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Flooding Risk and Potential Impacts on Water Infrastructure at Lawrence, Massachusetts

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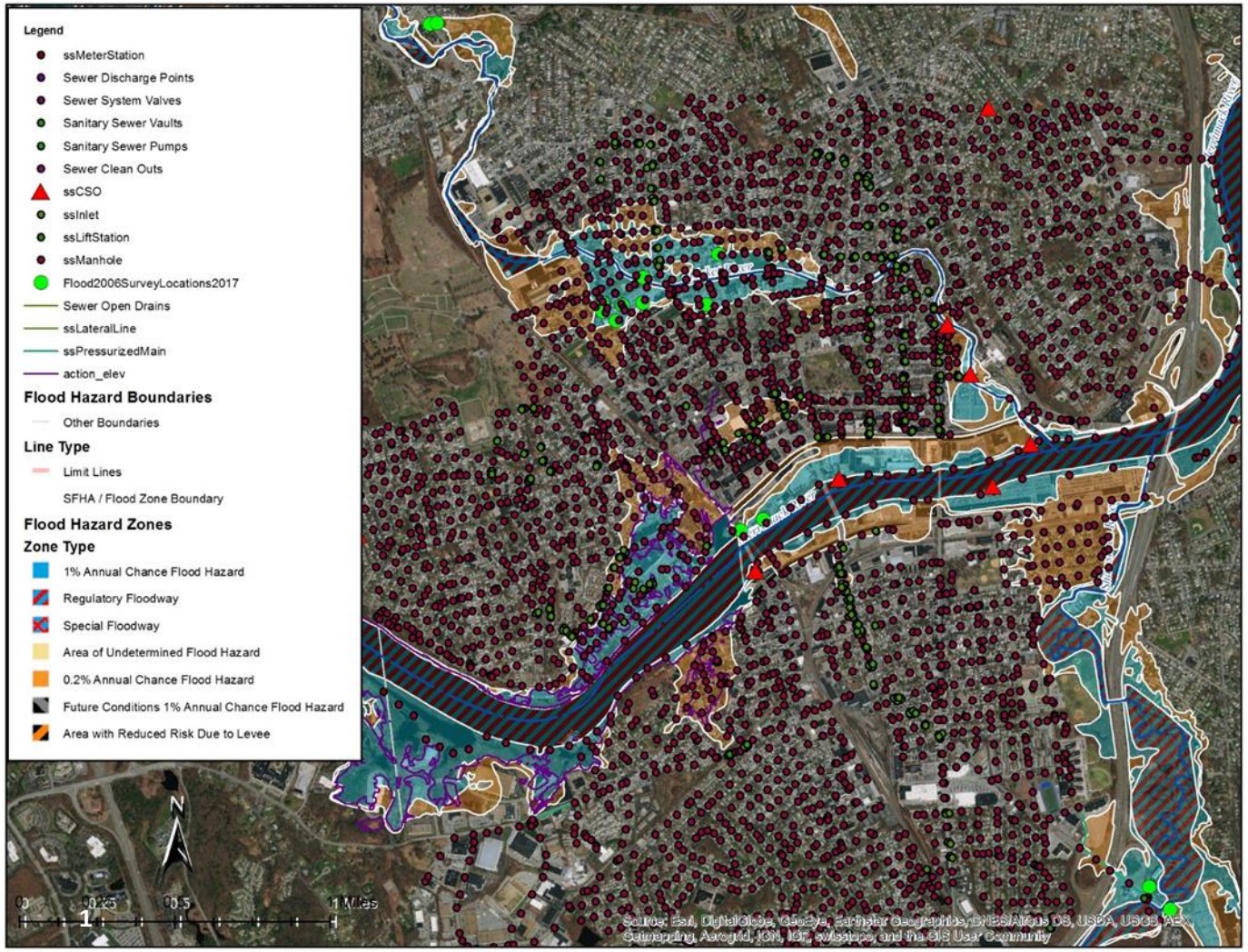
Office of Research and Development
National Risk Management Research Laboratory

Complex Hydrological Setting



- 3 Rivers
- Water plant at the river bank
- Dams and channel blockages
- Historic floods notably in 1936, 2006
- Changes in precipitation and hydrology

Main Objectives and Takeaways

Objectives:

- Evaluate flooding risk to the operation of water treatment plant and other water infrastructure
- Analyze potential mitigation / adaptation measures

Main findings:

- Flash flood risk high in Spicket River, impacting pipe network and sanitary sewer system and combined sewer system structures
- >2.4% annual probability (2.4 day-events/100yr) for inundating and impacting water plant operation at Merrimack River
- ~1% annual probability (1 flood event/100yr) for flood breaching the berm
- Upstream watershed precipitation as a forecasting indicator
- Detailed hydrological analysis, engineering and berm survey are recommended in inundation and water quality management

Flooding Risk Defined

Stream/River Flood Risk

- Riverine flood
- Flash flood
- Berm reach and inundation
- N% annual flood

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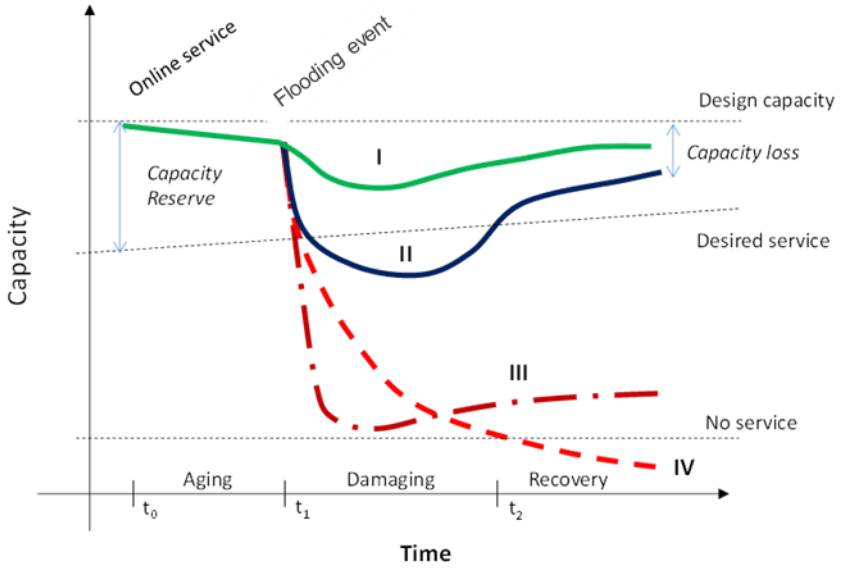
Flood risk to Water Infrastructure

- flooding and service interruption duration
- Days for service recovery
- Service and capacity loss
- Only flooding in damaging phase analyzed in N% annual inundation (or days)



Yang (2016); Levine et al. (2017)

Complex Hydrological Setting

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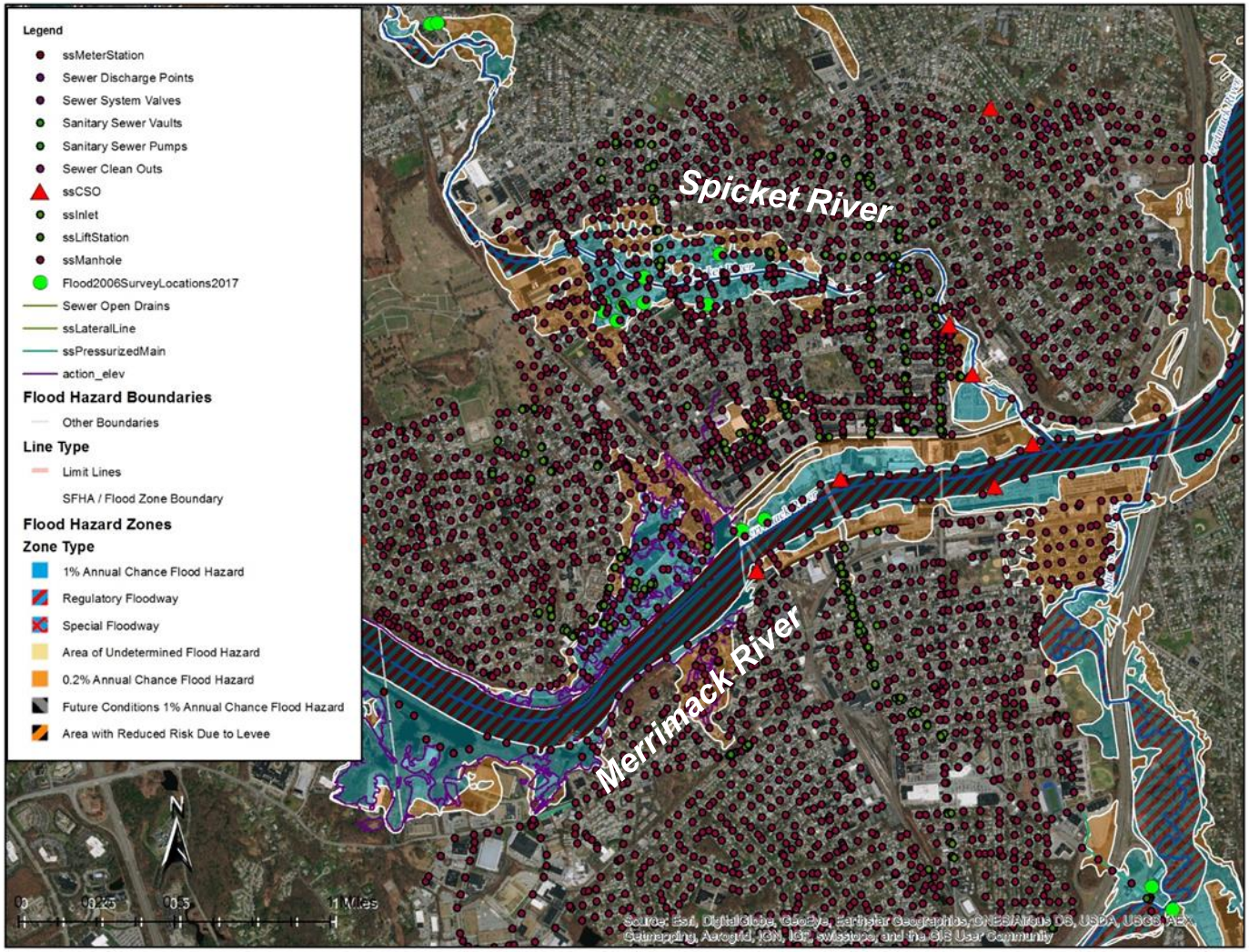
Spicket River



What Has Changed?

