An Urban Stream Manager's Guide to Field-Based Master Planning

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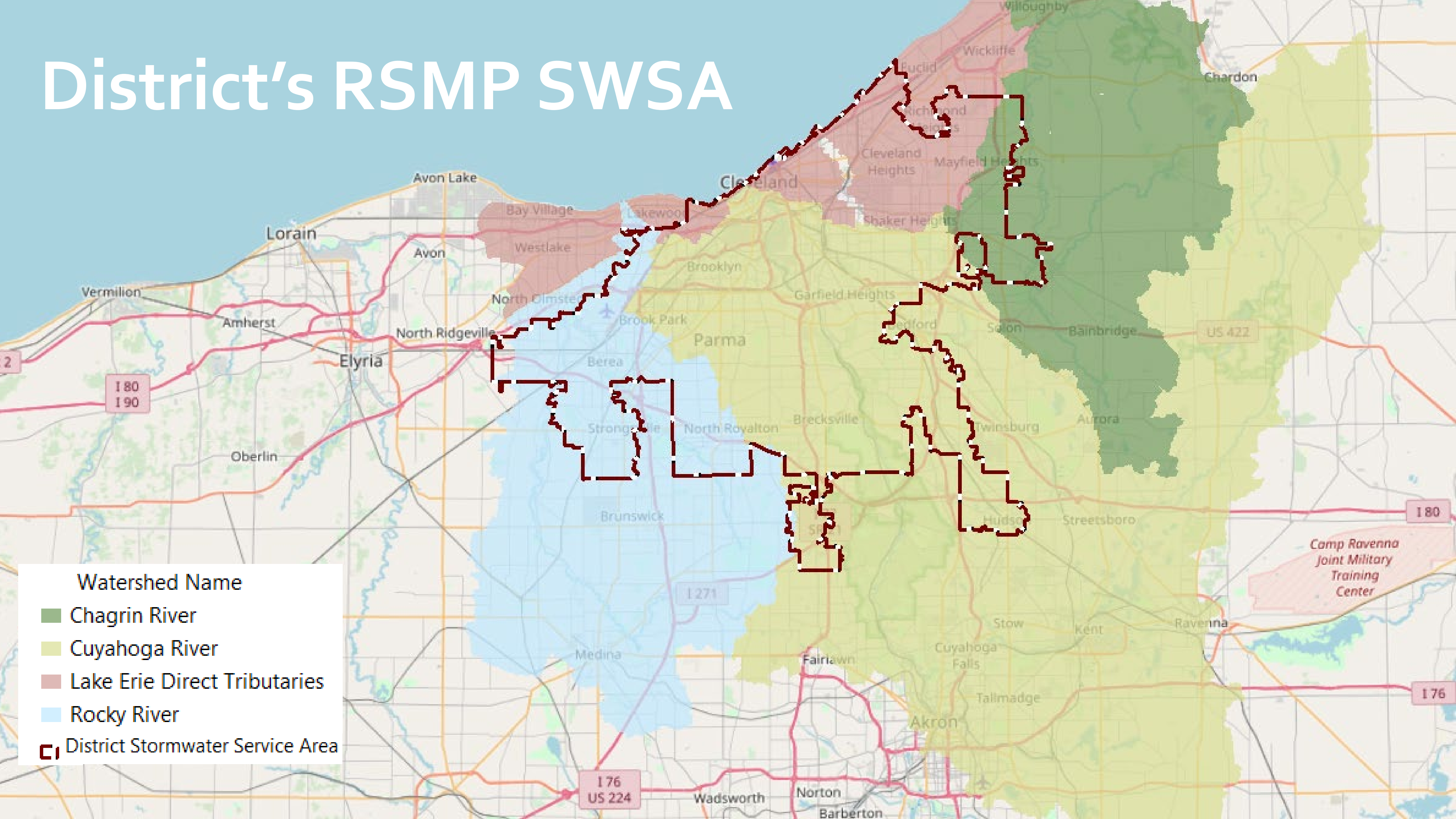
District's RSMP SWSA



Regional Stormwater Management Program (RSMP) Introduction: RSS Asset Counts

The RSMP is responsible for inspecting and maintaining the Regional Stormwater System (RSS), which is defined as:

- Approximately 300-acres of Drainage
- Intercommunity-related Problems

The RSS currently includes:

- 350 Miles of Open Stream
- 84 Miles of Culverted Stream Pipes
- 1,088 Roadway Crossings
- 22 Major Structures
- 91 Basins
- 25 Debris Racks
- 4,500+ BTUs (3,600+ buildings, 700+ transportation, and 250+ utility assets)

SWIM Vision

Safe conveyance of stormwater along healthy streams

SWIM Mission

Validated Predictive, Preventative, and Proactive SWIM Activities & Recommendations

by following a

Field-Focused, Function, & Risk-Based Stormwater Master Planning Approach to Asset Management

Safe Conveyance of Stormwater Along Healthy Streams

Stormwater Inspection: Condition Scores

SWIM Standard for Assigning Condition Ratings

Condition Rating	Sediment & Debris Accumulation (Crossings)	Sediment & Debris Accumulation (Basins)	Structural Integrity (Crossings)	Structural Integrity (Streams)	Hydraulic Performance (Crossings)
	[% Blocked]	[% Active Storage Lost]	[ODOT Culvert Rating]	[BEHI/NBS]	[Peak Water Level]
1	0 - 10%	<=5%	8 or 9	Low/Low	<50% flow area
2	10 - 25%	<=10%	6 or 7	Moderate/Low	>50% flow area
3	25 - 50%	<=20%	5	High/Moderate	Surcharged
4	50 – 75%	<=30%	3 or 4	High/High	Road Overtopped
5	>75 %	>30%	0, 1, or 2	Very High/ Very High	Road Impassable (D > 9-inches)

Stormwater Inspection

- ❑ **B**uilding, **T**ransportation, **U**tility (BTU)

EX: Assigning Structural Condition Rating (1-5) to a BTU along a stream:

- ➢ Condition Score #1: Assign BEHI/NBS condition rating to stream
- ➢ Condition Score #2: Infrastructure slope = Top of bank distance to infrastructure/bank height, where:
  - ➢ [1 > 5:1; 3 >2:1 but <= 3:1; 5<=1:1]
- ➢ Worst condition score assigned to BTU

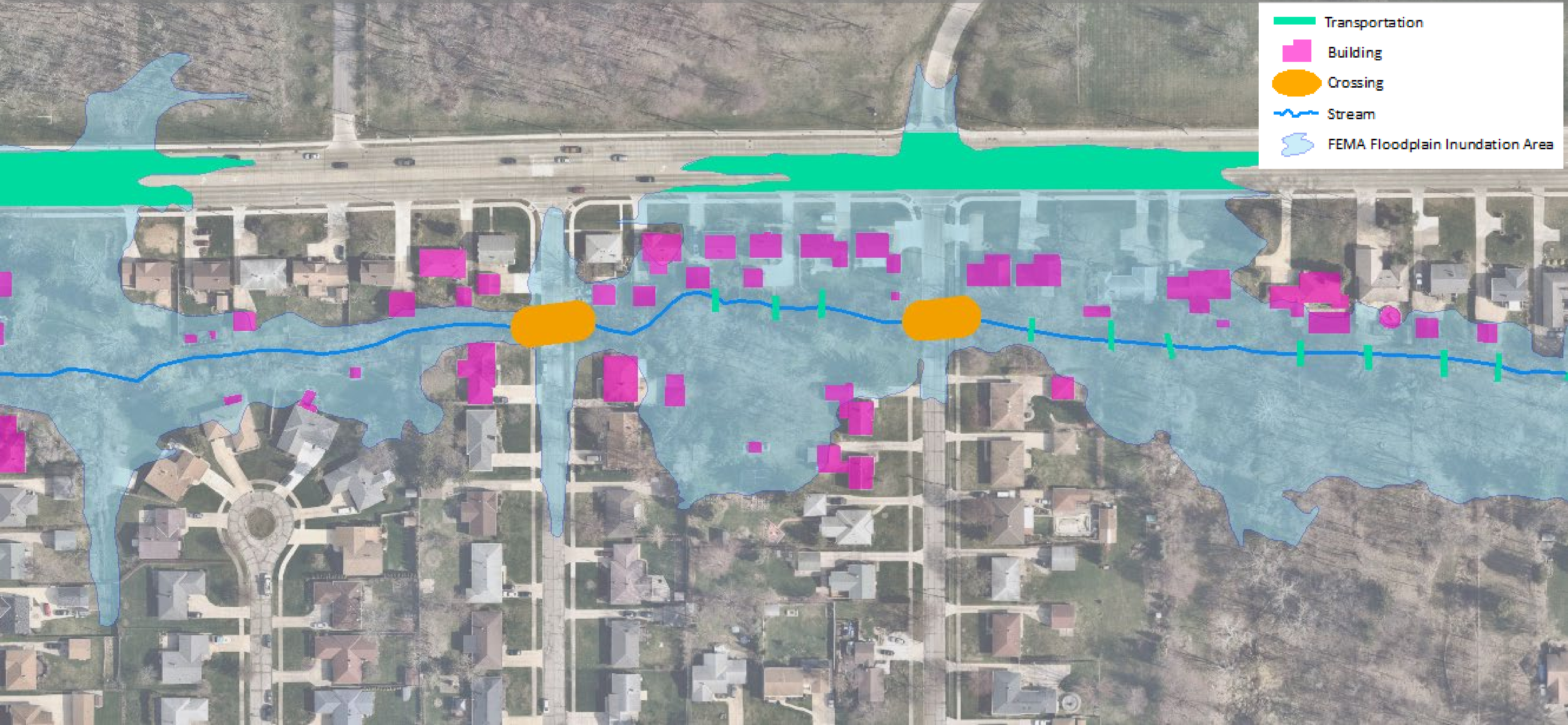
Rated '5' for risk of failure


A Christmas Story, 1983

Be sure to inspect and maintain your assets?

