more lines of thought about Lower Shaker Lake dam

4) Understanding the dam failure flood models
5) Size guidance guesswork for non-flood-hazard dam redesign

Ben Monreal
Shaker Heights
Professor of Physics, CWRU

My qualifications:

a) Taught environmental fluid mechanics at UC Santa Barbara: Physics 120 "Physics of California
b) Professional experience with complex regulatory systems, civil & geotechnical engineering
c) Live near and enjoy Lower Lake and adjacent parkland

- **Things I was right about:**
  - ODNR documents confirm: the Class I designation is due to University Circle flooding, not (e.g.) Doan Canyon recreational users or Coventry Road inundation
  - No flood in sunny-day breach scenario at normal pool height
- **Things I was wrong about:**
  - I had thought the "probable maximum flood" was "24 hours of inch-per-hour rain" but it is much much more intense than that
- **Useful new details:**
  - Emergency Action Plan has complete flood/hydraulic model outputs attached
  - Model results:
    - Sunny day failure (75 a-f, not shown on maps) but reportedly causes floods
    - 100-year flood failure (5" rain, inflow 2800 cuft/s, presumably 178 a-f breach)
    - PMF failure (24" rain, inflow 23,000 cuft/s, presumably 178 a-f "behind the dam" but 250+ a-f including freeboard)
  - With this plus some physics we can estimate how a new dam might perform

What hazards pushed it into Class I?

"Probable loss of human life" has been selected for University Circle

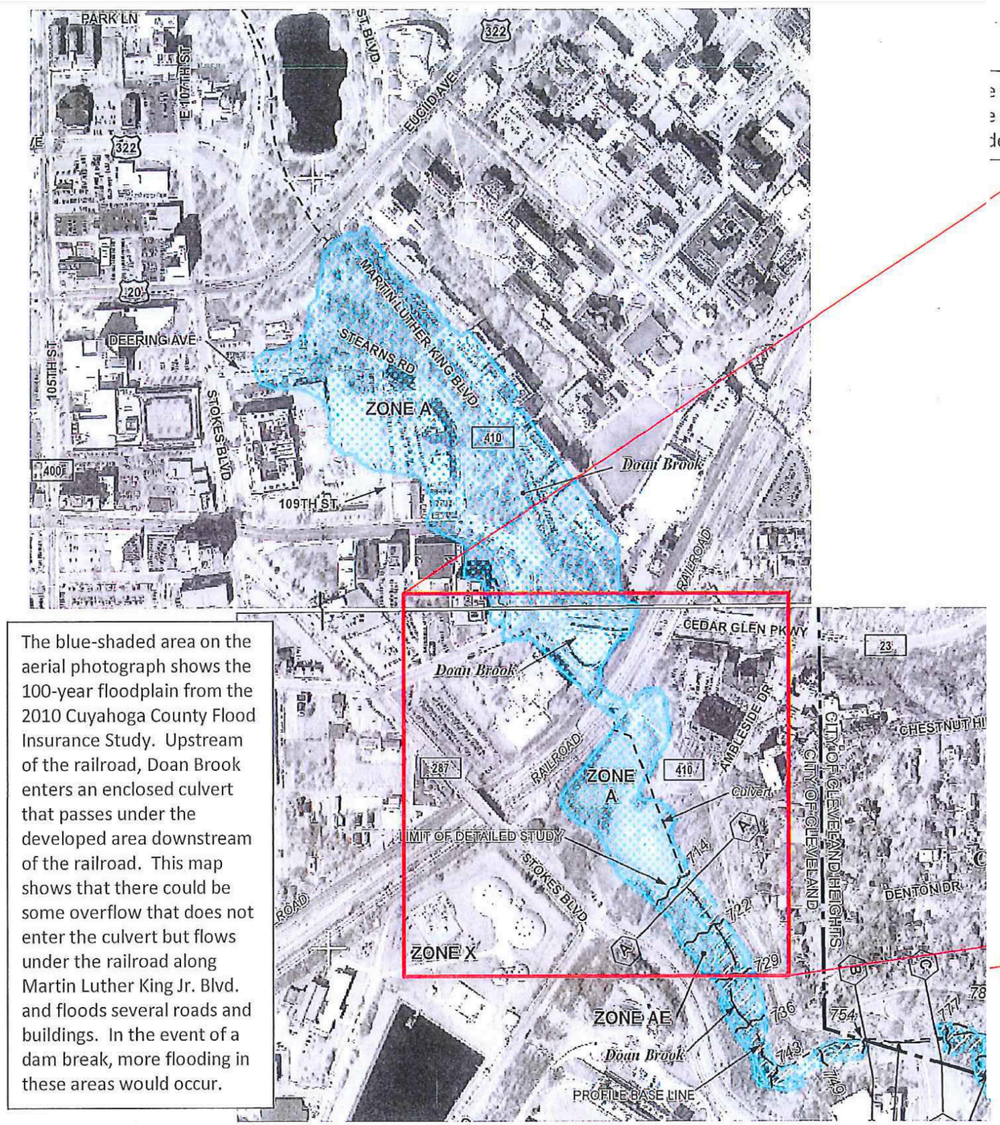
Upstream areas assessed with "class III" hazards at worst.

POTENTIAL DOWNSTREAM HAZARD

I	II					III		IV	-	-				
Probable loss of human life	Loss of public water supply or wastewater treatment facility, release of health hazardous waste	Flooding of structure or high-value property	Damage to high-value or Class I, II, III dam or levee	Damage to major road (US or state route), disruption of only access to residential or critical facility area	Damage to railroad or public utility	Damage to rural building, not otherwise high-valued property, or Class IV dam or levee	Damage to local road (county and township)	Loss restricted mainly to the dam or agricultural /rural land	No hazard to structure noted	*No hazard assessment; further investigation needed*	Distance downstream of dam to affected structure (feet)	Vertical distance from streambed to base of affected structure (feet)	Horizontal distance from stream to affected structure (feet)	
							A				0	0	0	Brook Rd/Lower Shaker Lake Dam
							B				300	11	0	Coventry Rd
							C				500	8	0	Fairhill Rd
									D		5000	13-30*	0	East Blvd.
E											7000	varies	varies	University buildings, roads, and other structures

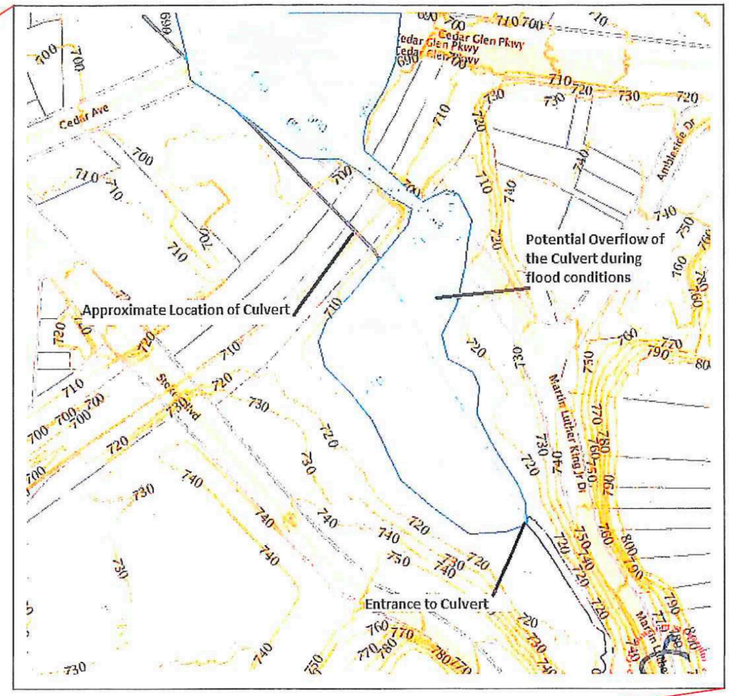
(from 2014 ODNR filing attached to 2022 emergency action plan)

But there is no hydraulic model attached to this hazard assessment. Just a 100-y floodplain map from 2010 and the statement that "there could be some overflow"



The blue-shaded area on the aerial photograph shows the 100-year floodplain from the 2010 Cuyahoga County Flood Insurance Study. Upstream of the railroad, Doan Brook enters an enclosed culvert that passes under the developed area downstream of the railroad. This map shows that there could be some overflow that does not enter the culvert but flows under the railroad along Martin Luther King Jr. Blvd. and floods several roads and buildings. In the event of a dam break, more flooding in these areas would occur.

e map below includes 2-ft contours obtained from the Cuyahoga County Auditor Website.
e map shows that overflow from the culvert will flow along Martin Luther King Jr Blvd,
der the railroad to developed areas downstream.



The culvert begins about 1.4 miles downstream of Lower Shaker Lake Dam and about 2.6 miles downstream of Upper Shaker Lake Dam.

Height Class:	IV		
Storage Class:	III		
Hazard Class (see next page)**:**	I	**Estimated Population at Risk:**	(16+)
Final Class:	I		

Class Changed (No)

This document has a place to mark if the dam classification has changed. In 2014 it was "no" but clearly it is possible for the classification to change.

2016 AECOM model

full results attached to 2021 Emergency Action Plan for each of three scenarios.

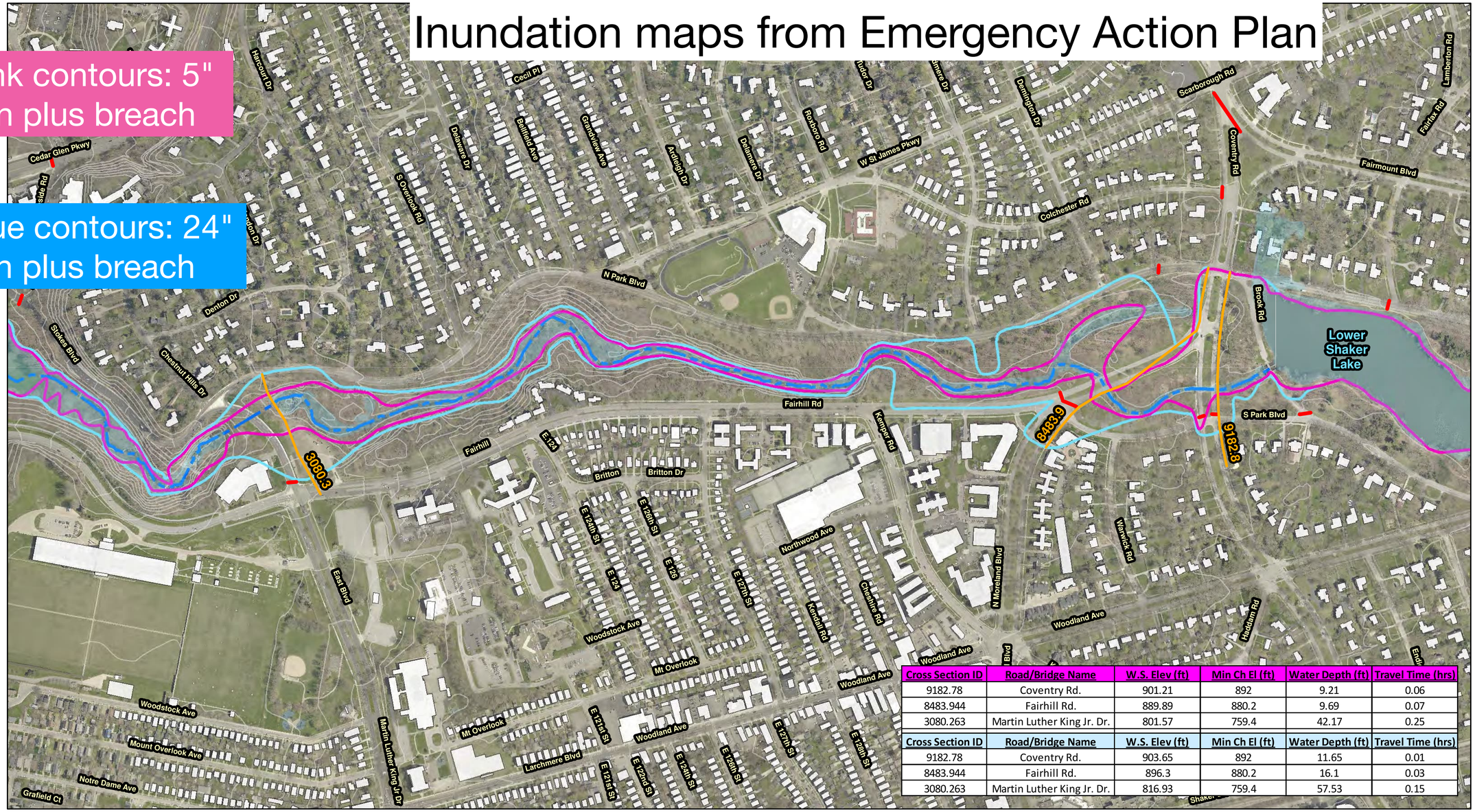
Table 2 – Dam Failure Scenarios			
Scenario	**Precipitation (in)**	**Distribution**	**Failure Mode**
Sunny Day	0.04*	SCS Type II 24-hr	Piping
100-year storm	5.46	SCS Type II 24-hr	Overtopping
PMF	25.50	ODNR Type II 24-hr	Overtopping

*Lowest rainfall depth allowed by HydroCAD

Software: HydroCAD v10.0 + HEC-RAS v4.1

Inundation maps from Emergency Action Plan

- Pink contours: 5" rain plus breach
- Blue contours: 24" rain plus breach



Cross Section ID	Road/Bridge Name	W.S. Elev (ft)	Min Ch El (ft)	Water Depth (ft)	Travel Time (hrs)
9182.78	Coventry Rd.	901.21	892	9.21	0.06
8483.944	Fairhill Rd.	889.89	880.2	9.69	0.07
3080.263	Martin Luther King Jr. Dr.	801.57	759.4	42.17	0.25

Cross Section ID	Road/Bridge Name	W.S. Elev (ft)	Min Ch El (ft)	Water Depth (ft)	Travel Time (hrs)
9182.78	Coventry Rd.	903.65	892	11.65	0.01
8483.944	Fairhill Rd.	896.3	880.2	16.1	0.03
3080.263	Martin Luther King Jr. Dr.	816.93	759.4	57.53	0.15

100 Year Dam Failure Limits
PMF Dam Failure Limits
River Centerline
Critical Cross Section
Critical Structure - PMF Dam Failure
Proposed Road Blocks
10' Contours
1% Annual Change (100 yr); Floodplain

NOTES:
1. 100-YEAR F LOOD LIMITS OBTAINED FROM CUYAHOGA COUNTY FLOOD INSURANCE STUDY (STUDY NO. 39035CV001A, DATED DECEMBER 3, 2010).
2. POTENTIAL AFFECTED AREAS SHOWN ARE A COMPOSITE OF 100-YEAR AND PROBABLE MAXIMUM FLOOD (PMF) FAILURES, EVACUATION FOR 100-YEAR FAILURE IS THE SAME FOR THE SUNNY DAY FAILURE, ONLY THE 100-YEAR FLOOD AND PROBABLE MAXIMUM FLOOD FAILURE LIMITS ARE SHOWN FOR CLARITY.
3. BECAUSE OF THE METHOD, PROCEDURES, AND ASSUMPTIONS USED TO DEVELOP THE FLOODED AREAS, THE LIMITS OF FLOODING SHOWN ARE APPROXIMATE AND SHOULD BE USED ONLY AS A GUIDELINE FOR ESTABLISHING EVACUATION ZONES. ACTUAL AREAS INUNDATED WILL DEPEND ON ACTUAL FAILURE CONDITIONS, DEBRIS JAMS, AND OTHER FACTORS AND MAY DIFFER FROM AREAS SHOWN ON MAPS.
4. TIMES TO PEAK FOR 100-YEAR AND PMF ARE FOR FLOODWAVE PEAK ARRIVAL TIMES. AREAS OF INUNDATION WILL EXPERIENCE FLOODING PRIOR TO THE FLOOD WAVE PEAK.