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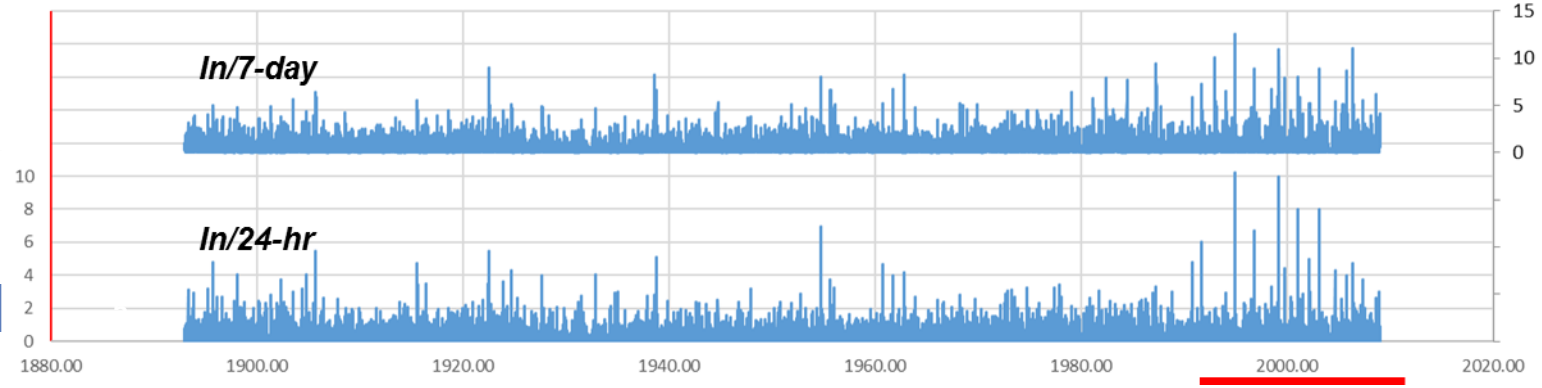
Spicket River

6 of 10 largest 24-hr precipitation after 90s

Date	P(in)	7-Day
1994.9	10.20	10.20
1999.2	10.00	20.20
2001.0	8.00	28.20
2003.1	8.00	36.20
1954.7	6.96	43.16
1996.8	6.72	49.88
1991.6	6.05	55.93
1922.5	5.46	51.19
1905.7	5.44	46.63
1938.7	5.13	43.76

May 2006 flash flood



Lawrence NWS station

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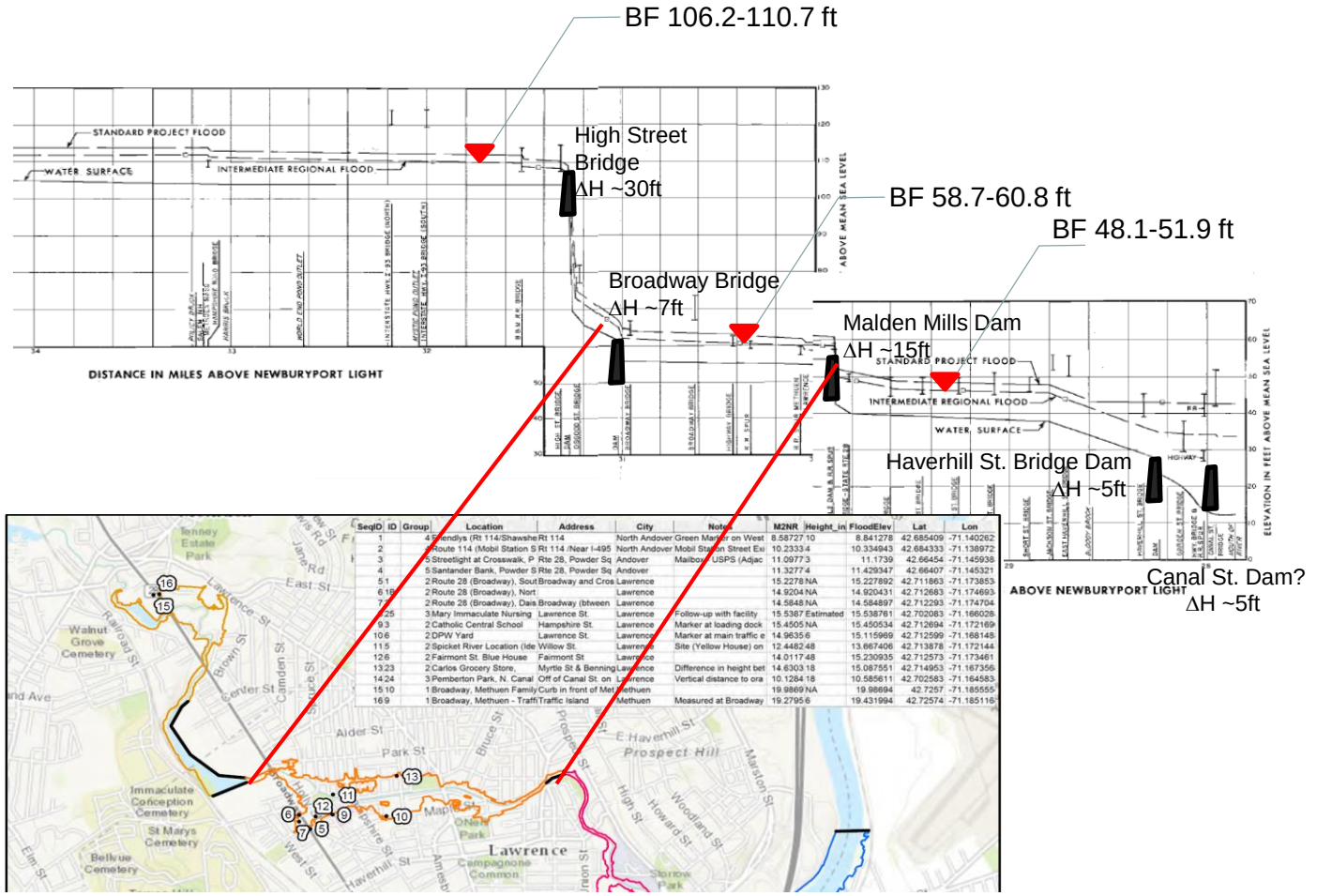
What Has Changed?



SeqID	ID	Group	Location	Address	City	Notes	M2NR	Height_in	FloodElev	Lat	Lon
1		4	Friendlys (Rt 114/Shawshe	Rt 114	North Andover	Green Marker on West	8.58727	10	8.841278	42.685409	-71.140262
2		3	Route 114 (Mobil Station S	Rt 114 /Near I-495	North Andover	Mobil Station Street Exi	10.23334		10.334943	42.684333	-71.138972
3		5	Streetlight at Crosswalk, P	Rte 28, Powder Sq	Andover	Mailbox - USPS (Adjac	11.09773		11.1739	42.66454	-71.145938
4		5	Santander Bank, Powder S	Rte 28, Powder Sq	Andover		11.32774		11.429347	42.66407	-71.145321
5	1	2	Route 28 (Broadway), Sout	Broadway and Cros	Lawrence		15.2278	NA	15.227892	42.711863	-71.173853
6	1B	2	Route 28 (Broadway), Nort		Lawrence		14.9204	NA	14.920431	42.712683	-71.174693
7		2	Route 28 (Broadway), Dais	Broadway (btween	Lawrence		14.5848	NA	14.584897	42.712293	-71.174704
8	25	3	Mary Immaculate Nursing	Lawrence St.	Lawrence	Follow-up with facility	15.5387	Estimated	15.538781	42.702083	-71.166028
9	3	2	Catholic Central School	Hampshire St.	Lawrence	Marker at loading dock	15.4505	NA	15.450534	42.712694	-71.172169
10	6	2	DPW Yard	Lawrence St.	Lawrence	Marker at main traffic e	14.9635	6	15.115969	42.712599	-71.168148
11	5	2	Spicket River Location (Ide	Willow St.	Lawrence	Site (Yellow House) on	12.44824	8	13.667406	42.713878	-71.172144
12	6	2	Fairmont St. Blue House	Fairmont St	Lawrence		14.01174	8	15.230935	42.712573	-71.173461
13	23	2	Carlos Grocery Store,	Myrtle St & Benning	Lawrence	Difference in height bet	14.6303	18	15.087551	42.714953	-71.167356
14	24	3	Pemberton Park, N. Canal	Off of Canal St. on	Lawrence	Vertical distance to ora	10.1284	18	10.585611	42.702583	-71.164583
15	10	1	Broadway, Methuen Family	Curb in front of Met	Methuen		19.9869	NA	19.98694	42.7257	-71.185555
16	9	1	Broadway, Methuen - Traffi	Traffic island	Methuen	Measured at Broadway	19.2795	6	19.431994	42.72574	-71.185116

Spicket River

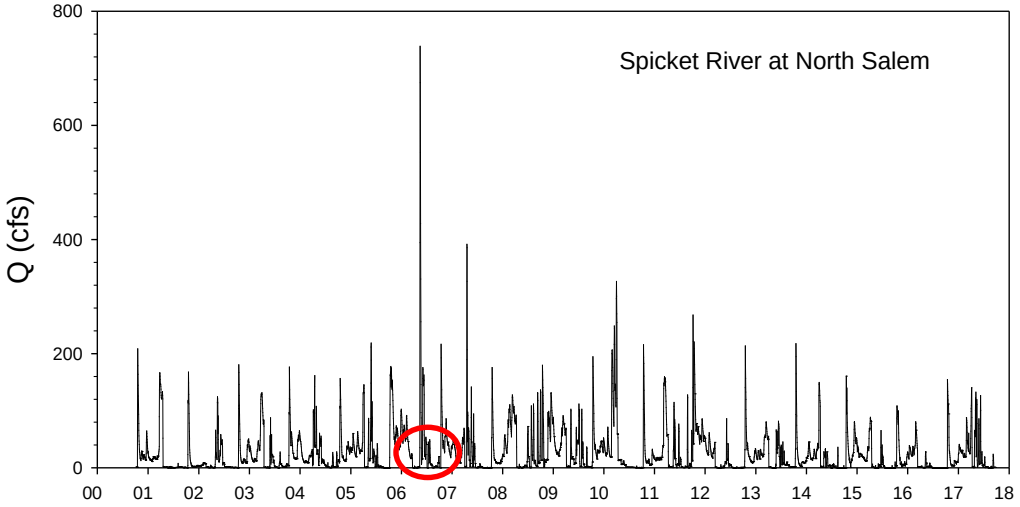
- Flood in 1936 and 2006 (Reconstructed recently)
- 2006 May Flood close to FEMA Base Flood elevations
- ***High-intensity precipitation and channel blockage as main factors***
- Future flooding risk high