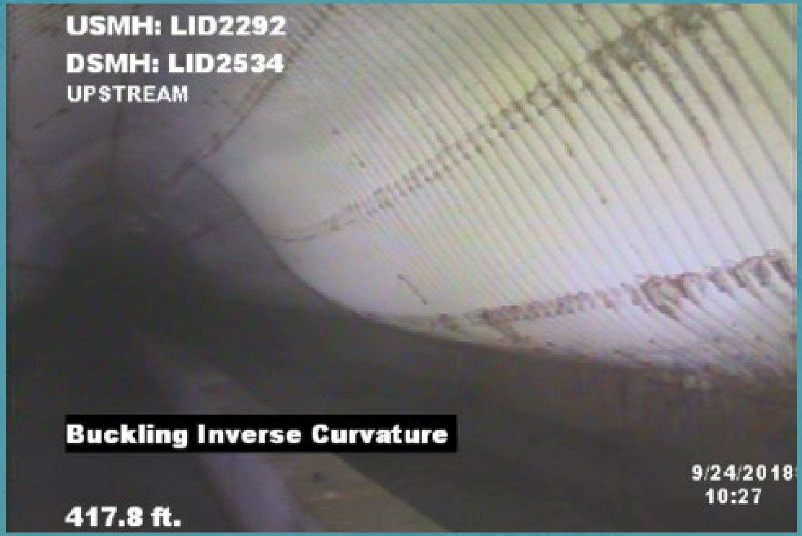
Problem Assets:
How Often to Inspect? What are the Maintenance Triggers?

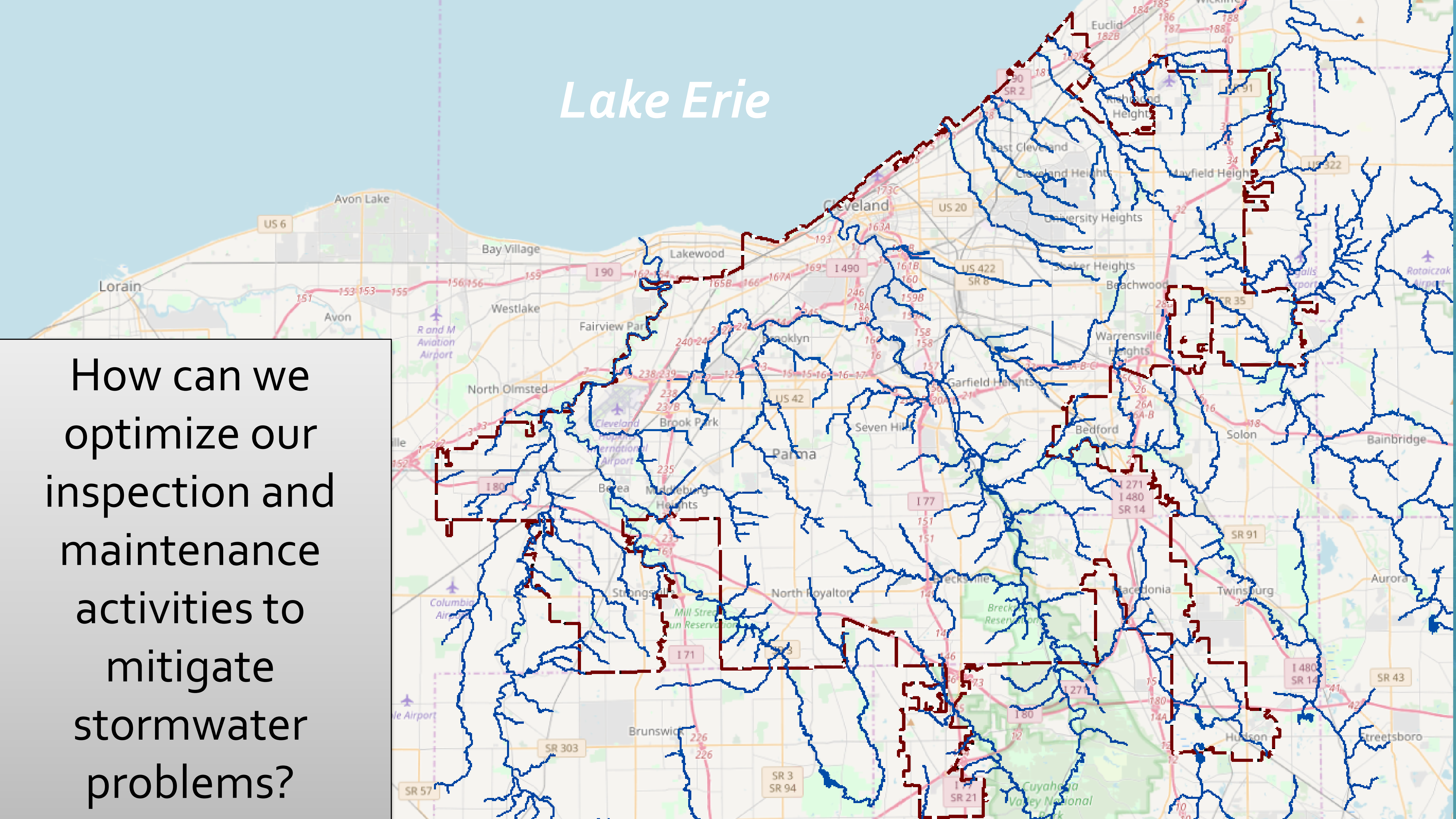
When and Where to Inspect after a Storm Event?
Can we perform maintenance that prevents flooding?



Where can we prevent an asset from failing?

When should we monitor, repair, or replace an asset?





How can we optimize our inspection and maintenance activities to mitigate stormwater problems?

Inspection Maintenance Action Plan

Goals:

- ❑ Assist Urban Stream Managers with better understanding their stormwater system for a range of stormwater related categories
- ❑ Provide information to support and optimize decision-making when planning field activities

Primary Sources:

- ✓ SWMP Field-Based Assessments
- ✓ SWMP H/H models
- ✓ Desktop GIS
- ✓ Typical Useful Life of Engineered Materials
- ✓ Typical Repair & Replacement Costs
- ✓ Historical Inspection and Maintenance Activities

Field-Based Master Planning Topics to Consider

- ❑ Overall Condition Assessment
  - Sediment & Debris Accumulation
    - "Is it clogged?"
  - Structural Integrity
    - "Is it broken?"
  - Hydraulic Performance
    - "Is it flooded?"

- ❑ Recommended Inspection Plan
  - Dry Weather:
    - Sediment & Debris Inspections
    - Structural inspections
  - Urgent Storm Response:
    - Normal: 1 to 10-year storm
    - Expanded: 25 to 50-year storm
    - Significant: >= 100-year storm*

*Where don't you field visit?

Field-Based Master Planning Topics to Consider cont.

❑ Recommended Maintenance Plan:

➢ Maintenance Triggers:

- Where sediment/debris blockage may lead to flooding (e.g., Building, Road)
- Where basin active storage loss may lead to increased emergency spillway activation

❑ Recommended Monitoring Plan:

➢ Flood Stage Monitoring

- Locations (e.g., high risk)
- Types (e.g., visual, stream gauge)
- Metrics for Notification (e.g., flood stages

➢ Additional Monitoring

- Problems (e.g., structural)
- Projects (e.g., time lapse)
- Maintenance (e.g., sediment, debris)

Field-Based Master Planning Topics to Consider cont.

- Life-cycle Cost Analysis
  - Inspection
  - Routine Maintenance
  - Repair
  - Replacement

- Failure Mode Effects Analysis (FMEA)
  - Listing and Analyzing Problems
  - Determining Root Causes and their Sources
  - Developing and Ranking Corrective Actions
  - Prioritizing Next Steps
  - Tracking Progress