0 37.5 75 150 Meters

0 125 250 500 Feet

Main Dike Failure

NEORSD
Lower Shaker Lake Dam
Dam Break Analysis
Shaker Heights, OH

AECOM

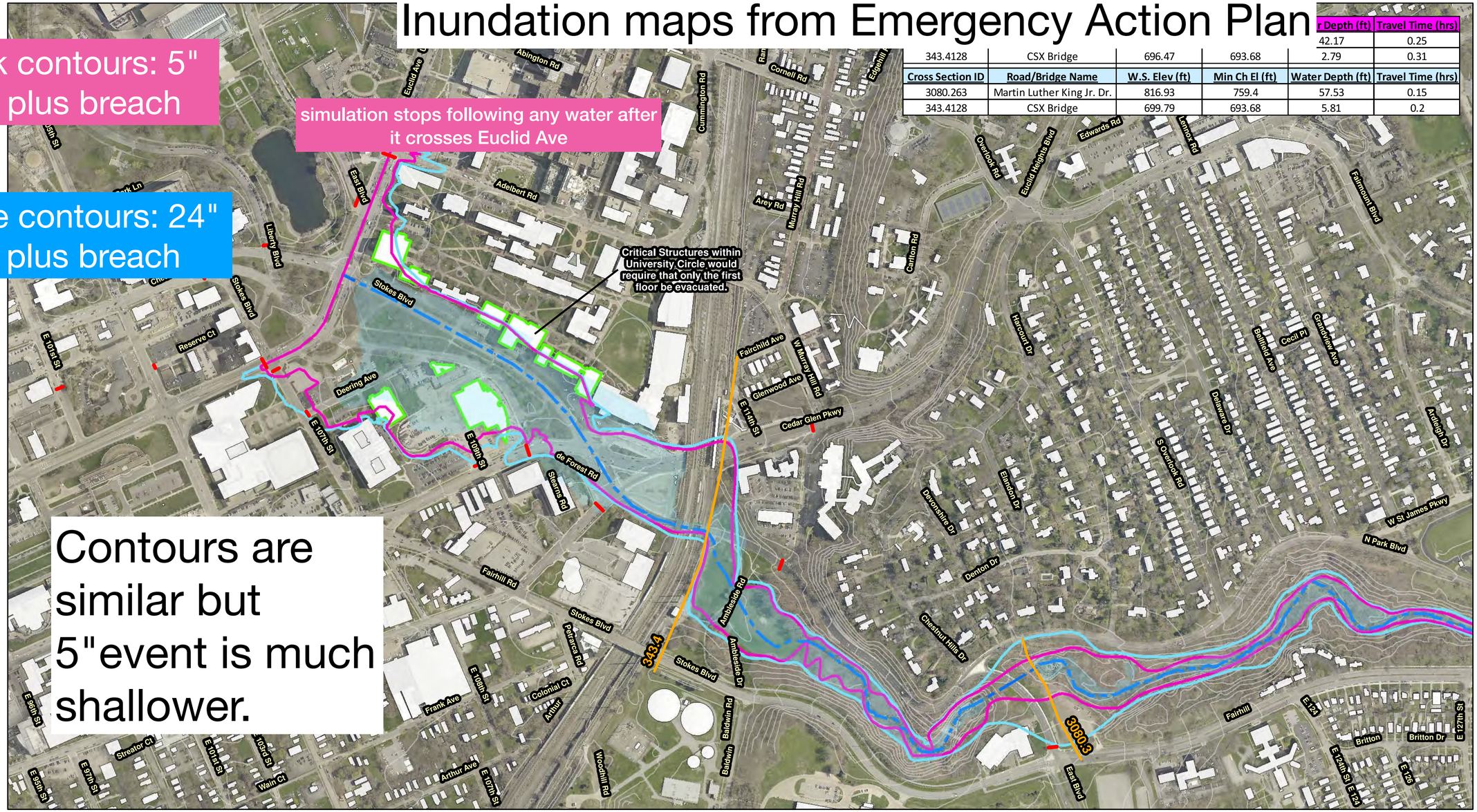
Figure C
Failure Inundation Map 1

Inundation maps from Emergency Action Plan

- Pink contours: 5" rain plus breach
- Blue contours: 24" rain plus breach

				r Depth (ft)	Travel Time (hrs)
				42.17	0.25
343.4128	CSX Bridge	696.47	693.68	2.79	0.31

Cross Section ID	Road/Bridge Name	W.S. Elev (ft)	Min Ch El (ft)	Water Depth (ft)	Travel Time (hrs)
3080.263	Martin Luther King Jr. Dr.	816.93	759.4	57.53	0.15
343.4128	CSX Bridge	699.79	693.68	5.81	0.2



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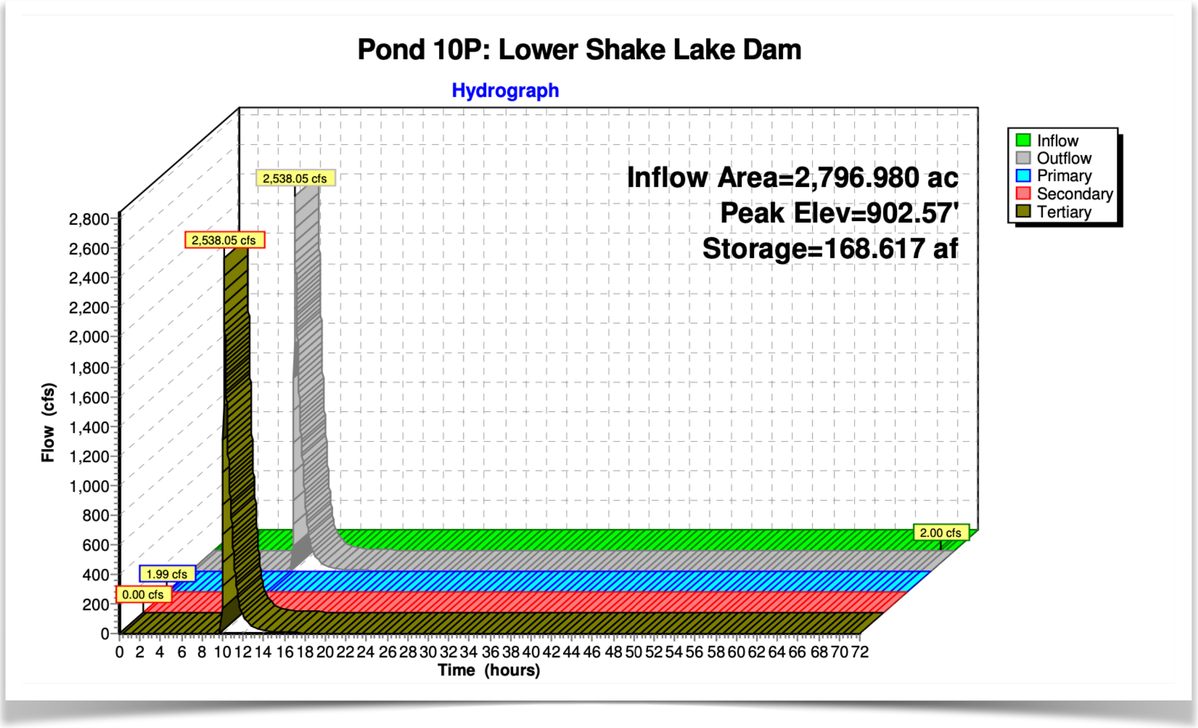
AECOM

Figure D
Failure Inundation Map 2

Highlights from AECOM model

A "sunny day" breach (hole in the middle of the dam):



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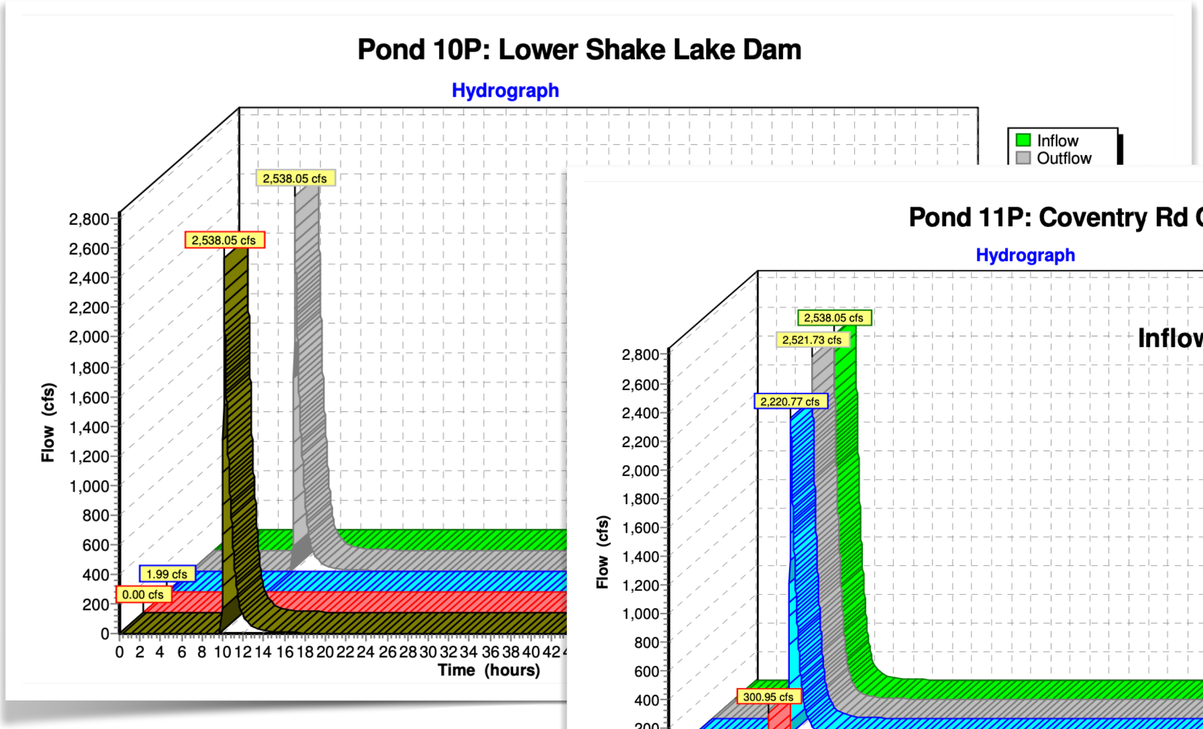