Impacted Water Infrastructures

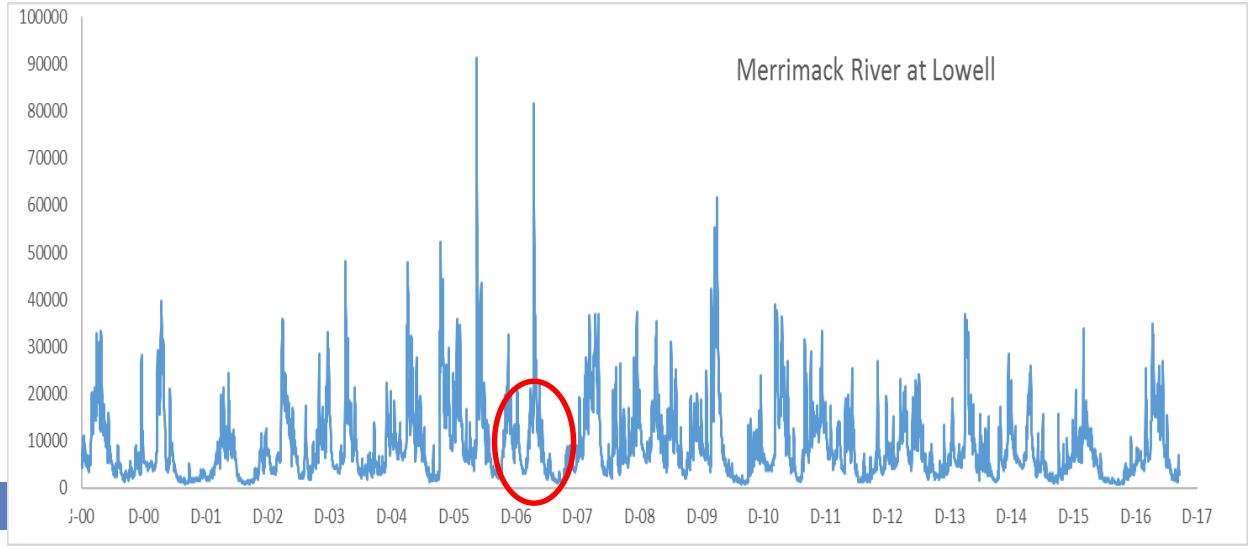
SS vaults / pumps / inlets / lift station

- Sewer infrastructure
- Pump and lift station operation
- Drinking water distribution pipes (under pressure)

Different Settings: Flash Flood vs Riverine Flood



Flash floods in ***Spicket River*** (A: 74.4 mile^2)



Riverine floods in ***Merrimack River*** (A: 5,010 mile^2)

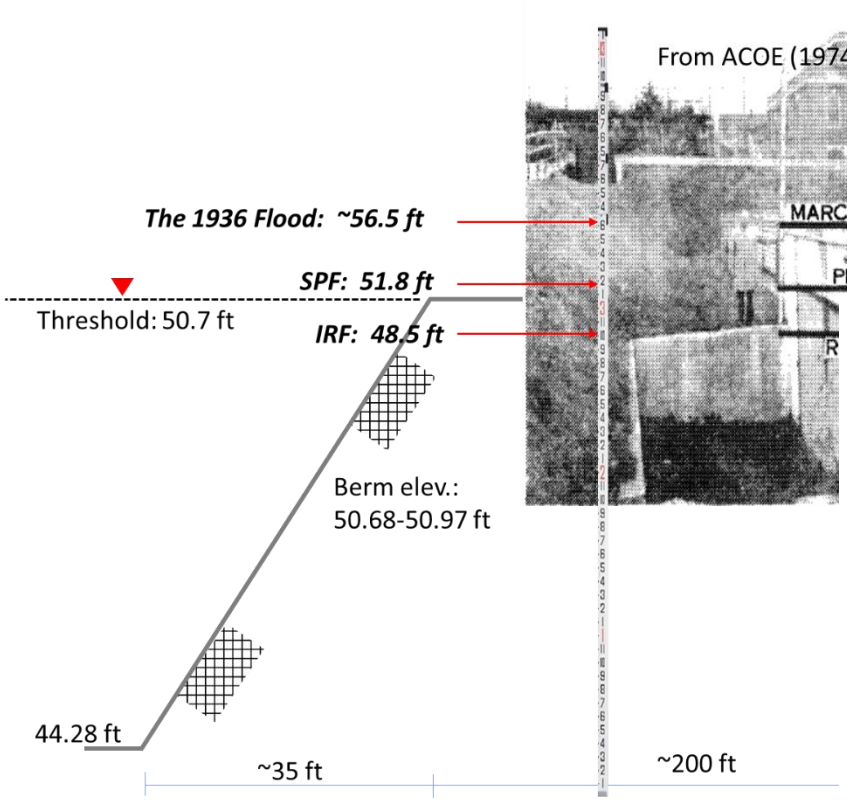
Less flash flooding

Large upstream watershed for long peaking time, but more sustained high flows.

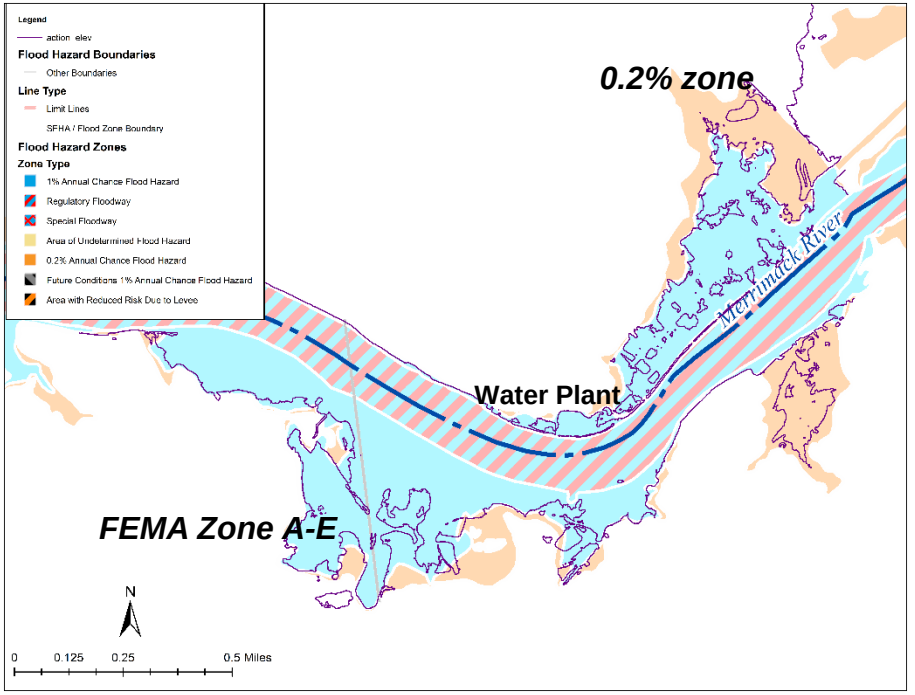
(The sponge effect)

The Existing Condition

Merrimack River



- Inundation @50.7 ft
- River flow @ 132,000 cfs
- Equal to FEMA ~1% annual flood
- ***Assessment and indicators***



