan Street.*
5	***JW PL***[2]	1yr – 2yr	Parking lot flooding depth is 0.3 feet during the 2 yr. and 1.2 feet during the 1000 yr.
6	***Jackson St***	2yr – 5yr	Roadway overtops by 0.4 feet during the 5 yr. and 1.6 feet during the 1,000 yr. *Although the road doesn't begin overtopping from brook flow until the 5yr event, surface flooding likely occurs during lower storms (1yr+) due to limited capacity of storm drainage system within Subbasin H. Overtopping flow flows along Jackson Street and ponds at Swan Street.*
7	***Bicknell***	< 1yr	Roadway / yard flooding depth is 0.5 feet during the 1 yr. and 2.5 feet during the 1,000 yr.
8	***Curtis***	1yr – 2yr	Roadway flooding depth is 0.5 feet during the 2 yr. and 2.7 feet during the 1,000yr
9	***BBC***[3] ***Inlet***	2yr – 5yr	Out of bank flooding depth upstream of the inlet is 0.5 feet at the 5 yr. and 3.0 feet at the 1,000 yr.
10	***Swan***	1yr – 2yr	Roadway flooding is 0.2 feet at the 2 yr. and 3.9 feet at the 1,000 yr. (*See Note 4)*
11	***Knox***	2yr – 5yr	Roadway flooding is 1 foot at the 5 yr. and 4.5 feet at the 1,000 yr. *(See Note 4)*
12	***Logan***	2yr – 5yr	Roadway flooding is 0.5 feet at the 5 yr. and 5.3 feet at the 1,000 yr. *(See Note 4)*
13	***Vine***	5yr – 10yr	Roadway flooding is 0.2 feet at the 10 yr. and 3.5 feet at the 1,000 yr.
1) Seales Pond Dam / 2) Jehovah's Witness Parking Lot / 3) Bloody Brook Culvert			
4) Bloody Brook Culvert is fully charged during the 5-year event.			

2.2.1 General Conclusions

The following general conclusions were drawn from the model results:

1. The Bloody Brook Corridor from East Street to its outfall at the Spicket River has limited hydraulic capacity that is driven by both limited capacities of each of the individual crossings as well as tailwater conditions that impact the system as a whole. Hydraulic capacity varies across the system from 5-year capacity at East Street to as low as <1-year capacity at the Bicknell Ave crossings.

2. The Bloody Brook Culvert has limited capacity that is driven both by specific individual sections that have limited capacity *(lowest capacity sections are the sections from Inlet to Conduit Street, and the sections from Logan Street to East Haverhill)* as well as tailwater conditions that are created by contributions of the downstream drainage areas *(K at Knox Street and L at Logan Street).*
    a. Combining these two conditions; the culvert only has capacity to accommodate a 2-year storm event; storm events larger than the 2-year result in surcharging of specific sections of the culvert that results in street flooding as all the storm drainage systems attempt to feed into this culvert.

Graphics #5 - #14 attached show the lateral extent of inundation during these various storm events.

2.3 Model Results – Climate Change Informed Predicted Future (CCIPF) Rainfall Data (NOAA Atlas 14++)

A broad overview of the model results utilizing the CCIPF rainfall data for each specific areas along the corridor is provided below:

Area ID	Area Description	Capacity Exceedance	Notes
1	***US of SPD***[1]	Varies	Significant amount of peak flow attenuation in subbasins upstream of dam.
2	***SPD***	10yr – 25yr	Dam overtops by 0.7 feet during 25yr and 2.5 feet during 1,000yr. *Dam and impoundment offer significant amount of peak flow attenuation.*
3	***Brook St.***	5yr – 10yr	Roadway overtops by 0.5 feet during the 10yr and 2.0 feet during the 1,000yr.
4	***East St.***	2yr – 5yr	Roadway overtops by 0.4 feet during the 5-year and 2.0 feet during the 1,000yr. *Although road doesn't begin overtopping from brook flow until the 5yr event, surface flooding occurs during lower storms (<1yr) due to the limited capacity of the storm drainage system*

			within Subbasin G. Most overtopping flow flows along East Street and down Jackson Street and ponds at Swan Street.
5	***JW PL[2]***	< 1yr	Parking lot flooding depth is 0.3 feet during the 1yr and 1.7 feet during the 1000yr.
6	***Jackson St***	1yr – 2yr	Roadway overtops by 0.4 feet during the 2yr and 2.3 feet during the 1,000yr. *Although the road doesn't begin overtopping from brook flow until the 2yr event, surface flooding likely occurs during lower storms (<1yr) due to limited capacity of storm drainage system within Subbasin H. Overtopping flow flows along Jackson Street and ponds at Swan Street.*
7	***Bicknell***	< 1yr	Roadway / yard flooding depth is 1 foot during the 1yr and 3.5 feet during the 1,000yr
8	***Curtis***	< 1yr	Roadway flooding depth is 0.7 feet during the 1yr and 4.5 feet during the 1,000yr
9	***BBC[3] Inlet***	1yr – 2yr	Out of bank flooding depth upstream of the inlet is 0.3 feet at the 2yr and 3.5 feet at the 1,000yr
10	***Swan***	< 1yr	Roadway flooding is 0.3 feet at the 1yr and 5.1 feet at the 1,000yr. (*See Note 4)*
11	***Knox***	1yr – 2yr	Roadway flooding is 1 feet at the 2yr and 5.7 feet at the 1,000yr *(See Note 4)*
12	***Logan***	1yr – 2yr	Roadway flooding is 0.4 feet at the 2yr and 6.3 feet at the 1,000yr *(See Note 4)*
13	***Vine***	2yr – 5yr	Roadway flooding is 0.5 feet at the 5yr and 4.0 feet at the 1,000yr
1) Seales Pond Dam / 2) Jehovah's Witness Parking Lot / 3) Bloody Brook Culvert			
4) Bloody Brook Culvert is fully charged during the 2-year event.			

2.3.1 General Conclusions

As expected, the model using the CCIPF rainfall data set placed far more strain on the Bloody Brook Corridor. Generally, it brought the capacity level of the various components down a full storm event (in some instances, two storm events). For example, the BBC Inlet, whose capacity is expected to be exceeded between a 2-year and 5-year storm event under current rainfall conditions will be expected to be exceeded between a 1-year and 2-year storm event under the CCIPF rainfall conditions.

Graphics #15 - #24 attached show the lateral extent of inundation during these various storm events.

3.0 FLOOD RELATED DAMAGE ASSESSMENT

A preliminary planning level assessment of the structure related damage expected for each recurrent storm event was completed utilizing the H&H model results, a structure inventory that was compiled from available assessor's and GIS data, and a FEMA sourced generic flood depth – percent damage curve[1]. The following sections provide a summary of the results of this planning level assessment for both the current rainfall data and the CCIPF rainfall data.

3.1 Damage Assessment with Current Rainfall (NOAA Atlas 14)

The table below presents the results of this preliminary planning level assessment of flood related flood damage at the structure level under existing conditions utilizing current rainfall data:

Existing Conditions - Preliminary Planning Level Damage Assessment (Structural Damage Only) (Current Rainfall)

		Structures Inundated	Total Damages	EAD	% of Total EAD	PVI
	Methuen	*4*	*$ 317,344*	*$ 244,787*	*11.6%*	
1-year	*Lawrence*	*0*	*$ -*	*$ -*	*0.0%*	
	Total	***4***	***$ 317,344***	***$ 244,787***	***11.6%***	$ 8,963,000
	Methuen	*5*	*$ 663,768*	*$ 278,856*	*13.2%*	
2-year	*Lawrence*	*0*	*$ -*	*$ 369,397*	*17.5%*	
	Total	***5***	***$ 663,768***	***$ 648,254***	***30.7%***	$ 23,736,000
	Methuen	*15*	*$ 1,195,273*	*$ 133,463*	*6.3%*	
5-year	*Lawrence*	*24*	*$ 2,462,649*	*$ 310,582*	*14.7%*	
	Total	***39***	***$ 3,657,922***	***$ 444,045***	***21.0%***	$ 16,259,000
	Methuen	*18*	*$ 1,473,988*	*$ 95,303*	*4.5%*	
10-year	*Lawrence*	*54*	*$ 3,748,994*	*$ 293,858*	*13.9%*	
	Total	***72***	***$ 5,222,982***	***$ 389,161***	***18.4%***	$ 14,249,000
	Methuen	*21*	*$ 1,702,782*	*$ 35,434*	*1.7%*	
25-year	*Lawrence*	*99*	*$ 6,046,284*	*$ 131,653*	*6.2%*	
	Total	***120***	***$ 7,749,066***	***$ 167,087***	***7.9%***	$ 6,118,000
	Methuen	*26*	*$ 1,840,606*	*$ 19,698*	*0.9%*	
50-year	*Lawrence*	*107*	*$ 7,119,065*	*$ 75,976*	*3.6%*	
	Total	***133***	***$ 8,959,672***	***$ 95,674***	***4.5%***	$ 3,504,000
	Methuen	*33*	*$ 2,098,919*	*$ 11,129*	*0.5%*	
100-year	*Lawrence*	*113*	*$ 8,076,234*	*$ 43,507*	*2.1%*	
	Total	***146***	***$ 10,175,153***	***$ 54,636***	***2.6%***	$ 2,001,000
	Methuen	*40*	*$ 2,352,546*	*$ 8,100*	*0.4%*	
200-year	*Lawrence*	*125*	*$ 9,326,575*	*$ 30,389*	*1.4%*	
	Total	***165***	***$ 11,679,120***	***$ 38,489***	***1.8%***	$ 1,410,000
	Methuen	*52*	*$ 3,047,653*	*$ 6,201*	*0.3%*	
500-year	*Lawrence*	*133*	*$ 10,932,804*	*$ 21,987*	*1.0%*	
	Total	***185***	***$ 13,980,457***	***$ 28,187***	***1.3%***	$ 1,033,000
	Methuen	*57*	*$ 3,479,520*	*$ 348*	*0.0%*	
1,000-year	*Lawrence*	*137*	*$ 12,210,963*	*$ 1,221*	*0.1%*	
	Total	***194***	***$ 15,690,484***	***$ 1,569***	***0.1%***	$ 58,000
Totals				***$ 2,111,891***	***/year***	**$ 77,331,000**
				$ 833,319	39%	Methuen
				$ 1,278,572	61%	Lawrence

1 A single depth-damage curve was used for each structure for this planning level assessment. The curve selected is that for a two-story, no basement, residential structure. The refined damage assessment that would be completed during subsequent planning/design will build a structure specific depth-damage curve for each individual structure. Additionally, the refined assessment would verify first floor elevations for all structures; the current assessment used LiDAR terrain data around the perimeter of each structure, which may differ from the actual first floor elevation at some structures.

The table shows the following:

1. The expected annual damage (EAD) is just over $2.1M. Approximately $0.8M or 39% of this damage is located in Methuen while the remaining $1.3M or 61% is located in Lawrence.

2. An EAD of $2.1M results in a Present Value Investment cost of $77M; meaning that a mitigation project geared to solve this flooding issue with implementation cost as much as $77M would still have a net benefit.

3. The bulk of this EAD is at the more frequent (more likely to occur) recurrent storm events; as shown in the following breakdown:

Category	EAD	PVI	% of Total
5-year and lower	$1.3M	$49M	64%
5-year – 10-year	$0.4M	$14M	18%
10-year – 25-year	$0.2M	$6M	8%
25-year – 50-year	$0.1M	$4M	5%
50-year – 100-year	$0.05M	$2M	3%
100-year +	$0.07M	$3M	4%

The EAD is lower for the less frequent (less likely to occur) recurrent storm events (i.e. 50-year, 100-year, 500-year, etc.). While the total damages of those storms are significant ($9M - $16M), the probability of the storm occurring is relatively low; as such, the contribution to EAD is less. Therefore, while EAD associated with less frequent storms is low, the high damages despite low risk likely justify designing to accommodate rare storm events.

4. Damages are only reported at the structure level and do not take into account other types of damages that are likely to occur during these various recurrent storm events. Once evaluated and accounted for, these other types of damages could be economically, societally, and environmentally significant. Examples of these other types of damages include, but are not limited to, the following:

    a. Economical:
        i. Infrastructure related damages to roadways and utilities
        ii. Monetary costs associated with Societal and Environmental damages

    b. Societal:
        i. Individual: Potential direct or indirect loss of life, impacts to quality of life and mental health
        ii. Emergency Response: Restricted access to individual homes and entire blocks
        iii. Community: Negative community-based impacts such as viewing the community poorly, potential desire for individuals to relocate out of the community

    c. Environmental:
        i. Release and spread of hazardous materials such as wastewater, petrochemicals, and other hazardous material within the inundation zones

3.2 Damage Assessment with Climate Change Informed Predicted Future (CCIPF) Rainfall Data (NOAA Atlas 14++)

The table below presents the results of this preliminary planning level assessment of flood related flood damage at the structure level under existing conditions utilizing the CCIPF rainfall data set:

Existing Conditions - Preliminary Planning Level Damage Assessment (Structural Damage Only) (Climate Change Informed Rainfall)						
		Structures Inundated	**Total Damages**	**EAD**	**% of Total EAD**	**PVI**
	Methuen	*4*	*$ 449,432*	*$ 388,721*	*9.7%*	
1-year	*Lawrence*	*0*	*$ -*	*$ 535,664*	*13.3%*	
	Total	***4***	***$ 449,432***	***$ 924,385***	***23.0%***	$ 33,846,000
	Methuen	*13*	*$ 1,108,567*	*$ 390,501*	*9.7%*	
2-year	*Lawrence*	*19*	*$ 2,146,950*	*$ 939,076*	*23.4%*	
	Total	***32***	***$ 3,255,516***	***$ 1,329,578***	***33.1%***	$ 48,682,000
	Methuen	*20*	*$ 1,494,777*	*$ 159,878*	*4.0%*	
5-year	*Lawrence*	*63*	*$ 4,113,558*	*$ 521,323*	*13.0%*	
	Total	***83***	***$ 5,608,335***	***$ 681,201***	***16.9%***	$ 24,942,000
	Methuen	*22*	*$ 1,702,782*	*$ 117,762*	*2.9%*	
10-year	*Lawrence*	*101*	*$ 6,312,901*	*$ 438,822*	*10.9%*	
	Total	***123***	***$ 8,015,683***	***$ 556,584***	***13.8%***	$ 20,379,000
	Methuen	*35*	*$ 2,222,620*	*$ 47,712*	*1.2%*	
25-year	*Lawrence*	*115*	*$ 8,314,482*	*$ 179,440*	*4.5%*	
	Total	***150***	***$ 10,537,102***	***$ 227,152***	***5.7%***	$ 8,317,000
	Methuen	*42*	*$ 2,548,579*	*$ 28,284*	*0.7%*	
50-year	*Lawrence*	*129*	*$ 9,629,503*	*$ 104,907*	*2.6%*	
	Total	***171***	***$ 12,178,082***	***$ 133,192***	***3.3%***	$ 4,877,000
	Methuen	*53*	*$ 3,108,267*	*$ 16,851*	*0.4%*	
100-year	*Lawrence*	*135*	*$ 11,351,993*	*$ 60,004*	*1.5%*	
	Total	***188***	***$ 14,460,260***	***$ 76,855***	***1.9%***	$ 2,814,000
	Methuen	*62*	*$ 3,632,018*	*$ 11,997*	*0.3%*	
200-year	*Lawrence*	*141*	*$ 12,649,534*	*$ 40,262*	*1.0%*	
	Total	***203***	***$ 16,281,552***	***$ 52,260***	***1.3%***	$ 1,914,000
	Methuen	*67*	*$ 4,366,287*	*$ 8,710*	*0.2%*	
500-year	*Lawrence*	*153*	*$ 14,191,950*	*$ 27,934*	*0.7%*	
	Total	***220***	***$ 18,558,237***	***$ 36,644***	***0.9%***	$ 1,342,000
	Methuen	*70*	*$ 4,801,949*	*$ 480*	*0.0%*	
1,000-year	*Lawrence*	*155*	*$ 15,212,039*	*$ 1,521*	*0.0%*	
	Total	***225***	***$ 20,013,988***	***$ 2,001***	***0.0%***	$ 74,000
Totals				***$ 4,019,849***	***/year***	**$ 147,187,000**
				$ 1,170,897	29%	Methuen
				$ 2,848,953	71%	Lawrence

The table shows the following:

1. The expected annual damage (EAD) is just over $4.0M, approximately double that of the damages incurred under the current rainfall data. Approximately $1.2M or 29% of this damage is located in Methuen while the remaining $2.9M or 71% is located in Lawrence.

2. An EAD of $4.0M results in a Present Value Investment cost of $147M; meaning that a

mitigation project geared to solve this flooding issue with implementation cost as much as $147M would still have a net benefit.

3. The majority of the EAD is at the more frequent (more likely to occur) recurrent storm events; as shown in the following breakdown:

Category	EAD	PVI	% of Total
5-year and lower	$2.9M	$107M	73%
5-year – 10-year	$0.6M	$20M	14%
10-year – 25-year	$0.2M	$8M	5%
25-year – 50-year	$0.1M	$5M	3%
50-year – 100-year	$0.1M	$3M	2%
100-year +	$0.1M	$3M	2%

The EAD is lower for the less frequent (less likely to occur) recurrent storm events (i.e. 50-year, 100-year, 500-year, etc.). While the total damages of those storms are significant ($12M - $20M), the probability of the storm occurring is relatively low; as such, the contribution to EAD is less. Therefore, while EAD associated with less frequent storms is low, the high damages despite low risk likely justify designing to accommodate rare storm events

4. Similar to the current rainfall data conclusions, note that these damages are only reported at the structure level and do not take into account other types of damages that are likely to occur during these various recurrent storm events. Once evaluated and accounted for, these other types of damages could be economically, societally, and environmentally significant. Examples of these types of damages include, but are not limited to, the list included within the current rainfall data conclusions on page 8 above.

4.0 GENERAL CONCLUSIONS OF EXISTING CONDITIONS EVALUATIONS

The following general conclusions can be drawn based upon the evaluations outlined above.

1. Bloody Brook Corridor is expected to sustain significant flooding during most recurrent storm events, particularly at and above the 5-year storm event when the runoff exceeds the capacity of the culverted section of the brook. There are many factors that contribute to this condition including:
   a. The corridor as a whole (open channel sections, road crossings, and the culverted section of the brook) all have limited hydraulic capacity.
   b. The majority of the watershed is highly developed with a high percentage of impervious surfaces that result in large volume and short response (flashy) stormwater runoff.

2. The expected flood related damage at the structure level is significant during the various recurrent storm events yielding an expected annual damage (EAD) of $2.1M, equating to an $77M present value investment (PVI) budget.

3. Climate change, particularly its impacts on rainfall, is expected to significantly worsen the flooding issue within the corridor. According to the economics assessment, climate change is expected to double the expected structure related flood damages yielding an EAD of $4.0M ($147M PVI budget).

5.0 GENERAL IMPROVEMENT OPTIONS

There are several improvement options that could be implemented in efforts to alleviate the flooding issues that exist along the Bloody Brook Corridor. Improvement options generally fall within two categories: In-Stream and Watershed-Wide.

1. **In-Stream:** As the name suggests, in-stream improvements are focused on improving the hydraulic conditions within the Bloody Brook “stream” itself. Examples of in-stream improvements specific to the Bloody Brook include stream channel rehabilitation, repairs/modifications to the Searles Pond Dam, culvert replacements, and modifications to the various storm drainage systems located in close proximity to the brook (both the open channel and culverted sections). Section 6 below provides a planning level in-stream improvement concept that has been developed for the Bloody Brook Corridor as part of this project. Other in-stream improvements that were screened out of this particular study include flood retainment structures[2] (new dams, detention ponds, etc.), flood containment structures (flood walls, berms, levees, etc.), property buyout and relocation assistance, structure floodproofing[3], and structure elevation.

2. **Watershed-Wide:** Watershed-Wide improvements are geared towards reducing the volume and rate of runoff from within the watershed. Through green infrastructure projects such as infiltration trenches/basins, conversion of unnecessary impervious surfaces to pervious surfaces, and rooftop storage/infiltration systems, the watershed gains infiltration / absorption potential which results in reduced runoff volume. These types of measures are typically effective in accommodating the most frequently/common occurring rain events (such as a 1-inch rain storm), which often offers an enormous improvement to water quality within the stream/brook during these frequent/common rain events. However, their effectiveness for reducing flooding and avoiding damages diminishes during larger storm events.

   The effectiveness of these types of projects within the Bloody Brook watershed is fairly limited by the surficial geology of the watershed, which primarily consists of soils with a Hydrologic Soil Group rating of “C”; this soil type has a slow infiltration rate and absorption potential. Although, as some of these projects involve the removal and replacement of the soils with free draining soils and systems, there is certainly some effectiveness in these types of projects.

   Land use restrictions through a watershed-wide land use management plan can help preserve the portions of the watershed that are currently in a natural and hydrologically beneficial state (such as forests, wetlands, and other vegetated areas).

   Section 7 below provides a planning level assessment of potential watershed-wide measures that are available within the watershed.

[2] Large scale flood retainment structures near or along the brook itself were screened out of this study. Smaller scale (parcel level) detention ponds and storage systems are likely a viable watershed-wide improvement options

[3] Although not particularly identified within Section 6, floodproofing of some of the structures located in close proximity to the stream/brook is likely a cost effective approach in addition to the in-stream improvements. The results of the hydraulic model can be used to determine which structures warrant floodproofing measures during subsequent phases of this project.

6.0 POTENTIAL IN-STREAM IMPROVEMENTS

6.1 In-Stream Improvement Project (Concept Level)

An in-stream improvement concept to mitigate the flooding issues within the corridor was developed as part of this project. The following provides a tabulated summary of the improvement, estimated cost, and level of protection for each location along the corridor. Graphic #25 attached provides a map view of these proposed improvements. Table 1 below if for the open channel sections of the brook from the Searles Pond impoundment to the inlet of the Bloody Brook Culvert while Table 2 on the following page is for the culverted section of the brook from the inlet of the Bloody Brook Culvert to its outfall at the Spicket River.