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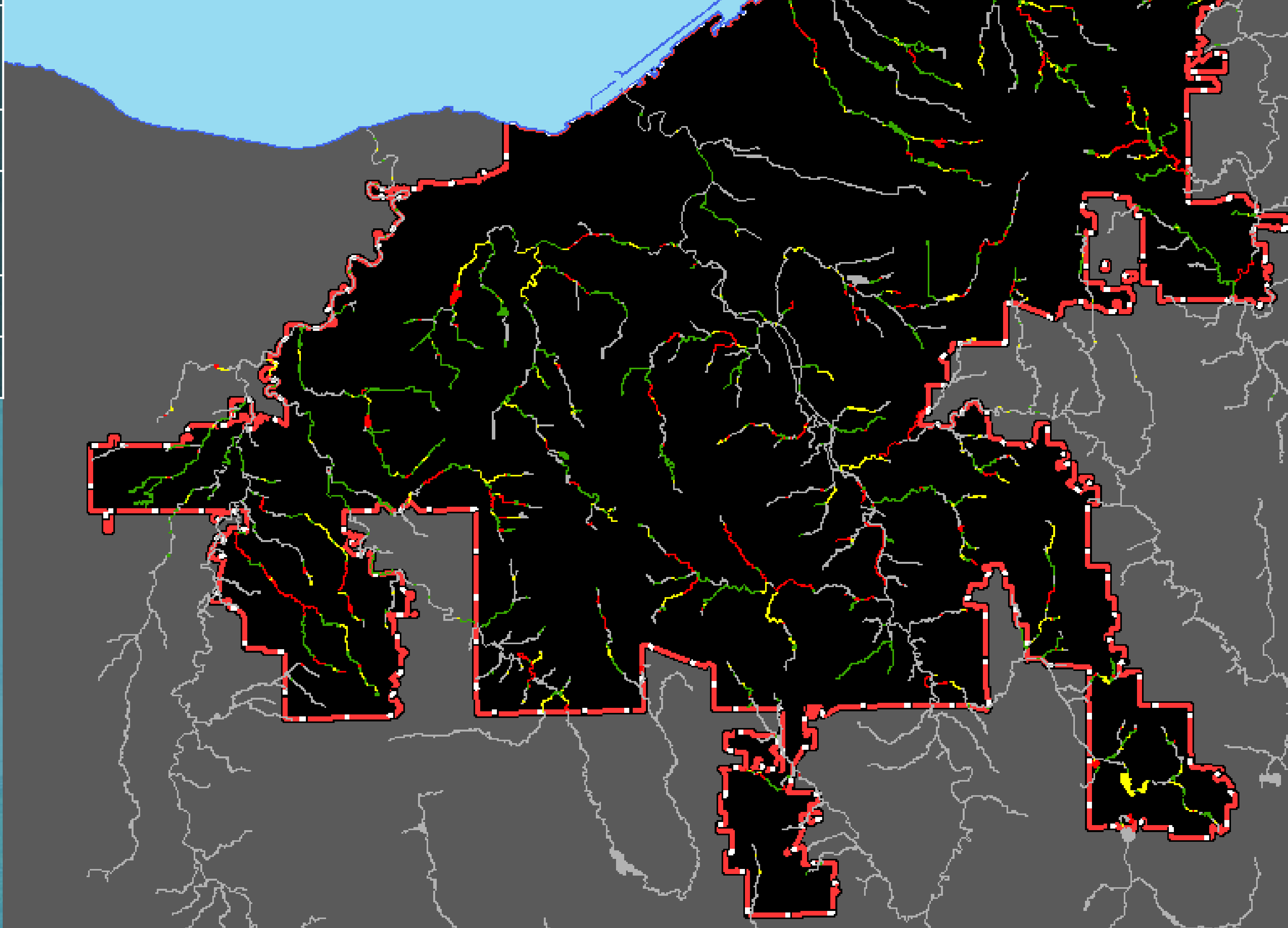
*Where don't you field visit?

Asset Class Type	Overall Grade	Average Structural Condition	Assets Inspected
Crossings	B-	2.3	1,005
Culverted Streams	B-	2.5	92
Basins	B-	2.4	83
Major Structure	C	2.9	12
Streams	B-	2.3	820
Total	B-	2.4	2,012

- 70% of RSS assigned Condition Scores
- 381 RSS assets with
- D or F structural grade

Northeast Ohio Regional Sewer District

May 2019
SWSA State of the Infrastructure
Structural Grade: B-



Assigning Inspection Frequency by Structural Integrity Condition

Inspection Frequencies for Crossings

Conduit Structural Condition Score	Average Inspection Frequency (Years)		
	Corrugated Metal Pipe	Concrete Pipe	Other Materials
1	5	10	10
2	4	5	5
3	2	2	2
4	1	1	1
5	1	1	1

Inspection Frequencies for Culverted Streams

Conduit Structural Condition Score	Average Inspection Frequency (Years)		
	Corrugated Metal Pipe	Concrete Pipe	Other Materials
Routine PACP Inspections of All Conduits			
All	5	5	5
Additional Targeted Inspections			
1	5	5	5
2	4	5	5
3	2	2	2
4	1	1	1
5	1	1	1

Average Inspection Frequencies for Streams

Lateral/Vertical Stability Condition Score	Stream Reach Inspection Frequency (Years)		BTU Site Inspection Frequency (Years)
	High	Low	
1	5	10	10
2	5	10	5
3	3	5	2
4	3	5	1
5	3	5	0.5

Average Inspection Frequencies for Basins

Structural Condition Score	Inspection Frequency (Years)
1	5
2	5
3	2
4	1
5	0.5

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Overall Condition Assessment Example: Structural Integrity

Summary of Recommended Annual Inspection Requirements for Cuyahoga River South Watershed

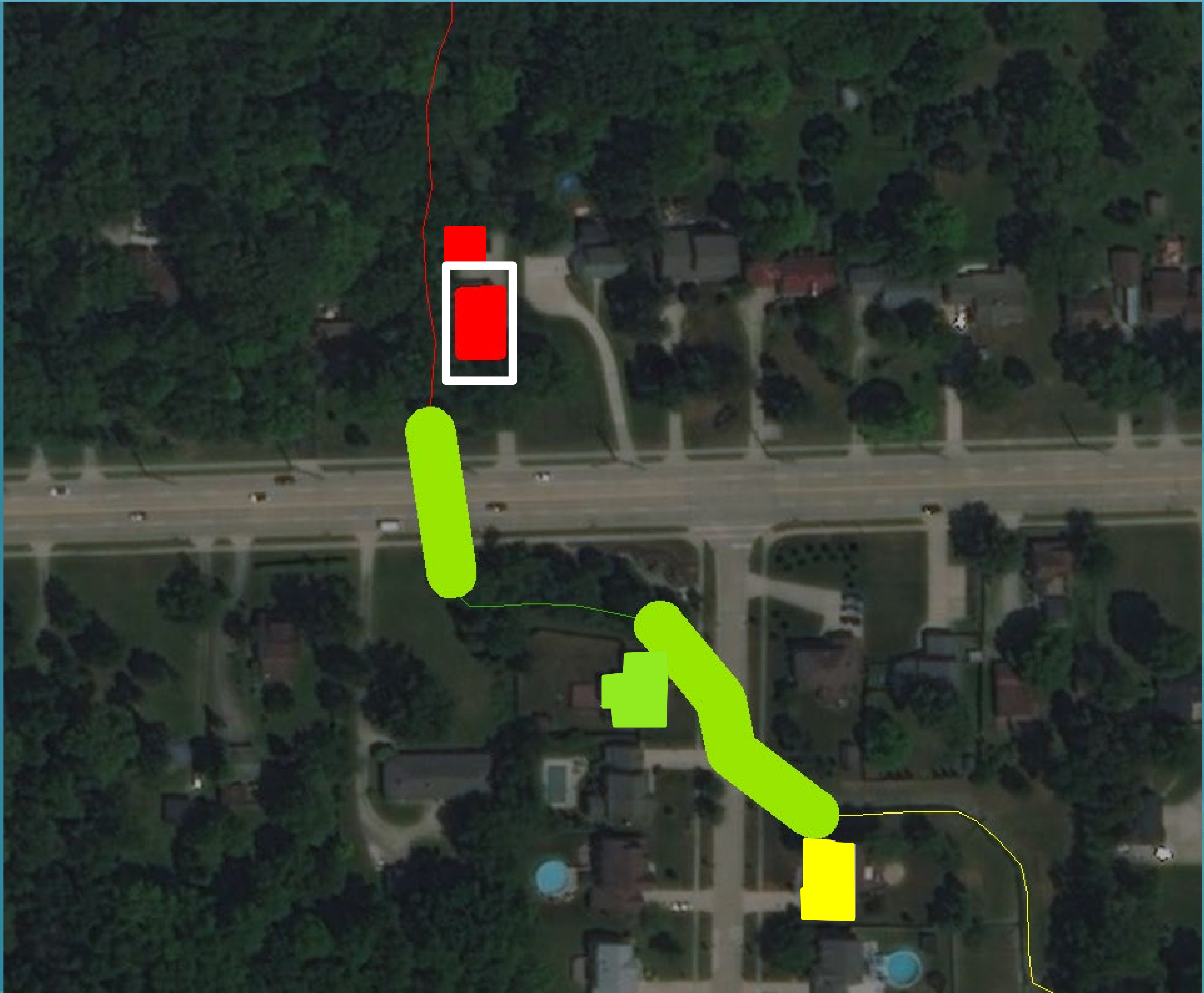
Type of Inspection	Average Annual Inspection Requirements		
	Crew-Hours	Staff-Hours	Burdened Labor Cost
Chronic Sediment and Debris Accumulation			
▪ Basins	16.8	33.6	$1,848
Structural Integrity Inspections			
▪ Crossings	374.9	749.7	$41,234
▪ Culverted Streams	271.0	541.9	$29,807
▪ Stream Reaches	319.5	639.1	$35,150
▪ BTUs Threatened by Erosion	514.2	1,028.4	$56,562
Total	**1,496.4**	**2,992.7**	**$164,601**

Assigning Structural Condition scores to BTUs

1. Condition Rating #1: stream lateral erosion following BEHI/NBS approach

2. Condition Rating # 2: Measure infrastructure slope (TOB distance to infrastructure/Bank Height)

3. Assign highest condition rating to BTU




Asset #: BL00148_B007
Strongsville
19892 Royalton Road
Structural BRE= 24
Structural Grade = D
BTU: Residence
Inspection Frequency: Annual

Estimating Bank Erosion Rates along Stream Reaches: "Cheesy Poof" Method
CLE Airport Debris Rack

Following the BEHI/NBS "cheesy poof" method, high percentage of the Abram Creek sediment load is estimated to be generated between the CLE debris rack and SR 237

The same stream reach is the primary source of LWD at the CLE debris rack and sediment at the outlet structure

Currently exploring how best to prioritize streambank stabilization projects service-area wide:

1) Mitigate Risk (Public Safety/Public Health)
2) Reduce maintenance frequency/cost
3) Improve stream function

Field-Based Master Planning Topics to Consider

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- Sediment & Debris Accumulation
  - "Is it clogged?"
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  - "Is it broken?"
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  - "Is it flooded?"