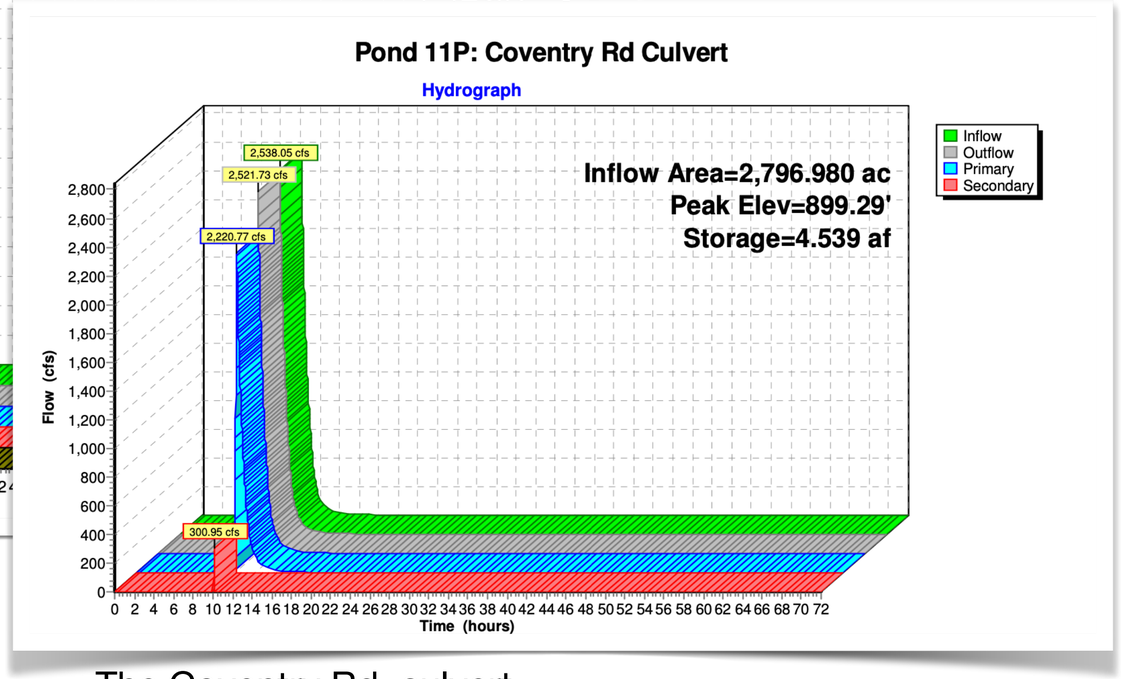

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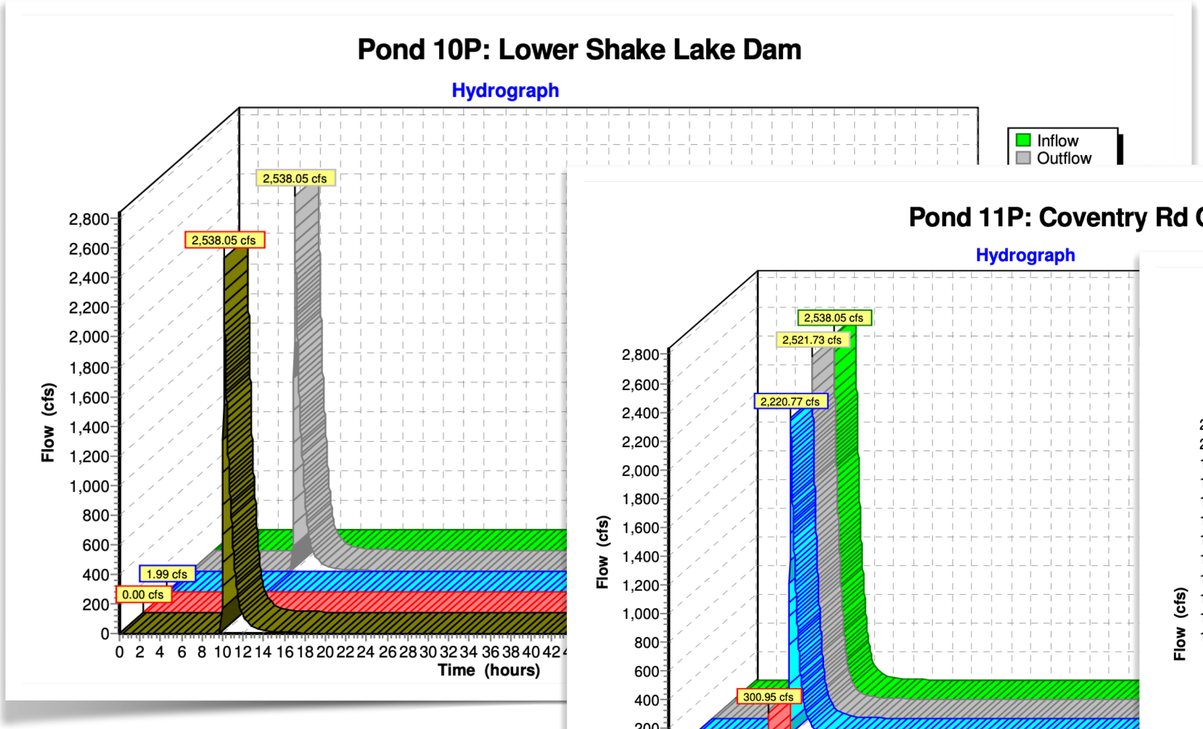

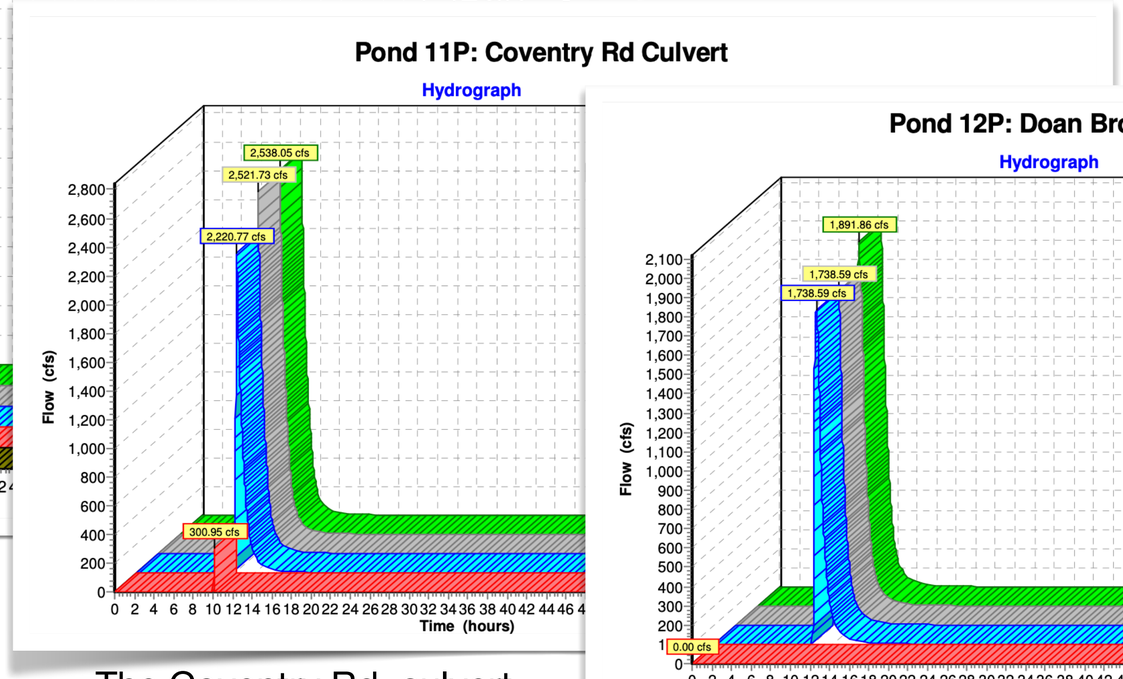

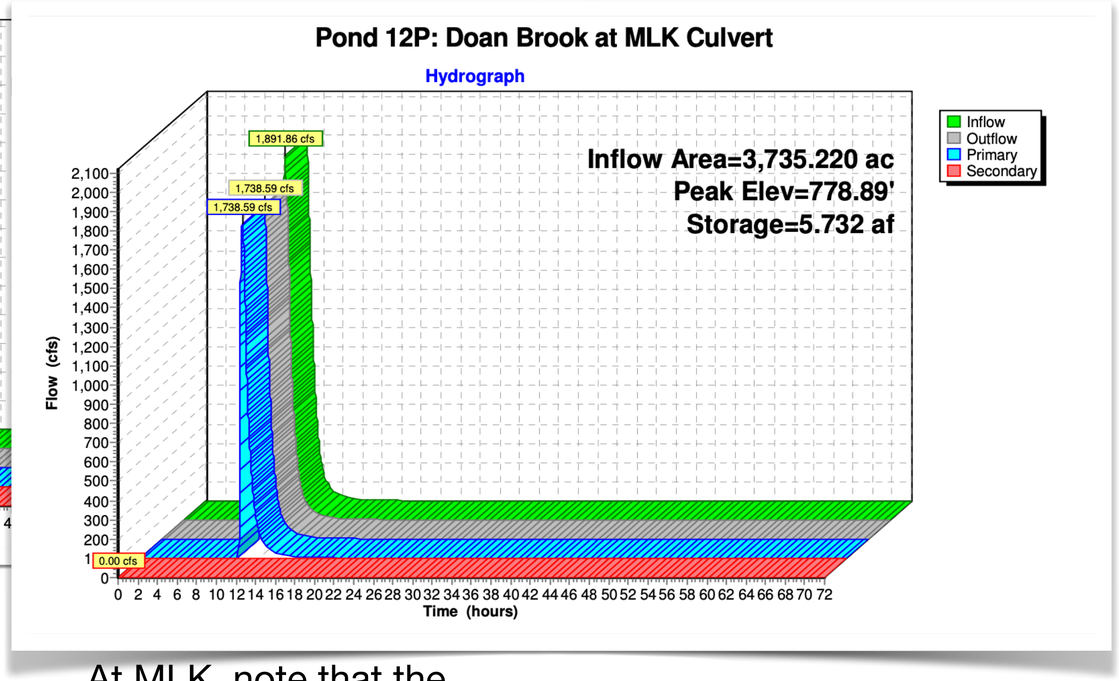

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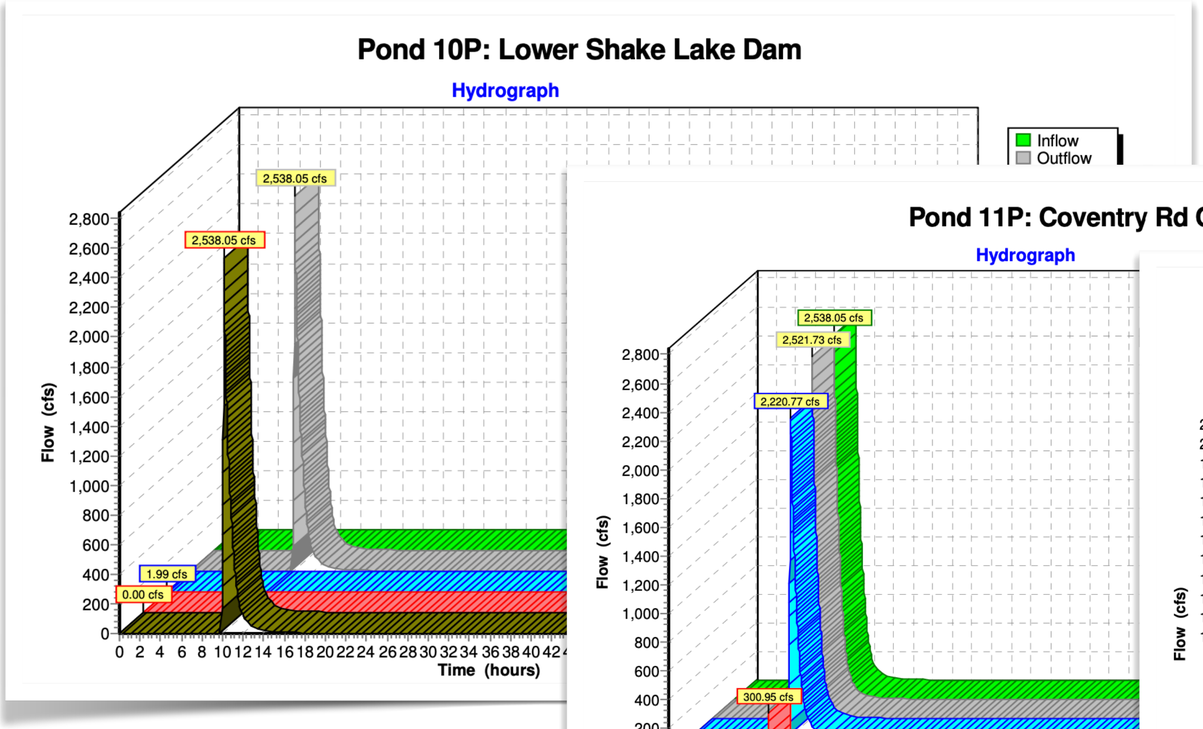

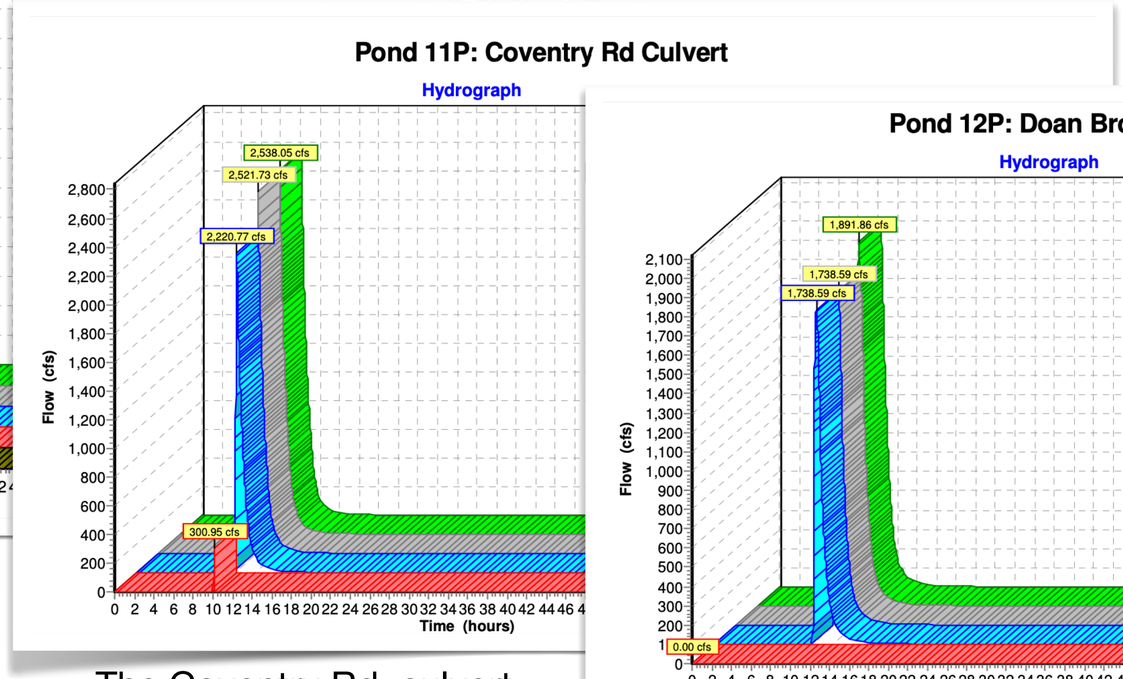

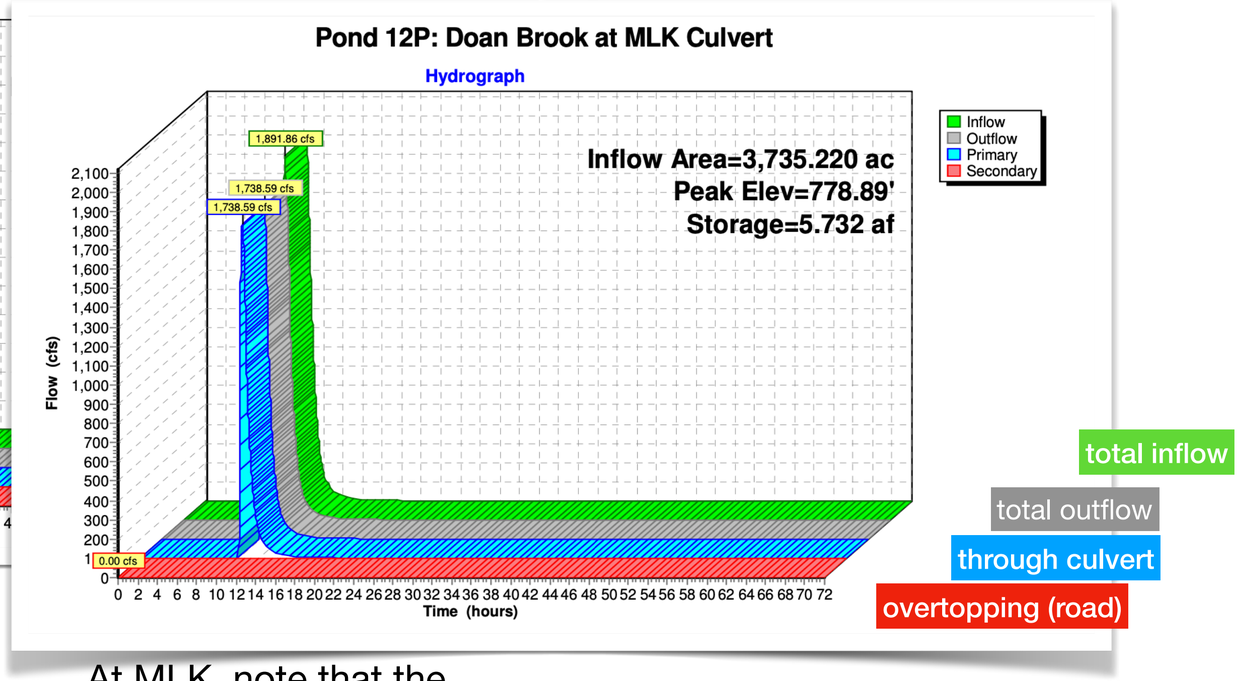

total inflow

total outflow

through culvert

overtopping (road)