IN-STREAM IMPROVMENTS TABLE 1 OF 2 (Open Channel Section - Sealres Pond to Bloody Brook Culvert)

ID	Name	Description	Size	Length	Capacity Exceeded		Cost
			FT	FT	Atlas 14	14++	$M
0	US of Searles Pond	No specific action other than watershed management as flooding does not appear to be a significant issue within this area	-	-	-	-	-
1	Searles Pond Dam	Dam repairs and modifications to restore river like conditions within the impoundment and maximize flood attenuation potential. *(See Note 1)*	-	-	500	100	***2.0 M***
2	Brook Street	Replace existing culvert with a 6-foot wide by 5-foot high (6x5) culvert. A 6x7 culvert will be installed and infilled 2 feet with stream bed material per stream crossing guidelines, typical all culvert replacements up until #13	6x5	40	500	100	***1.2 M***
3	Channel - Brook to East	Stream channel rehabilitation inclusive of debris removal, regrading to stable section, installing steam bed and bank material adequate to resist scour, establish sustainable vegetation, typical all stream channel rehabilitation areas	-	1340	-	-	***1.2 M***
4	East Street	Replace existing culvert with a 10x5 culvert	10x5	55	500	100	***1.3 M***
5	JW Parking Lot	Replace existing culvert with a 10x5 culvert	10x5	35	500	100	***1.0 M***
6	Channel - East to Jackson	Stream channel rehabilitation	-	340	-	-	***0.6 M***
7	Jackson Street	Replace existing culvert with a 10x5 culvert	10x5	42	500	100	***1.2 M***
8	Channel - Jackson to Curtis	Stream channel rehabilitation	-	1050	-	-	***1.2 M***
9	Bicknell 1	Replace existing culvert with a 12x6 culvert	12x6	60	500	100	***1.1 M***
10	Bicknell 2-5	Replace existing culverts with driveway bridge crossings	bridges	*15' spans*	*200*	*50*	***1.1 M***
11	Curtis	Replace existing culvert with section of open channel up to Curtis Street and a 12x6 culvert under Curtis Street	12x6	50	200	50	***1.3 M***
12	Channel - Curtis to CVS	Stream channel rehabilitation	-	220	-	-	***0.6 M***
A	**Bloody Brook Open Channel Section Improvements Total**						**13.8 M**

Note 1: *Searles Pond Dam Modifications and Alternatives*

Modifications expected at Searles Pond Dam includes the following as conceptually developed:

1. Replacement of the low level outlet pipe with a new conduit capable of maintaining river-type flow conditions within the current impoundment area. This will not only provide increased storage capacity within the impoundment, but will also restore river-type conditions with vegetated wetland river banks within the impoundment that is currently shallow (1 to 2 feet) and is not offering ecological benefit. Alternative to restoring river-type conditions within the impoundment, modifications could be tailored to maintain the

impoundment at its current operating level.

2. Replacement of the primary spillway conduit with a controllable system designed to limit outflows during moderate to high storms and through operations provide increased capacity during severe storms (200-yr+ under current rainfall and 50-yr+ under CCIPF rainfall)
3. Regrading / raising of the dam to a uniform elevation of El. 118.0. This elevation is the current grade of the abutments and is 2.5 feet higher than the low point of the dam (near the spillway).

Alternative to the dam modifications option, removal of the dam is a viable alternative. Removal would result in increased outflows to the downstream channel that would need to be accounted for in the form of increasing the hydraulic capacity of the proposed improvements downstream as needed.

IN-STREAM IMPROVMENTS TABLE 2 OF 2 (Bloody Brook Culvert Section)							
ID	Name	Description	Size	Length	Capacity Exceeded		Cost
			FTxFT	Ft	Atlas 14	14++	$M
13	Inlet to Swan DMH	Replace existing culverts with a 10x6 culvert	10x6	270	200	50	***2.3 M***
14	*Swan DMH*	*Replace existing manholes with a 12-foot wide x 12-foot long x 8-foot high (12x12x8) structure with a large grating system, typical all new manhole structures*	*12x12x8*	-	*200*	*50*	***.4 M***
15	Swan to Knox DMH	Replace existing culvert with a 10x6 culvert	10x6	520	200	50	***2.7 M***
16	*Knox DMH*	*Replace existing manholes with a 15x15x10 structure*	*15x15x10*	-	*200*	*50*	***.4 M***
17	Knox to Jackson DMH#1	Install a new 7' conduit	7' Pipe	250	200	50	***1.8 M***
18	*Jackson DMH#1*	*Install a new 10x10x10 structure*	*10x10x10*	-	*500*	*50*	***.4 M***
19	Jackson DMH#1 to Jackson DMH#2	Install a new 7' conduit	7' Pipe	290	500	50	***2.1 M***
20	*Custer DMH and Line to Jackson DMH#2*	*Replace existing manhole at Custer Street with a new 8x8x8 structure and a new 4' conduit from the Custer DMH to the new Jackson DMH#2 structure*	*8x8x8 4' Pipe*	*130*	*500*	*50*	***1.0 M***
21	*Jackson DMH#2*	*Install a new 10x10x10 structure*	*10x10x10*	-	*500*	*50*	***.6 M***
22	Jackson DMH#2 to Jackson DMH#3	Install a new 7' conduit	7' Pipe	300	500	50	***2.2 M***
23	*Logan DMH and Line to Jackson DMH#3*	*Replace existing manhole at Logan Street with a new 8x8x8 structure and a new 4' conduit from the Logan DMH to the new Jackson DMH#3 structure*	*4' Pipe*	*215*	*500*	*50*	***1.0 M***
24	*Jackson DMH#3*	*Install a new 10x10x11 structure*	*10x10x11*	-	*500*	*50*	***.4 M***
25	Jackson DMH#3 to Jackson DMH #4	Install a new 7' conduit	7' Pipe	290	500	50	***2.1 M***
26	*Jackson DMH #4*	*Install a new 10x10x13 structure*	*10x10x13*	-	*500*	*50*	***.4 M***
27	Jackson DMH #4 to Sheridan DMH	Install a new 7' conduit	7' Pipe	350	1,000	100	***2.5 M***
28	*Sheridan DMH*	*Install a new 15x15x10 structure*	*15x15x10*	-	*1,000*	*100*	***.4 M***
29	Sheridan to J&JDMH *(Three dmh's along run)*	Install a new 7x7 culvert and three DMH structures (9x9x10) at bends in alignment	7x7	470	> 1,000	100	***4.9 M***
30	*J&J DMH*	*Install a new 15x15x10 structure*	*15x15x10*	-	> 1,000	*500*	***.4 M***
31	J&J DMH to Webster DMH	Install a new 10x8 culvert	10x8	240	> 1,000	500	***3.1 M***
32	*Webster DMH*	*Install a new 15x15x10 structure*	*15x15x10*	-	> 1,000	*500*	***.4 M***
33	Webster DMH to EHav DMH *(Two dmh's along run)*	Install a new 8x8 culvert and two DMH structures (10x10x10) at bends in alignment	8x8	350	> 1,000	500	***4.0 M***
34	*EHav DMH*	*Install a new 15x15x10 structure*	*15x15x10*	-	> 1,000	*500*	***.4 M***
35	EHav DMH of Vine DMH *(Two dmhs along run)*	Install a new 8x8 culvert and two DMH structures (10x10x10) at bends in alignment	8x8	260	> 1,000	500	***3.4 M***
36	*Vine DMH*	*Install a new 15x15x13 structure*	*15x15x13*	-	> 1,000	*500*	***.4 M***
37	Vine DMH to outfall *(Two dmhs along run)*	Install a new 8x8 culvert	8x8	400	> 1,000	500	***4.8 M***
B	**Bloody Brook Culverted Section Improvements Total**						**42.7 M**
C	**In-Stream Improvements Total**						**56.7 M**

The proposed in-stream project outlined in the tables above has an estimated cost of $57M and would increase the level of protection of this area from the 2-year storm (current level of protection) to between 200-year to 1,000-year storm protection/capacity[4]. Additionally, the project is not expected to result in the displacement of any individuals, although temporary/permanent easements will likely be needed to allow for construction of many of the proposed components.

Comparing the estimated cost of this in-stream project to the present value investment cost of the structural related damages yields a Benefit Cost Ratio (BCR) of 1.5 using current rainfall data and 3.0 using CCIPF rainfall data. A project with that high of a BCR that offers vastly increased flood protection and improved quality of life for 600+ households within 200+ structures throughout 20+ blocks of an environmental justice community would be eligible and highly competitive for funding opportunities through a variety of grant programs (state and federal); particularly the Building Resilient Infrastructure and Communities (BRIC) grant that is available annually through FEMA (November-January application period).

Although this in-stream improvements concept has many “gray” infrastructure components, there are many “green” / nature-based components and benefits associated with the concept. These include:

1. Conversion of the shallow (1-2 foot deep) Searles Pond impoundment to a natural river with vegetated wetland banks
2. Rehabilitation of 3,000 linear feet (LF) of stream channel
3. Upgrading of 10 road-stream crossings to stream crossing compliant crossings
4. Capability of incorporating stream side green infrastructure within the various project components

Graphics #31-#34 attached show the lateral extent of inundation during the 100-year through 1,000-year storm events under current rainfall conditions (14) while Graphics #35-#40 show the lateral extent of inundation during the 25-year through 1,000-year under CCIPF rainfall conditions (14++).

6.2 Open Channel Alternative

Alternative to components 13-37 described above, the option of restoring the Bloody Brook to an open, natural channel was developed and evaluated. Graphic #26 attached shows a map view of the alignment that was developed. This option was determined to require the following:

#	Measure	Quantity	Cost
0	Improvements 1 through 12 provided above	-	***$13M***
1	Property Buyout & Relocation Assistance	41 each	***$31M***
2	Bridge Construction	9 each	***$18M***
3	Stream Construction	3,400 linear feet	***$7M***
4	Utility Crossing Modifications	Estimate	***$10M***
5	Environmental Hazard Mitigation	Estimate	***$10M***
A	Total	-	**$89M**

[4] Note that the hydraulic modeling of this alternative conservatively assumed existing conditions within the watershed with none of the watershed-wide improvements implemented. The implementation of watershed-wide improvements would likely result in slight decreases in storm flows through the brook, resulting in an even higher level of protection of the various components along the brook.

This option is approximately 1.5 times the cost of the base concept and also results in the displacement of 41 structures (160+ households) within this environmental justice community. It should also be noted that the extent of the potential environmental hazards that exist underground that would be unearthed (and remain unearthed) under this option is fully unknown; therefore, actual costs could be significantly higher than the $10M estimated provided above.

However, the option would offer several benefits that the “culvert improvement program” will likely not offer including:

1. Increased Level of Protection: *The open channel could likely be designed to have higher capacity than maintaining the brook as culverted.*
2. Less Prone to Clogging: *Although the size of the proposed culvert replacement under the base concept are likely sufficient to avoid debris clogging, there is always an inherent risk of clogging in an underground culverted system. An open channel is certainly less prone to clogging and also allows maintenance personnel better access to identify and remove areas of debris.*
3. Ecological Restoration: *Converting a culverted brook to an open channel brook has numerous benefits related to ecological restoration.*

7.0 POTENTIAL WATERSHED-WIDE IMPROVEMENTS

7.1 Watershed Wide Improvements

Although flooding was the primary focus of this planning level watershed study, it should be recognized that flooding is not the only issue within the corridor. There are also issues related to water quality within the brook as well as other ecological and environmental factors along the corridor. There are numerous improvements that could be implemented within this watershed to improve these other issues as well; some of which could also provide some level of relief to the flooding issue. The two improvement types that were the focus of this study were Watershed Management Strategies as well as Green Stormwater Infrastructure (GSI) Improvements.

1. ***Watershed Management Strategies***: Although much of the Bloody Brook Watershed is highly developed, there are several areas within the watershed that are undeveloped woodlands and wetlands that offer great benefit to the watershed in their current state. It would be best management practice to conserve these areas in their current state through land use restrictions and to expand and nurture these areas through specific resource area management programs.

   Additionally, there may be open/unused lots within the watershed that could be converted (through purchase or discussions/agreements with the landowner) to a land cover type that is valuable to the watershed; such as converting unused paved areas, buildings, or bare areas to a wooded area, rain garden, or other nature-based land cover type that benefits the watershed. Dependent on the type of land cover chosen, this type of action would not only help to reduce the storm runoff from the converted site itself, but also potentially offer other benefits to the watershed including improved water and air quality, reduction in heat island effect and carbon emissions, improvements to the ecosystem within the community, among others.

2. ***Green Stormwater Infrastructure (GSI) Improvements***: As stated previously and presented within Graphic #2, the Bloody Brook Watershed is highly developed and comprised of a significant percentage of impervious areas; impervious areas that currently translates to 100% runoff during all storm events, thereby negatively impacting several watershed conditions such as water quality and flooding. Therefore, implementing GSI improvements that are targeted at these impervious areas would offer a great benefit to the watershed.

   As part of this study, a watershed wide GSI improvements assessment was completed, which identified areas of impervious land cover as a whole as well as different subcategories (roadways, structure rooftops, and other impervious) and evaluated GSI improvements for each specific subcategory. Graphics #27 - #29 show the map views of the three different impervious area types. The assessment was completed at both the subbasin and watershed wide level. The table on the following page provide a tabulated summary of this assessment with the pages following providing some a general summation of the assessment.

Drainage Area	Drainage Area (acres)	Existing CN	Existing Impervious		Green Infrastructure										
					Permeable Pavement (Parking Lot and Driveways)		Perm Pavement Effect on CN		Roadways to Remain Impervious		***ROW GSI With Perm Pavement***	Impervious Structures		***Rain Barrels (Structures)***
			Area (Acres	*Percent*	Area (Acres)	*Percent*	CN	Value Reductio	Acres	*Percent*	Each	Acres	*Percent*	Each
A	33	72	**4**	*13%*	***2***	*41%*	71	*1*	2	*51%*	***44***	0	*9%*	***17***
B	119	72	**42**	*35%*	***19***	*45%*	65	*7*	15	*35%*	***292***	8	*20%*	***231***
C	30	74	**4**	*13%*	***1***	*19%*	73	*1*	2	*52%*	***40***	1	*30%*	***47***
D	100	77	**32**	*32%*	***13***	*41%*	73	*4*	6	*19%*	***120***	13	*41%*	***149***
E	62	80	**21**	*34%*	***7***	*34%*	76	*4*	8	*39%*	***166***	6	*27%*	***147***
F	74	75	**18**	*25%*	***9***	*47%*	72	*3*	4	*22%*	***82***	6	*31%*	***60***
G	55	77	**16**	*29%*	***6***	*41%*	75	*2*	5	*31%*	***96***	4	*29%*	***93***
H	50	83	**18**	*37%*	***4***	*24%*	81	*2*	8	*45%*	***164***	6	*31%*	***196***
I	13	81	**5**	*38%*	***2***	*38%*	77	*4*	1	*23%*	***22***	2	*39%*	***55***
J	26	82	**11**	*44%*	***5***	*43%*	77	*5*	2	*21%*	***48***	4	*36%*	***82***
K	81	86	**49**	*61%*	***19***	*39%*	80	*6*	16	*33%*	***324***	14	*29%*	***415***
L	46	88	**31**	*67%*	***11***	*35%*	81	*7*	9	*30%*	***186***	11	*35%*	***344***
M	68	86	**40**	*59%*	***15***	*37%*	81	*5*	12	*29%*	***232***	14	*35%*	***433***
Total	756		**292**	*39%*	***112***	*38%*			91	31%	***1816***	89	31%	***2269***

The following presents a general summation of this assessment:

1. The Bloody Brook Watershed has **292 acres** of impervious land cover, which translates to almost **40%** of the entire watershed (756 acres). Of this 292 acres, there are:
   A. **91 acres** of roadway *(31% of all impervious areas and 12% of the entire watershed)*
   B. **89 acres** of structure rooftops *(31% and 12%);* there are 2,269 structures within the watershed.
   C. **112 acres** of “other impervious areas” *(38% and 15%);* these areas are primarily comprised of parking lots and driveways.

2. GSI improvements that were evaluated for the roadways were right-of-way (ROW) type GSI’s such as tree box filters. An evaluation criterion was established to determine the number of filters needed for each subbasin and the watershed as a whole[5]. Using this criterion, the following was determined:
   - Slightly more than **1,800** tree box filters (totaling 6 acres and 24 acre-feet) would be needed watershed wide to accomplish this goal. Utilizing an average cost of $8,000/filter, this measure would be expected to cost just under **$15M**.
     i. As identified within the criterion, this measure would be capable of eliminating all runoff from the roadways up to a total rainfall depth of 1-inch. ***The collection of the first 1-inch of runoff from roadways would offer a significant benefit to the water quality within the storm drainage systems as well as the Bloody Brook.***
     ii. The measure would also offer a benefit to rainfall events where depths exceeded 1-inch, as it would still skim off the first 1-inch of rain from the roadways. However, its impact would be diminished with increasing rainfall depths.

3. Two measures of GSI improvements were evaluated for the rooftops of the 2,269 structures located within the watershed.
   - Measure #1 was to provide each structure with **4 above grade rain barrels,** which

[5] The criteria used was for the treatment/storage of up to 1-inch of runoff from the roadways themselves. For the purposes of this assessment, it was assumed that each filter would take the form of a 10-foot square by 4-foot deep filter installed along the roadway shoulder at targeted locations

the homeowner would be responsible for tying into the roof downspouts, maintaining, and ensuring that the barrels are emptied in advance of a storm. The measure was estimated to cost $300/structure; carried through for all 2,269 structures within the watershed results in a total cost of **$0.7M**.

i. This measure was determined to be capable of eliminating runoff from structure rooftops up to a total depth of 0.2 inches (a little under 1/4 of an inch). However, actual benefit of this measure would likely be less given reliance upon all homeowners to participate consistently.

ii. ***Although the runoff reduction of this measure is minimal, there is some benefit provided from a water usage conservation standpoint, as water stored could be used by the homeowner for non-potable water purposes during periods of water supply shortages.***

- Measure #2 would be to install **4 below grade soak away barrels** at each structure. Installation would be completed by a specialty contractor and not by the homeowner. The measure was estimated to cost $2,500/structure; carried through for all 2,269 structures within the watershed results in a total cost of **$5.7M**.

i. The capability of this measure is difficult to assess; however, it would likely only be slightly higher (maybe an increased total rainfall depth capacity from 0.2 to 0.3 inches) than Measure #1 due to the fact that the poorly draining soils that are predominant within the watershed would likely limit the rate of infiltration of the runoff from the underground barrel into the adjacent and underlying soils.

ii. ***Similarly, to Measure #1, although the runoff reduction of this measure is minimal, there is some benefit provided from a water usage conservation standpoint***

4. GSI improvement that was evaluated for all other impervious areas (i.e. parking lots and driveways), was conversion from impervious pavement to a pervious surface coverage (either permeable pavement, gravel, or (where possible) some type of vegetated surface.
   - The watershed has a total of 112 acres of these other impervious areas, which theoretically could qualify to be converted from impervious to pervious surfaces. This measure was estimated to cost $80/SY ($0.387M/Acre); carried through for the 112 acres within the watershed results in a total cost of **$44M**.

i. This measure would not only offer a great benefit in avoidance of runoff from these areas during 1-inch or less storms, but would also offer infiltration and runoff volume reduction for larger storm events. Potential degree of runoff volume was evaluated for each subbasin; in general, this measure may provide flood reduction as noted below:

- 1-year storm: *10%-30% reduction in peak flow.*
- 10-year storm: *3%-15% reduction in peak flow*
- 25-year storm: *2%-10% reduction in peak flow*
- 100-year storm: *1%-8% reduction in peak flow*

ii. It is difficult to correlate this percent reduction in peak flows to a tangible/monetary benefit to the watershed without incorporating it within the H&H model and completing a comparison evaluation to assess benefit. However, it is likely that the benefit provided related to flood reduction alone is relatively small and less than the cost of the measure; particularly for the subbasins located upstream of Searles Pond Dam where significant flood attenuation already exists.

In summary, the watershed wide GSI assessment revealed the following potential GSI improvements for the watershed:

ID	Impervious Type	Acres	%	GSI Type	GSI Quantity	Cost
A	Roadways	91	12%	ROW (i.e. tree box filters)	1,800 each (6 acres)	$15M
B-1	*Structure Roofs*	*89*	*12%*	*Rain Barrels*	*2,269 structures*	*$0.7M*
B-2	Structure Roofs	89	12%	Soak Aways	2,269 structures	$5.7M
C	Other Impervious	112	15%	Convert to Pervious Land Cover	112 acres	$44M
Total		***292***	***39%***			***$65M***

Note that this assessment was completed at a large scale (subbasin and watershed wide level). This assessment could be utilized to complete a targeted assessment to identify specific locations to begin implementation of this watershed wide GSI improvement program. Also note that this is by no means a complete assessment of all potential GSI improvements that are available within the watershed. Other improvements such as underground storage could be effective at targeted locations at the parcel level.

7.2 Potential GSI Sites Identified within the Corridor (East Street to Logan Street)

In addition to the watershed-wide assessments described above, a GSI site search was performed withing the portion of the corridor that experiences frequent flooding; focused primarily along Jackson Street and its cross streets from as far north as East Street to as far south as Logan Street.

The site search revealed 52 potential sites where infiltration trenches and basins and other GSI features appear feasible and effective. In some areas, the measure could be tied to the upgradient storm drainage system to allow for the measure to provide infiltration of low flows from the storm drainage system itself. The sites were evaluated to determine a preliminary prioritization rating with a scale of 1 to 3 (1 being highest priority/benefit and 3 being lowest priority/benefit). Note that this prioritization is preliminary and based only a review of aerial and street view imagery and the individual site's location relative to the H&H model results, known hydraulic limitations within the brook and storm drainage systems, as well as a relative comparison of all 52 sites. Graphic #30 attached provides a plan view of the 52 sites.

Of the 52 sites, 14 received a priority rating of "1", 12 received a priority rating of "2", and 27 received a priority rating of "3". The table to the right provides the information for each of the 52 sites. Costs estimates were not developed for each of these 52 sites; however, costs of each site would likely vary between $20K and $300K.