❑ Recommended Inspection Plan

- Dry Weather:
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- Urgent Storm Response:
  - Normal: 1 to 10-year storm
  - Expanded: 25 to 50-year storm
  - Significant: >= 100-year storm*

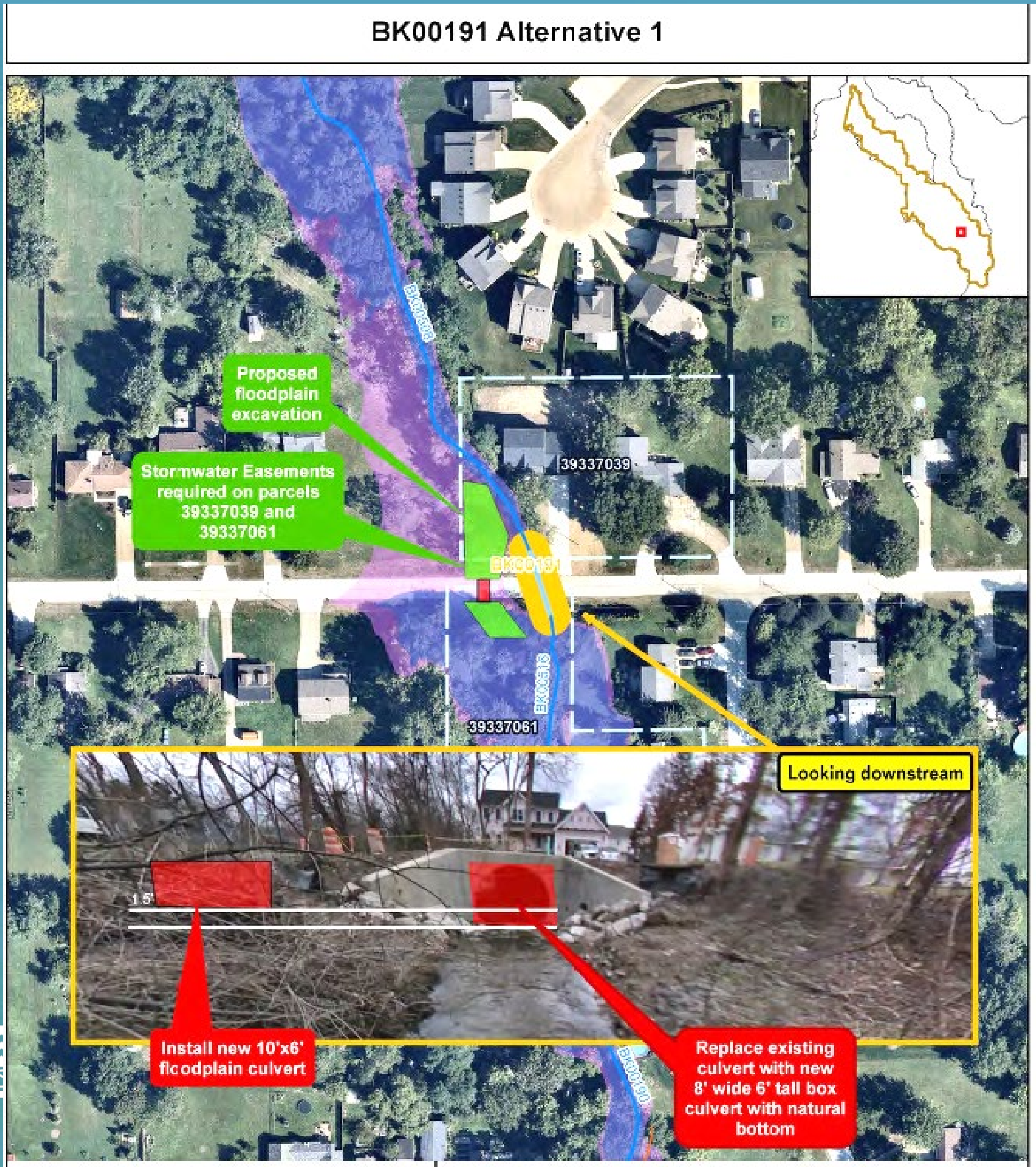
    *Where don't you field visit?

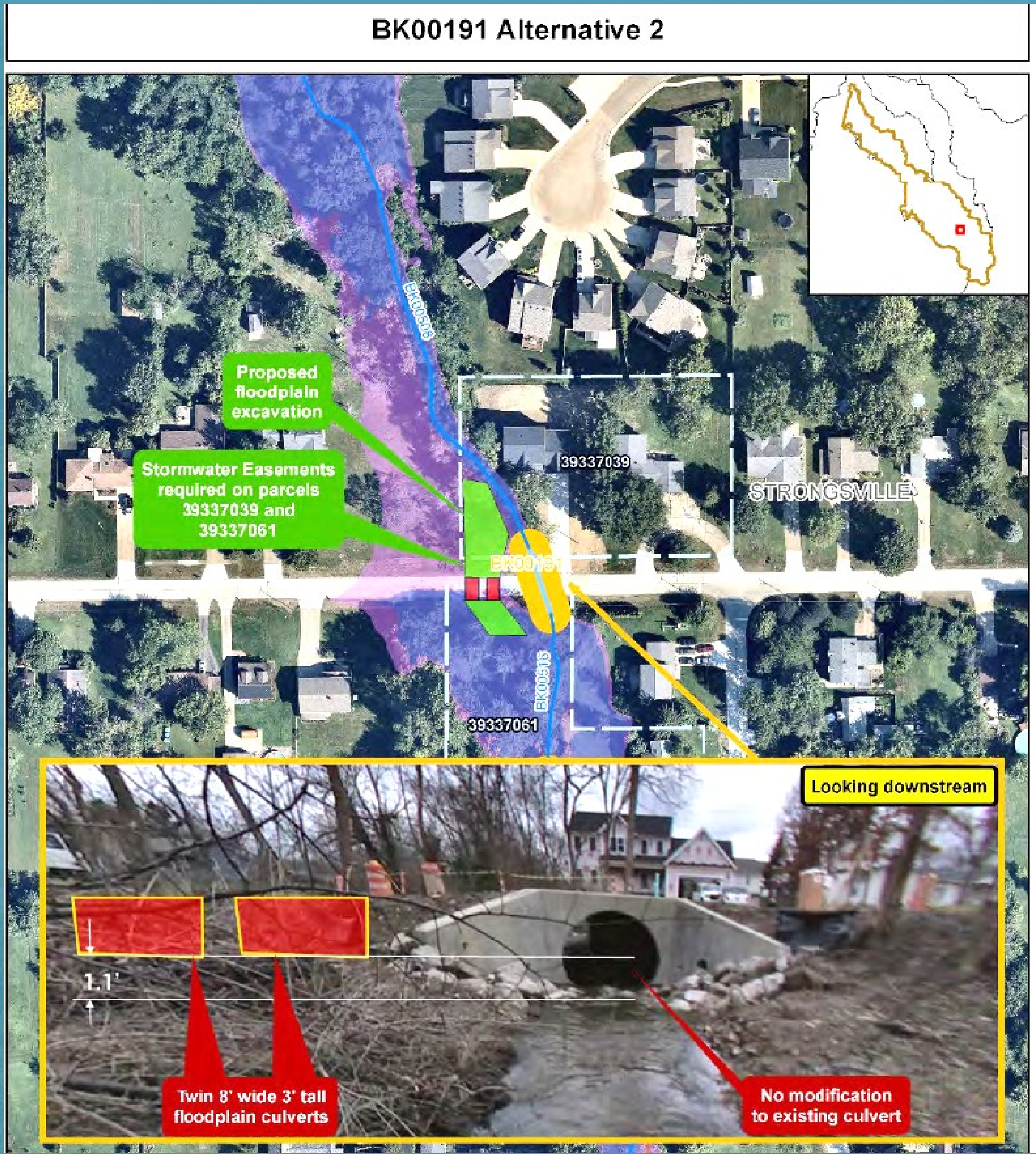
Consider Stream Function when Assessing Hydraulic Performance

Model culverts with sediment buildup under baseline conditions where stream function is stable

Consider Stream Function when Improving Hydraulic Performance

Evaluate increasing capacity within the floodplain (not stream channel)