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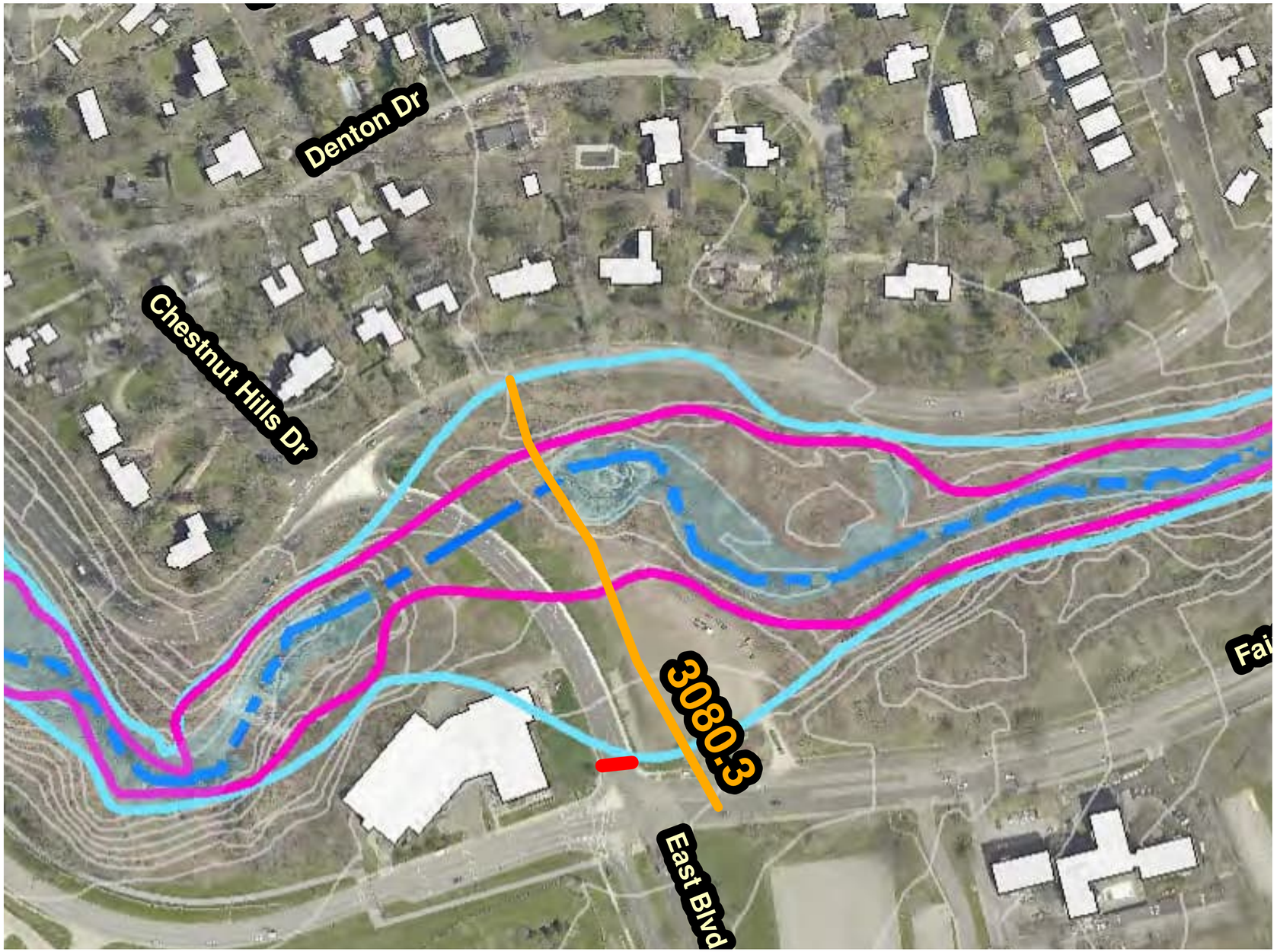

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780.00	6.480
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AECOM model has volume-vs-depth data for each sub-basin like this.

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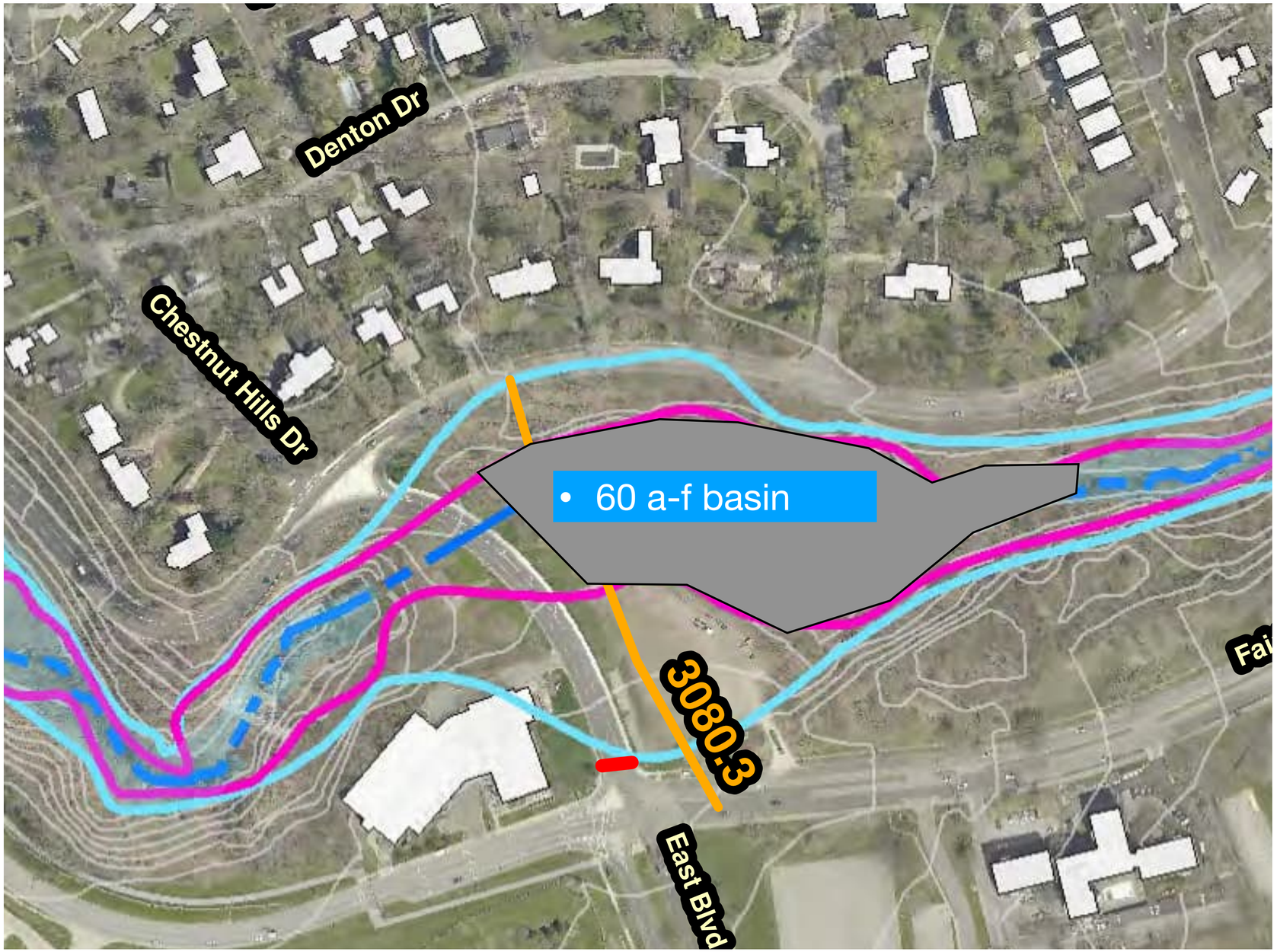

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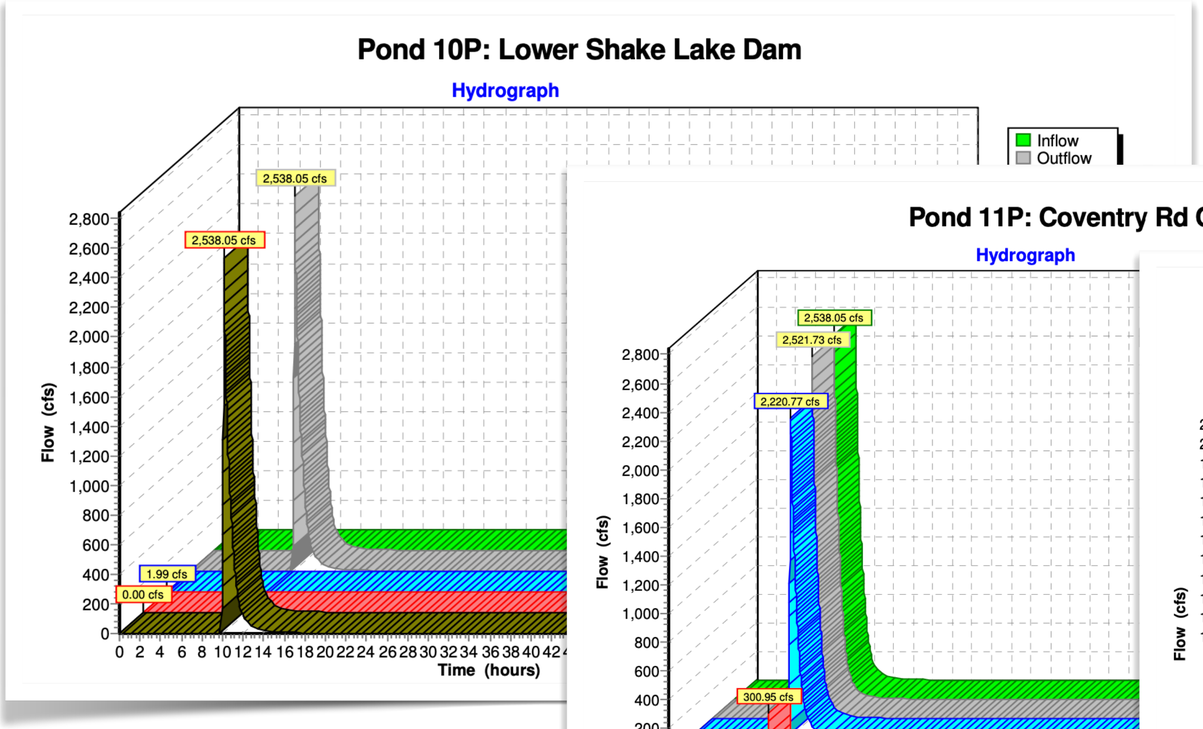