GSI Site Search (East Street to Logan)						
ID	FID	Area (SY)	Area (Acres)	Location Desctiption	GSI Type	Priority
0	0	1205	0.25	East @ Jackson SE	IB Tied to SD	1
1	1	958	0.20	JW Along East	IB	1
2	2	3659	0.76	Bicknell Shoulder	IB	1
3	3	1350	0.28	Curtis	IB	1
5	5	427	0.09	Jackson	IT ROW	1
10	10	1710	0.35	JW PL	IT&IB Tied to SD	1
12	12	317	0.07	JW PL	IB	1
13	13	210	0.04	Jackson	IT ROW	1
14	14	203	0.04	Jackson @ Curtis	IT ROW	1
15	15	750	0.15	Jackson @ Walgreens	IT ROW	1
16	16	302	0.06	Jackson	IB	1
17	17	266	0.05	Swan @ Jackson	IT	1
18	18	626	0.13	Mobil Island	IB	1
36	36	75	0.02	Mobil	IT	1
4	4	323	0.07	Jackson	IT ROW	2
11	11	122	0.03	JW PL	IT PL	2
19	19	1053	0.22	CVS	IT	2
20	20	165	0.03	Swan @ CVS	IT ROW	2
21	21	3827	0.79	Planet Fitness PL	IT/IB	2
32	32	204	0.04	Jackson @ Longwood	IT ROW	2
33	33	477	0.10	Jackson @ AFMarino	IT ROW	2
37	37	535	0.11	Conduit and Knox	IT ROW	2
38	38	643	0.13	Conduit and Knox	IT ROW	2
42	42	698	0.14	Jackson @ Knox	IT ROW	2
51	51	993	0.21	Swan Jackson Montogmery	IT ROW	2
52	52	386	0.08	Jackson	IT ROW	2
6	6	263	0.05	Walgreens	IT PL	3
7	7	58	0.01	Walgreens	IT PL	3
8	8	37	0.01	Walgreens	IT PL	3
9	9	590	0.12	Walgreens	IT PL	3
22	22	115	0.02	Planet Fitness PL	IT	3
23	23	54	0.01	Planet Fitness PL	IT	3
24	24	42	0.01	Planet Fitness PL	IT	3
25	25	53	0.01	Planet Fitness PL	IT	3
26	26	28	0.01	Planet Fitness PL	IT	3
27	27	33	0.01	Planet Fitness PL	IT	3
28	28	40	0.01	Dunkin	IT	3
29	29	48	0.01	Dunkin	IT	3
30	30	95	0.02	Dunkin PL	IT	3
31	31	53	0.01	Planet Fitness PL	IT	3
34	34	405	0.08	Jackson @ Montgomery	IT ROW	3
35	35	417	0.09	Swan @ Conduit	IT ROW	3
39	39	233	0.05	Iglesia Church @ Montgomery	IT	3
40	40	57	0.01	Jackson @ Know	IT ROW	3
41	41	31	0.01	Jackson @ Know	IT ROW	3
43	43	1687	0.35	Apartment Complex @ Knox	IB Tied to SD	3
44	44	227	0.05	Knox	IT	3
45	45	120	0.02	Knox @ Cornish	IT	3
46	46	270	0.06	Knox @ Cornish	IT	3
47	47	191	0.04	Jackson @ Custer	IT	3
48	48	997	0.21	Bruce St Island	IB	3
49	49	149	0.03	Jackson @ Custer	IT	3
50	50	216	0.04	Jackson @ Logan	IT	3

IT: Infiltration Trench; IB: Infiltratyion Basin; SD: Storm Drainage System; ROW: Right of Way; PL: Parking Lot

8.0 SUMMARY AND RECOMMENDED NEXT STEPS

The Bloody Brook corridor is at high risk of flooding during even low to moderate storm events, as shown in the model results and as experienced during past rainfall events; this risk is expected to significantly increase with climate change.

Measures are available within the brook itself (in-stream) as well as within the contributing watershed (watershed wide) that could result in a significant reduction in this flooding issue, as well as other issues currently present within the brook (water quality) and secondary issues that stem from the flooding issue (economical, environmental, societal). Screening level economics suggest that the monetized flood related damages that exist currently are higher than the expected costs of potential improvements; both the in-stream improvements concept outlined in Section 6 as well as some of the watershed-wide measures outlined in Section 7. Combining the net benefit with the project outcome of vastly increased flood protection and improved quality of life for 600+ households within 200+ structures throughout 20+ blocks of an environmental justice community, this project should be eligible and highly competitive for funding opportunities through a variety of grant programs (state and federal).

As the corridor, risk of flood related damages, and the potential solutions span the Methuen-Lawrence corporate boundary, coordination and collaboration between the two cities will serve a critical role in achieving a comprehensive, complete, and efficient project.

Potential next steps to advance this project may include the following:

Watershed-Wide Improvements:

1. Expand, refine, prioritize, and package the watershed-wide components outlined within this memorandum to expand from the current broad concept level to the project(s) level. As many of these projects will be located on private property, engagement with private property owners will be required early on and/or prior to this process.
2. Explore grant funding for the engineering, design, permitting, and construction phases of the projects identified. Numerous funding opportunities including revolving funds, grants, and other loans are available for these types of projects at both the state and federal level. The Section 319 Nonpoint Source Competitive Grants Program is one example of a federal grant that is available for these types of projects.
3. Complete the engineering, design, and permitting phases for the projects identified.
4. Complete the construction phases of the projects identified.
5. Implement active maintenance and management programs for the projects.

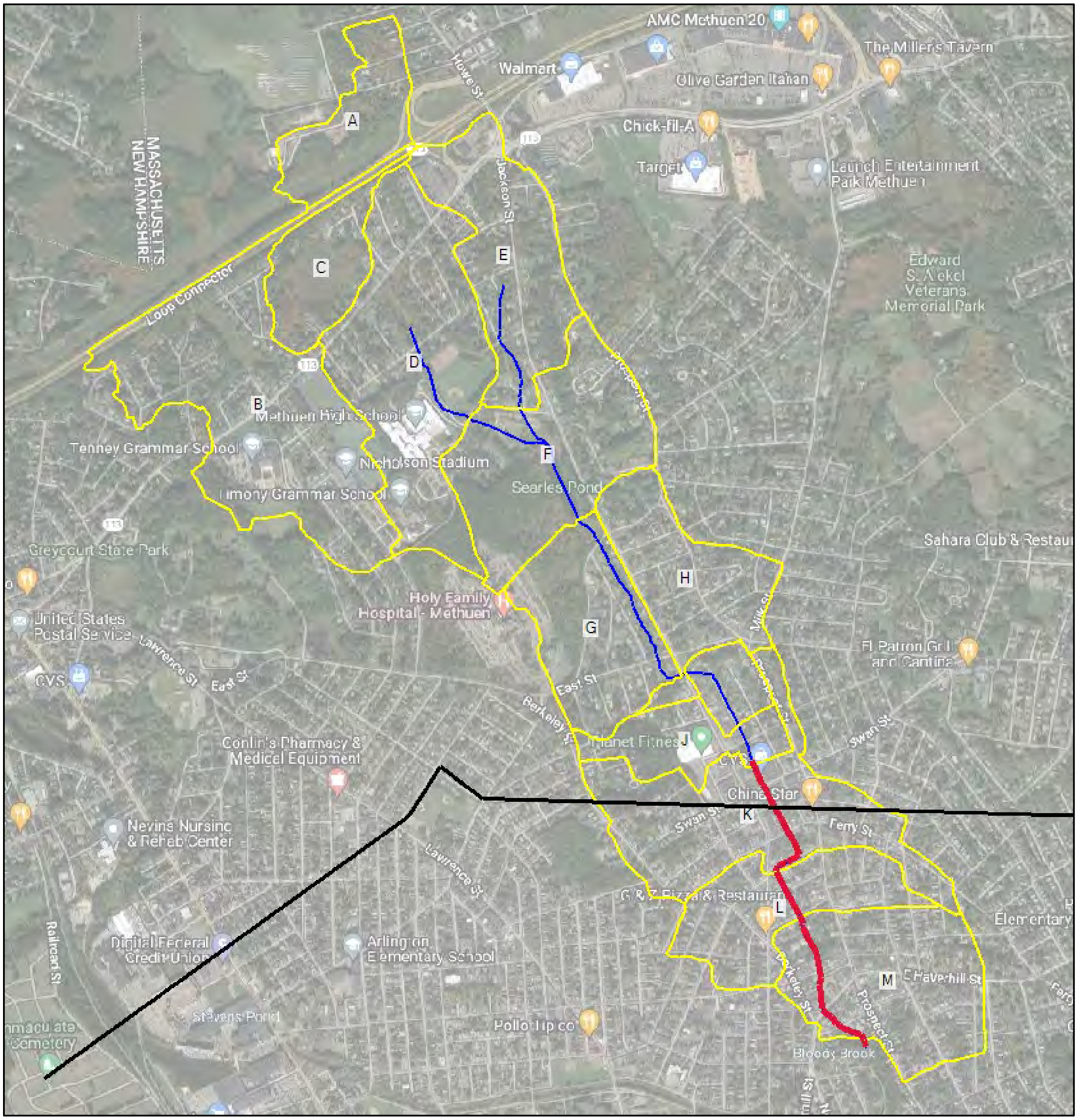
In-Stream Improvements:

1. Refine the in-stream improvements project from the current planning level phase to conceptual design.
    a. Refine and advance the project approach based upon input from the cities, project partners, and the community. Constructability review and easement coordination would be completed at this phase.
    b. Refine the H&H modeling as needed to incorporate watershed-wide improvements and any refinements made to the project approach from (a) above.
    c. Refine the economics analysis utilizing more in depth and structure specific depth-

damage curves.
    d. Refine the opinions of probable costs
    e. Develop plans and figures to support grant applications
2. Explore grant funding for each phase of the project.
    a. Coordination with MEMA would be a helpful and worthwhile first step to guide the project team towards the most appropriate path for grant funding for this project
    b. The work at Searles Pond Dam would be eligible to apply to the EOEEA Dams and Seawall Repair or Removal Program. Although the program is competitive, the current hazard potential and condition rating for the dam, the ecological and resiliency benefits of the proposed dam modifications project, and the environmental justice community that would benefit for the project should contribute to a high ranking within the program.
    c. The FEMA BRIC program is directly applicable for this project, and with the level of reduced damages provided by the project combined with the environmental justice community that it benefits should contribute to a high ranking within this program.
    d. State funding may be available for certain components including programs through MADER and MVP such as the Culvert Replacement Municipal Assistance, MVP Planning, and MVP action grant programs.
3. Complete the engineering, design, and permitting phases for the project.
4. Complete the construction phases of the project.
5. Implement active maintenance and management programs for the project.

The conceptual measures outlined within this report for addressing flooding issues in the Bloody Brook Corridor represent a significant undertaking for the City, both in consideration of scope, capital investment, and limits of disturbance. As such, phasing of the improvements program is a likely method for project implementation. Feasible phasing approaches may take a variety of forms; however, in the development of the phasing plans, incremental impacts to downstream reaches should be considered to avoid unintended short-term exasperation of flooding concerns that could result from upstream improvements conveying additional flow to downstream infrastructure.

APPENDIX A:
Supporting Graphics



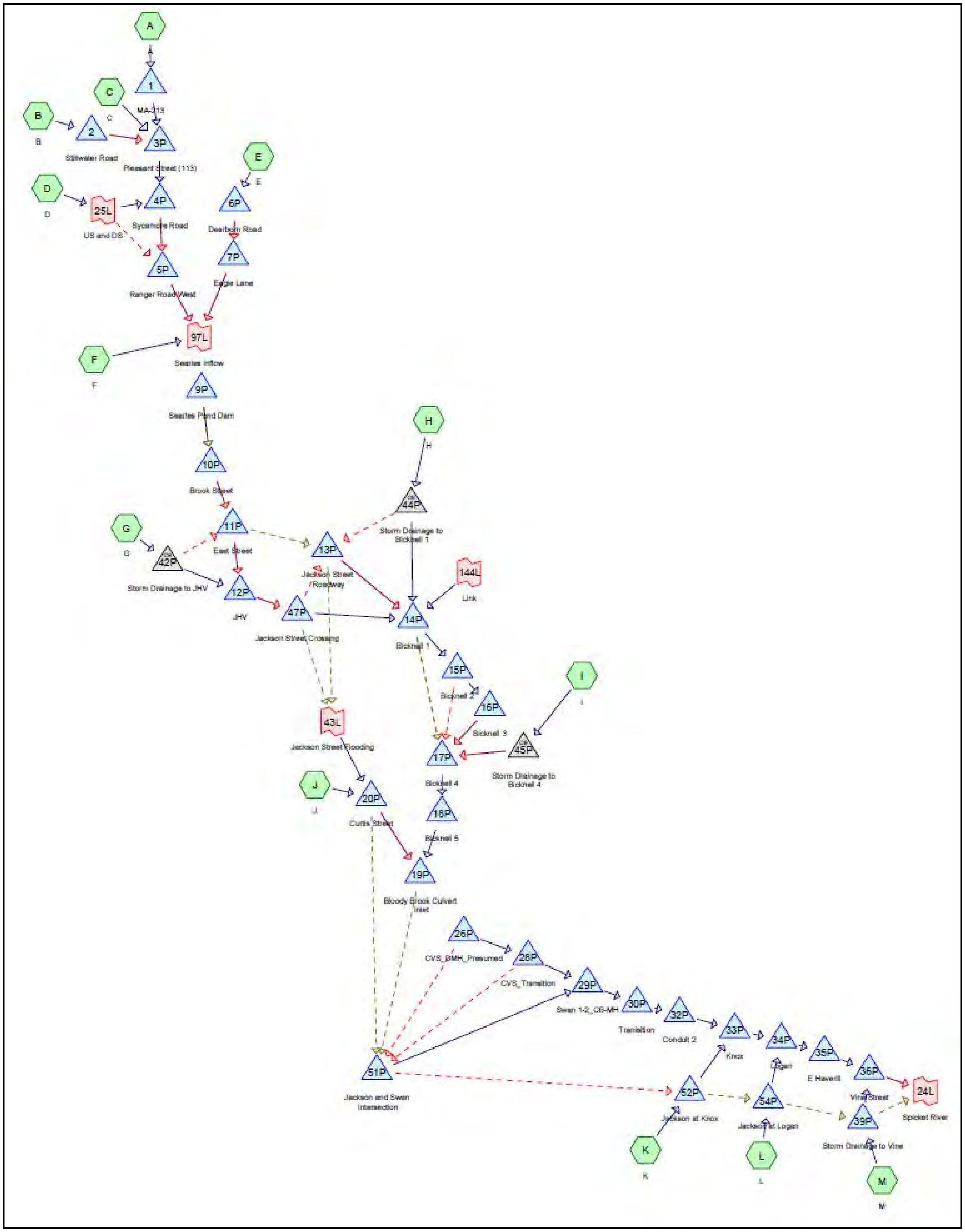
Graphic 1: Bloody Brook watershed and subbasin delineation. Note the 13 individual subbasins A-M. Note blue line

DA ID	Area		Baseflow	% Imp	CN		LFP	Tc	Soils (HSG %)		
	Acres	SM	CFS	%	Total	Pervious Only	FT	MIN	A&B	C	D
A	33	0.05	0.10	13%	72	68	2,360	103	22%	78%	0%
B	119	0.19	0.37	35%	72	58	2,370	110	65%	35%	0%
C	30	0.05	0.09	13%	74	70	1,030	70	41%	59%	0%
D	100	0.16	0.31	32%	77	67	2,940	111	23%	77%	0%
E	62	0.10	0.19	34%	80	71	2,440	85	13%	87%	0%
F	74	0.12	0.23	25%	75	67	1,970	57	20%	80%	0%
SPD Total	***418***	***0.65***	***1.31***	***29%***							
G	55	0.09	0.17	29%	77	68	2,670	69	12%	88%	0%
H	50	0.08	0.16	37%	83	74	2,650	54	0%	100%	0%
I	13	0.02	0.04	39%	80	69	820	21	47%	53%	0%
J	26	0.04	0.08	44%	82	70	1,950	59	2%	98%	0%
K	81	0.13	0.25	61%	86	67	2,840	76	5%	95%	0%
L	46	0.07	0.14	67%	87	64	1,680	54	0%	100%	0%
M	68	0.11	0.21	59%	86	68	2,700	87	0%	100%	0%
DS Total	***339***	***0.53***	***1.06***	***51%***							
Total	**757**	**1.18**	**2.37**	**39%**							

Graphic 2: Drainage Area parameter table.

Storm Event	24- hr Rainfall Depth (in)		
	NOAA	NOAA+	NOAA++
1-Year	2.52	2.75	3.05
2-Year	3.13	3.42	3.80
5-Year	4.13	4.53	5.03
10-Year	4.96	5.46	6.07
25-Year	6.10	7.08	7.87
50-Year	6.93	8.26	9.18
100-Year	7.86	9.81	10.90
200-Year	9.02	11.25	12.50
500-Year	10.80	14.04	15.60
1000-Year	12.40	16.38	18.20

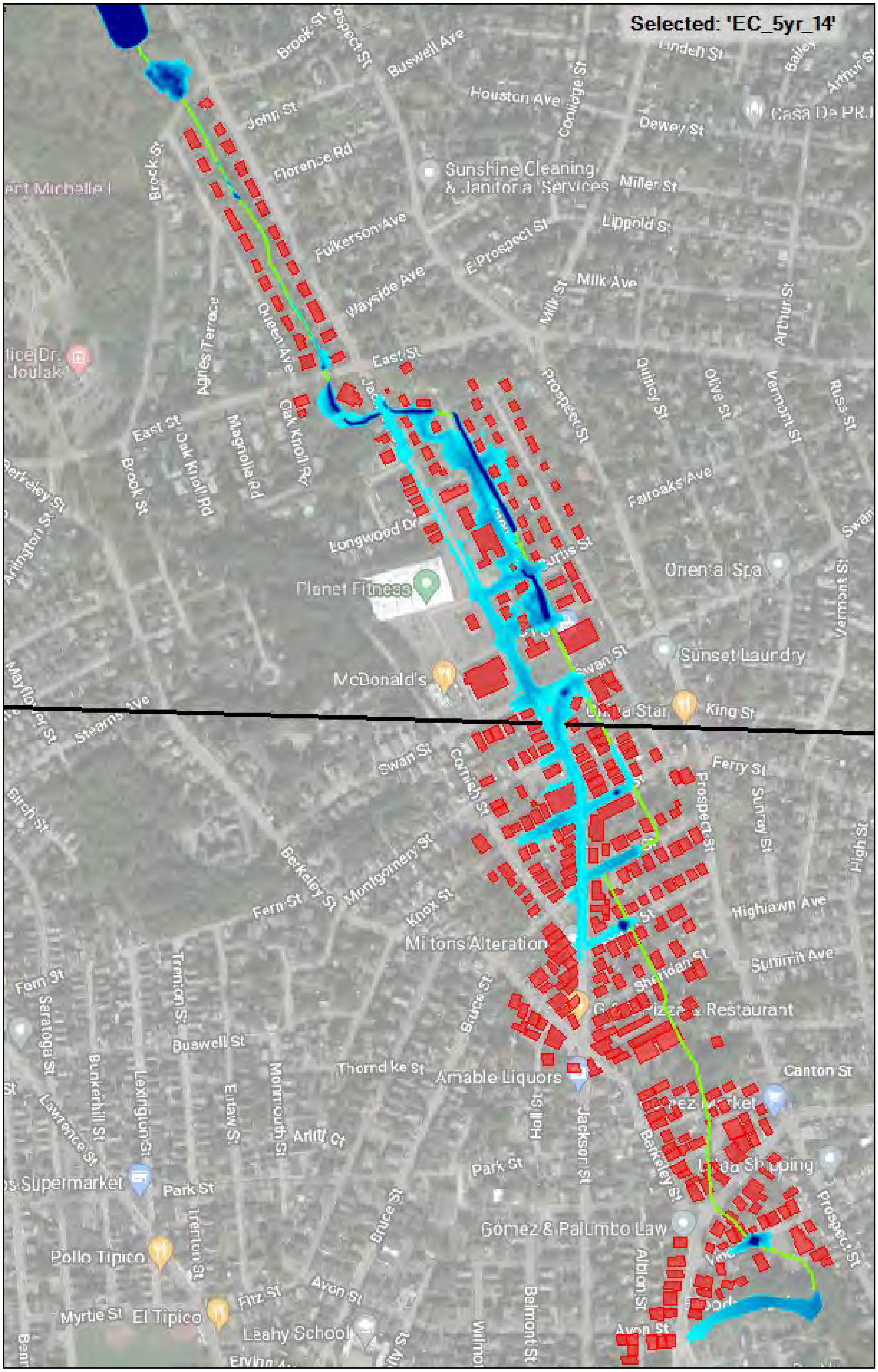
Graphic 3: Rainfall depth values for the Bloody Brook watershed for recurrent storm events 1-year through 1,000-year utilizing **NOAA Atlas 14**, NOAA Atlas 14 +, **NOAA Atlas 14 ++.**



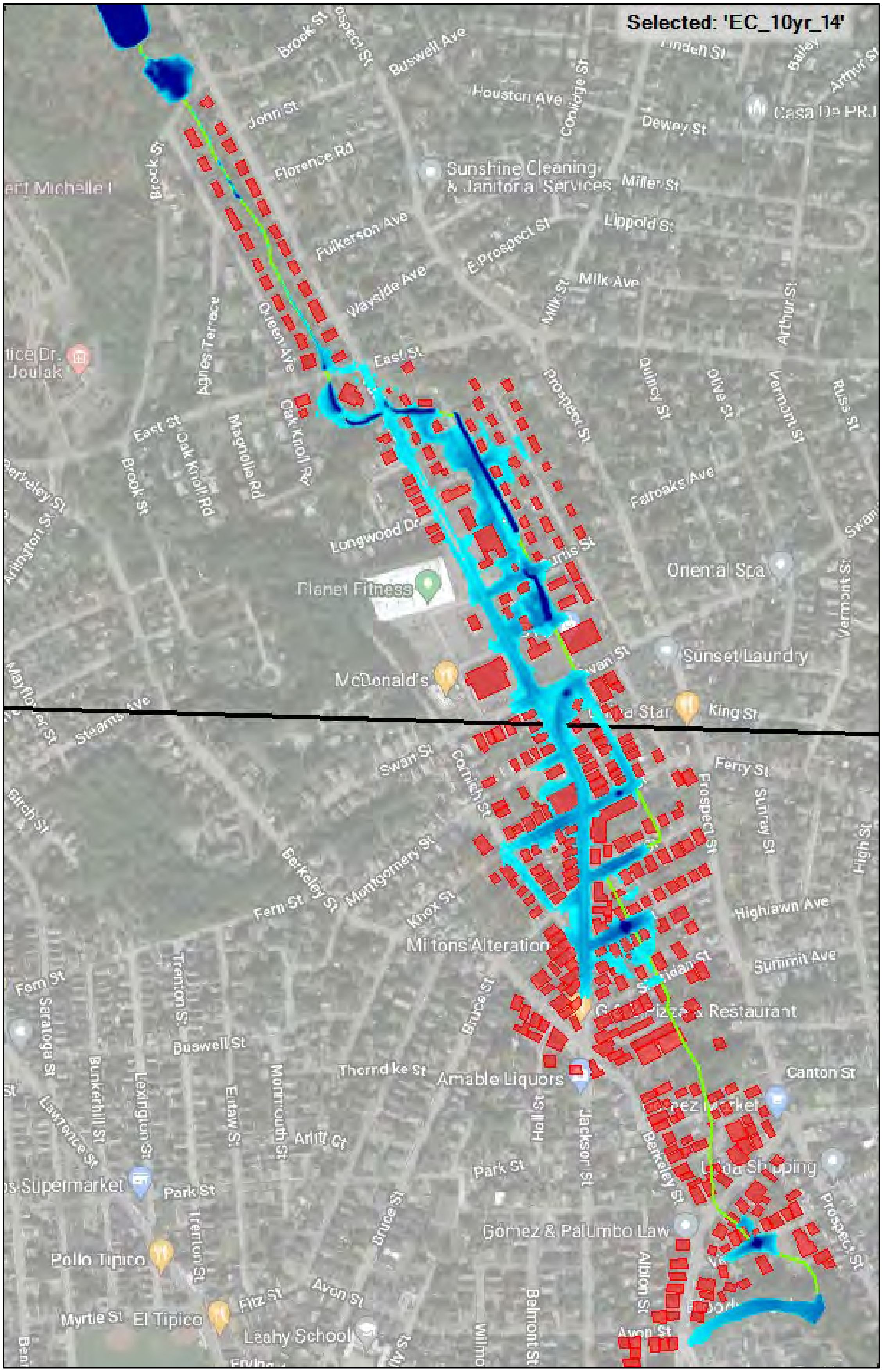
Graphic 4: HydroCAD Model routing diagram

Graphic 5: Extent of flood inundation (blue shade) during a **1-year** event under existing conditions (EC) and current rainfall conditions (14) (typical graphics 5-14). **4 structures** experience first floor flooding during this event (all in Methuen). *The black line is Methuen-Lawrence city line, the red shapes are all of the structures included within the flood damage assessment, the green line is the centerline alignment of the Bloody Brook, and the blue shade is a depth raster that ramps from shallow flood depths (represented by the lighter blue shades) up to 3 feet and greater flood depths (represented by dark blue shade). All are included on all inundation graphics.*

Graphic 6: Extent of flood inundation (blue shade) during a **2-year** event; Note shallow surface flooding beginning along Jackson and Swan and moderate flooding along Bicknell Ave and Curtis Street. **6 structures** experience first floor flooding during this event (all in Methuen).