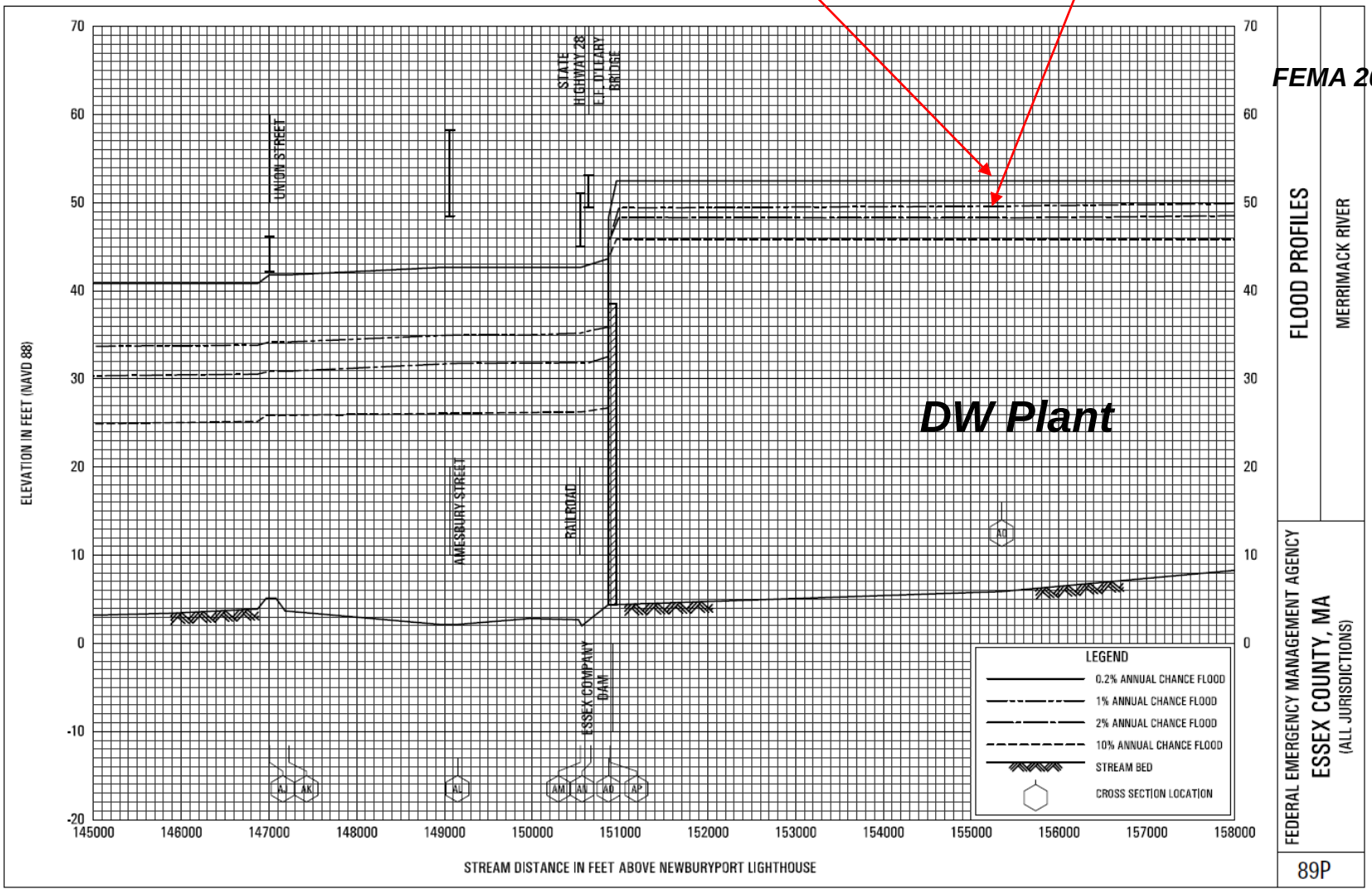
The Existing Flood Management

Merrimack River

0.2% flood: 52.5 ft

1% Base flood: 49.6 ft

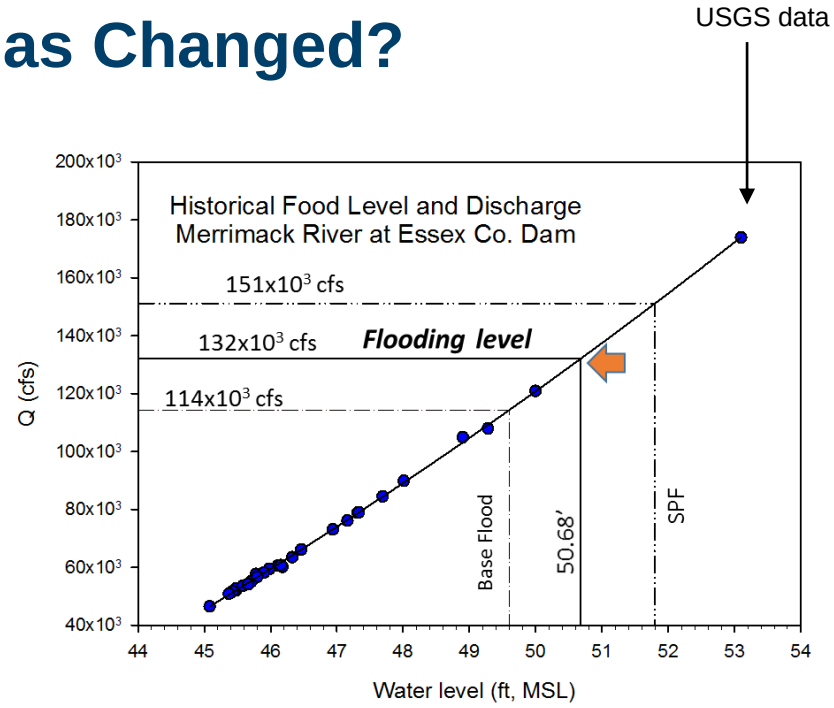
FEMA 2018

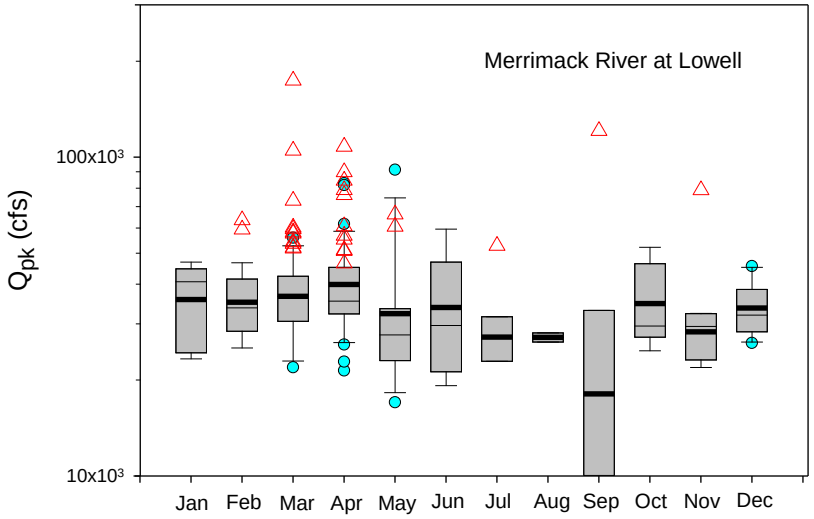


What Has Changed?

Merrimack River

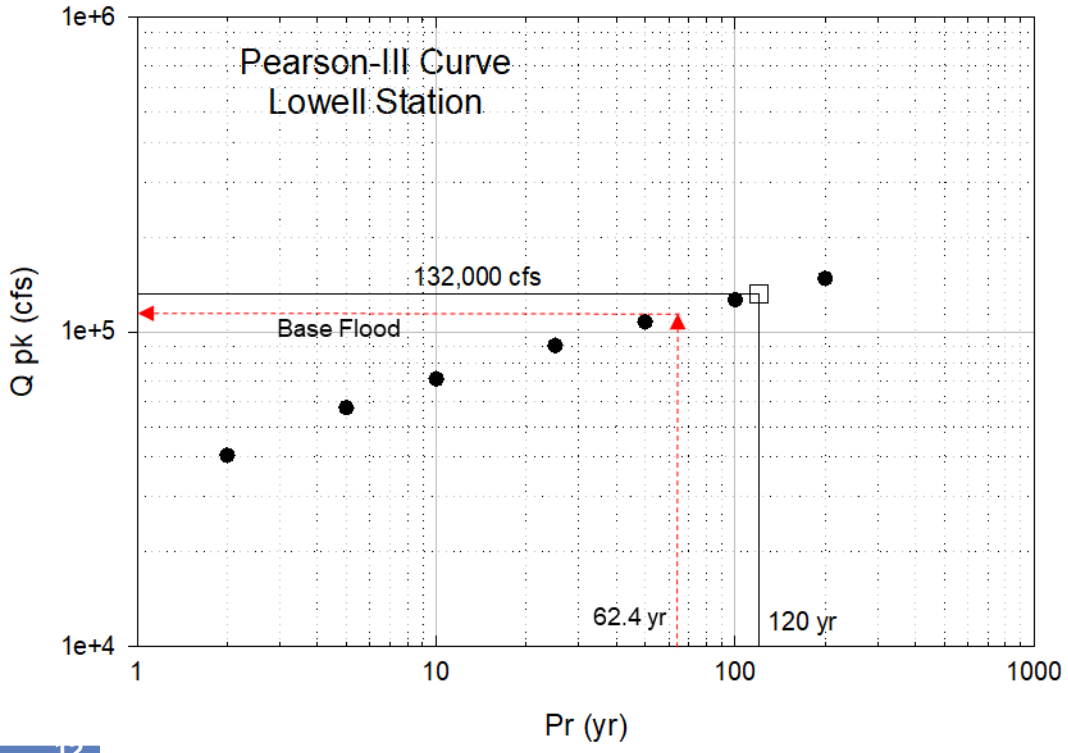
- At Lawrence, flooding levels determined from the berm, ACOE SPF, and FEMA Base Flood
- Most high flows (and floods) occur in March, April, and May
- Low flow in summer months
- Indicated by 1852-1969 floods, and by 108 high flow events after 1967





What Has Changed?

- ❑ Flow using Lowell Station
- ❑ Flood elevation using Lawrence Station



Merrimack River at Lowell

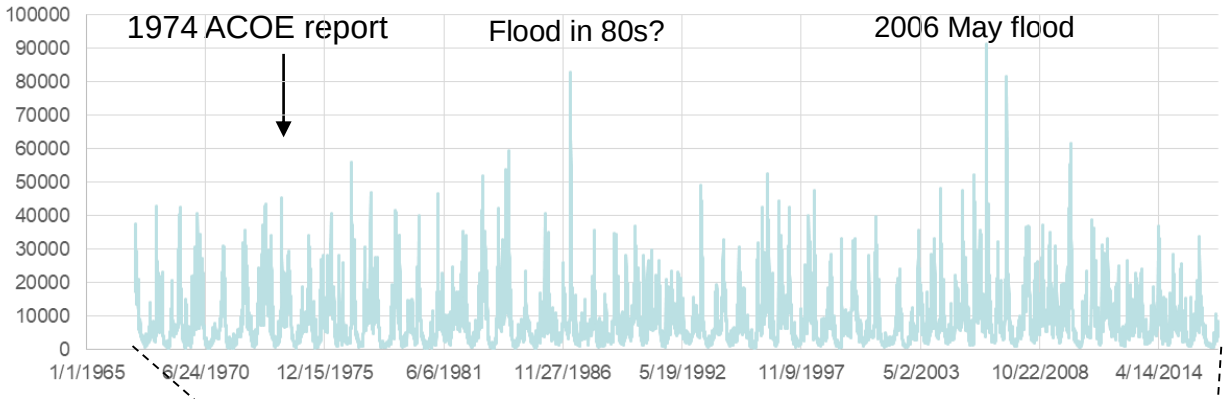
- Using Pearson-III flow distribution
- Only count for maximum flow in a year
- 132,000 cfs flow (@berm elevation) is for 120 yr flood at Lowell
- The FEMA map and ACOE design calculation are consistent with the practices
- 1% FEMA base flood designation at the treatment plant location: 62.4-yr RI

What Has Changed?