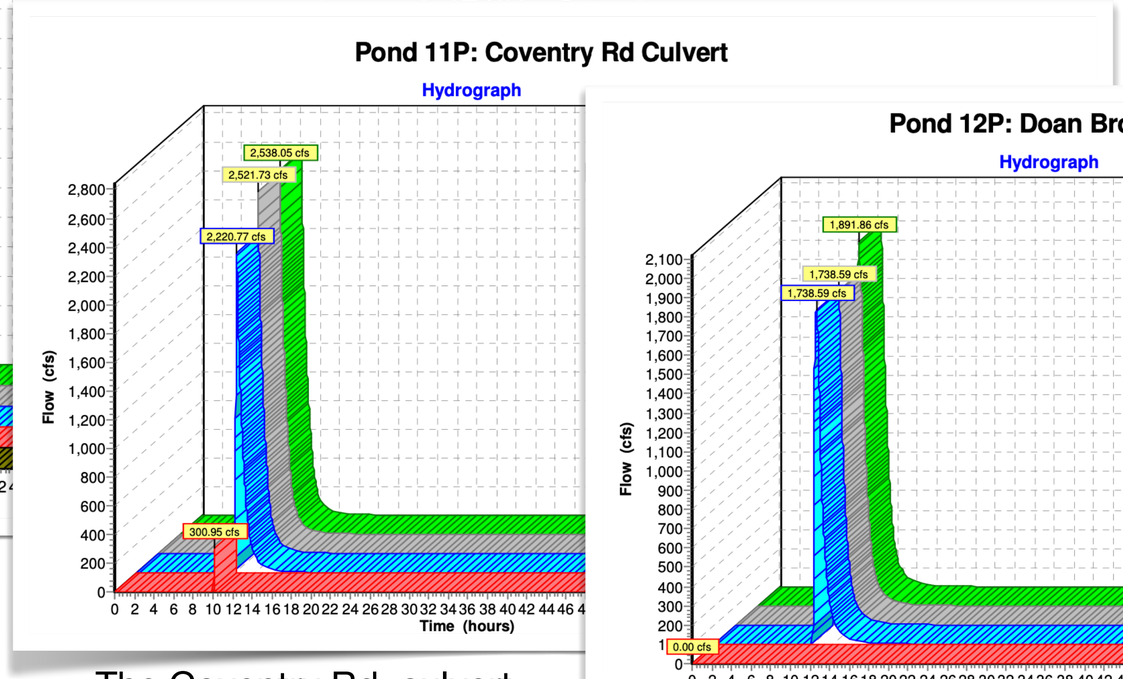

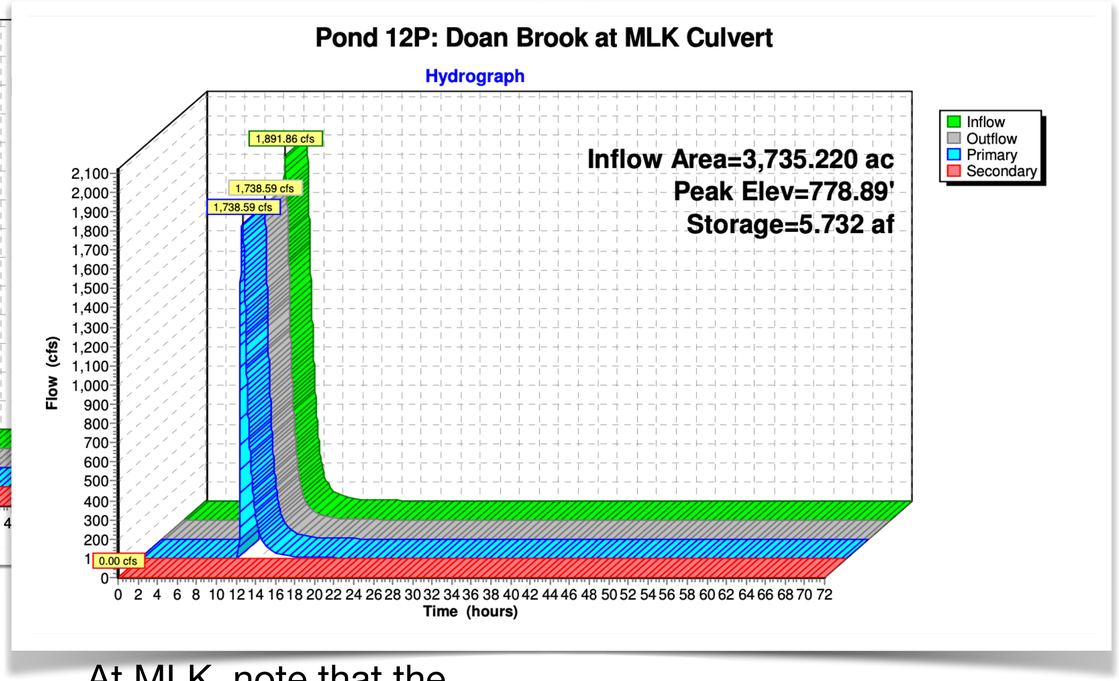

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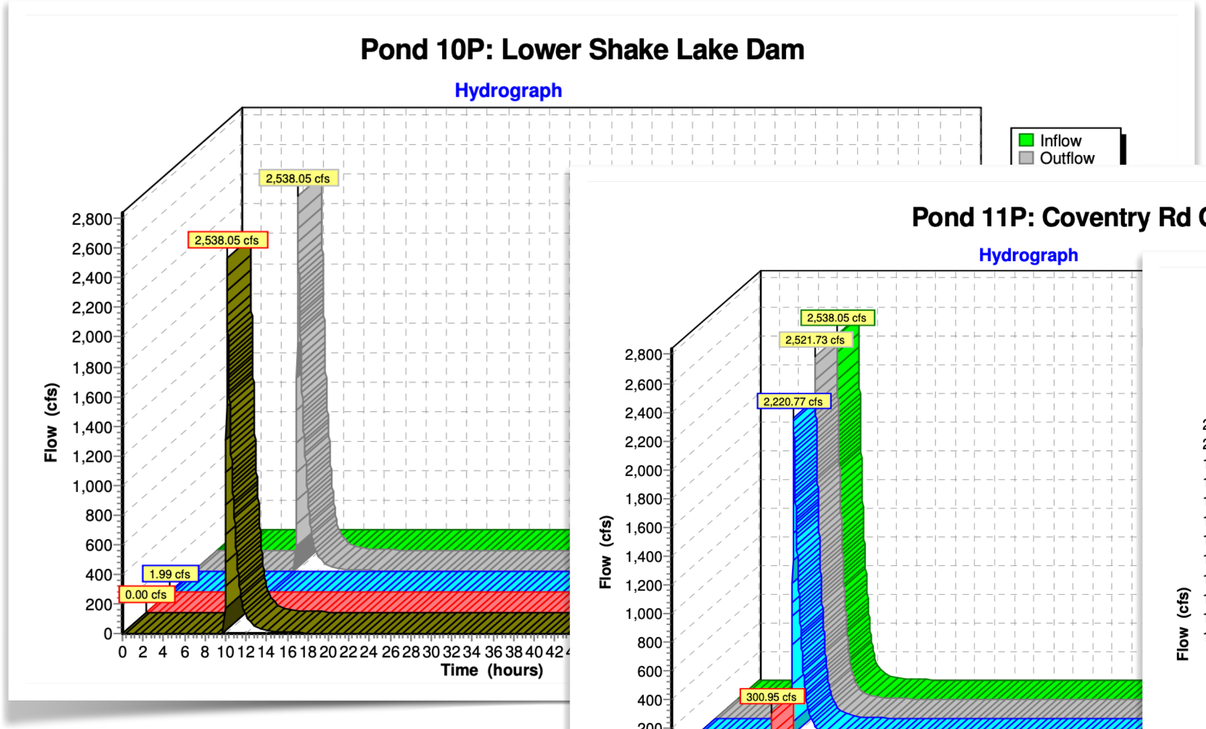

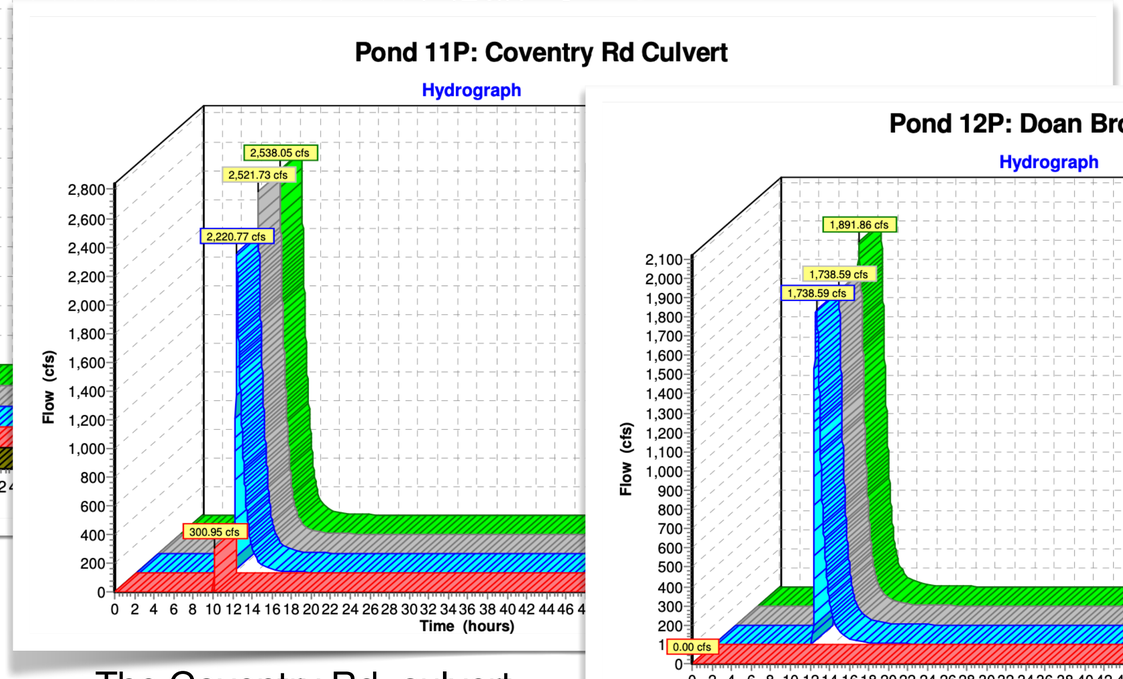

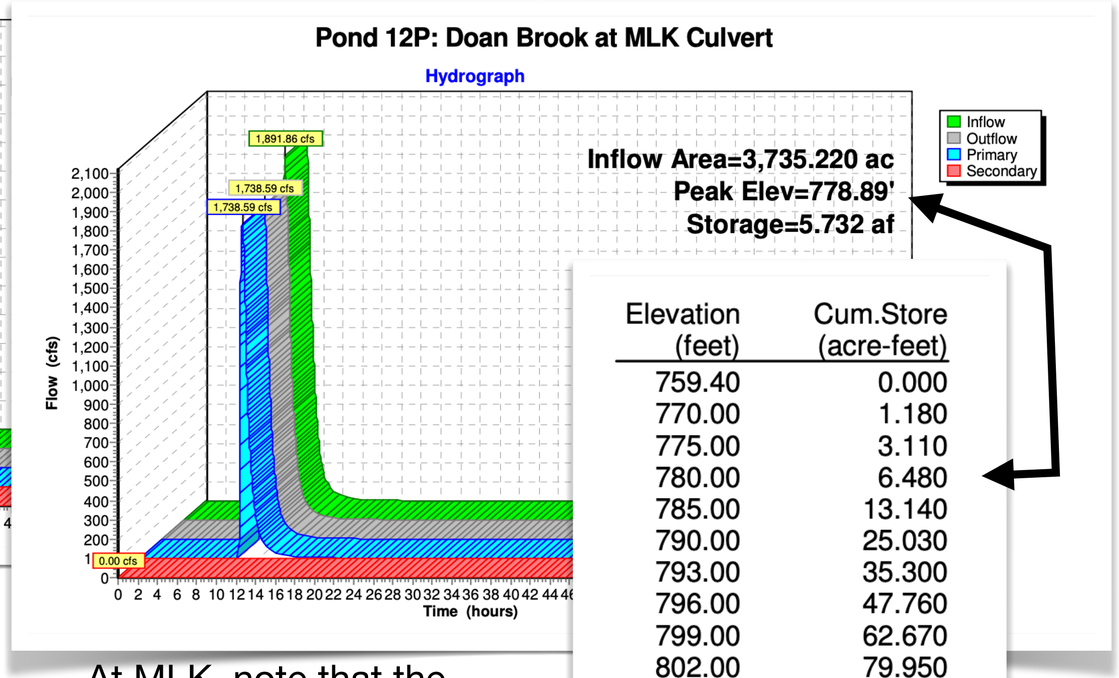

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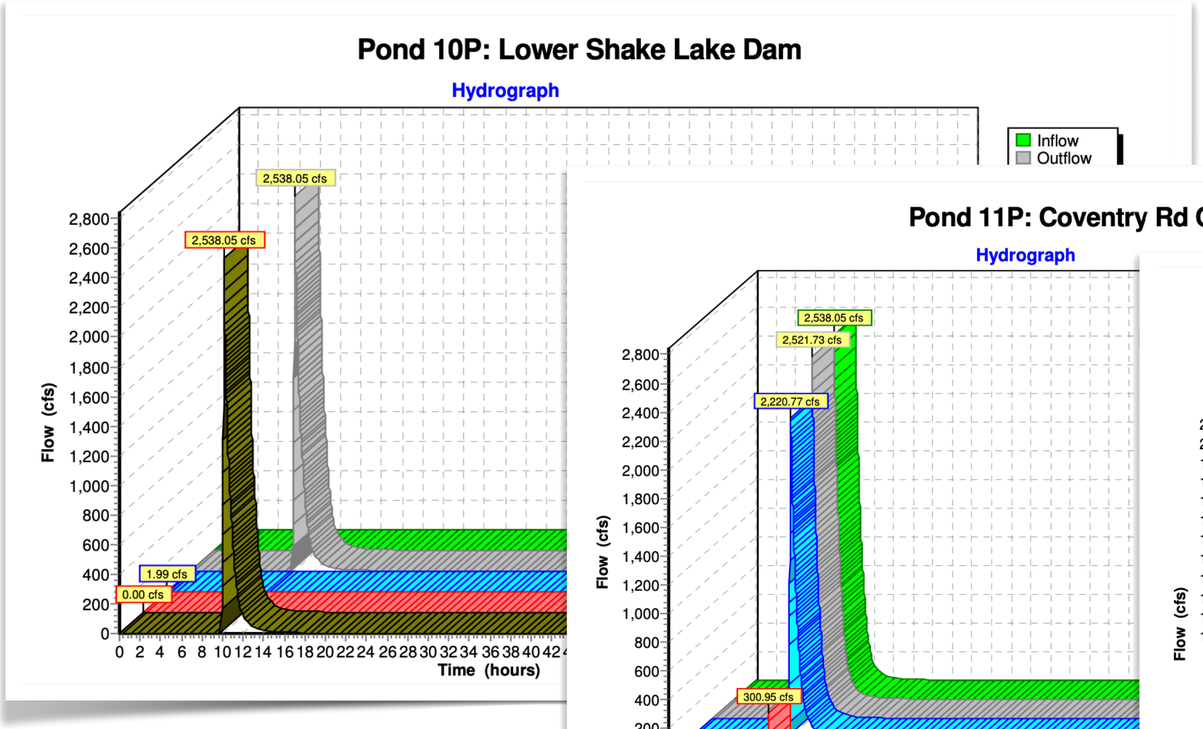