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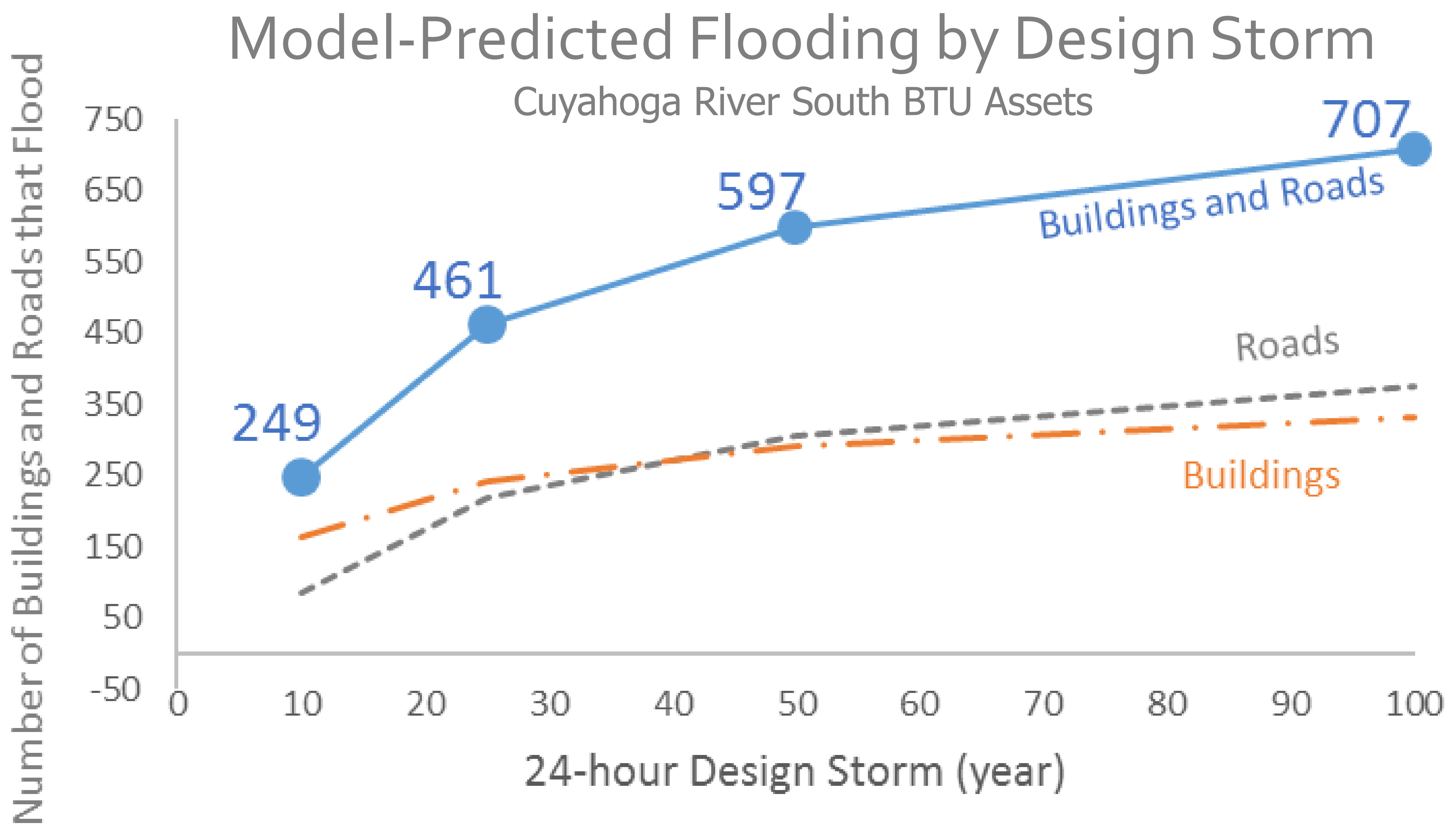
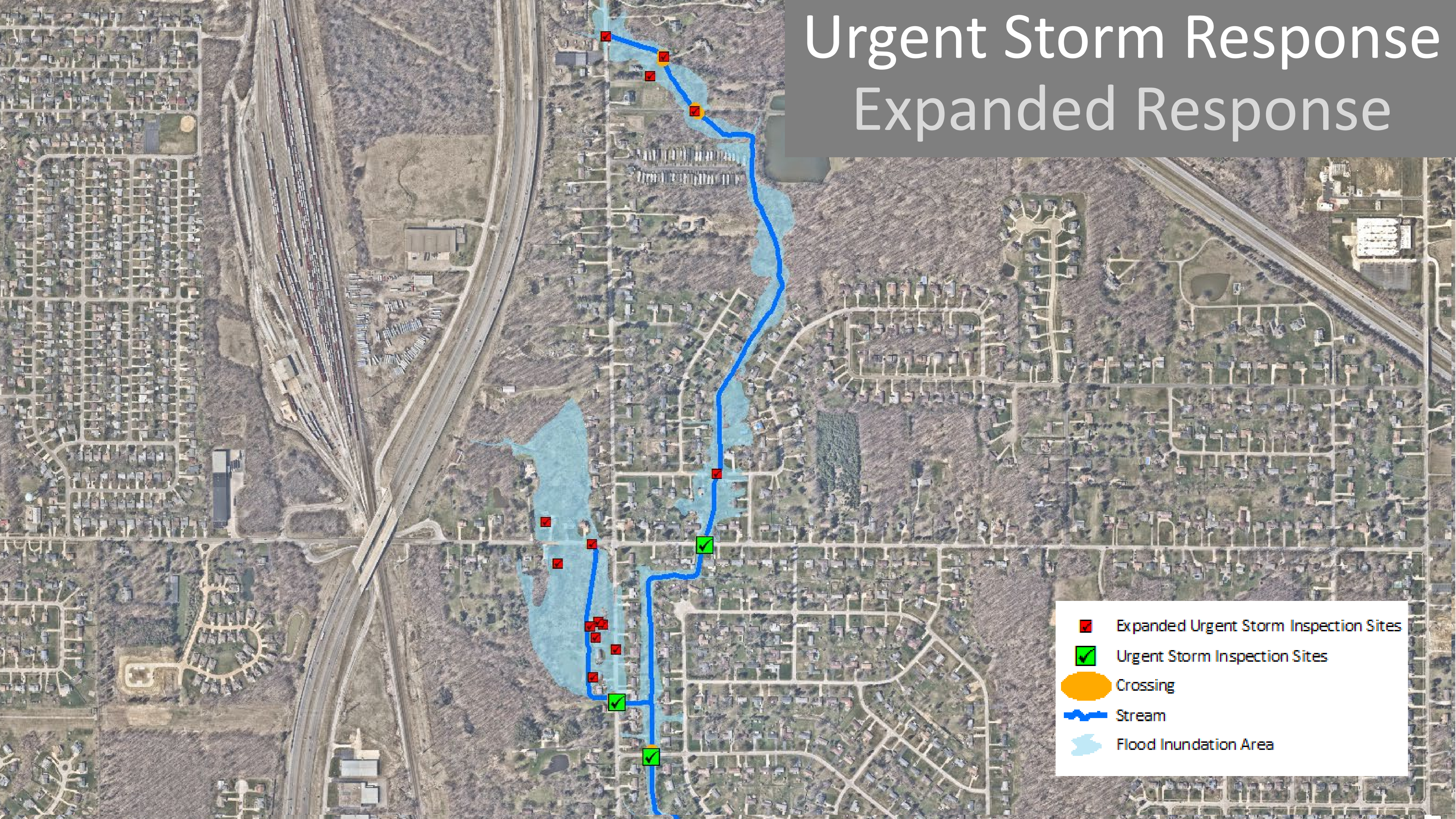


Model-Predicted Flooding by Design Storm
Cuyahoga River South BTU Assets
Number of Buildings and Roads that Flood
750
650
550
450
350
250
150
50
-50
0
10
20
30
40
50
60
70
80
90
100
24-hour Design Storm (year)
249
461
597
707
Buildings and Roads
Roads
Buildings

Urgent Storm Response
Expanded Response



Field-Based Master Planning Topics to Consider cont.

Recommended Maintenance Plan:

- Maintenance Triggers:
  - Where sediment/debris blockage may lead to flooding (e.g., Building, Road)
  - Where basin active storage loss may lead to increased emergency spillway activation

Recommended Monitoring Plan:

- Flood Stage Monitoring
  - Locations (e.g., high risk)
  - Types (e.g., visual, stream gauge)
  - Metrics for Notification (e.g., flood stages
- Additional Monitoring
  - Problems (e.g., structural)
  - Projects (e.g., time lapse)
  - Maintenance (e.g., sediment, Debris)

Maintenance Triggers: Sediment and Debris Blockage

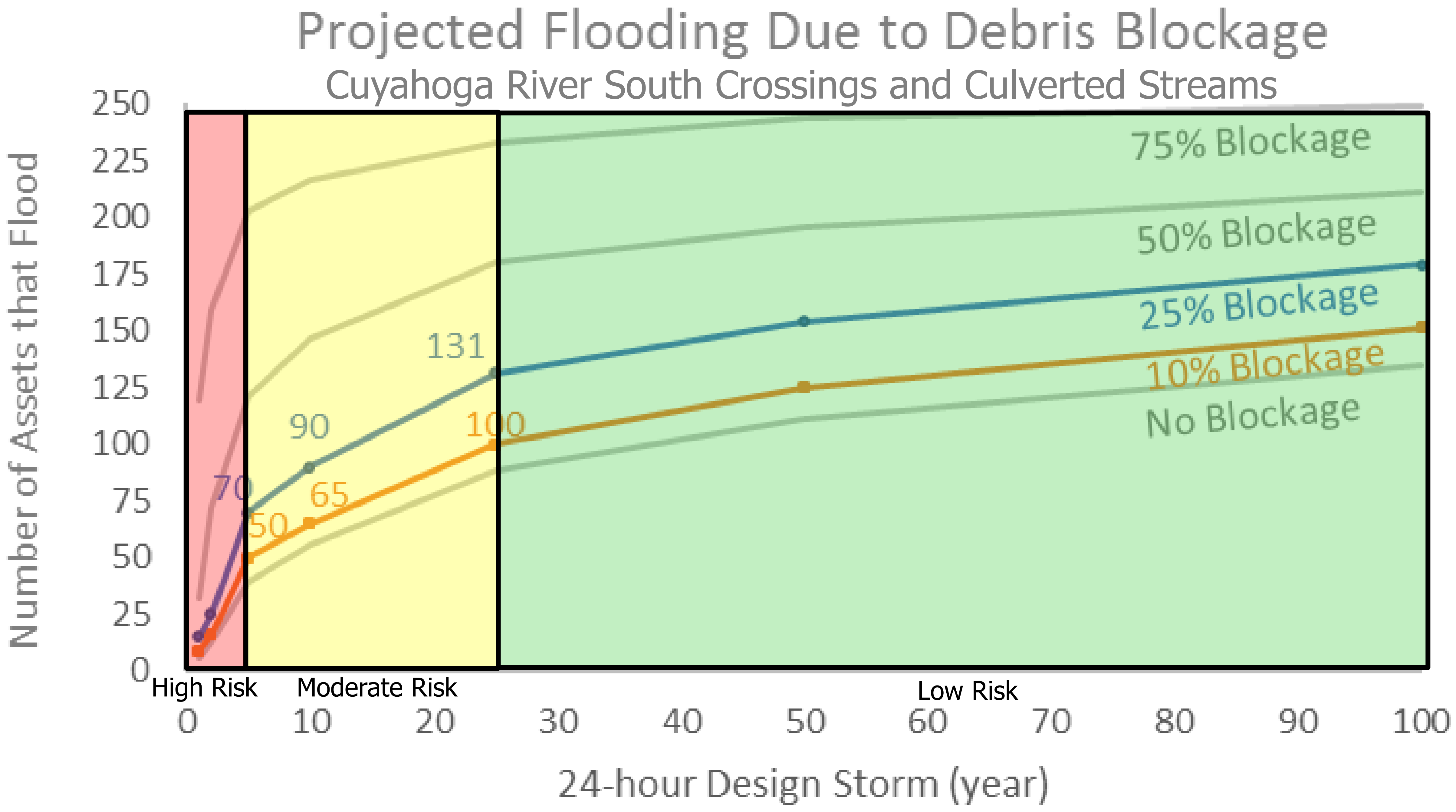
Goal:

Identify what assets the standard debris blockage protocol should be adjusted to mitigate flooding

Methodology:

Applied a "Stress Test" by reducing the flow area for each culvert to understand at what percent blockage does flooding begin for each design storm

Calculations based upon the orifice equation by defining:
- H/H modeled peak flow (Qp) by Design Storm
-Depth when flooding first occurs
-Adjusting the culvert flow area until Qp was achieved for the flooding depth



Projected Flooding Due to Debris Blockage
Cuyahoga River South Crossings and Culverted Streams
Number of Assets that Flood
250
225
200
175
150
125
100
75
50
25
0
75% Blockage
50% Blockage
25% Blockage
10% Blockage
No Blockage
131
90
100
70
65
50
High Risk
Moderate Risk
Low Risk
0
10
20
30
40
50
60
70
80
90
100
24-hour Design Storm (year)

RSS Asset ID	First BTU Flooded		Design Storm						
	BTU Type	BTU Asset ID	1-year	2-year	5-year	10-year	25-year	50-year	100-year
CC00069_001	Local_Road	CC00069_T001	47%	30%	4%	-53%	-113%	-162%	-217%
CC00071_001	Local_Road	CC00071_T001	81%	72%	60%	46%	26%	10%	-9%
CC00077_001	Local_Road	CC00077_T001	86%	78%	66%	56%	48%	42%	38%
CC00087_001	Driveway	CC00087_T001	66%	52%	24%	2%	-31%	-59%	-86%
CC00089_001	Local_Road	CC00089_T001	86%	79%	66%	56%	42%	29%	15%
CC00091_001	Local_Road	CC00091_T001	90%	85%	77%	70%	65%	62%	58%
CC00109_001	Local_Road	CC00109_T001	80%	67%	48%	36%	22%	15%	8%
CC00111_001	Arterial_Road	CC00111_T001	79%	65%	45%	33%	19%	11%	4%
CC00123_001	Local_Road	CC00123_T001	89%	85%	75%	66%	51%	30%	12%
CC00127_001	Local_Road	CC00127_T001	83%	77%	64%	51%	29%	-1%	-27%
CC00135_001	Local_Road	CC00135_T001	91%	82%	68%	49%	27%	4%	-24%
CC00137_001	Local_Road	CC00137_T001	81%	73%	55%	31%	-3%	-42%	-75%
CC00155_001	Local_Road	CC00155_T001	59%	44%	36%	25%	-12%	-64%	-113%
CC00161_010M	Local_Road	CC00161_T001	68%	50%	30%	25%	23%	20%	21%
CC00169_001	Local_Road	CC00169_T001	69%	62%	51%	41%	24%	9%	-8%
CC00171_001	Non_Res. Road	CC00171_T001	24%	-5%	-52%	-93%	-143%	-181%	-213%
CC00173_001	Local_Road	CC00173_T001	53%	35%	9%	-16%	-46%	-69%	-88%
CC00175_001	Driveway	CC00175_T001	78%	68%	53%	38%	15%	-12%	-47%
[illegible]	Driveway	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CC00179_001	Non_Res. Road	CC00179_T001	81%	70%	65%	51%	33%	15%	-5%
CC00081_001	Highway	CC00081_T001	60%	38%	3%	-24%	-52%	-70%	-82%
CC00093_001	Highway	CC00093_T001	66%	49%	19%	-6%	-23%	-37%	-50%

Applied a "Stress Test" by reducing the flow area for each culvert to understand at percent blockage does flooding begin for each design storm.

Calculated based upon the orifice equation by defining:
-Depth to flooding
-Culvert flow area
-H/H modeled peak flow

Used to Identify when standard debris blockage protocol should be adjusted at an asset to mitigate flooding

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Understanding Where LWD collects and Why

Consider Culvert Width compared to Stream Channel Width

Pre-Construction

Post-Construction

Field-Based Master Planning Topics to Consider cont.

❑ Recommended Maintenance Plan:

- Maintenance Triggers:
  - Where sediment/debris blockage may lead to flooding (e.g., Building, Road))
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❑ Recommended Monitoring Plan:

- Flood Stage Monitoring
  - Locations (e.g., high risk)
  - Types (e.g., visual, stream gauge)
  - Metrics for Notification (e.g., flood stages
- Additional Monitoring
  - Problems (e.g., structural)
  - Projects (e.g., time lapse)
  - Maintenance (e.g., sediment, Debris)

Maintenance Triggers: Sediment Accumulation at Basins

Goal:

Identify what basins the standard sediment accumulation protocol should be adjusted to mitigate adverse impacts (e.g., downstream flooding)

Methodology:

Applied a "Stress Test" by reducing the active storage volume for each basin to estimate what percent volume loss does the emergency spillway activate by design storm.

Percentage calculated using H/H modeling

Assumed active storage volume lost from the basin invert

Maintenance Triggers: Sediment Accumulation in Basins

When Lost Active Storage Leads to Emergency Spillway Activation

Basin Asset ID	Total Active Storage Volume	Current Active Storage Volume	Percent Active Storage Lost	Active Storage Volume Loss to Activate Emergency Spillway During Design Storm			
				10-year	25-year	50-year	100-year
	CY	CY	%				
BR00182	30,160	27,804	8%	10%	-27%	-50%	-73%
BR00341	67,557	65,806	3%	-18%	-30%	-38%	-46%
BR00230	41,514	40,853	2%	28%	17%	11%	3%
BR00384	134,582	133,309	1%	65%	50%	40%	29%
BR00282	34,604	34,327	1%	37%	10%	-3%	-9%
BR00284	97,929	97,284	1%	63%	59%	46%	33%
BR00146	83,407	82,313	1%	2%	-7%	-11%	-15%
BR00149	41,579	38,722	7%	21%	0%	-6%	-9%
BR00210	335,177	328,861	2%	56%	47%	38%	25%
BR00212	47,062	41,920	11%	52%	43%	35%	24%

Field-Based Master Planning Topics to Consider cont.

- Recommended Maintenance Plan:
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  - Additional Monitoring
    - Problems (e.g., Structural)
    - Projects (e.g., Time Lapse)
    - Maintenance (e.g., Sediment, Debris)

Flood Stage Monitoring Recommendations

Monitoring Methods:

- ❑ Visual
  - – Site Visits
  - – Trail Cam
- ❑ Stream Gauge
  - – Four NWS Flood Stages
  - – Notifications
- ❑ Rain Gauge/GARR
  - – Area Density
  - – Notification for storms of interest

NWS Flood Stages:

- Action – Potential Significant Hydrologic Activity
- Minor Flooding – Inundation of Roads
- Moderate Flooding – Inundation of structures and roads near streams
- Major Flooding – Extensive inundation of structures and roads

SWMP Flood Stage Criteria

Table 12-34 Definition of Flood Conditions Triggering each Flood Response Action Level

BTU Asset	Criti-cality	Preparation Begins		Minor Flooding Begins		Moderate Flooding Begins		Major Flooding Begins[1]	
		Condi-tion	Action Level	Condi-tion	Action Level	Condi-tion	Action Level	Condi-tion	Action Level
Hospital/School	9	1	3-ft below ground elevation at foundation	2	1-ft below ground elevation at foundation	3	Ground elevation at foundation	4	First floor elevation
Insured/Occupied Non-Residential	8	1	3-ft below ground elevation at foundation	2	1-ft below ground elevation at foundation	3	Ground elevation at foundation	4	First floor elevation
Insured/Occupied Residence	6	2	1-ft below ground elevation at foundation	3	Ground elevation at foundation	4	First floor elevation	4	First floor elevation of 5 or more residences
Highway/Railroad	9	1	8 ft below road overtopping depth	2	5 ft below road overtopping depth	3	1 ft below overtopping depth	4	Inundation begins
Arterial Road	8	2	5 ft below road overtopping depth	3	1 ft below overtopping depth	4	Overtopping depth	5	Overtopped and impassible (>9 inches)
Local Road	6	3	1 ft below overtopping depth	4	Overtopping depth	5	9-inches above overtop-ping depth (impassible)	5+	3 or more roads impassible
Parking Lot, Drive, Walk, Trail	4/5	3	1 ft below overtopping depth	4	Overtopping depth	5	9-inches above overtopping depth	5+	9-inches above entire parking lot
Basins w Class I/II Dam	9	2	5 ft below dam crest/ overtopping elevation	3	3 ft below dam crest/ overtopping elevation	3+	Emergency spillway activation elevation	4	Dam crest/overtopping elevation
Basin w/ Class III Dam	6	2	5 ft below dam crest/ overtopping elevation	3	3 ft below dam crest/ overtopping elevation	3+	Emergency spillway activation elevation	4	Dam crest/overtopping elevation

[1] No major flooding level will be defined if the reported BTUs flooding for the Project Area does not reach any of the indicated thresholds.