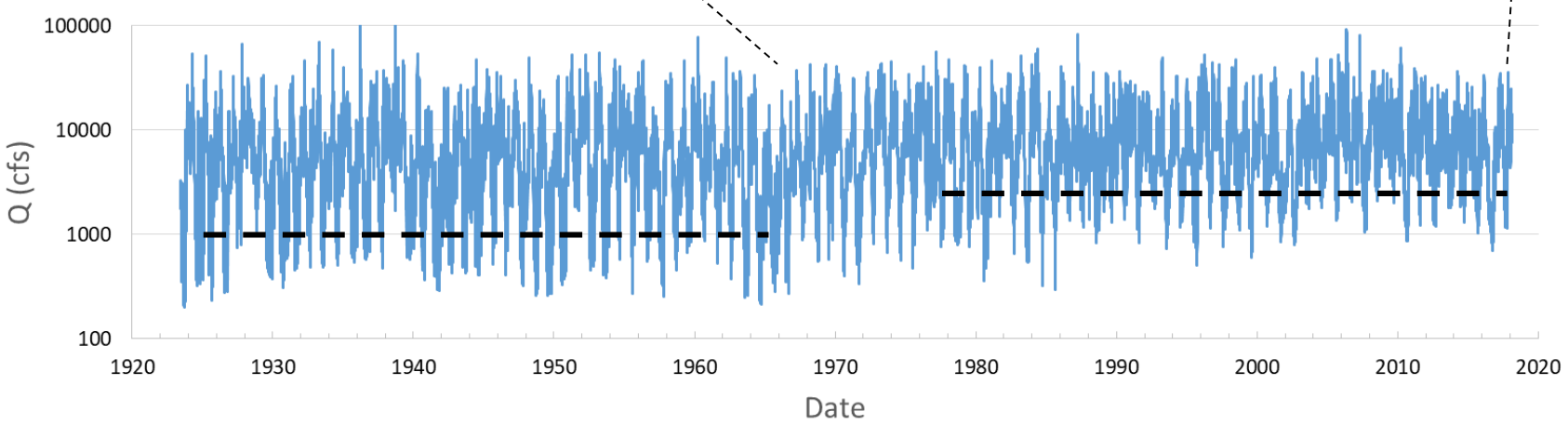
Merrimack River

- Changes in hydroclimatic conditions
- Flood return interval analysis based on flow data of 95-yrs at Lowell

Lawrence



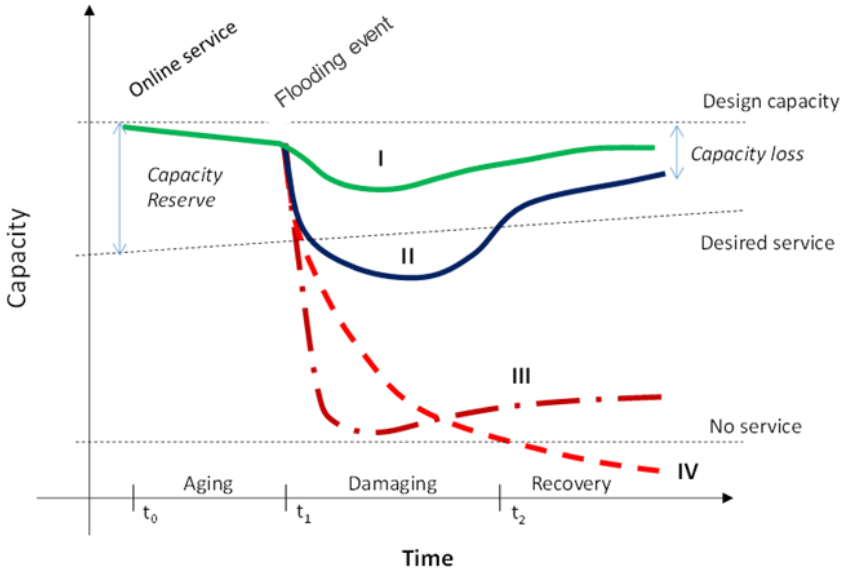
Lowell



What Has Changed?

Flood-inundation over the berm as the important design factor for treatment plant operation

- Probability of flooding event at a given RI
- Probability of days of inundation at a given RI

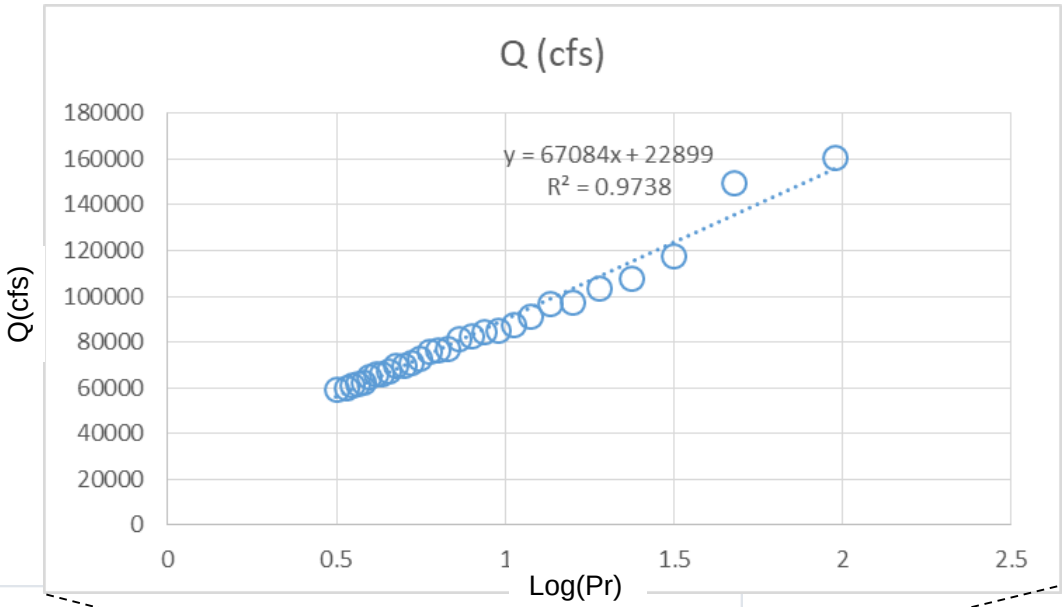


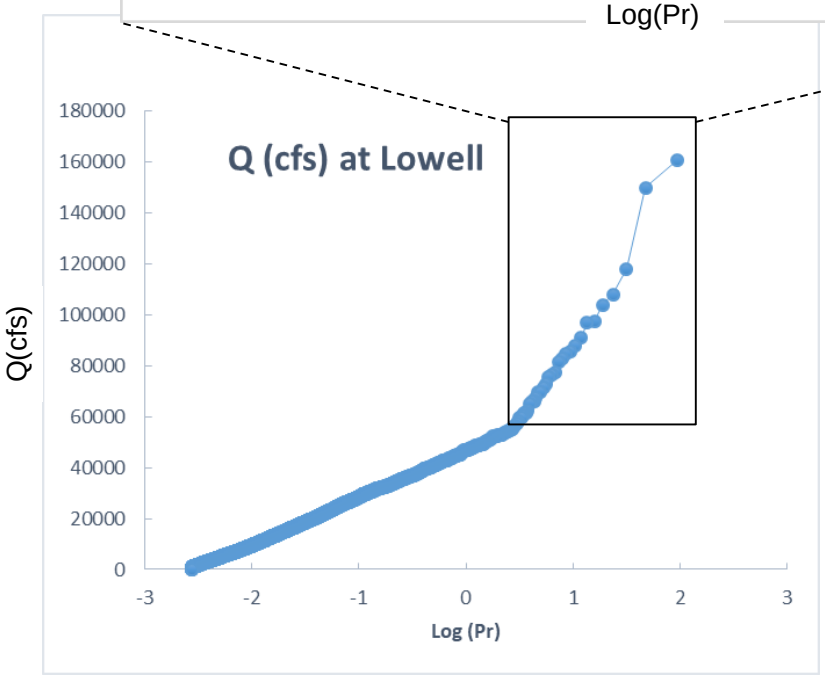
What Has Changed?

Merrimack River:

Plant inundation risk

- Inundation level at 132,000 cfs has a 42.2 yr return interval, or 2.4 day-events in 100 years
- Or in average 2.4 days of inundation in each flooding events
- Additional flow received b/w Lowell and Lawrence, making annual chance >2.4%
- Base flood FEMA flood designation at the location

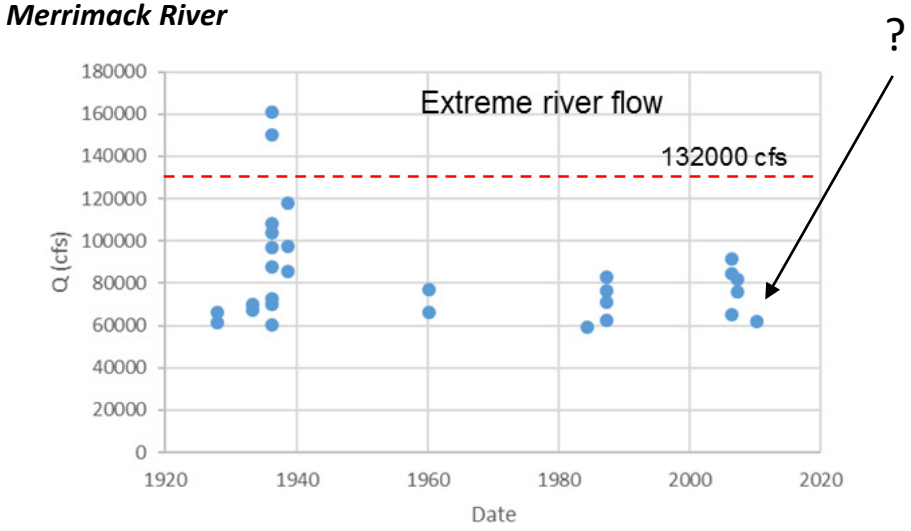




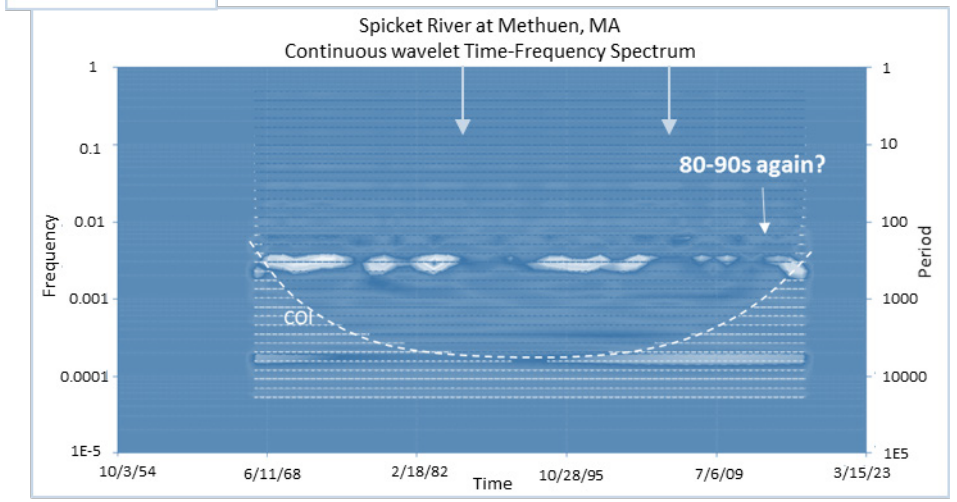
What Has Changed?