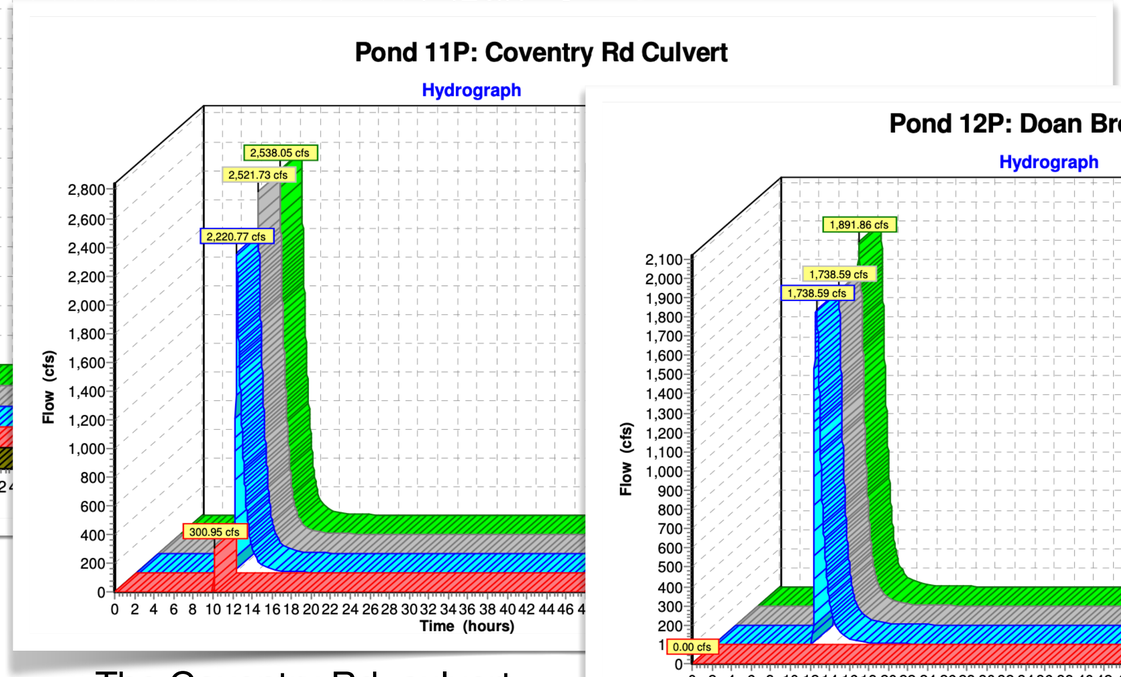

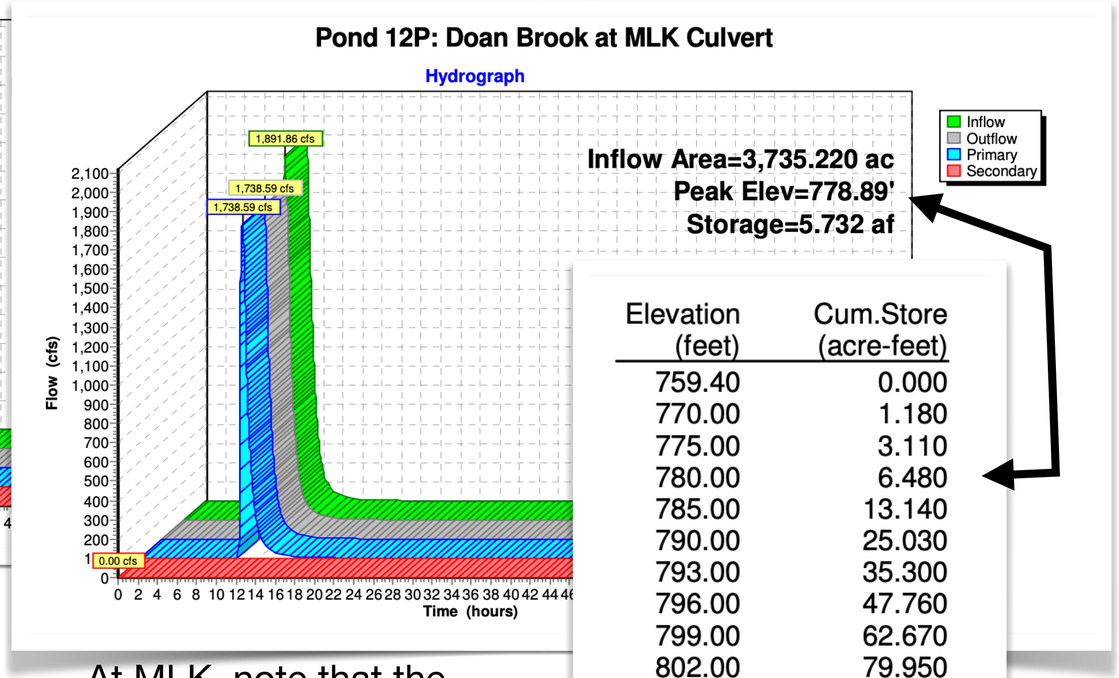

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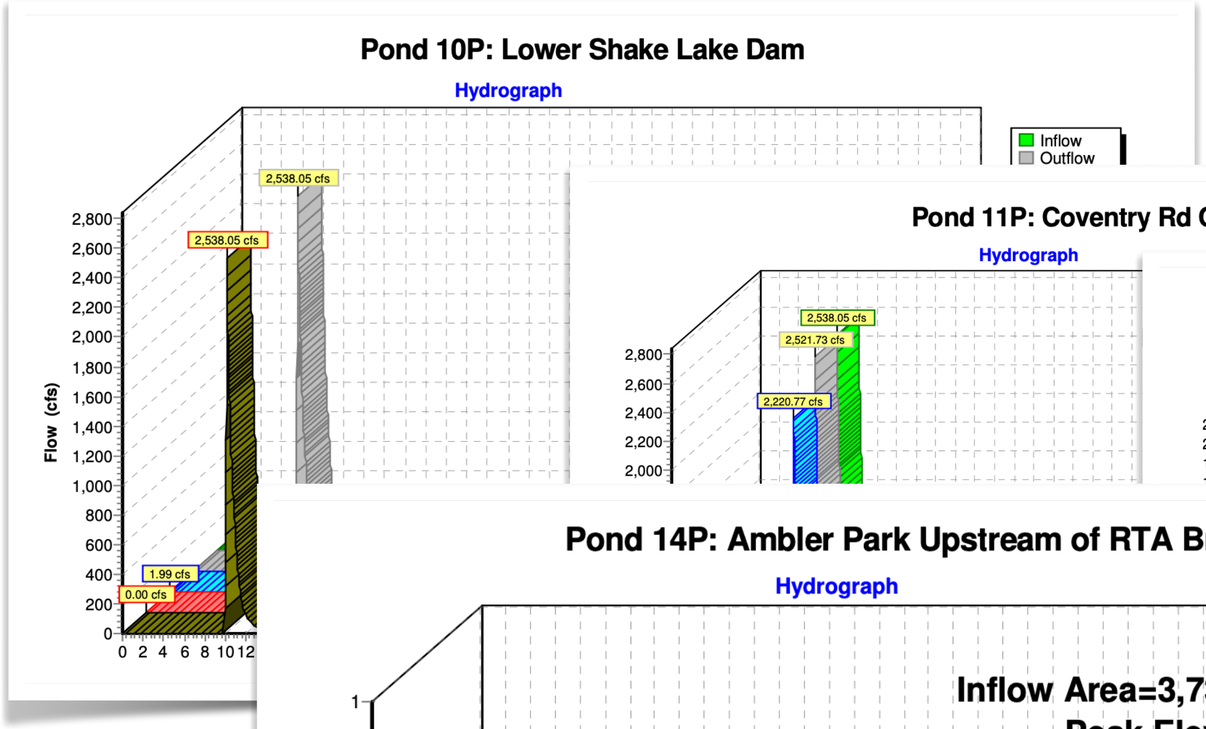

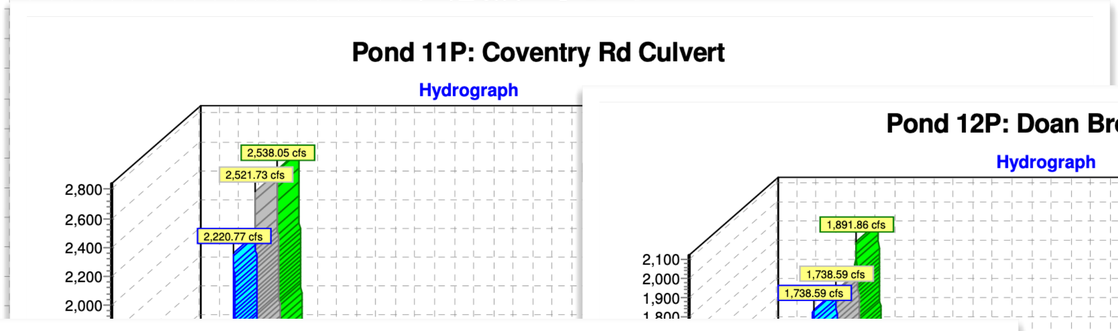

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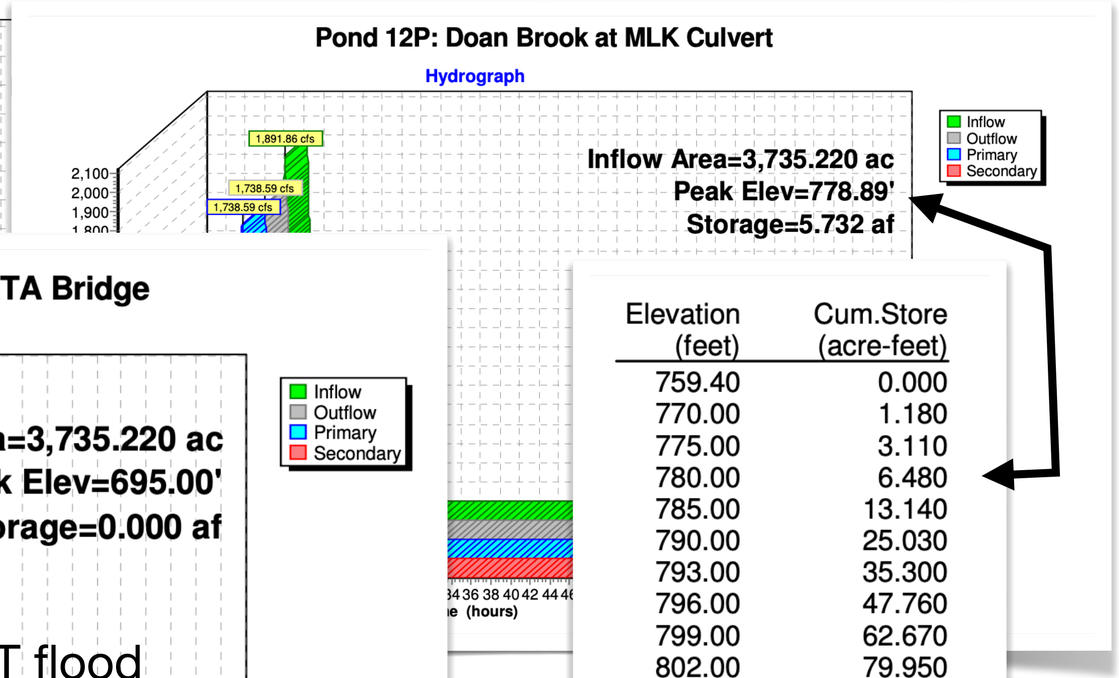
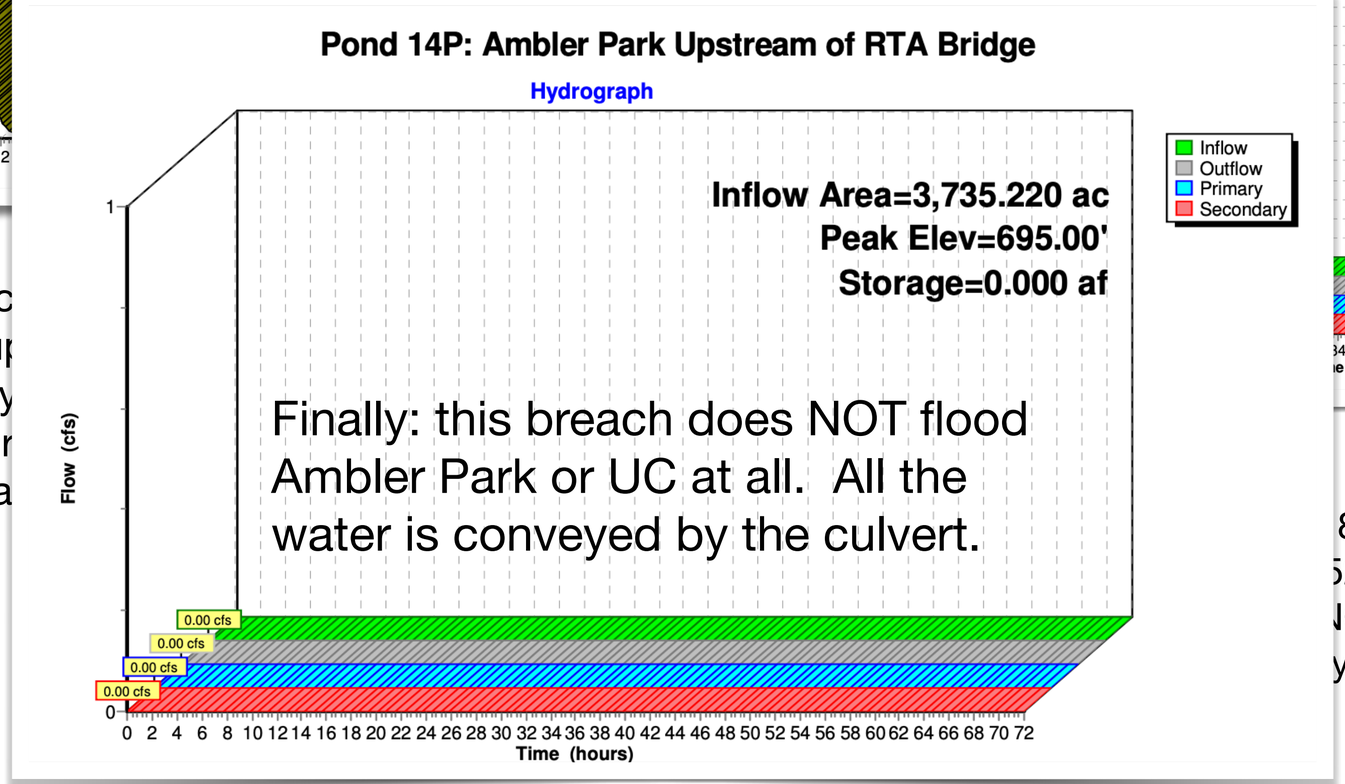


Elevation (feet)	Cum.Store (acre-feet)
759.40	0.000
770.00	1.180
775.00	3.110
780.00	6.480
785.00	13.140
790.00	25.030
793.00	35.300
796.00	47.760
799.00	62.670
802.00	79.950
803.00	83.000
804.00	93.000
805.00	99.920
808.00	122.800
811.00	149.160
812.00	190.000
813.00	200.000
814.00	250.000
815.00	300.000
816.00	350.000



Finally: this breach does NOT flood Ambler Park or UC at all. All the water is conveyed by the culvert.