Graphic 7: Extent of flood inundation (blue shade) during a **5-year** event; Note flooding along most streets. **42 structures** experience first floor flooding during this event (16 in Methuen and 26 in Lawrence).



Graphic 8: Extent of flood inundation (blue shade) during a **10-year** event; Note flooding along most streets. **82 structures** experience first floor flooding during this event (19 in Methuen and 63 in Lawrence).

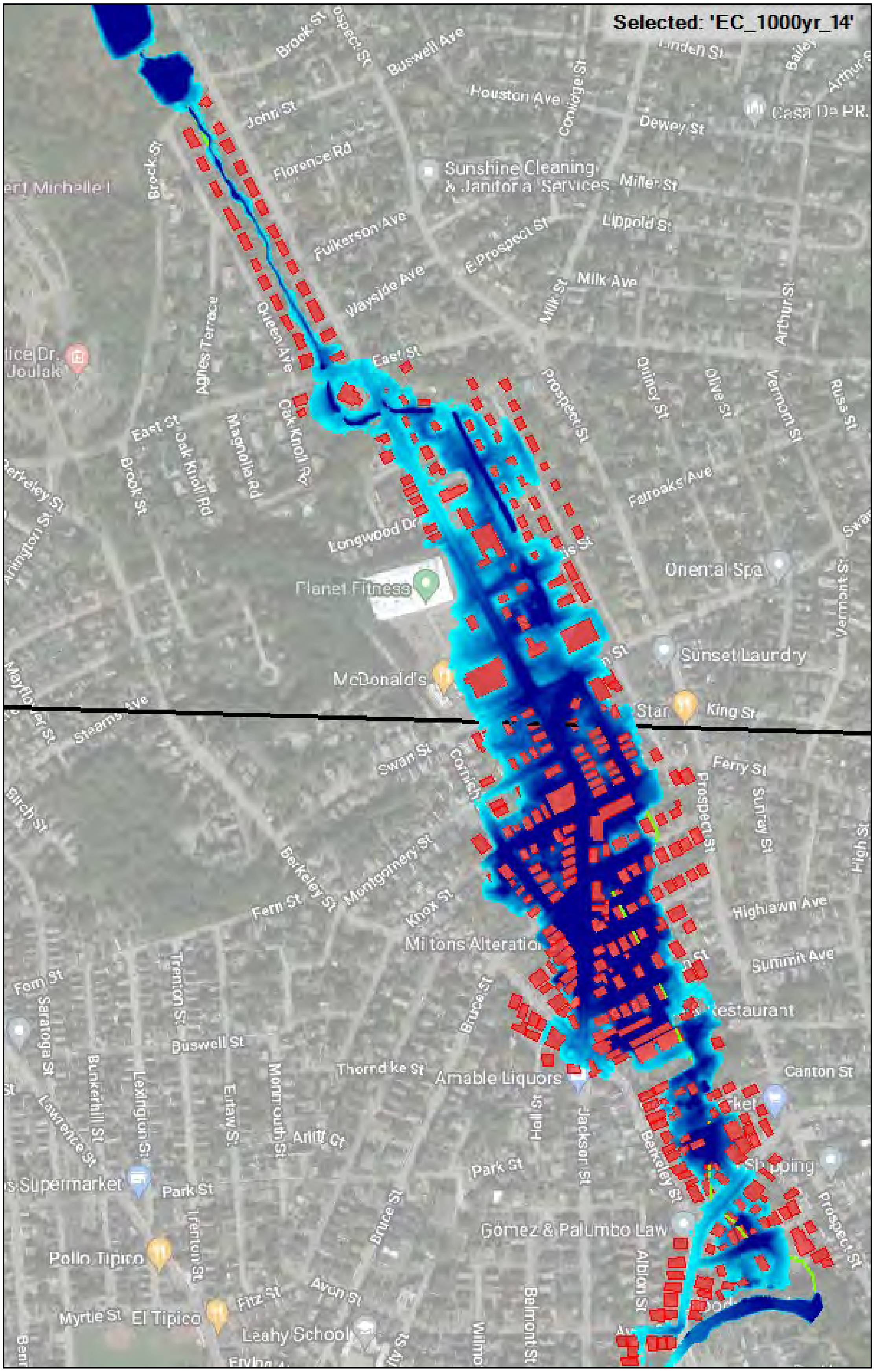
Graphic 9: Extent of flood inundation (blue shade) during a **25-year** event; Note flooding along all streets as well as spillover flooding from Sheridan Street to the residential area between Sheridan Street and Vine Street. **142 structures** experience first floor flooding during this event (23 in Methuen and 119 in Lawrence).

Graphic 10: Extent of flood inundation during a **50-year** event; **158 structures** experience first floor flooding during this event (28 in Methuen and 130 in Lawrence).

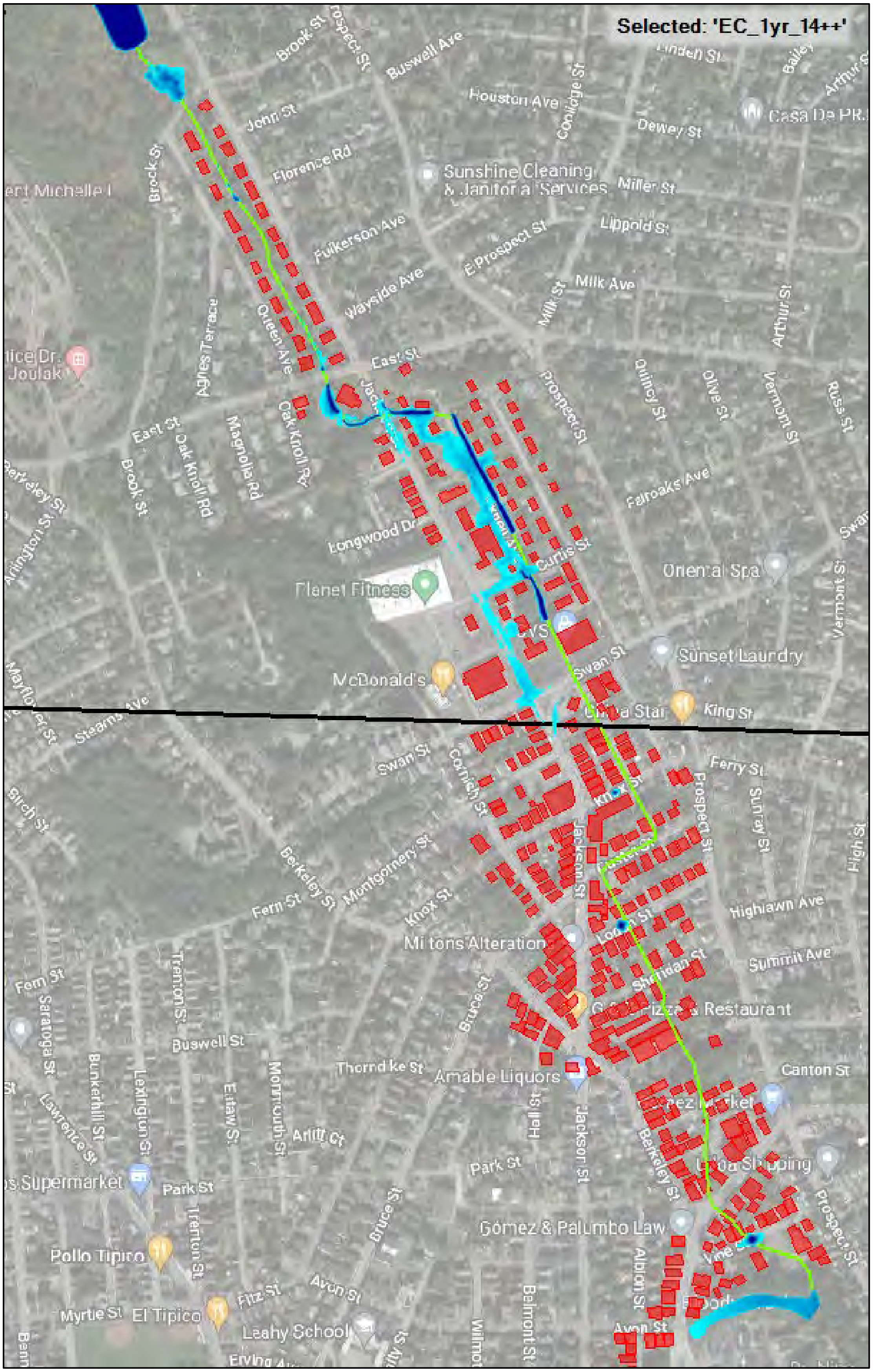
Graphic 11: Extent of flood inundation during a **100-year** event; **172 structures** experience first floor flooding during this event (36 in Methuen and 136 in Lawrence).

Graphic 12: Extent of flood inundation during a **200-year** event; **195 structures** experience first floor flooding during this event (43 in Methuen and 152 in Lawrence).

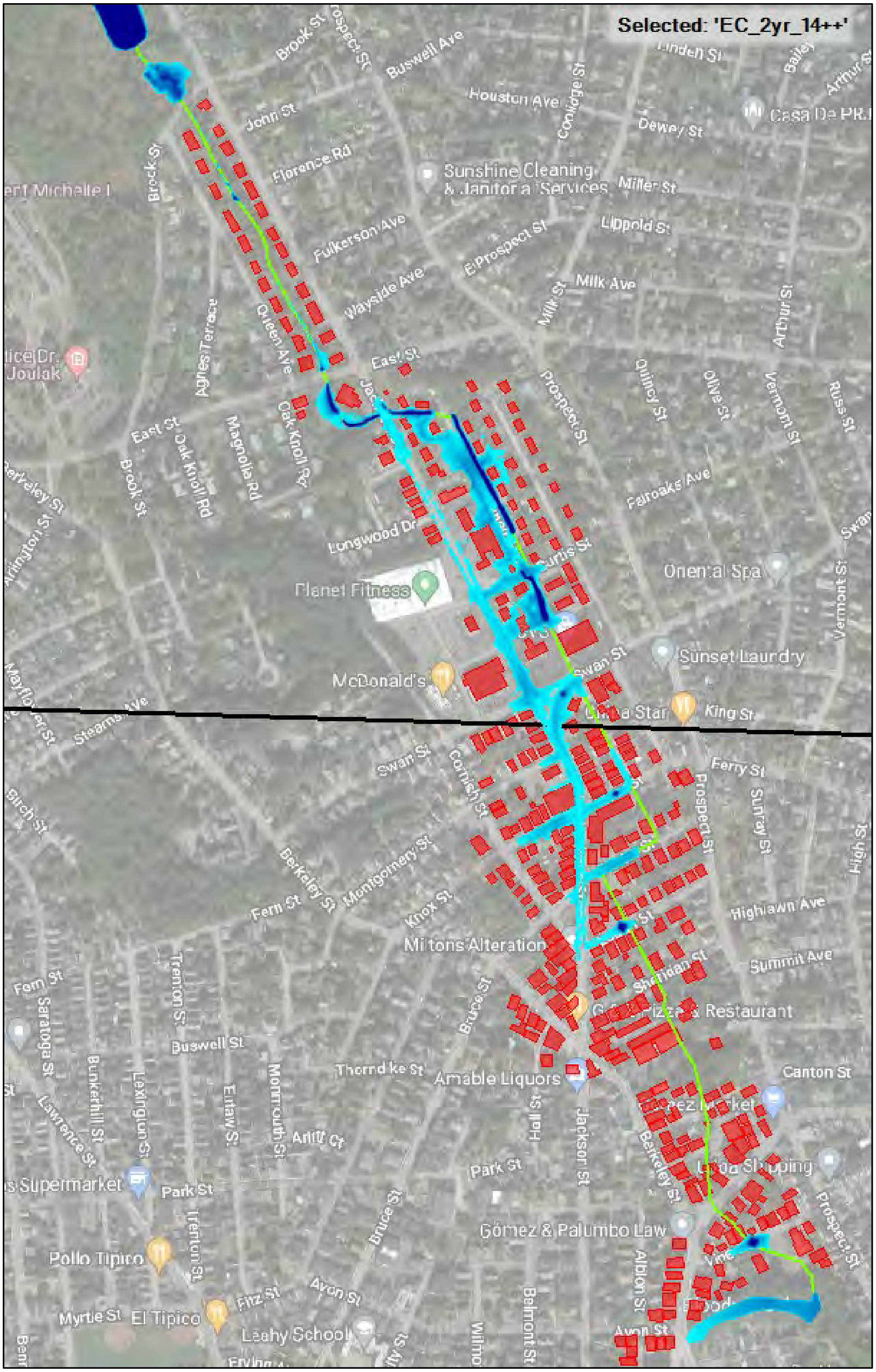
Graphic 13: Extent of flood inundation during a **500-year** event; **219 structures** experience first floor flooding during this event (57 in Methuen and 162 in Lawrence).



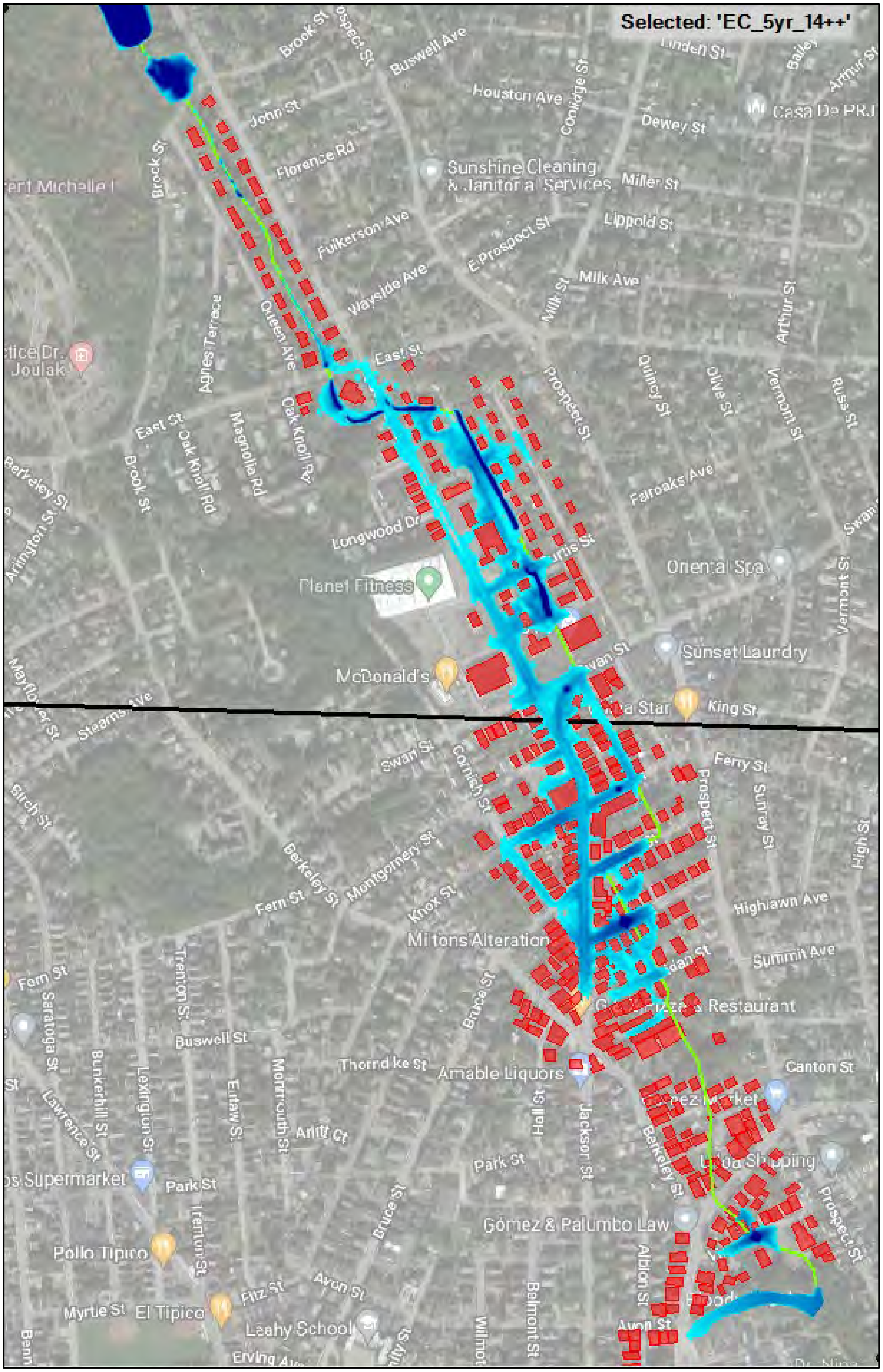
Graphic 14: Extent of flood inundation during a **1,000-year** event; **232 structures** experience first floor flooding during this event (62 in Methuen and 170 in Lawrence).



Graphic 15: Extent of flood inundation during a **1-year** event under existing conditions (EC) under CCIPF rainfall conditions (14++) (typical graphics 15-24); **4 structures** experience first floor flooding during this event (all in Methuen).

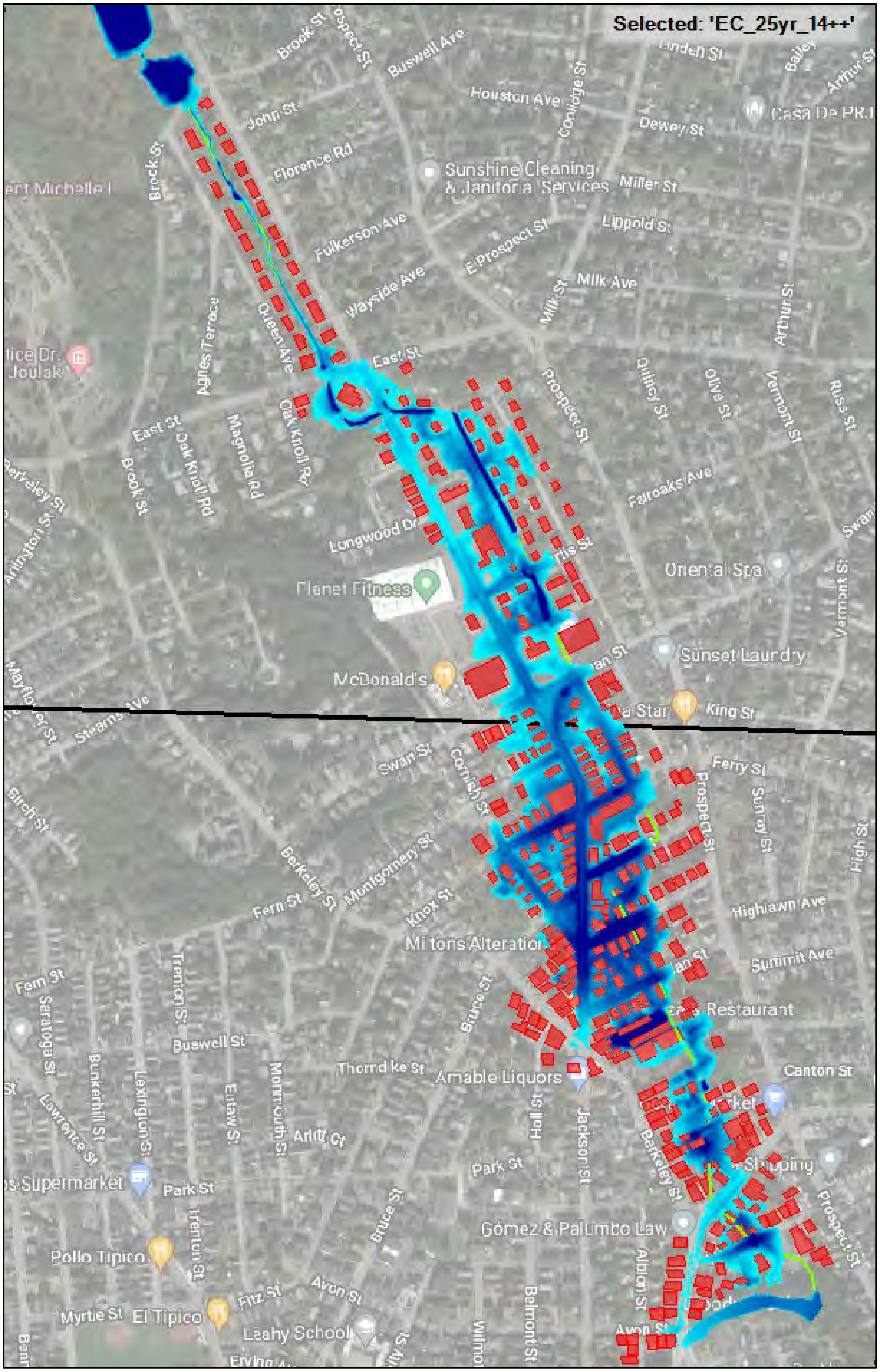


Graphic 16: Extent of flood inundation during a **2-year** event; **35 structures** experience first floor flooding during this event (14 in Methuen and 21 in Lawrence).