- Large floods in probability distribution
- Periodically occurred, ~25 yrs, consistent with Atlantic climate system
- The current phase

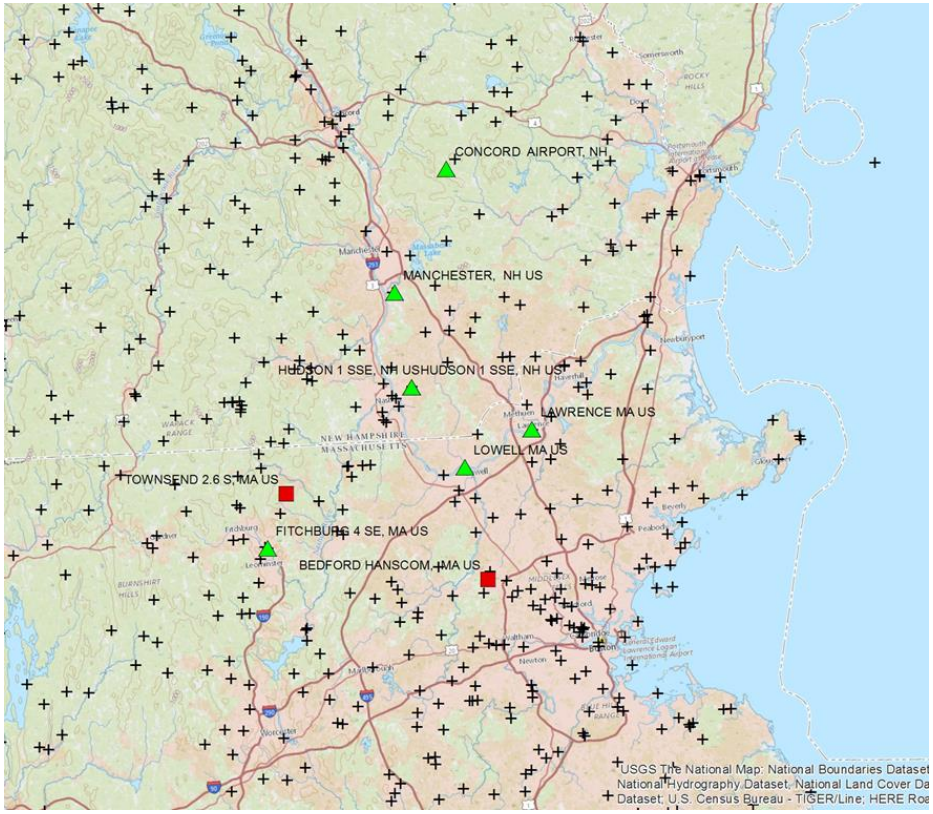
Merrimack River



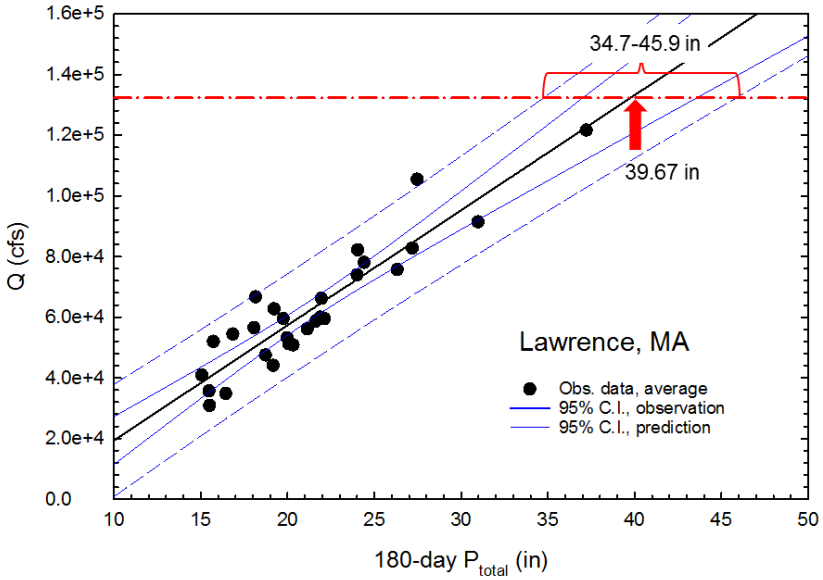
Spicket River



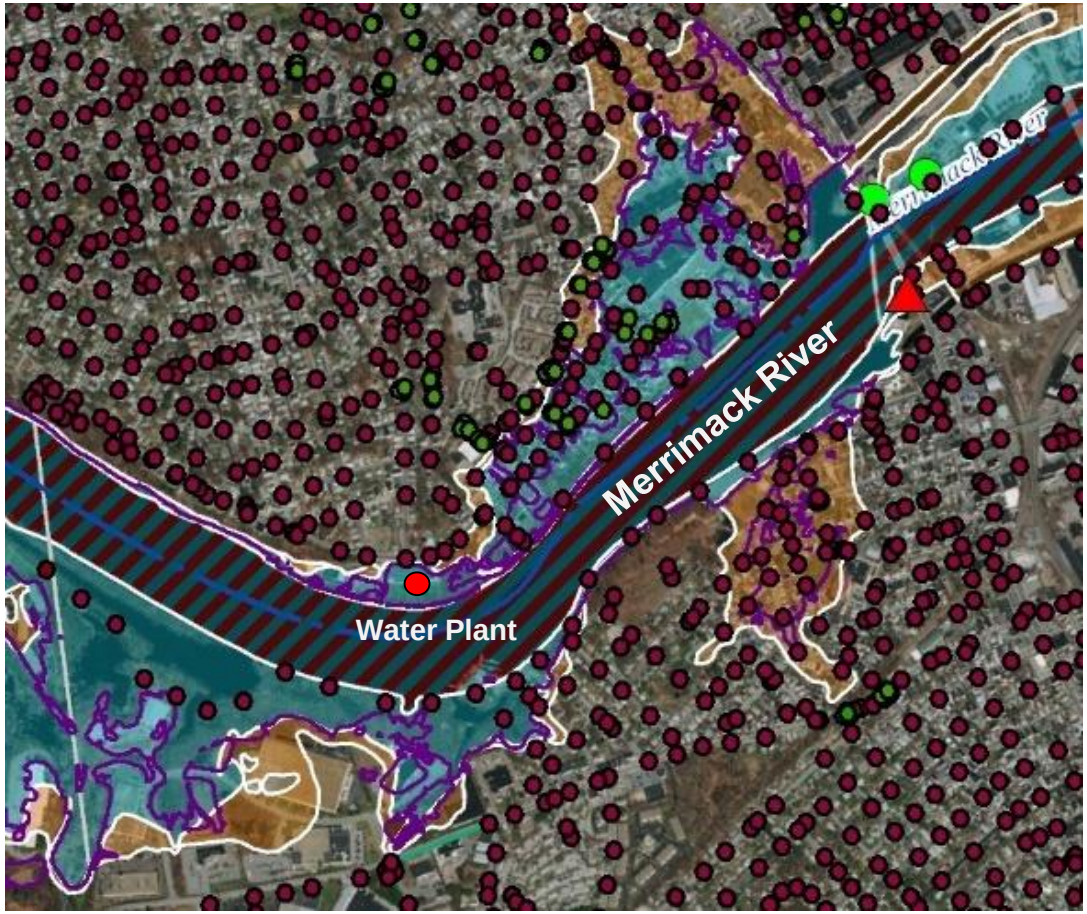
Potential Warning Indicator



- Monitor 180-day precipitation total in 6 USHCN stations in Merrimack watershed upstream of Lawrence
- Estimated range for the flood level at 132,000 cfs river flow
- Can be used as an warning indicator