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Proposed Flood Stage Monitoring Plan by Project Area

Project Area ID	Monitoring Location		Monitoring Method	Rationale	Storm Response Stages (ft msl)			
	Asset ID	Description			Act.	Min.	Mod.	Maj.
Brandywine Creek Subwatershed								
ICPA01	IC00296	USGS Gage 04206413	Recording Stage	Measures subwatershed flows	968.6	969.6	970.3	976.0
ICPA02	IC00087	Led			2	1008.2	1008.9	1010.1
BRPA01, BRPA03	BR00103	USG				963.2	963.5	969.3
BRPA05	BR00411	Inlet t			0	1077.0	1077.8	N/A
BRPA07	BR00181	Crossir				990.5	993.5	993.5
BRPA08	BR00358	La				1000.4	1000.6	1005.0
BRPA09	BR00215	Ingle			9	1005.9	1008.3	N/A
BRPA10	BR00217	Atter			9	1019.9	1019.9	N/A
BRPA11	BR00234	Brandy			9	1037.9	1038.6	N/A
BRPA12	BR00251	Gort			0	1079.0	1080.4	N/A
BRPA13	BR00261	Owen			1	1043.1	1043.2	1049.4
BRPA14	BR00283	Upper			5	1075.5	1076.3	1079.5
BRPA15	CULVERTLINE-61 (Local)	Behinc			0	1045.0	1045.0	1048.0
BRPA16	BR00409	Ravenna St Crossing	Visual	Roadway and building flooding	1080.6	1081.6	1082.3	N/A
BRPA17	STORM-3482	E. Streetsboro Street	Visual	Manhole where flooding begins	1063.5	1064.5	1065.3	1067.8
BRPA18	BR00239	Valley View Road crossing	Visual	Upstream flooding	1045	1046	1046	N/A

Table 12-12 Recommended Flood Stage Monitoring Sites in the Cuyahoga River South Watershed

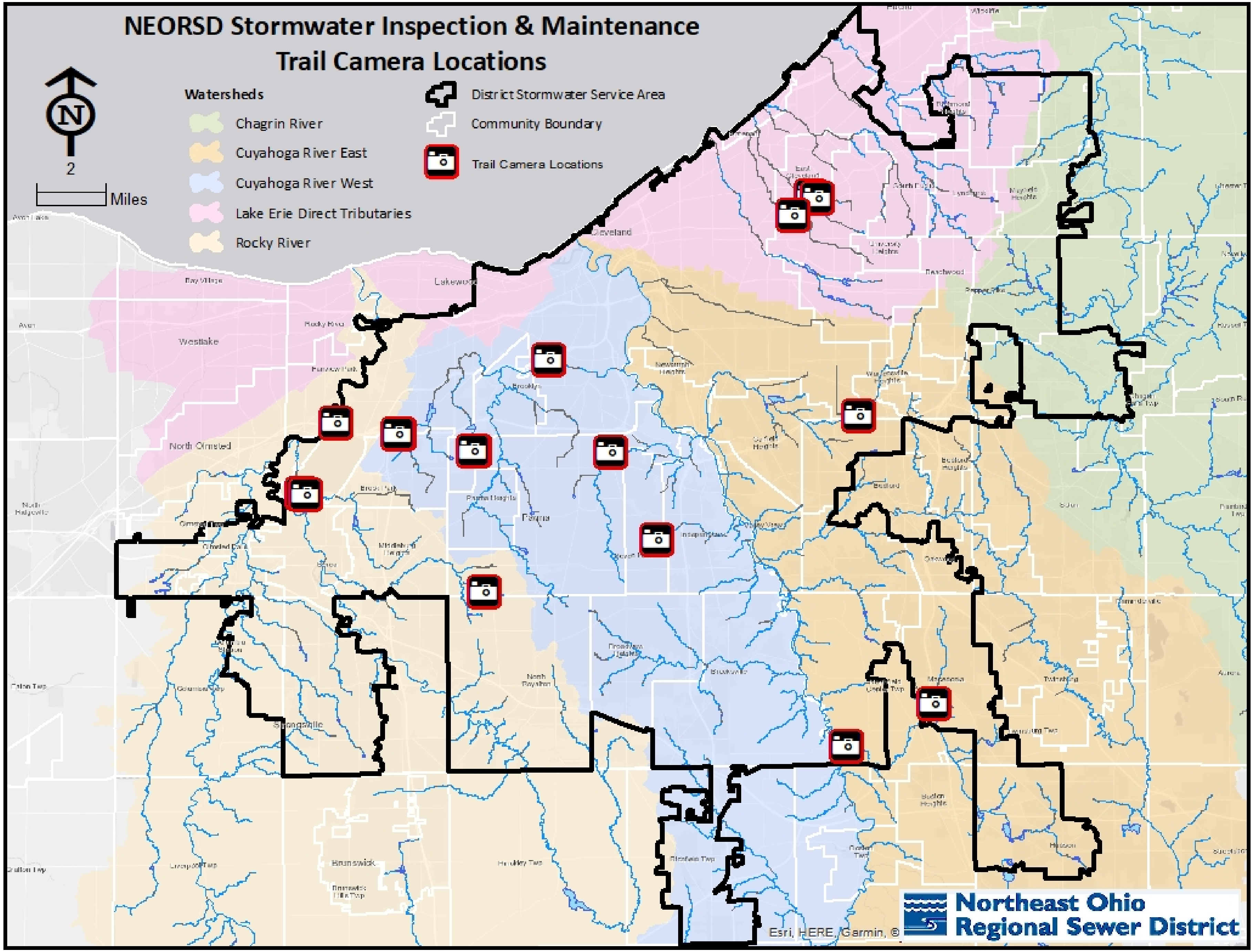
Type of Monitoring	Number of Sites
Visual	38
Trail Cam	8
Recording Stage Meter	6

Using Trail Cams to Support the RSMP

The SWIM group currently maintains 22 trail cameras throughout the SWSA

Primary Goals:

- Better understand RSS storm event response (Flooding)
- Help identify and support Maintenance & Construction projects
- Improve response time
- Improve effective site inspections



Preventative Maintenance Example

4/9/17: 1.62-inch Rain Event

April 18: Debris rack is clear pre-storm event

4/20/17: LWD nearly 100% blocking debris rack post storm; Generated 80 CY of LWD

4/19/17: Peak of storm at 8:15 pm

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Preventative Maintenance Example cont.

5/18/17: 1.52-inch Rain Event

Basin was cleaned prior to an equivalent storm event, which prevented the emergency spillway from activating

May 18, 2017: Maintenance removed LWD

May 28, 2017- Peak storm event at 8:00 pm

Trail Cam Example: CLE Airport Debris Rack

April 14, 2018: Debris rack is clear prior to storm event

April 16: Peak storm and debris accumulated on debris rack

- April 16 2018 storm (2.91-inches) generated 48 CY of LWD
- Used a trail camera to identify and quantify maintenance projects without a field visit

April 17: Maintenance performed next day to remove 48 CY LWD

Debris rack is clear post April 17 maintenance project

Field-Based Master Planning Topics to Consider cont.

- Life-cycle Cost Analysis
  - Inspection
  - Routine Maintenance
  - Repair
  - Replacement

- Failure Mode Effects Analysis (FMEA)
  - Listing and Analyzing Problems
  - Determining Root Causes and their Sources
  - Developing and Ranking Corrective Actions
  - Prioritizing Next Steps
  - Tracking Progress

Table 12-31 Cuyahoga River South Watershed – District Stormwater Service Area Replacement/Renewal Requirements for RSS Crossings and Culverted Streams

Asset ID	Material	Useful Life (Years)	Condition Score	Action Needed (years)	Length (Feet)	Replacement Cost ($M)	Depreciating Value ($M)
HA00291_001	Concrete	100	2	60	80	$600,000	$9,479
HA00295_001	Concrete	100	2	60	49	$220,500	$3,483
HA00295_002	Concrete	100	2	60	49	$220,500	$3,483
HA00299_001	Concrete	100	2	60	140	$1,050,000	$16,588
HA00307A_001	Concrete	100	2	60	140	$1,050,000	$16,588
HA00307A_005	Concrete	100	2	60	140	$1,050,000	$16,588
BA00004	Corrugated_Metal	30	4	6	15	$67,500	$11,074
BA00004	Corrugated_Metal	30	4	6	15	$67,500	$11,074
BA00015	Concrete	100	5	0	53	$238,500	$238,500
BA00147B	Concrete	100	1	80	208	$934,888	$11,686
BA00153A	Masonry	100	1	80	315	$2,364,824	$29,560
BA00155	Concrete	100	3	40	572	$4,289,422	$107,236
TS00004	Concrete	100	4	20	355	$1,597,500	$79,875
TS00101	Concrete	100	4	20	927	$4,172,640	$208,632
TU00011A	Concrete	100	5	0	336	$1,512,000	$1,512,000
WD00068	Corrugated_Metal	30	4	6	1,784	$8,027,966	$1,317,088
Yellow Creek North Fork							
NF00037A_001	Concrete	100	1	80	36	$540,000	$6,398
NF00039_001	Corrugated_Metal	30	1	24	424	$3,180,000	$125,592
NF00049_001	Concrete	100	2	60	33	$247,500	$3,910
Total	**302**	**Conduits**	**266**	**Parents**	**35,819**	**$208,161,260**	**$42,040,544**

Notes:
1. All assets listed are conduits associated with crossings, except rows highlighted yellow, which represent culverted streams.
2. Unit per-length replacement costs based on CRS SWMP conduit replacement project costs, including associated costs (e.g. end structures). Four cost categories based on equivalent conduit diameter (i.e., square root of height * width): $700 per foot (equivalent diameter up to 2-foot); $4,500 per foot (equivalent diameter between 2-foot and 8-foot); $7,500 per foot (equivalent diameter between 8-foot and 15-foot); and $45,400 per foot (equivalent diameter larger than 17-foot).
3. No replacement costs provided if cross-section data missing in asset record, used to define unit cost
4. Depreciating value of asset is present worth if replaced in year action needed.