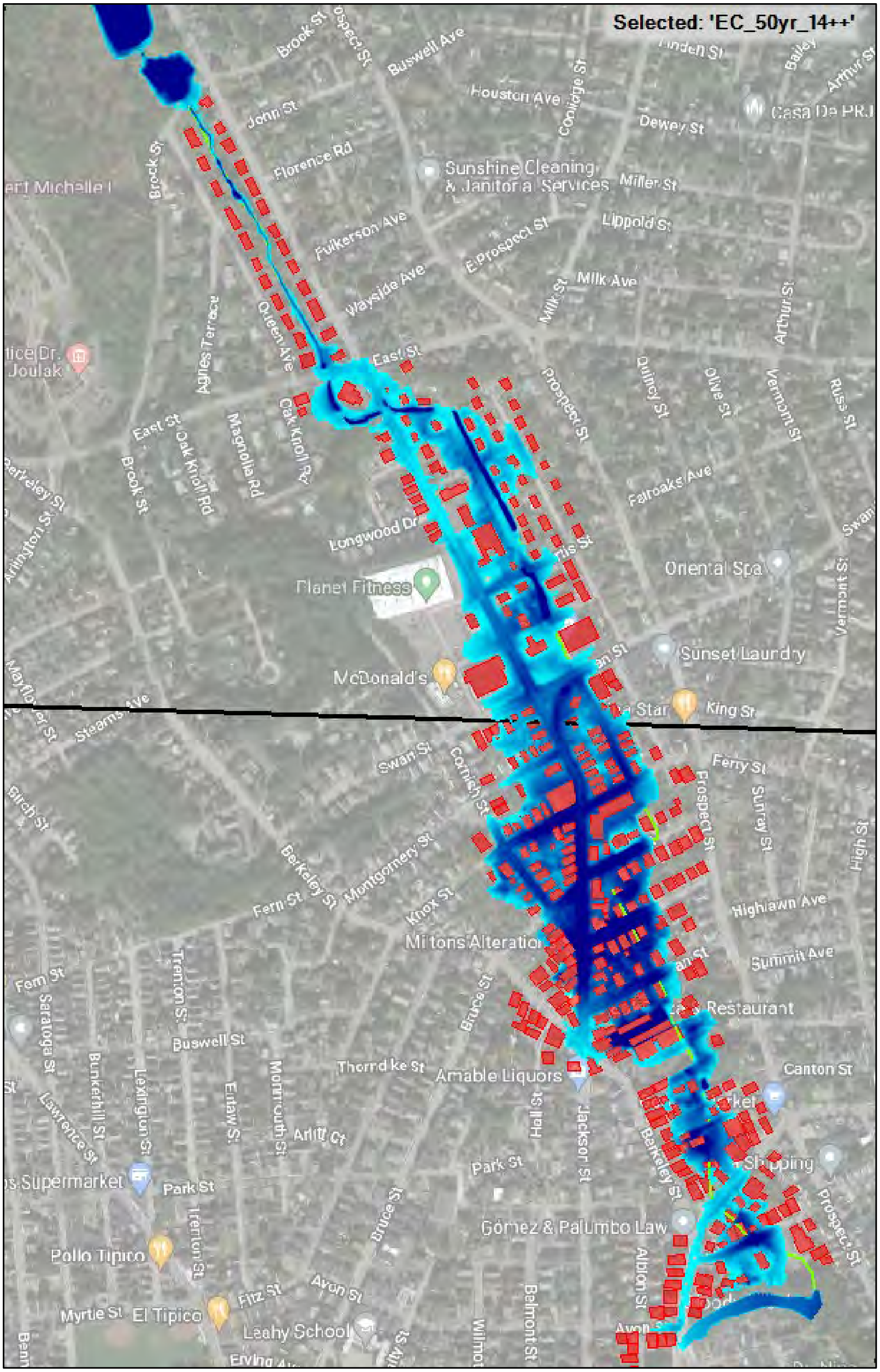


Graphic 17: Extent of flood inundation during a **5-year** event; **96 structures** experience first floor flooding during this event (21 in Methuen and 75 in Lawrence).

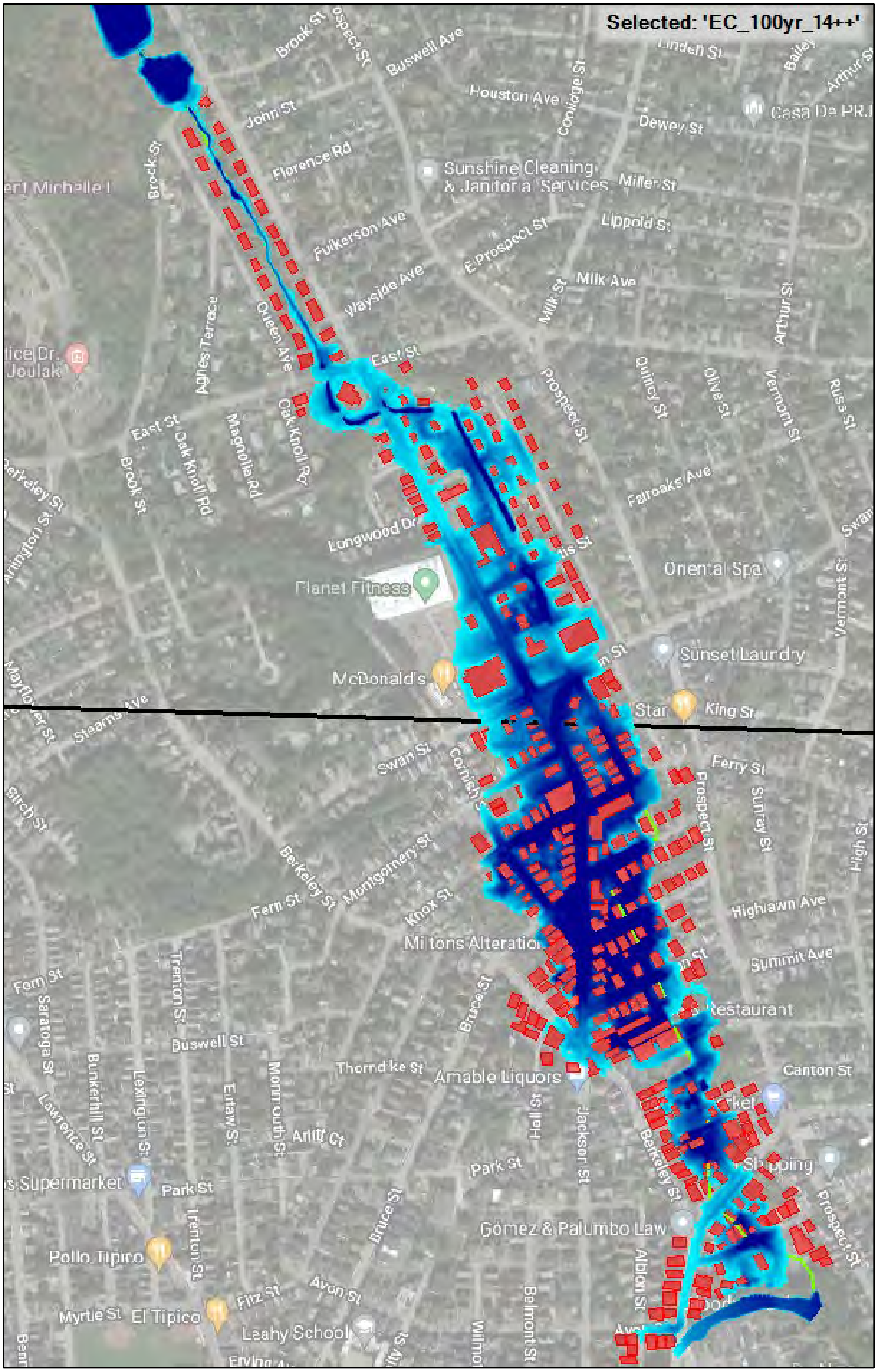
Graphic 18: Extent of flood inundation during a **10-year** event; **146 structures** experience first floor flooding during this event (24 in Methuen and 122 in Lawrence).



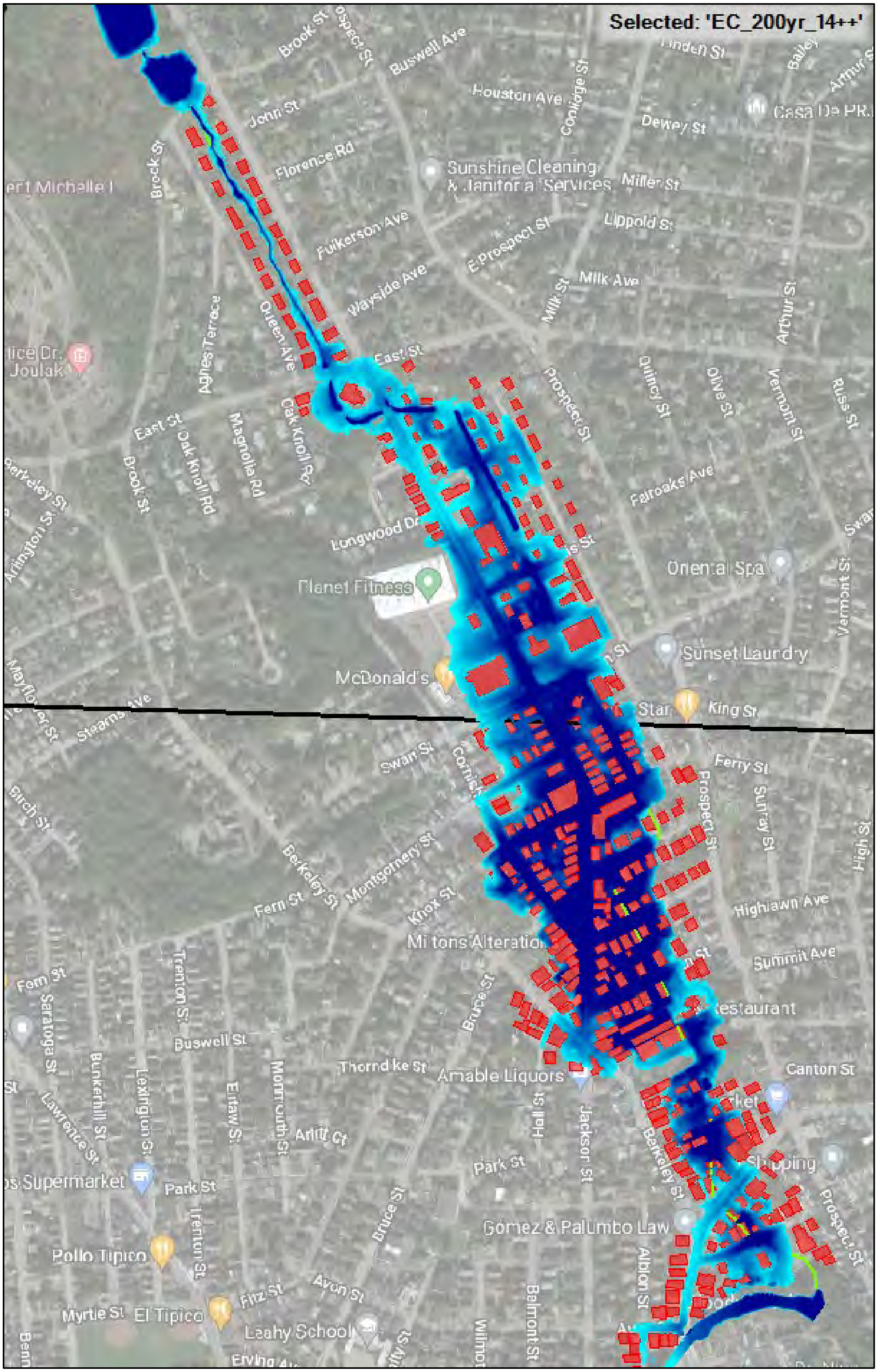
Graphic 19: Extent of flood inundation during a **25-year** event; **176 structures** experience first floor flooding during this event (38 in Methuen and 138 in Lawrence).



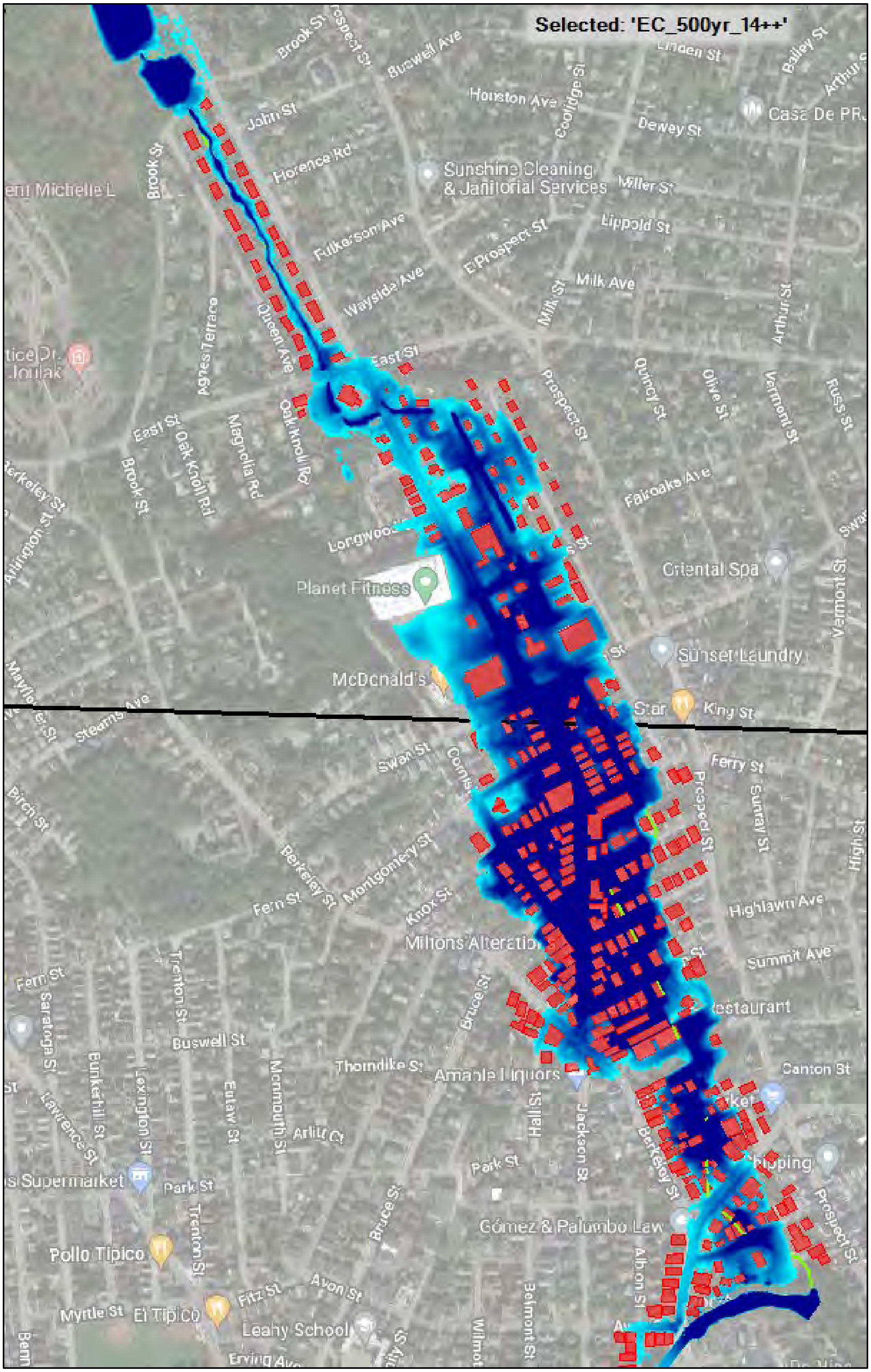
Graphic 20: Extent of flood inundation during a **50-year** event; **202 structures** experience first floor flooding during this event (45 in Methuen and 157 in Lawrence).



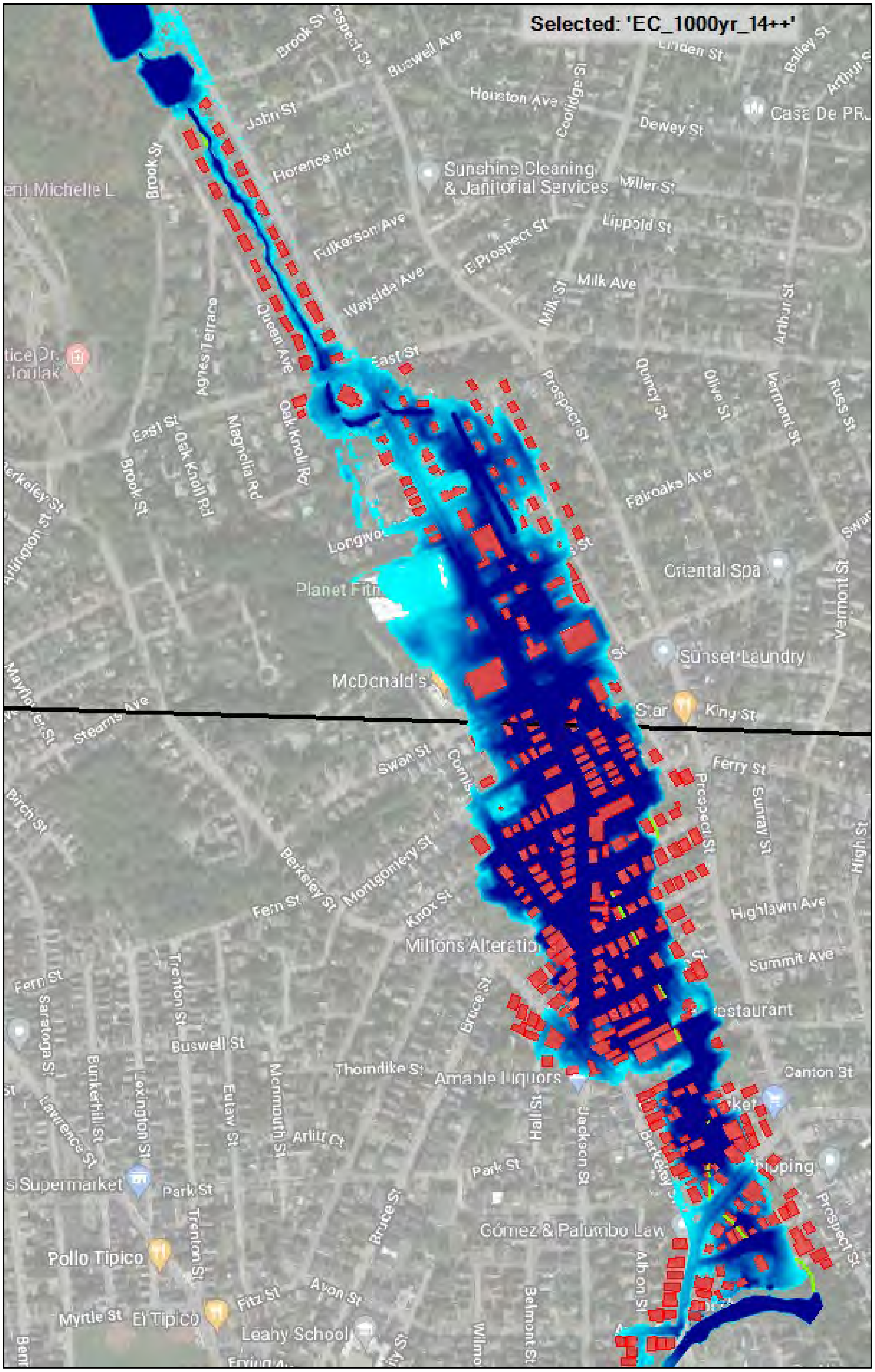
Graphic 21: Extent of flood inundation during a **100-year** event; **225 structures** experience first floor flooding during this event (58 in Methuen and 167 in Lawrence).



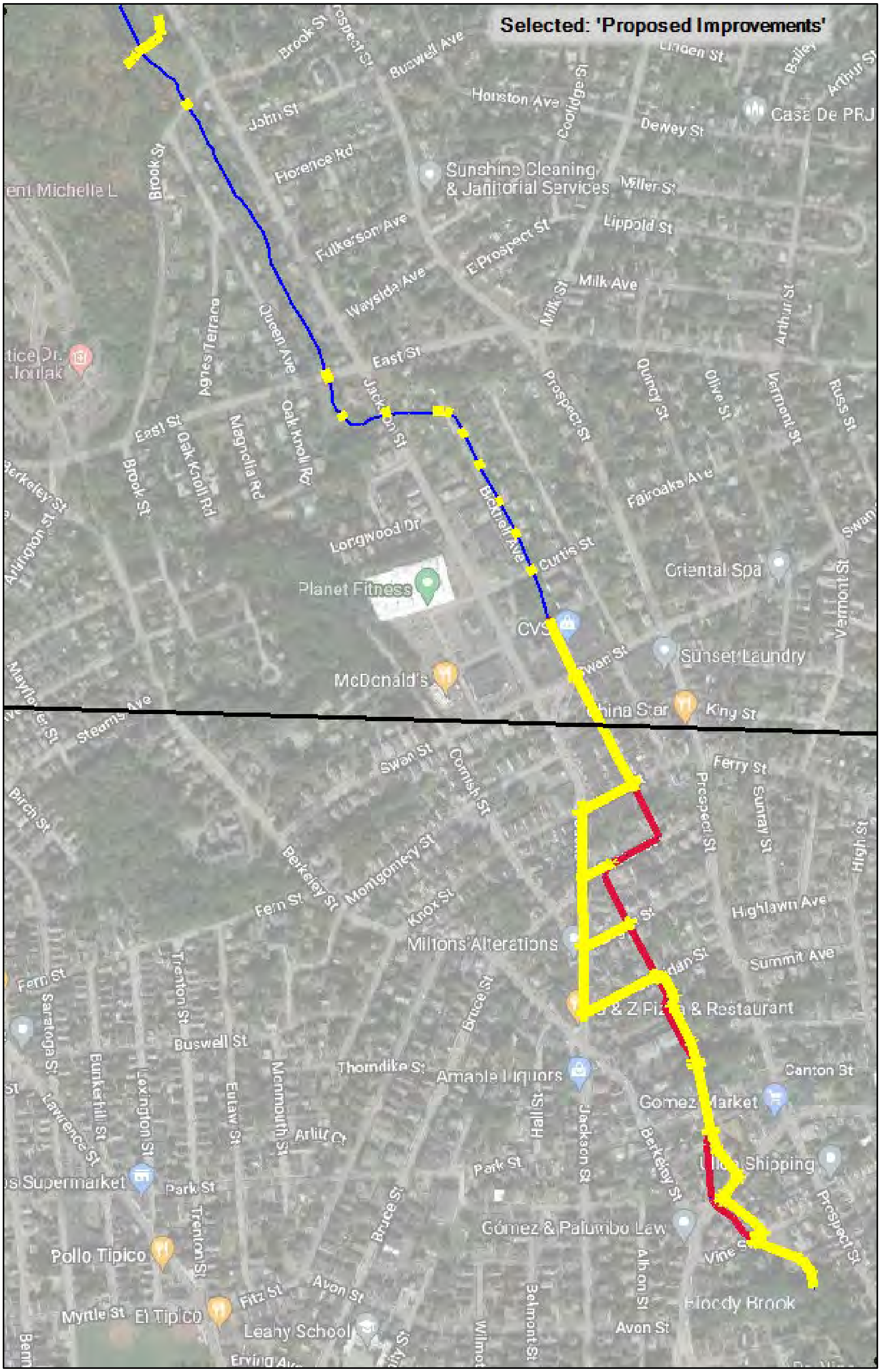
Graphic 22: Extent of flood inundation during a **200-year** event; **241 structures** experience first floor flooding during this event (73 in Methuen and 187 in Lawrence).