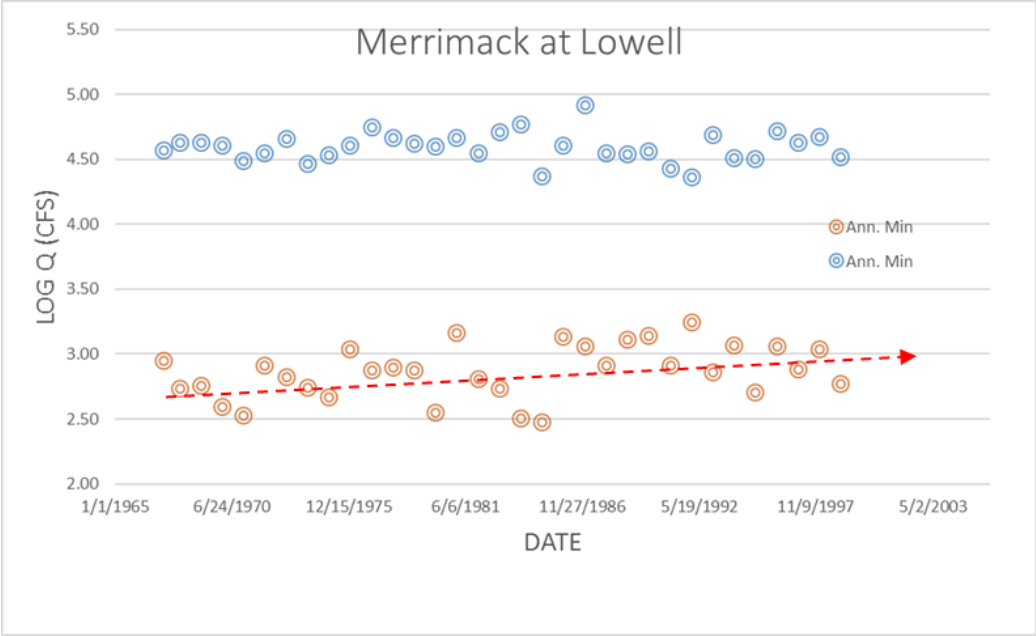


Infrastructure and Water Quality Impacts



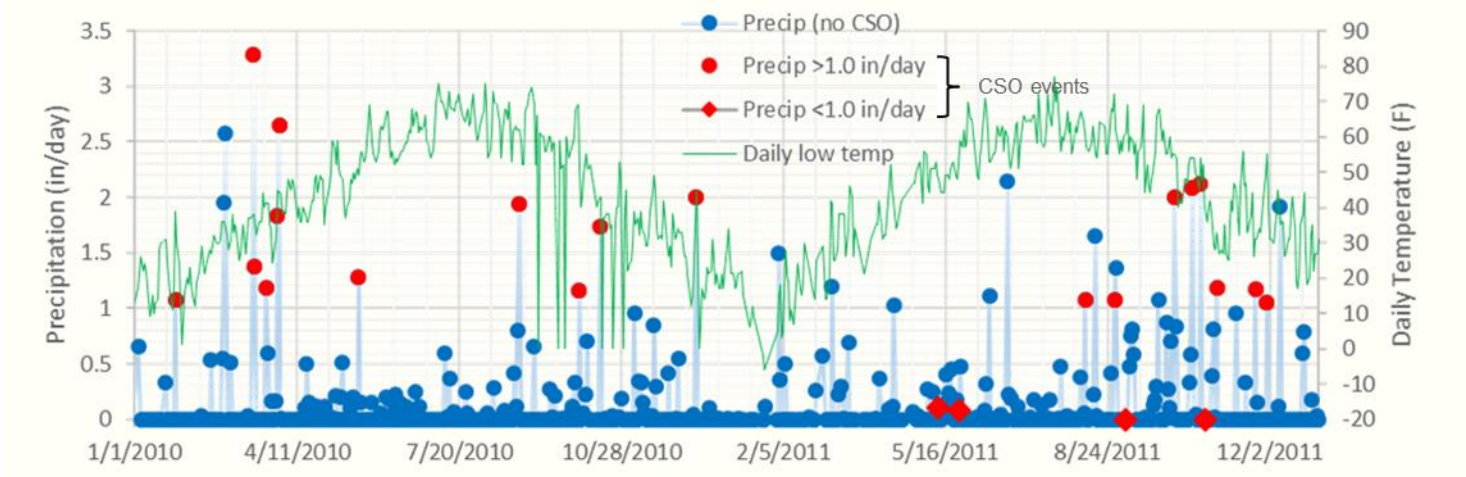
- Flow at 132,000 cfs (berm elevation) has a 120 year RI or 0.8% annual flood
- FEMA Base Flood is at the plant: 49.6 ft or 114,000 cfs, equals to 62.4-yr RI or 1.6% annual flood. [Comment and input needed]
- Plant inundation at berm elevation has 42.2-yr RI or 2.4% annual probability
- Impacts to the water plant and operation
- Impacts to sewer systems along Water Street above the dam

Infrastructure and Water Quality Impacts



- Minimum flow and regional base precipitation increased since 1950s.
- (Possibly due to land use/land cover and precipitation in the watershed)
- Less channel flow capacity for flood with implications for CSO events
- Relationship to CSO events

CSO events occurred when Precipitation >1 in/day



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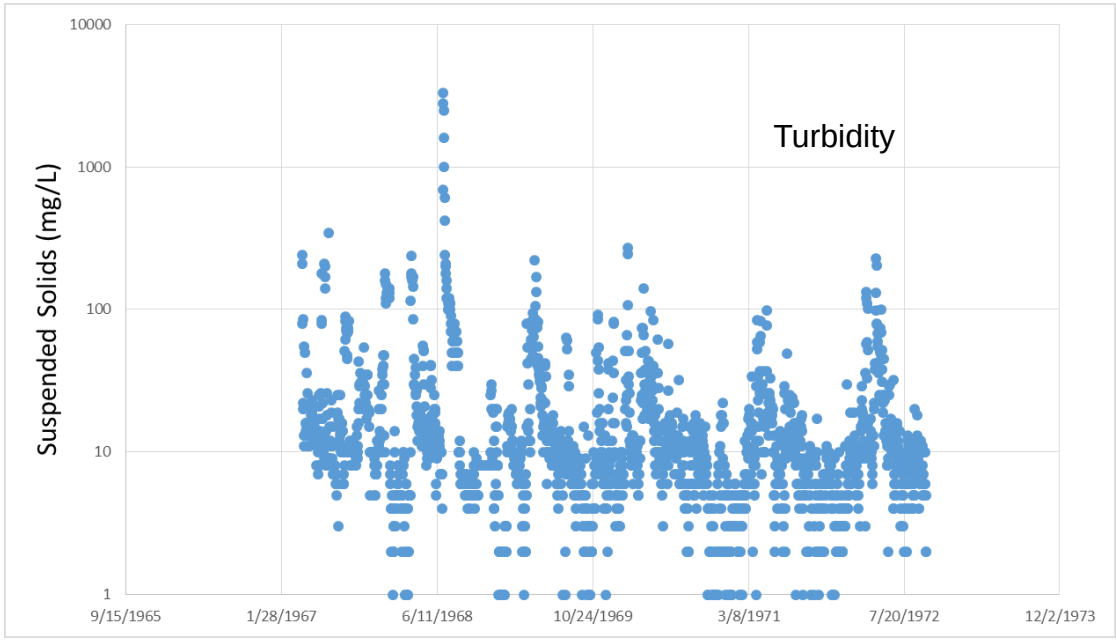
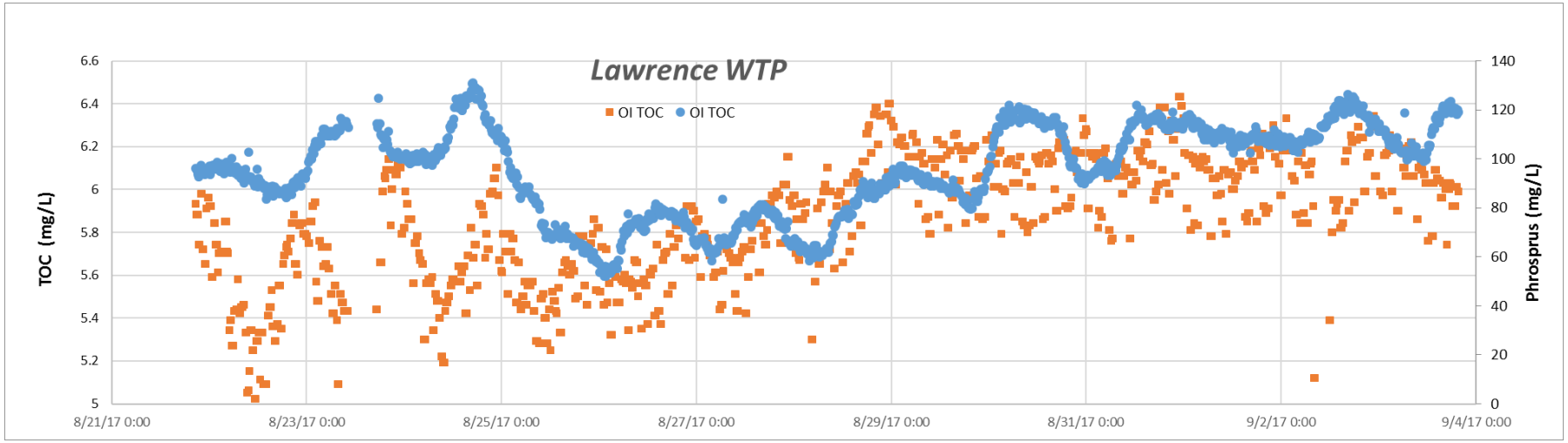
Infrastructure and Water Quality Impacts





- Water quality changes with flow, potentially impacting plant operation
- Real-time monitoring network at Andover and Lawrence

Summary and Suggestions

- Spicket River: High flash flood risk due to the increasing downpours and channel blockage
- Impact pipe network and SSS/CSS structures
- Merrimack River: Berm designed against 100 yr flood or 1% annual flood. The BF elevation appears equal to 1.6% annual flood
- Inundation to water treatment plant is at 2.4% annually or 2.4 day-events per 100 years. Inundation duration is 2.4 days per event. The risk of losing service is high
- Base flow increased, with implications to CSO events
- This study is an assessment only. Detailed hydrological analysis, engineering and berm survey are recommended for flood mitigation measures