Methodology:

1. Assign Useful Life by Material

2. Define Remaining Useful life by Material and Structural Condition Score

3. Estimate Replacement Cost by Pipe Dimensions/LF

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Budgeting for Asset Replacement by Condition Score

Table 12-32 Replacement/Renewal Period and Costs for RSS Assets in Cuyahoga River South Watershed

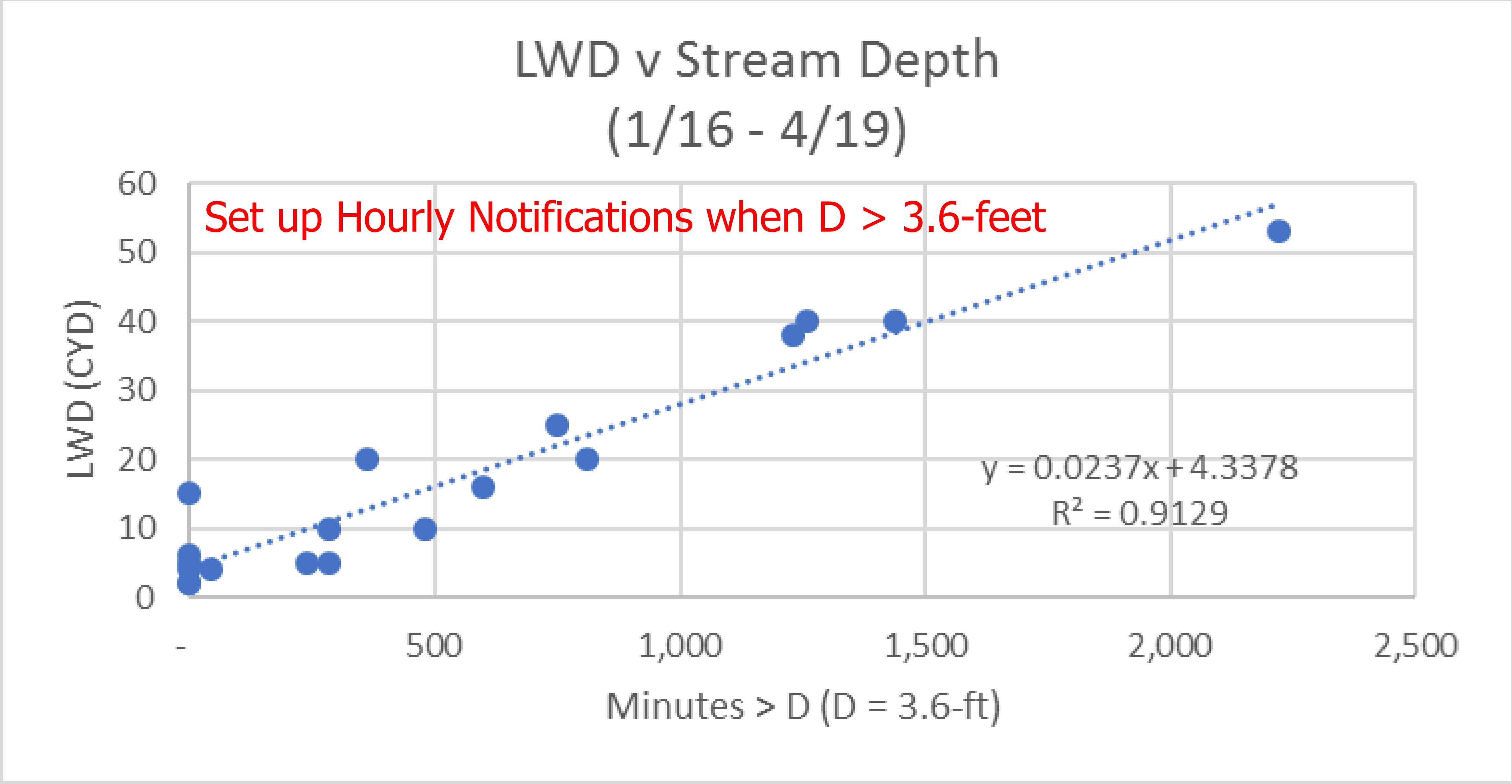
Condition Score	Corrugated Metal Pipe			Concrete Pipes			Other Pipe Materials		
	Action Needed (years)	Length (Miles)	Replacement Cost ($M)	Action Needed (years)	Length (Miles)	Replacement Cost ($M)	Action Needed (years)	Length (Miles)	Replacement Cost ($M)
5	Now	4,465	$21.2	Now	2,132	$13.0	Now	45	$0.3
4	0-6	4,432	$20.7	0-20	1,738	$8.4	0-20	434	$2.4
3	6-12	1,777	$11.0	20-40	2,989	$23.1	20-40	243	$1.5
2	12-18	1,980	$9.6	40-60	11,207	$70.4	40-60	1,092	$7.5
1	18-24	934	$5.5	60-80	594	$4.5	60-80	473	$3.1
0	30	1,215	$5.5	100	8	$0.0	60-80	61	$0.5
Total		**14,803**	**$73.5**		**18,668**	**$119.5**		**2,348**	**$15.2**

Note: Replacement cost represents the complete replacement of the conduit with a concrete pipe, and all associated costs for end structures, pavement replacement, etc. The unit replacement cost represents an average of the total project costs for crossing/culverted stream replacement from the CRS SWMP baseline solutions and system enhancements, in 2018 dollars.

Next Steps

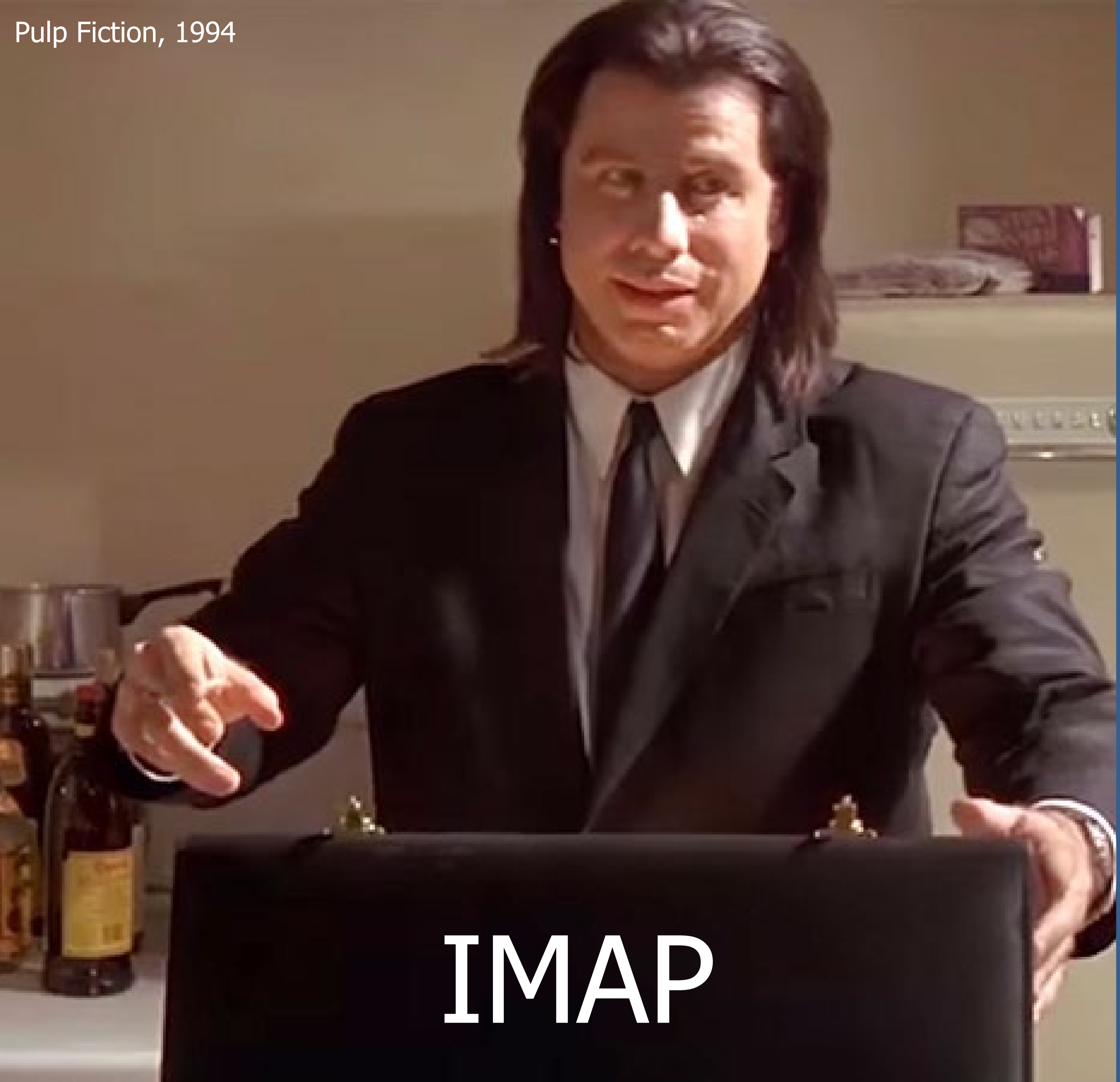
- Under Development:
  - General Assessments: Asset Class Type, Community, Subwatershed, Drainage Area, Impervious Area, Slope
  - Predictive Analytics: Correlating Watershed Characteristics and Meteorological Data to Field Observations
  - Failure Mode Effects Analysis (FMEA): Mitigating Problems cost-effectively (Understanding problems, root causes and their sources, then developing cost-effective solutions)

Applying Predictive Analytics to Estimate LWD Example: CLE Debris Rack



Pulp Fiction, 1994

We Happy?



Pulp Fiction, 1994

Yeah, We Happy

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