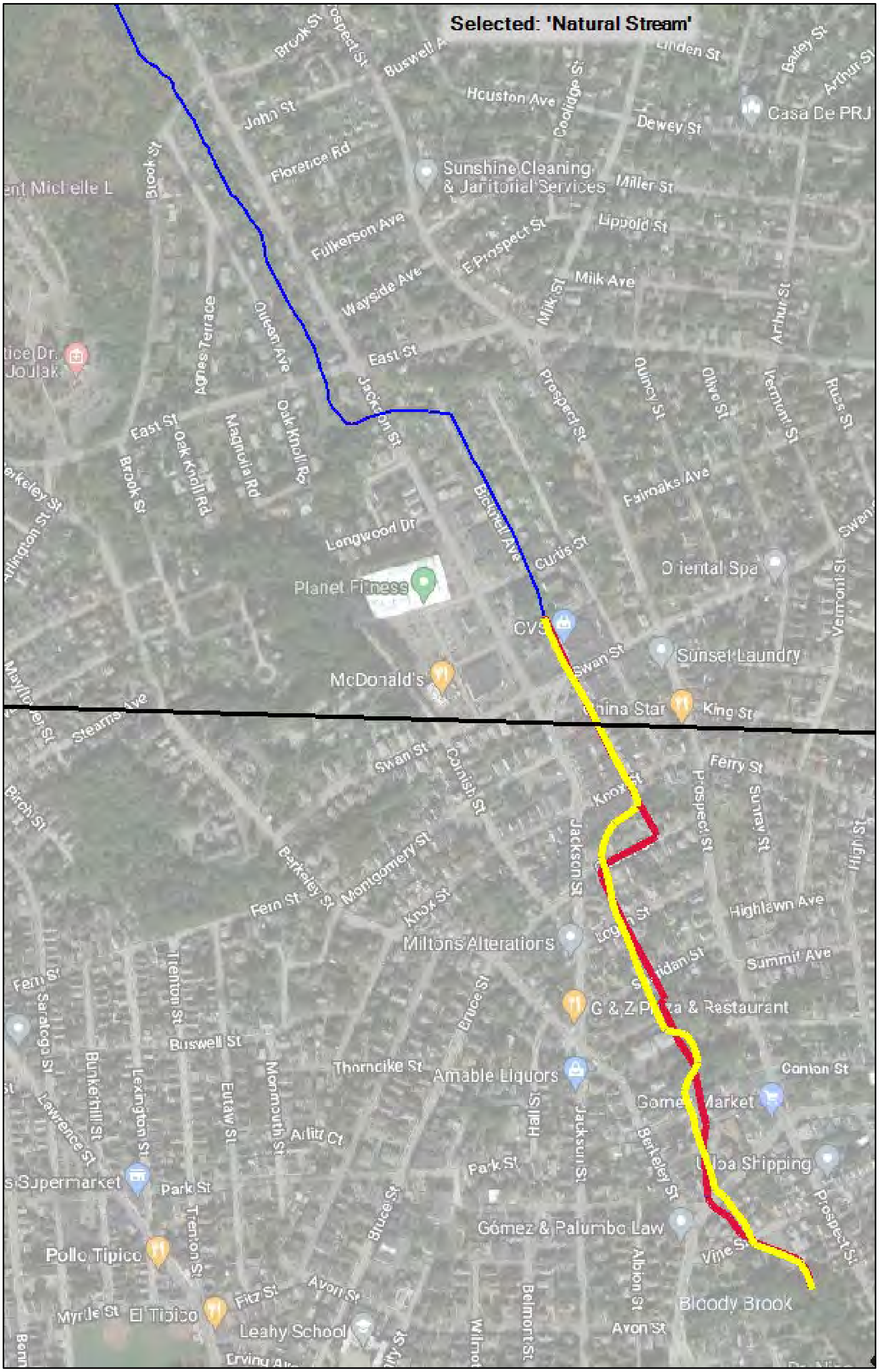
Graphic 23: Extent of flood inundation during a **500-year** event; **260 structures** experience first floor flooding during this event (73 in Methuen and 187 in Lawrence).



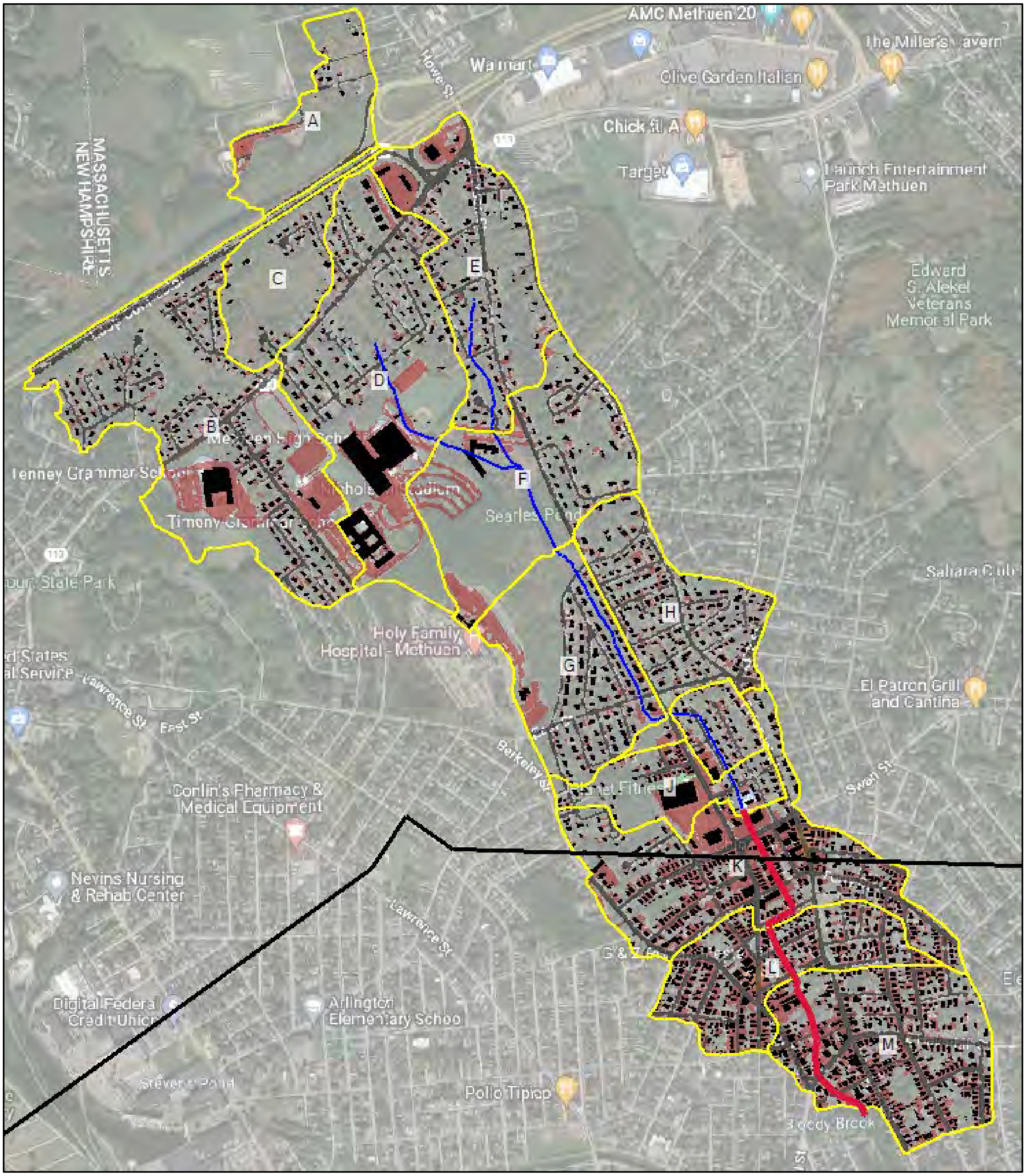
Graphic 24: Extent of flood inundation during a **1,000-year** event; **266 structures** experience first floor flooding during this event (77 in Methuen and 189 in Lawrence).



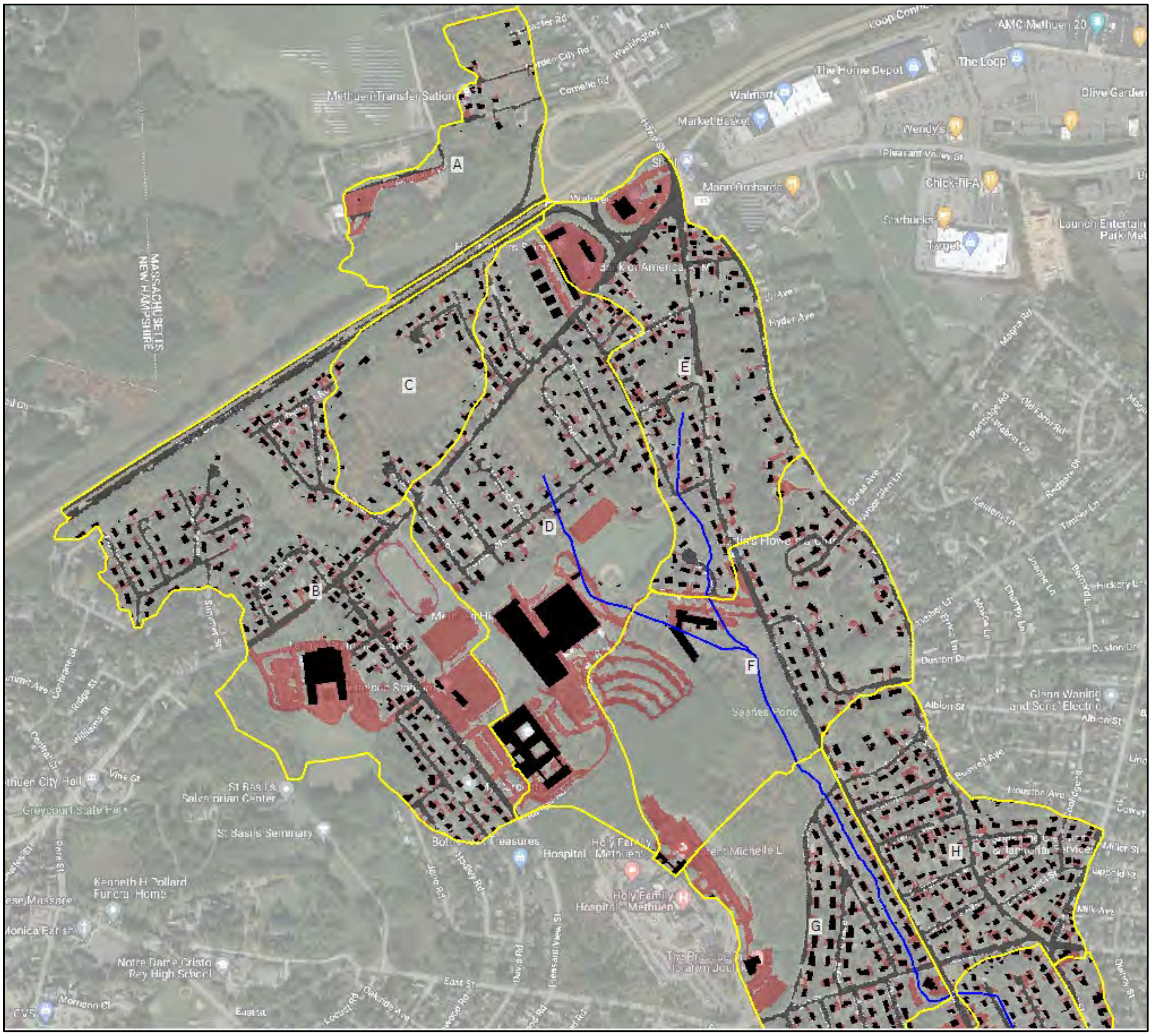
Graphic 25: Map view of the proposed in-stream improvements project; alignment of improvements identified with yellow lines. Components not identified include the stream rehabilitation from Brook Street to the inlet of the Bloody Brook Culvert.



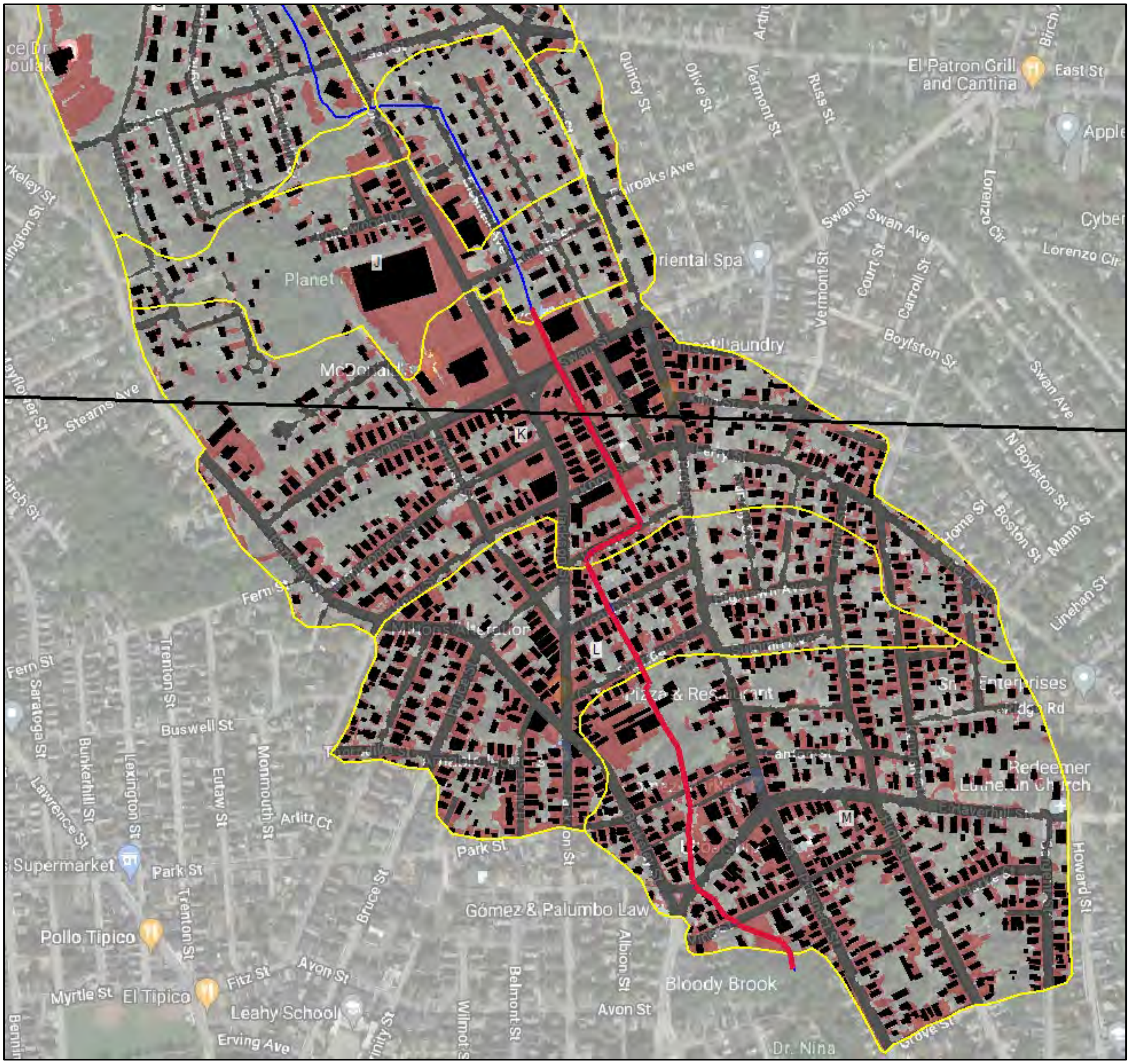
Graphic 26: Map view of the conceptual alignment of the natural open channel alternative.



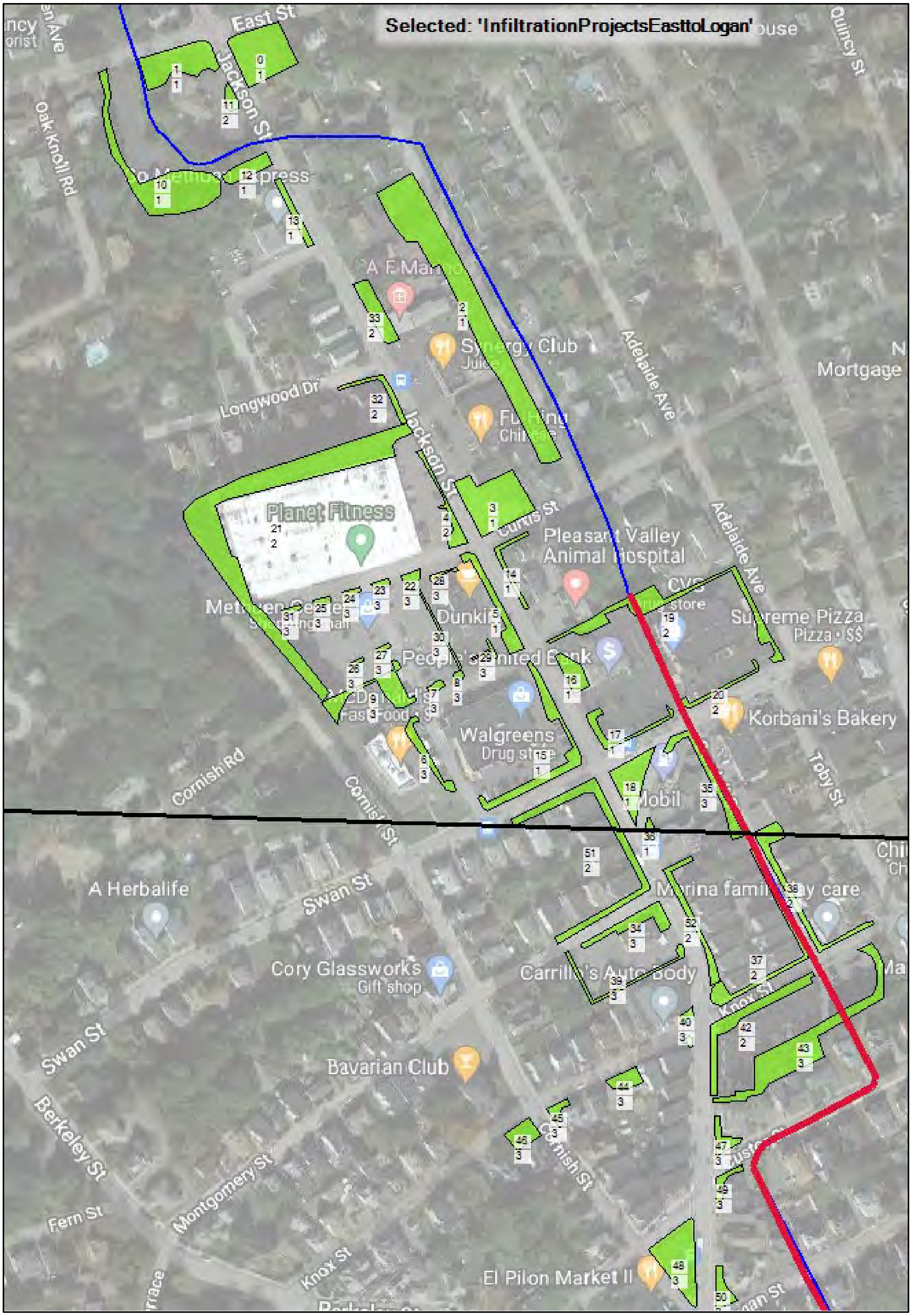
Graphic 27: Impervious areas within the bloody brook watershed. Black shade is structure rooftops, gray shade is roadways, and brown shade is other impervious areas (parking lots, driveways, etc.) that could be converted to a pervious land cover. Note the areas of undeveloped vegetation (forests, wetlands, etc.) land, particularly within drainage areas A-G that warrant protection and enhancement through land use management measures.