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Supplemental Slides

Design Precipitation in New England Coastal Areas

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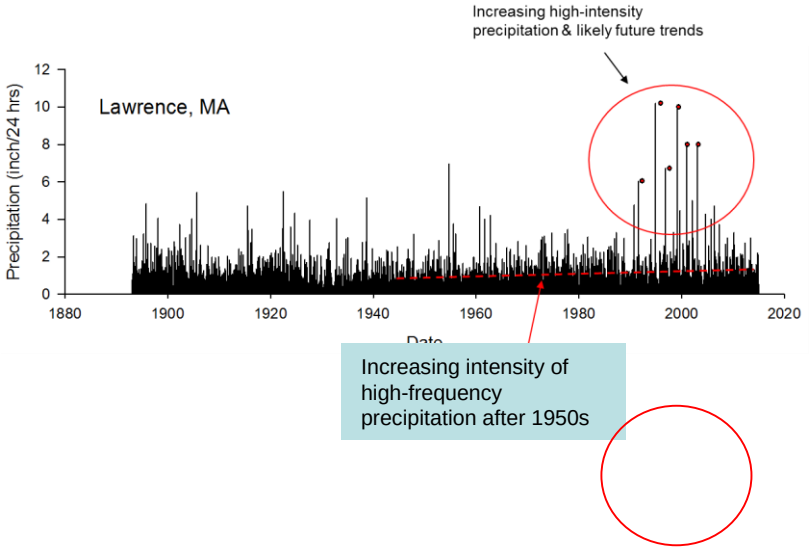
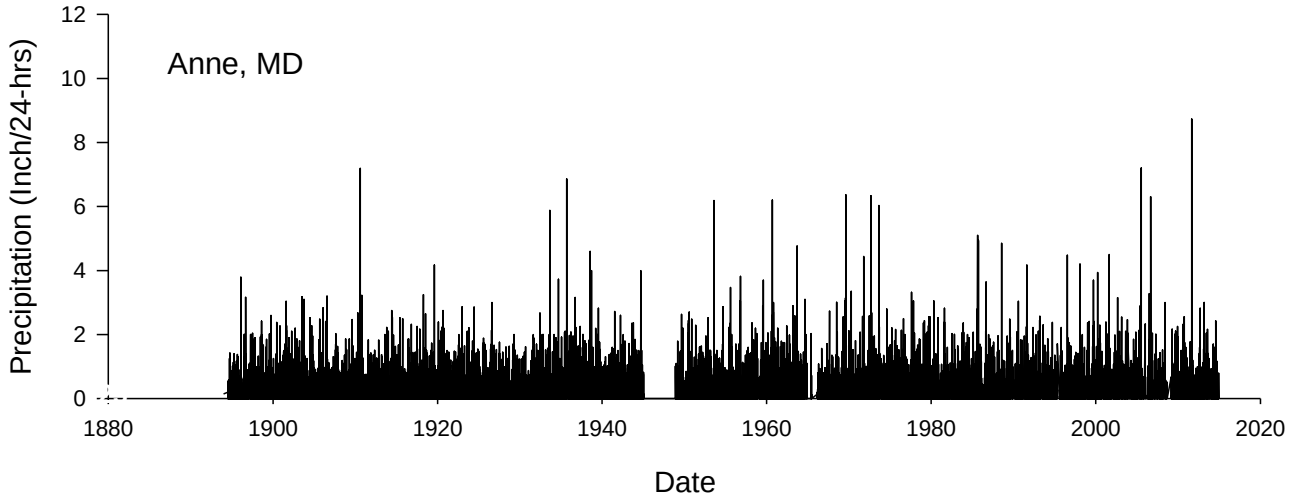
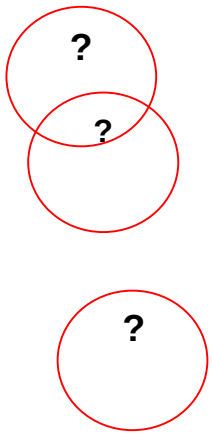


- Some coastal areas have seen a large increase of high-intensity precipitation since 1990s.
- The change is not in historical records used for Altlas-14 design curve





Changes in Design Precipitation?

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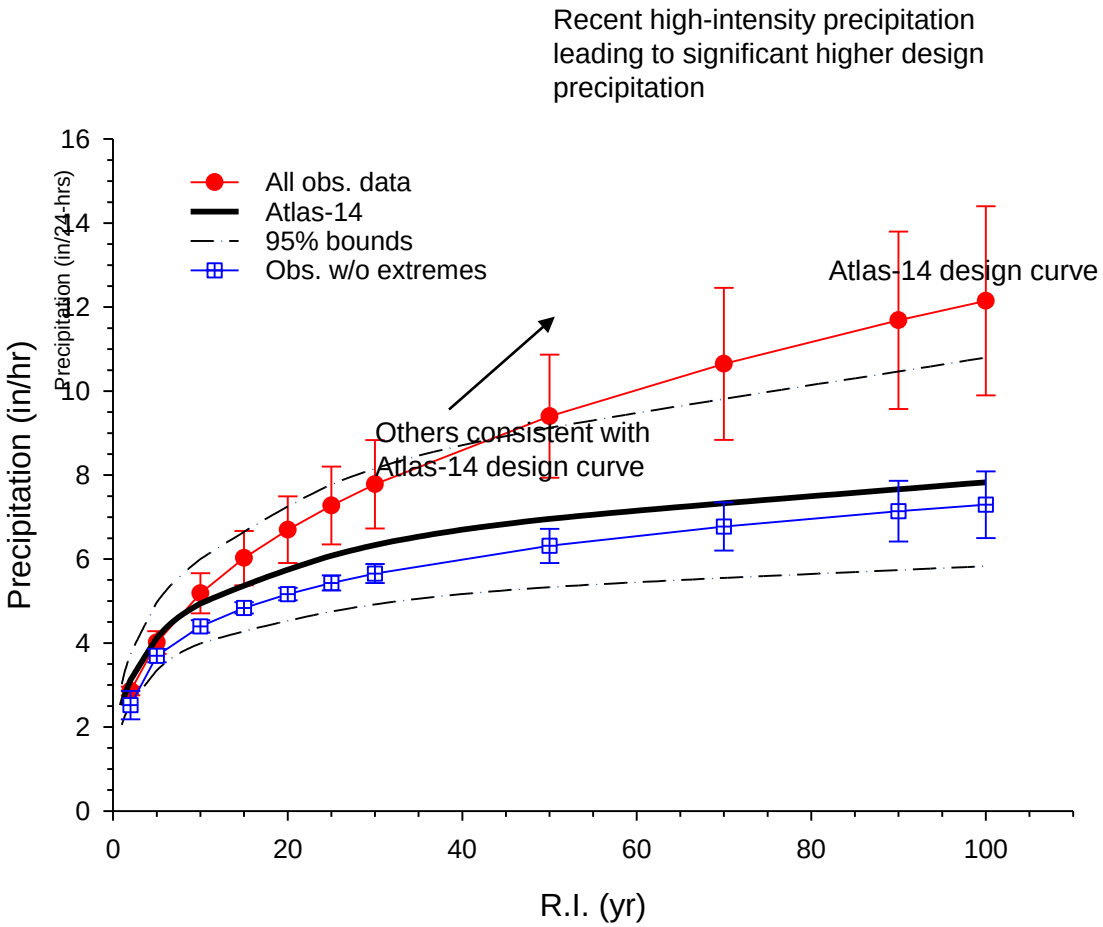


Case Study

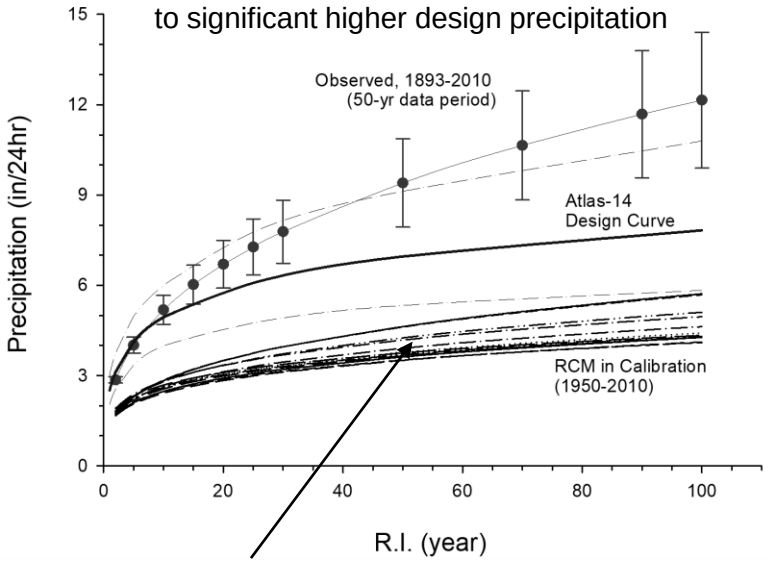
- One example in Lawrence, MA
- Combined sewer overflow (CSO) occurred more often in recent decades

- High-intensity precipitation after 1990s, changes the design precipitation curves
- Precipitation before 1990s agrees with Atlas-14 regional design values
- The aging water infrastructure now may not have enough capacity

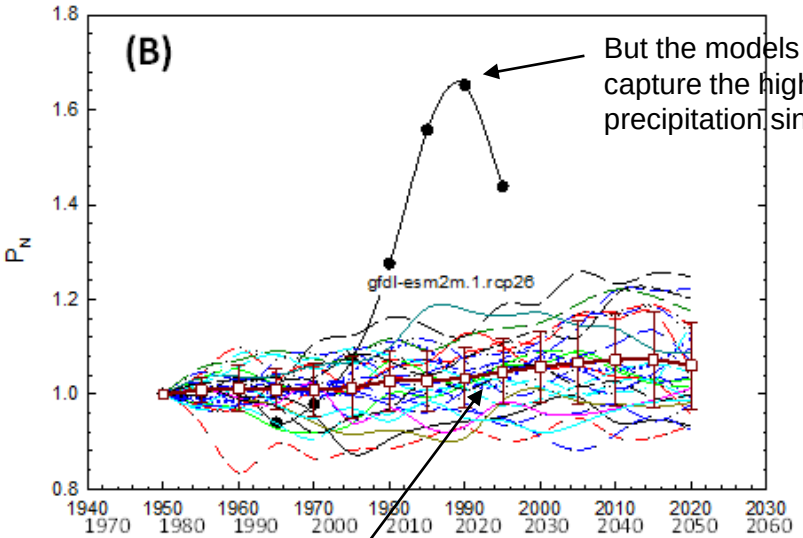
Climate Model Outputs for Design Storms: Challenges

- CMIP5 downscaling data of 132 model runs are unreliable for calibration (1950-2010)
- Future projections to year 2050 may be significantly underestimated, due to the high-intensity precipitation after 1990s
- What can we do?

Recent high-intensity precipitation leading to significant higher design precipitation



All RCMs significantly under-predict design storm across the board



But the models do not capture the high-intensity precipitation since 1990s

CIMP5 average and envelop indicate small increase in 2-year 24-hr design storm