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Highlights from AECOM model

A "sunny day" breach (hole in the middle of the dam):

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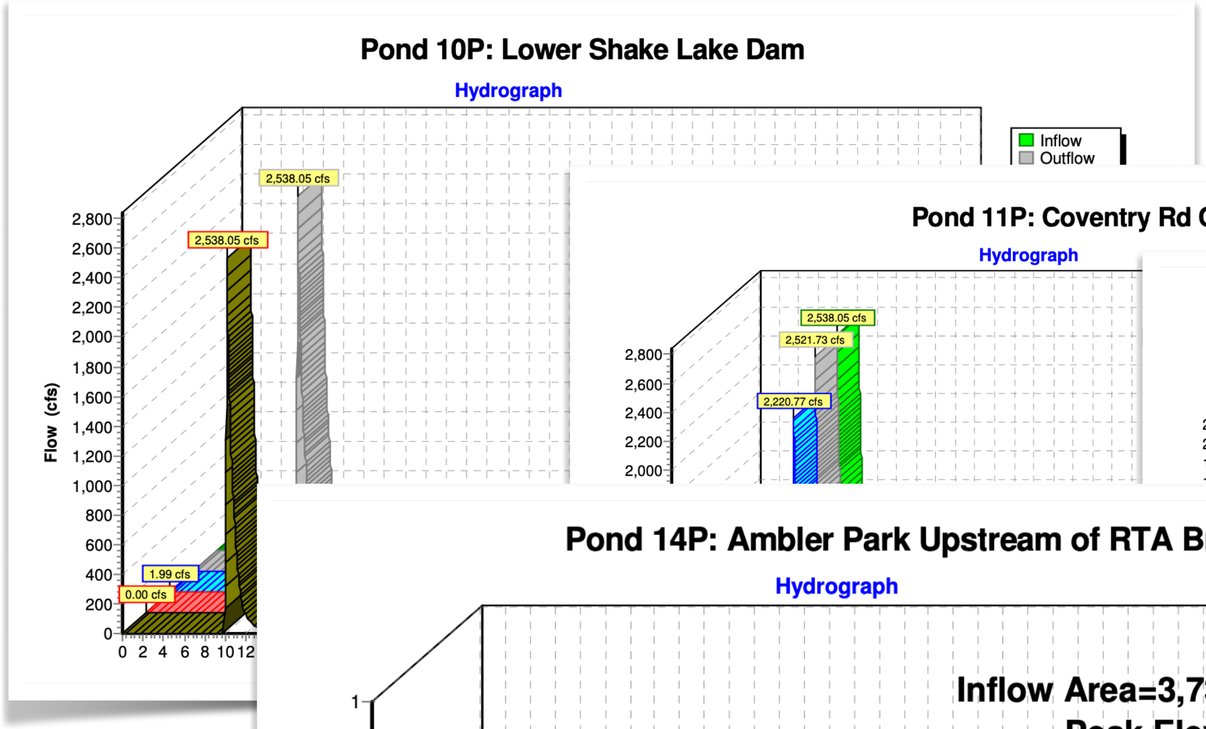

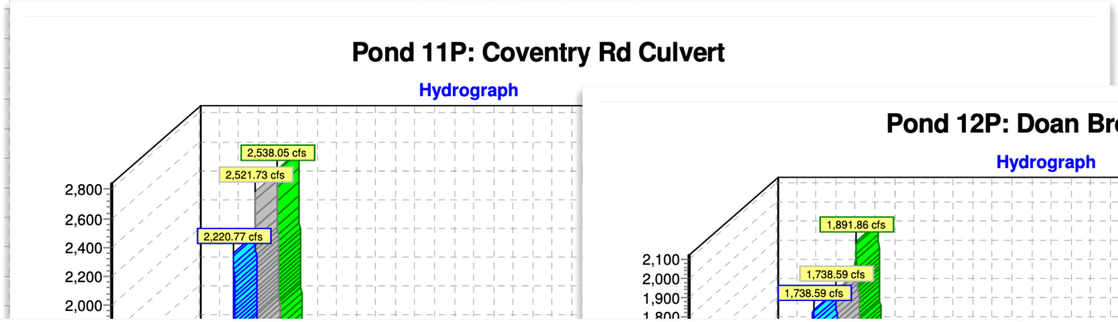

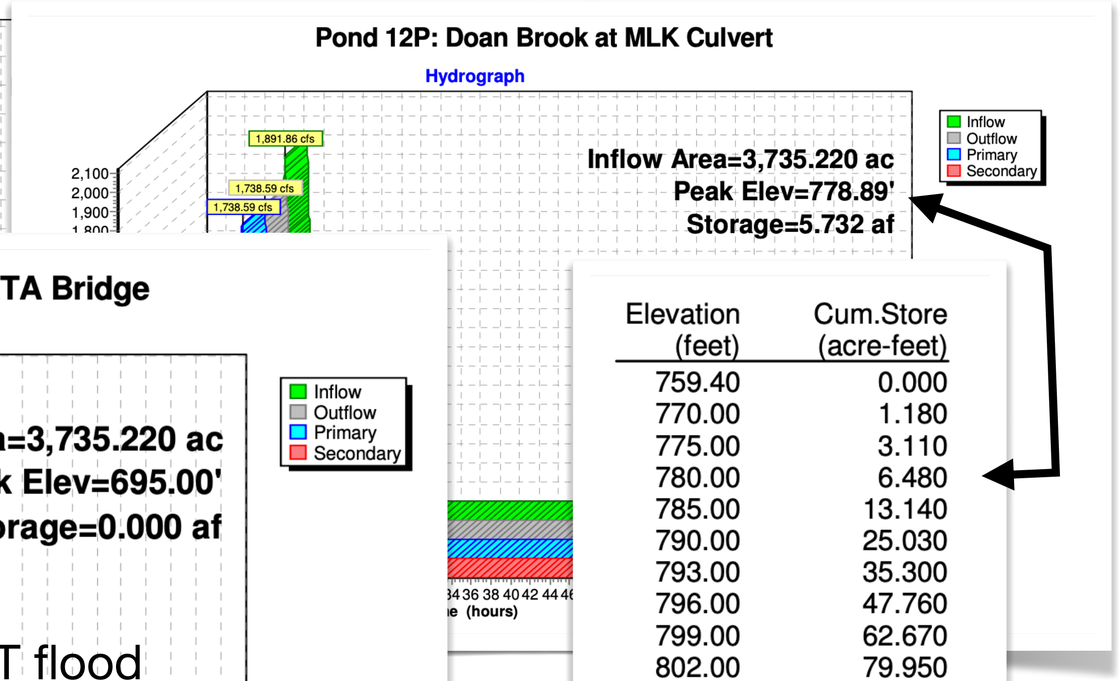

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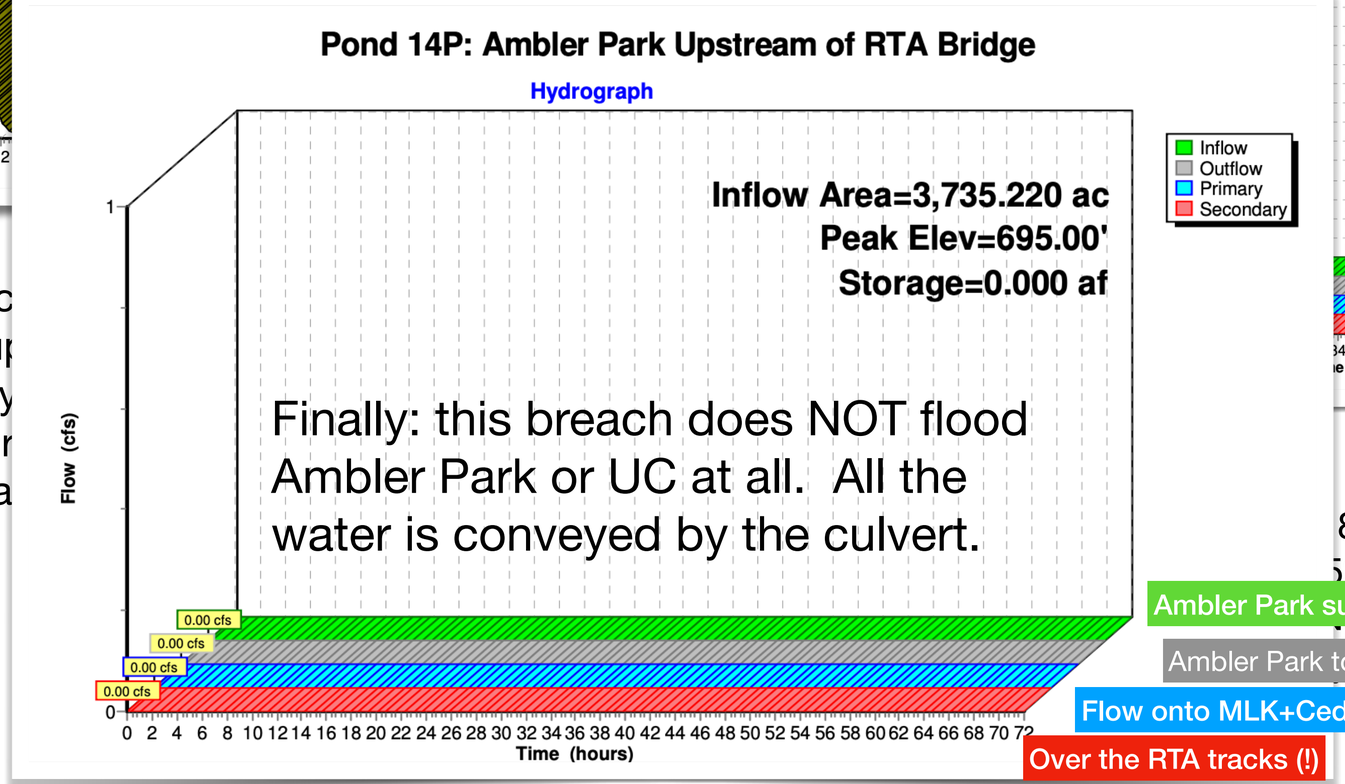
799.00	62.670
802.00	79.950
803.00	83.000
804.00	93.000
805.00	99.920
808.00	122.800
811.00	149.160
812.00	190.000
813.00	200.000
814.00	250.000
815.00	300.000
816.00	350.000



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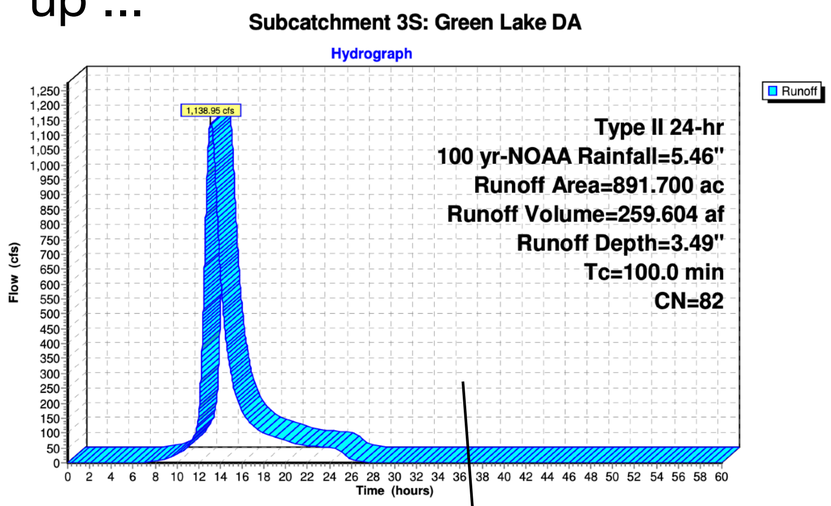
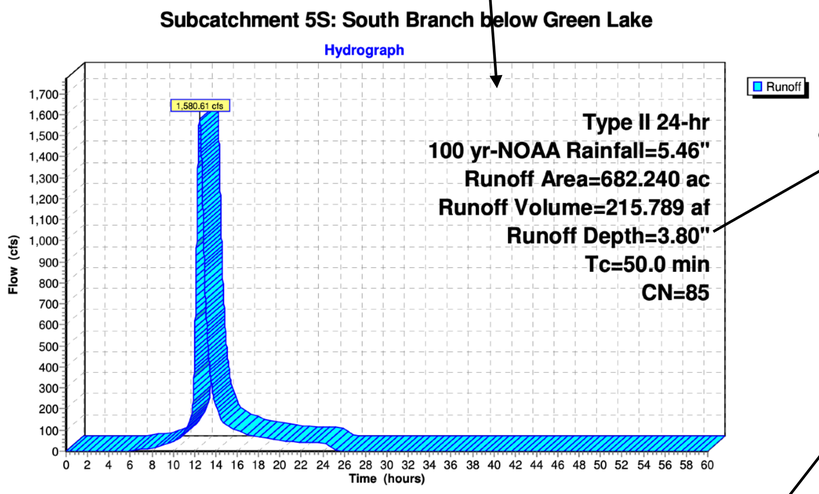
Highlights from AECOM model

The model specifies a VERY INTENSE brief rainfall. All the small catchments are modeled and added up ...





100-year 5" storm

north branch

south branch

rainfall on lake

lower lake

Doan Canyon

Ambler Park

flood?