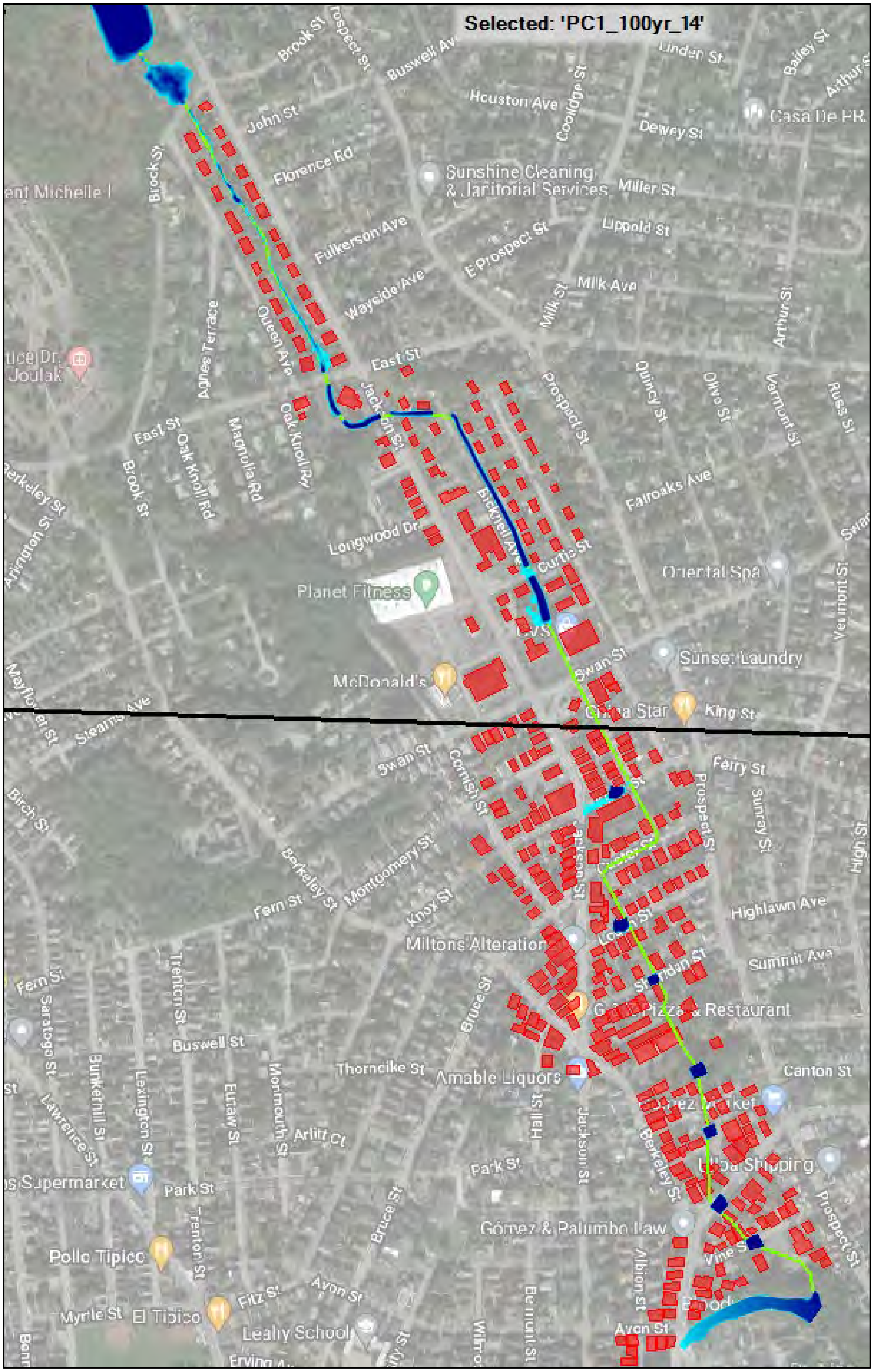
Graphic 28: Closer view of the northern (upstream) portion of Graphic #26.



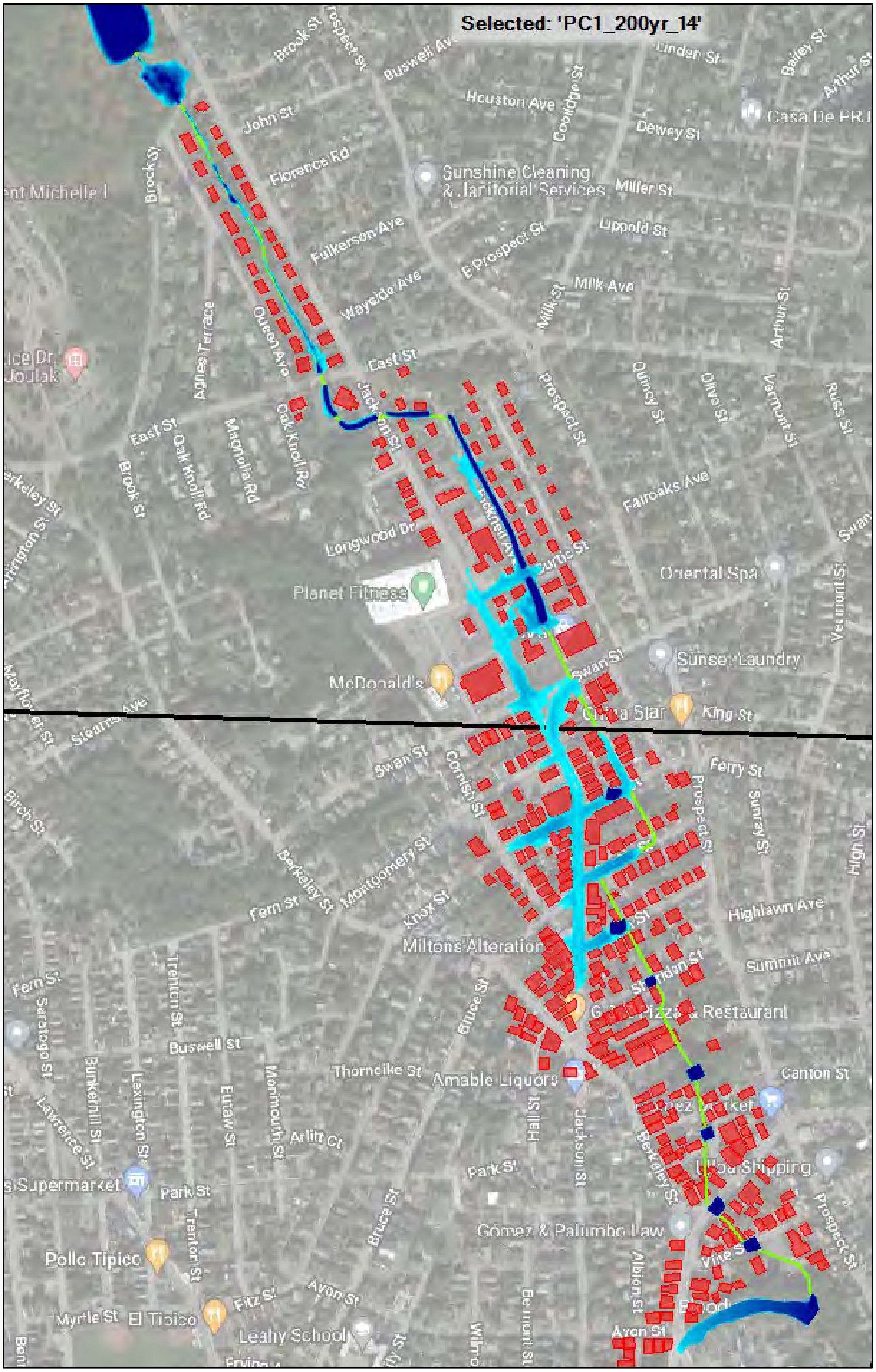
Graphic 29: Closer view of the southern (downstream) portion of Graphic #26.



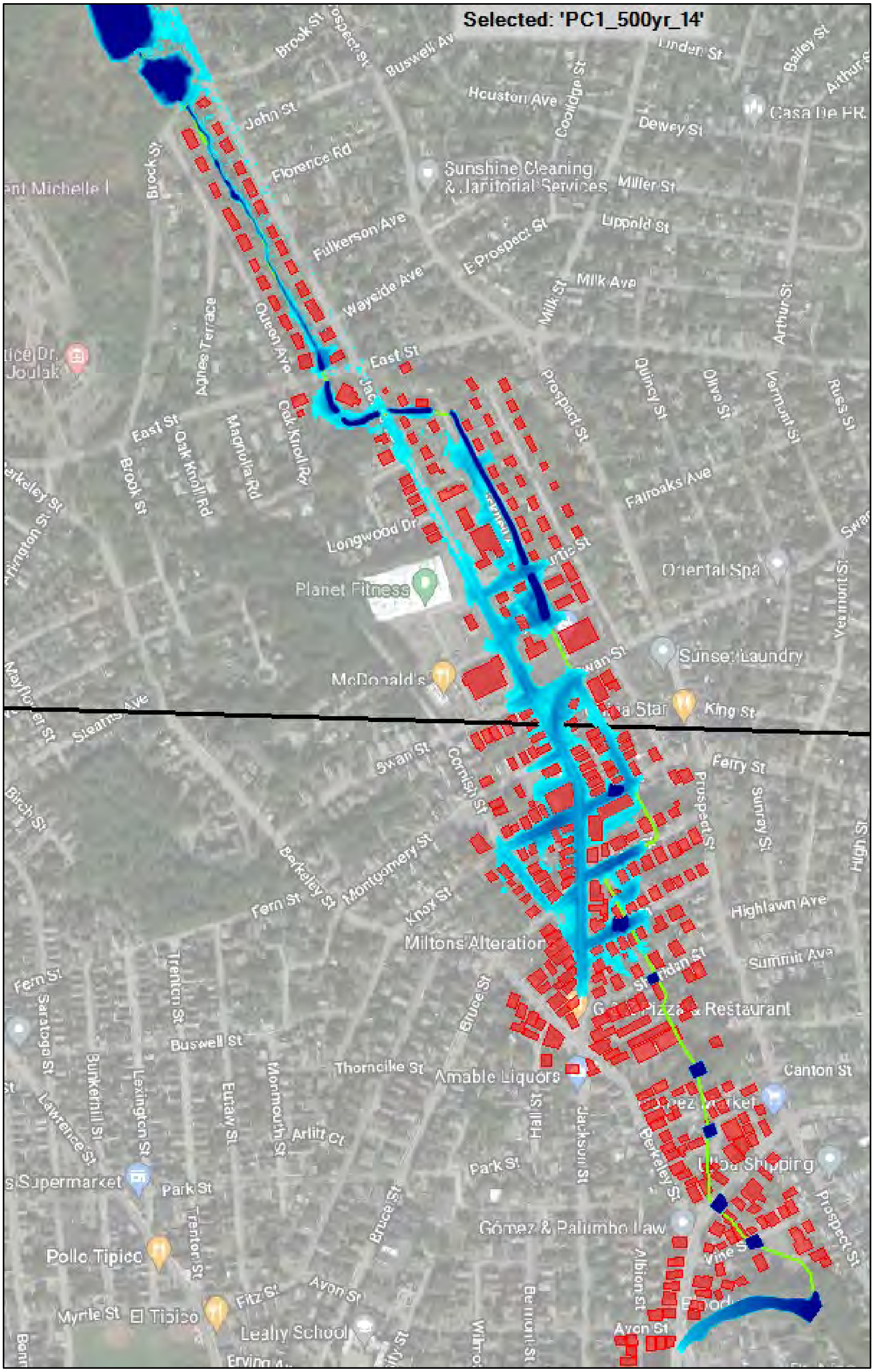
Graphic 30: Map view of the potential GSI projects identified by the site search within the portion of the corridor that experiences frequent flooding; focused primarily along Jackson Street and its cross streets from as far North as East Street to as far South as Logan Street. Note green shade is project footprint, top label is project ID, and bottom label is priority rating (1-3).



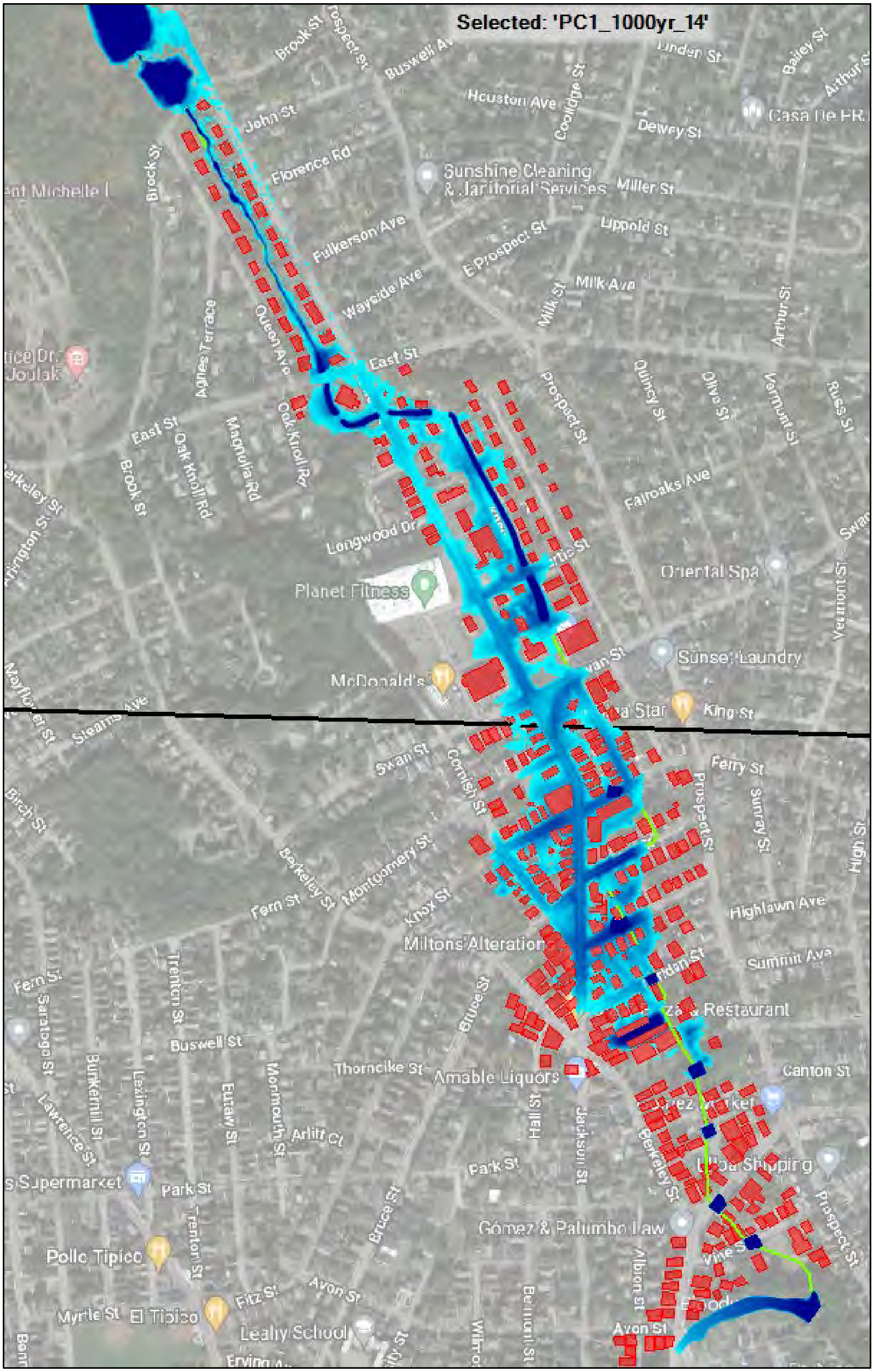
Graphic 31: Extent of flood inundation during a **100-year** event with the in-stream improvements project(s) completed (PC) under current rainfall conditions (14) (typical 31-34); **1 structure** experiences first floor flooding during this event (in Methuen). *Note that all storm events less than the 100-year do not result in any out of bank flooding or structure inundation; therefore, their inundation graphics have not been included.*



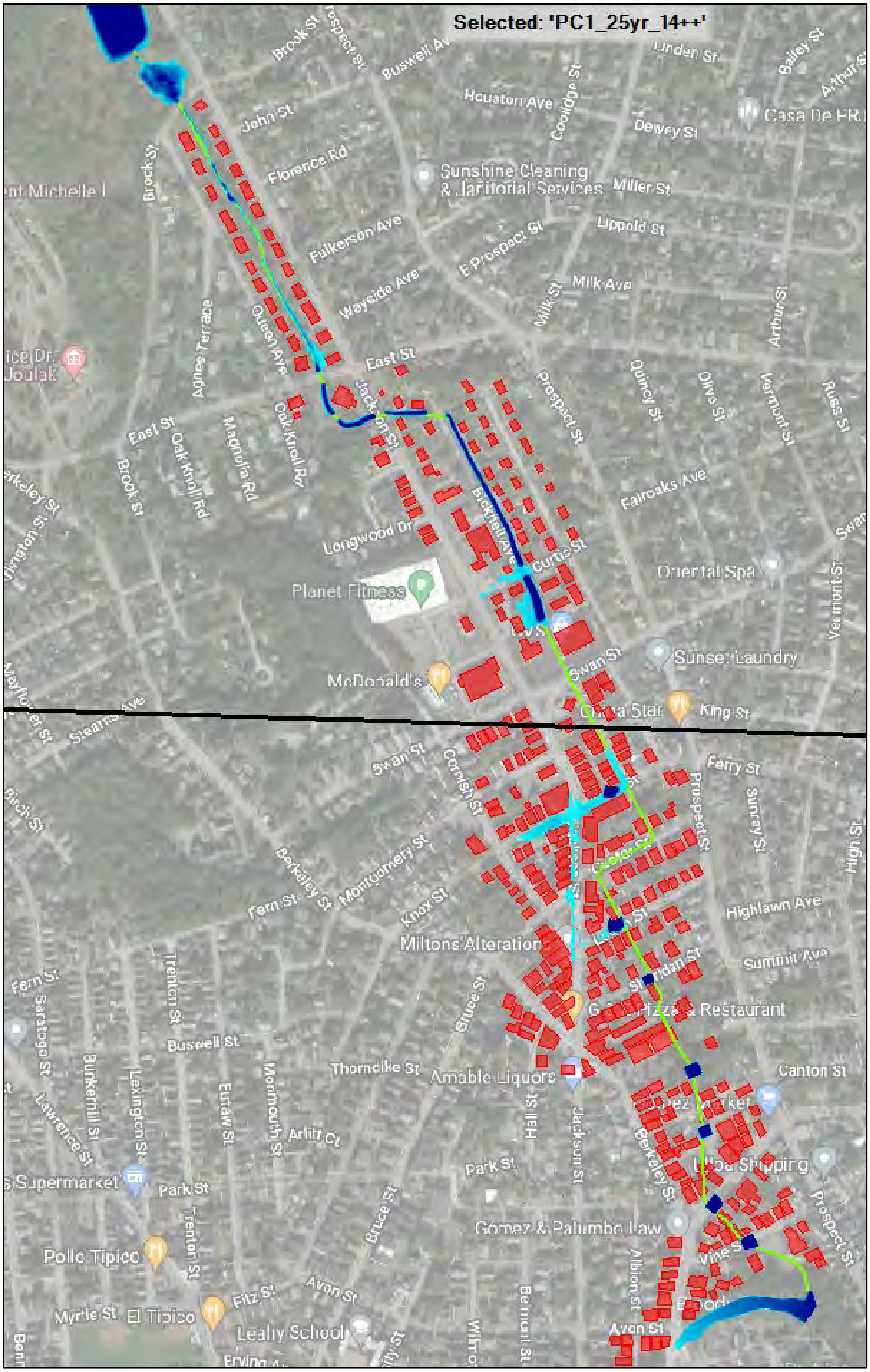
Graphic 32: Extent of flood inundation during a **200-year** event; **47 structures** experience first floor flooding during this event (6 in Methuen and 41 in Lawrence).



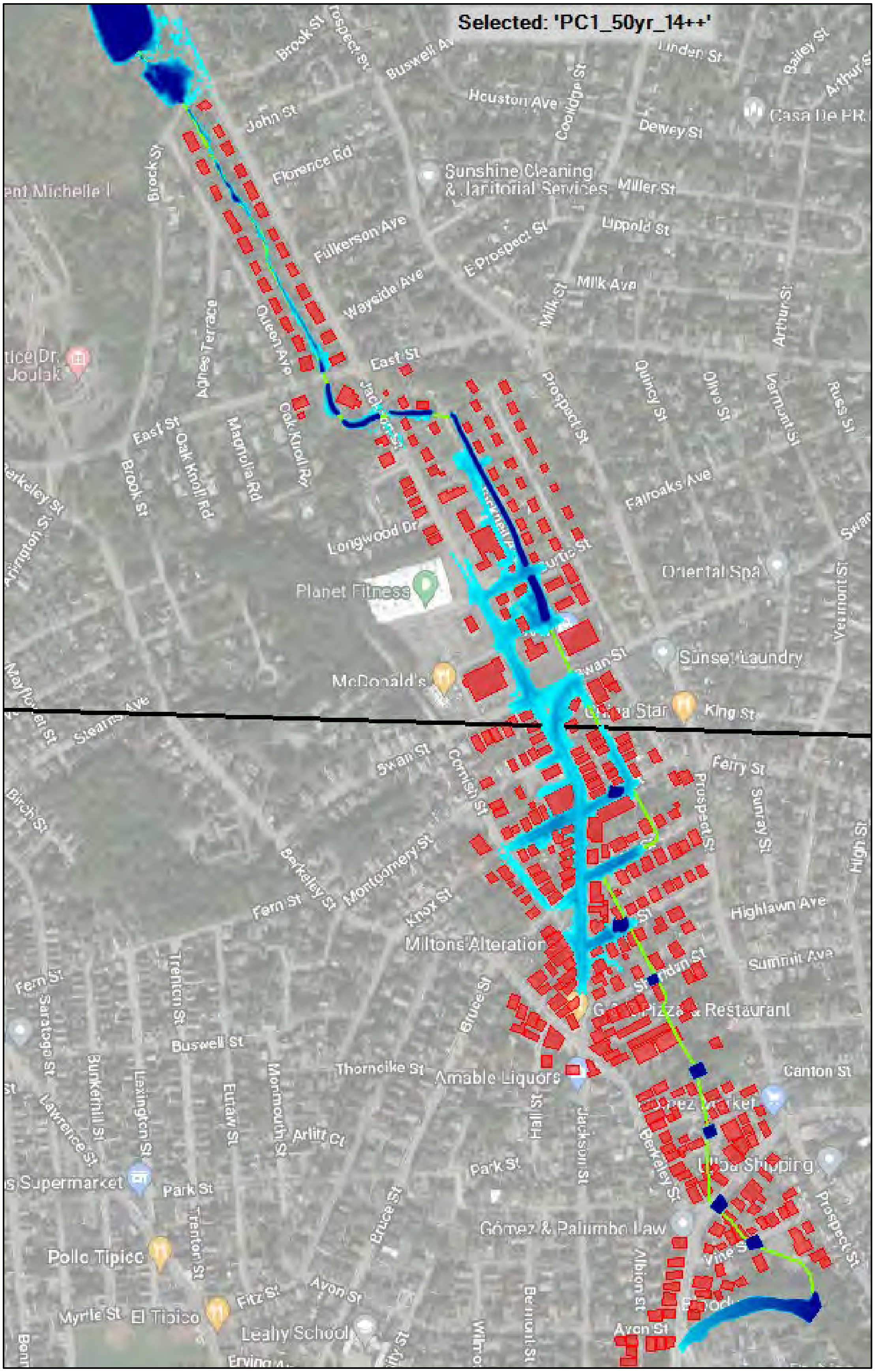
Graphic 33: Extent of flood inundation during a **500-year** event; **100 structures** experience first floor flooding during this event (21 in Methuen and 79 in Lawrence).



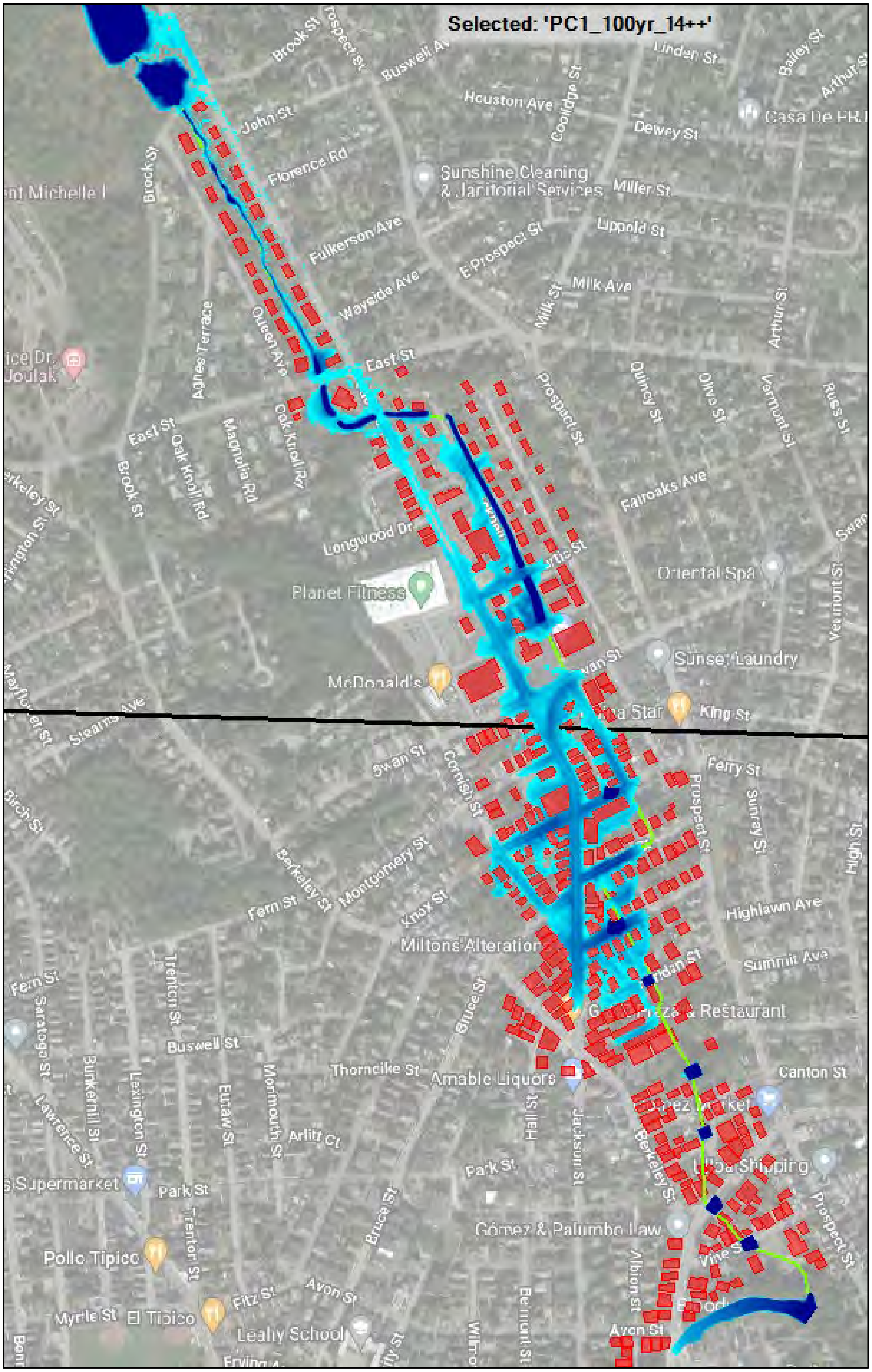
Graphic 34: Extent of flood inundation during a 1,0**00-year** event; **138 structures** experience first floor flooding during this event (38 in Methuen and 100 in Lawrence).



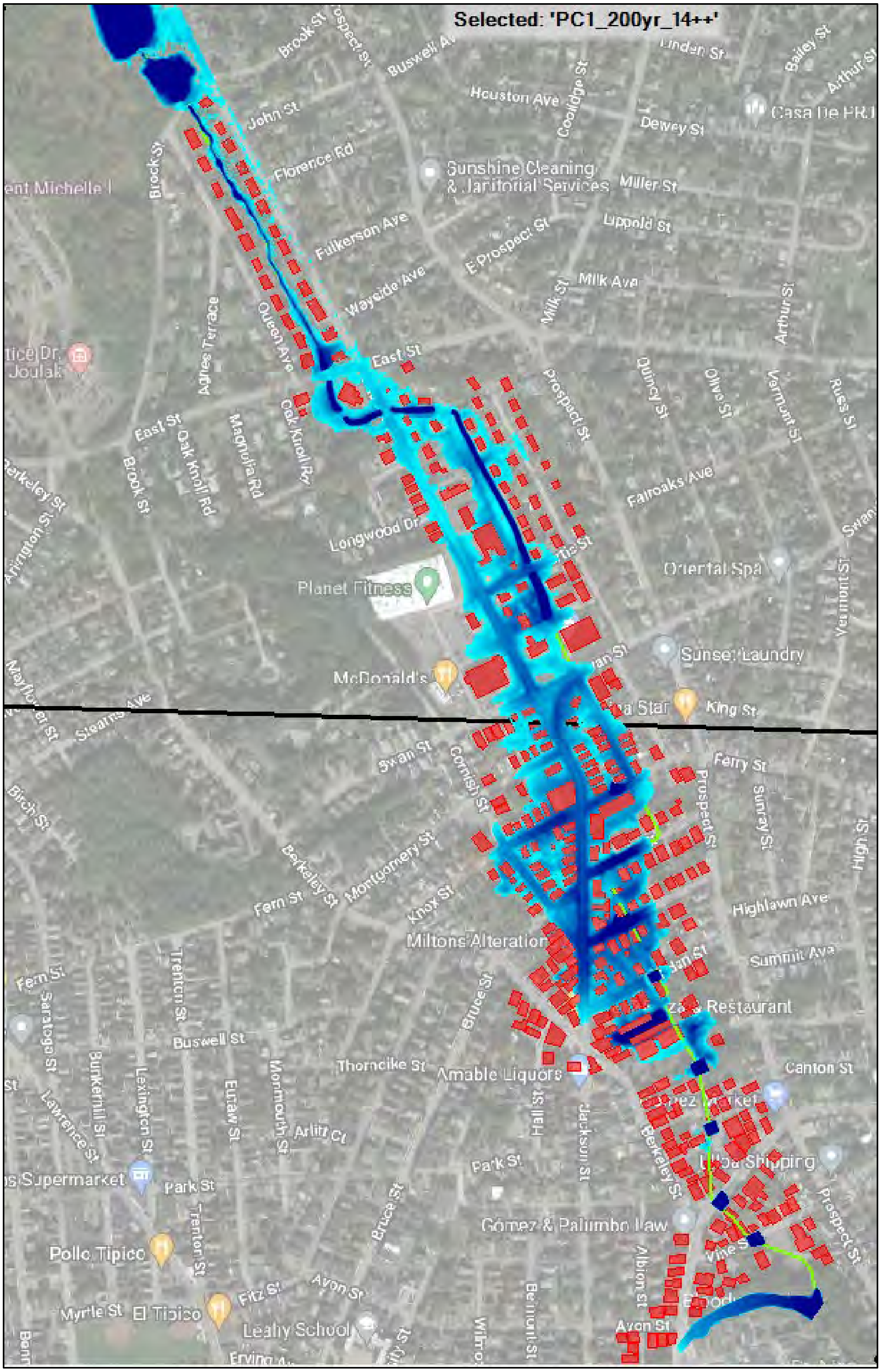
Graphic 35: Extent of flood inundation during a **25-year** event with the in-stream improvements project(s) completed (PC) under CCIPF rainfall conditions (14++) (typical 35-40); **8 structures** experiences first floor flooding during this event (1 in Methuen and 7 in Lawrence). *Note that all storm events less than the 25-year do not result in any out of bank flooding or structure inundation; therefore, their inundation graphics have not been included.*



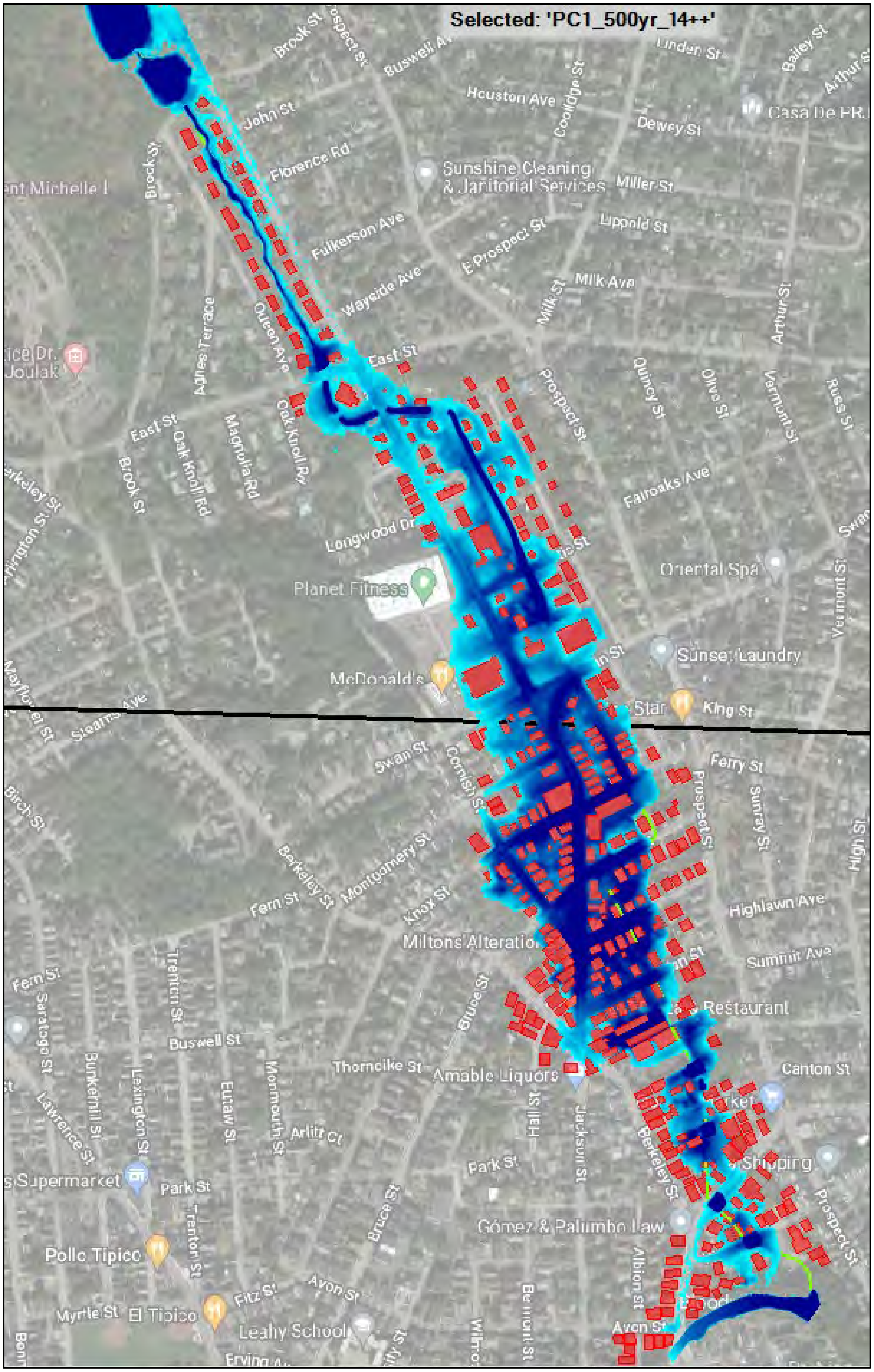
Graphic 36: Extent of flood inundation during a **50-year** event; **68 structures** experience first floor flooding during this event (12 in Methuen and 56 in Lawrence).



Graphic 37: Extent of flood inundation during a **100-year** event; **118 structures** experience first floor flooding during this event (26 in Methuen and 92 in Lawrence).



Graphic 38: Extent of flood inundation during a **200-year** event; **151 structures** experience first floor flooding during this event (48 in Methuen and 103 in Lawrence).



Graphic 39: Extent of flood inundation during a 5**00-year** event; **219 structures** experience first floor flooding during this event (66 in Methuen and 153 in Lawrence).

Graphic 40: Extent of flood inundation during a **1,000-year** event; **244 structures** experience first floor flooding during this event (73 in Methuen and 171 in Lawrence).

APPENDIX B:
Photographs of Bloody Brook Corridor

Photo No. 1.: Searles Impoundment looking Upstream/North

Photo No. 2.: Searles Pond Dam Low-Level Outlet Upstream End. Note Debris Accumulation at Approach.

Photo No. 3.: Searles Pond Dam Spillway Upstream End. Generally clear of debris.

Photo No. 4.: Brook Street Crossing Upstream End – Stone Headwall is cracked and split on top but no major impediment to flow.

Photo No. 5.: Brook Street Crossing Downstream End – Note large stones potentially impeding the flow of the stream. Stone masonry walls are slightly deteriorated.

Photo No. 6.: Brooks Street – East Street Channel looking downstream. Note the extensive overgrowth of vegetation resulting in hydraulic restriction

Photo No. 7.: Brooks Street – East Street Channel. Open Channel at 1/3 of the length from Brooks Street – looking downstream. Note bare unprotected banks prone to erosion.

Photo No. 8.: Brooks Street – East Street Channel. Open Channel at 1/2 of the length from Brooks Street looking downstream. Note bare banks prone to erosion and rubber tire retaining wall.

Photo No. 9.: Brooks Street – East Street Channel. Open Channel at 2/3 of the length from Brooks Street – looking upstream.

Photo No. 10.: Brooks Street – East Street Channel. Open Channel at 2/3 of the length from Brooks Street – looking downstream. Note limited freeboard (less than 2 feet) from stream bottom to adjacent residential property.

Photo No. 11.: Brooks Street – East Street Channel. Open Channel 100-ft away from Brooks Street – looking upstream. Note limited freeboard (less than 2 feet) from stream bottom to adjacent residential property.

Photo No. 12.: Brooks Street – East Street Channel. Open Channel 100-ft away from Brooks Street – looking downstream. Note limited freeboard (less than 2 feet) from stream bottom to adjacent residential property.

Photo No. 13.: East Street – Approach Channel. Channel is generally clear of debris but slopes to the abutments are very shallow.

Photo No. 14.: East Street – Crossing Upstream End. Culverts are silted in about halfway and accumulates debris from the upstream end during high flows.

Photo No. 15.: East Street – Crossing Downstream End. Invert is silted.

Photo No. 16.: Jehovah's Witness Parking Lot – Channel between East Street and Parking Lot looking Upstream.

Photo No. 17.: Jehovah's Witness Parking Lot – Upstream Invert. Note debris at inlet creating upstream water levels 1-foot higher than invert.

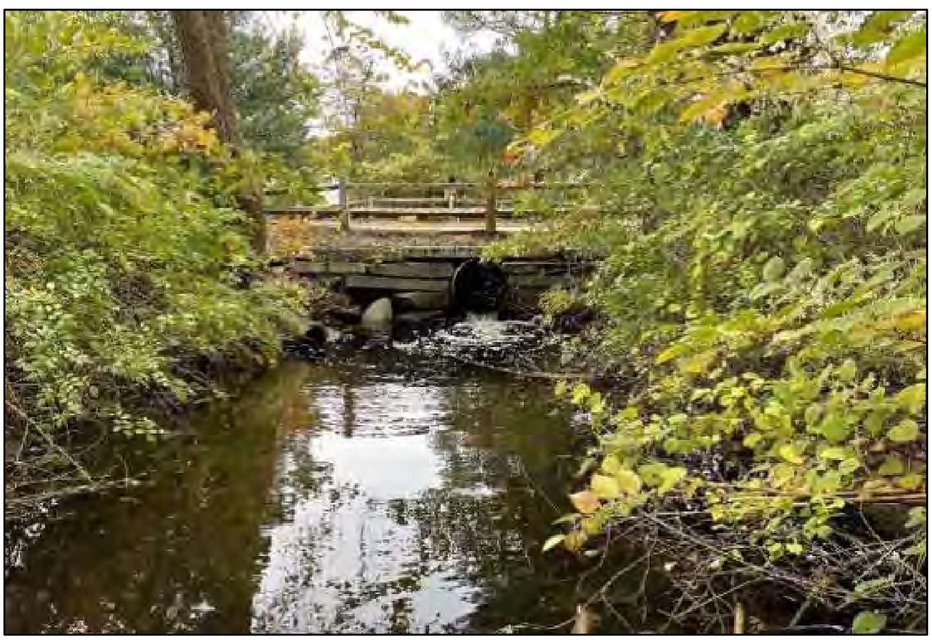


Photo No. 18.: Jehovah's Witness Parking Lot –Downstream headwall and Channel.

Photo No. 19.: Jackson Street – looking upstream.

Photo No. 20.: Jackson Street – looking downstream

Photo No. 21.: Jackson Street – Downstream Invert. Note the limited height (less than 2 feet) due to apparent sedimentation issues.

Photo No. 22.: Bicknell Avenue Culvert #1 – Channel from Jackson Street. Note narrow channel with highly erodible banks.

Photo No. 23.: Bicknell Avenue Culvert #1 – Upstream Invert. Note the sediment accumulation at the pipe culvert and at the center of the channel.

Photo No. 24.: Bicknell Avenue Culvert #1 – Downstream Invert. Note that sediment has accumulated in the middle of the channel and is growing vegetation.

Photo No. 25.: Bicknell Avenue Culvert #1 – Bicknell Avenue Culvert #2 Channel looking downstream. Note the sedimentation and unprotected banks prone to erosion.

Photo No. 26.: Bicknell Avenue Culvert #2 – Upstream Invert.

Photo No. 27.: Bicknell Avenue Culvert #2 – Bicknell Avenue Culvert #3 Channel looking upstream.

Photo No. 28.: Bicknell Avenue Culvert #3 looking downstream

Photo No. 29.: Bicknell Avenue Culvert #4 upstream invert.

Photo No. 30.: Bicknell Avenue Culvert #4 downstream invert

Photo No. 31.: Bicknell Avenue Culvert #4 – Bicknell Avenue Culvert #5 Channel looking upstream.

Photo No. 32.: Bicknell Avenue Culvert #5 upstream invert.

Photo No. 33.: Bicknell Avenue Culvert #5 looking downstream. Note apparent sage in top of pipe at mid-length (estimated at 1 foot).

Photo No. 34.: Bicknell Avenue Culvert #4 – Bicknell Avenue Culvert #5 Channel looking upstream.

Photo No. 35.: Channel between Curtis Street and inlet of Bloody Brook Culvert. Note overgrowth, sedimentation, and channel banks prone to erosion.

Photo No. 36.: Final crossing behind CVS Parking Lot. Slight debris accumulation on the cage of the outlet.

Photo No. 37.: Bloody Brook Culvert Outfall to Spicket River

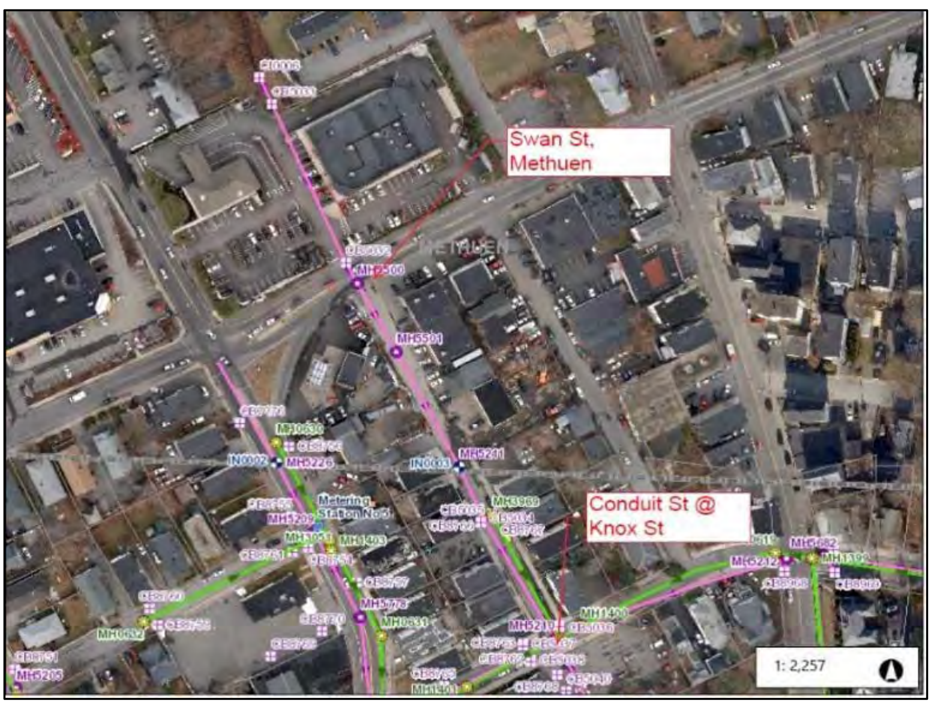


Photo No. 38.: Downstream Channel Path – Clip #1

Photo No. 39.: Downstream Channel Path – Clip #2

Photo No. 40.: Downstream Channel Path – Clip #3

Photo No. 41.: Downstream Channel Path – Clip #4

Photo No. 42.: Downstream Channel Path – Clip #5

Photo No. 43.: Downstream Channel Path from CVS Parking Lot – Overall. Stream discharges to the Spicket River and eventually the Merrimack River.

APPENDIX C:
Report Limitations

LIMITATIONS

Use of Report

1. This report has been prepared for the exclusive use of the City of Methuen for specific application to the Bloody Brook Watershed Planning Study in accordance with generally accepted engineering practices. No other warranty, expressed or implied, is made.

2. The material in this report reflects Pare's judgment in light of the information available to it at the time of preparation. Any use, reliance on, or decisions made based on this report, its findings or conclusions by any third party are the sole responsibility of such third parties.

3. Pare Corporation accepts no responsibility for damages, if any, suffered by any third party as a result of their use of, decisions made or actions taken based on this report.

Hydrologic & Hydraulic Model Limitations

1. The H&H results discussed herein as well as the conclusions that have been drawn from those results are based on the assumed model conditions and H&H processes and procedures that were used. Some of the processes involved with H&H analyses are theoretical and subject to engineering judgment and estimation.

2. Variations between the assumed model conditions and actual event conditions (rainfall, ground surface conditions, debris clogging, etc.) are likely; as such, deviations between model results and actual conditions are likely.