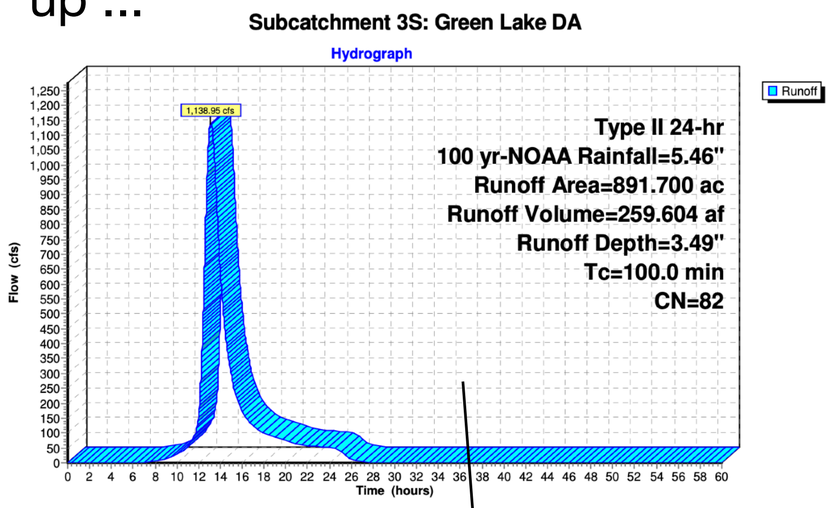
culvert?

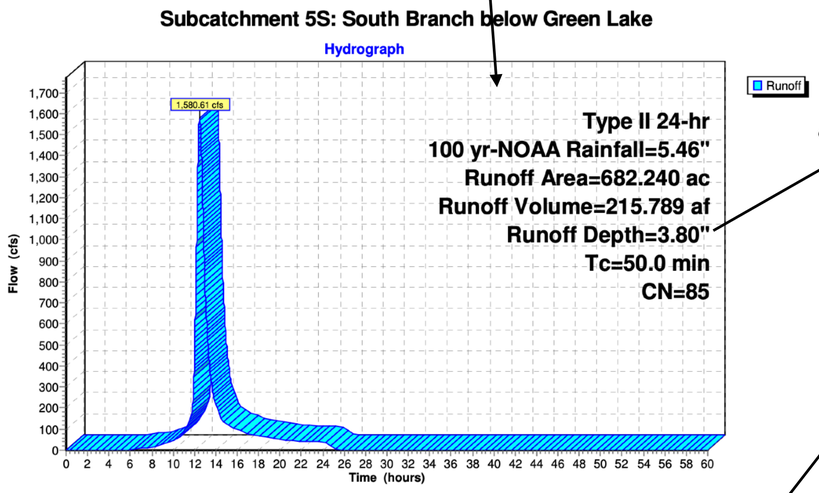
Highlights from AECOM model

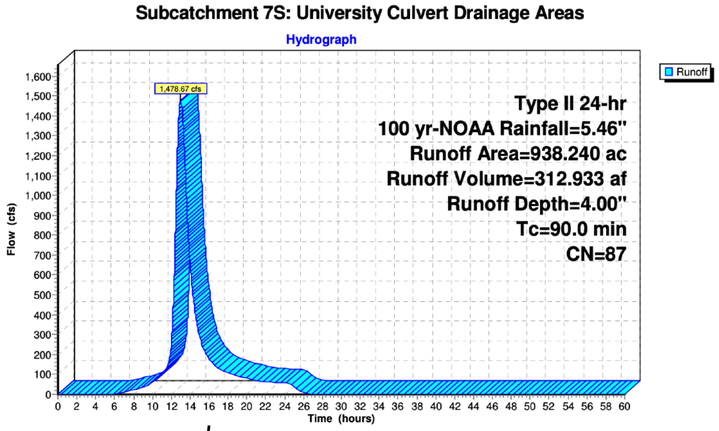
100-year 5" storm

The model specifies a VERY INTENSE brief rainfall. All the small catchments are modeled and added up ...

A lot of water shows up mid-canyon from an Ambler Heights storm drain!







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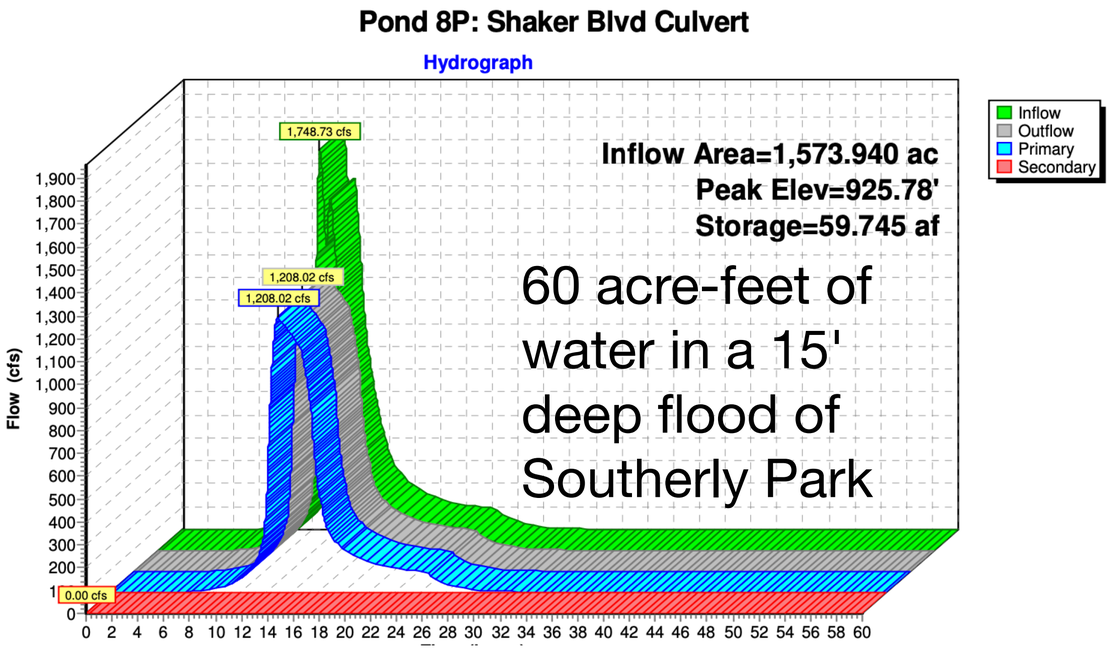
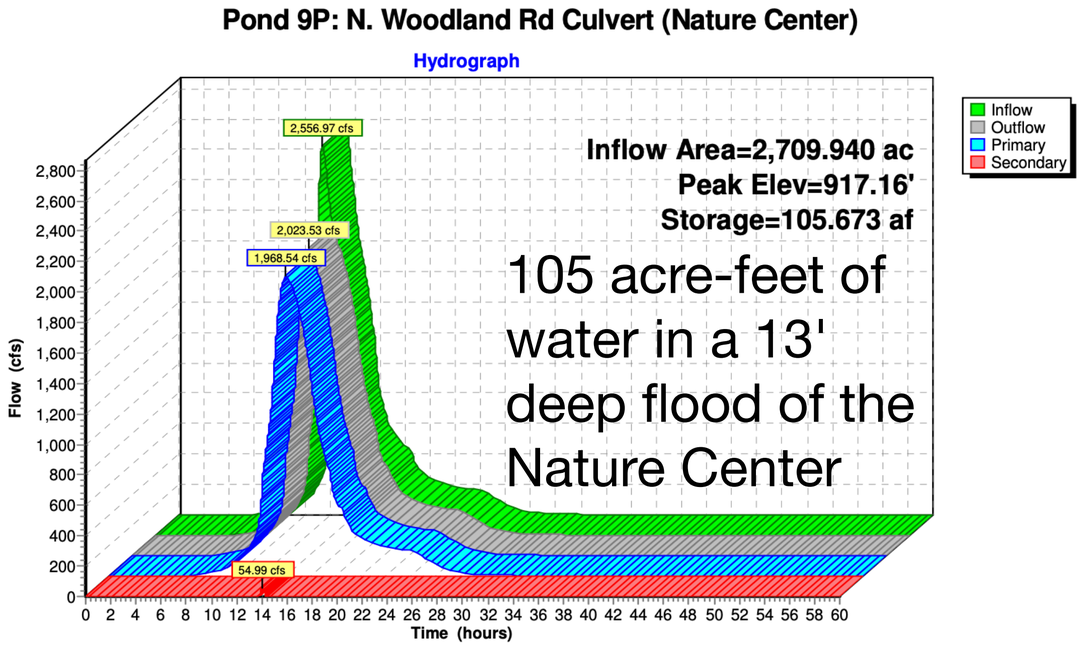
Highlights from AECOM model

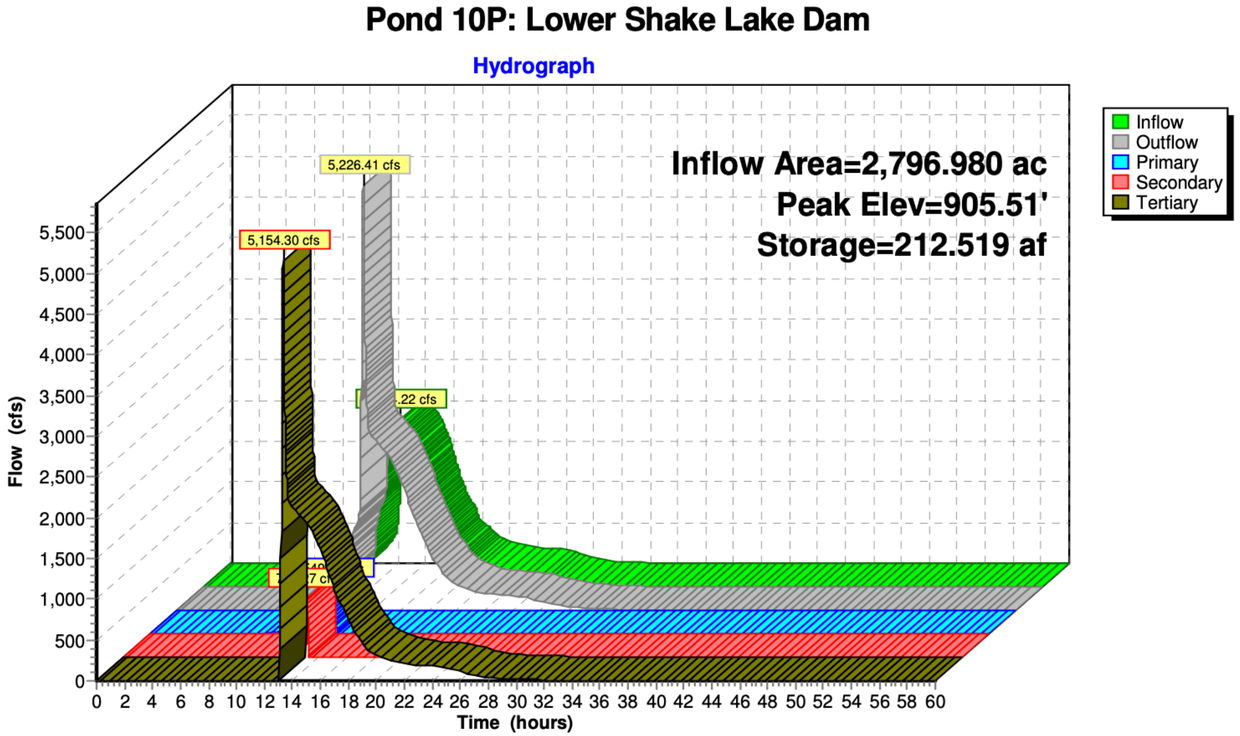
100-year 5" storm plus dam breach



60 acre-feet of water in a 15' deep flood of Southerly Park



105 acre-feet of water in a 13' deep flood of the Nature Center



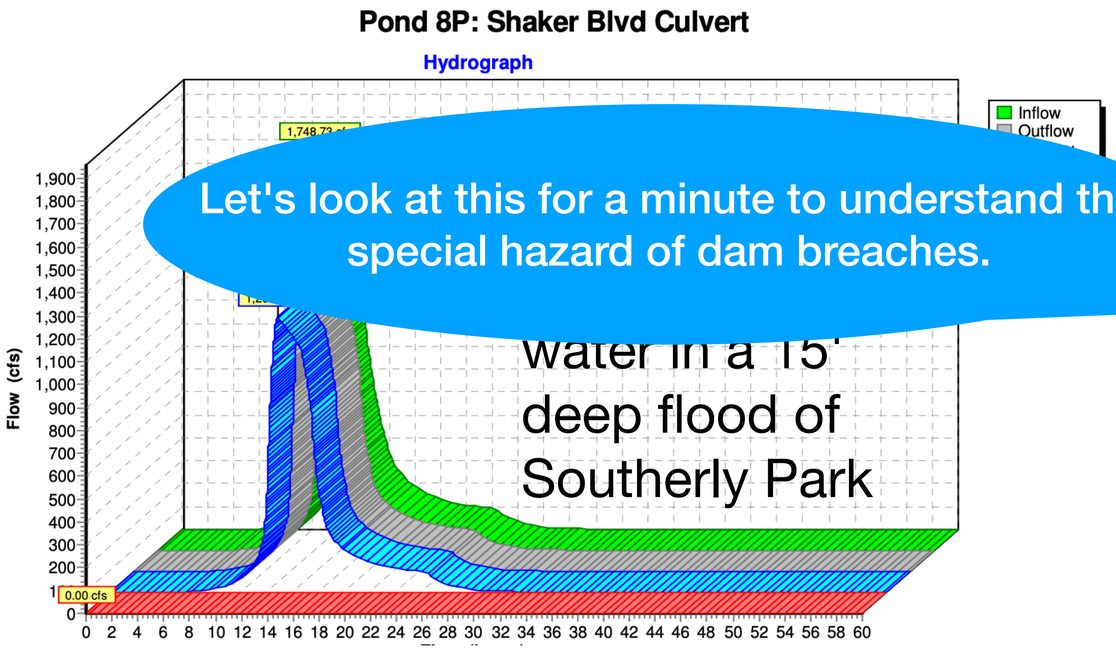
Lower Lake gets up to 905.51 elevation (212 a-f), overtops ("secondary"), then breaches ("tertiary").

Outflow peaks at 5154 cfs. Short-duration peak is the lake draining; long tail is ongoing storm inflows.

Let's look downstream.

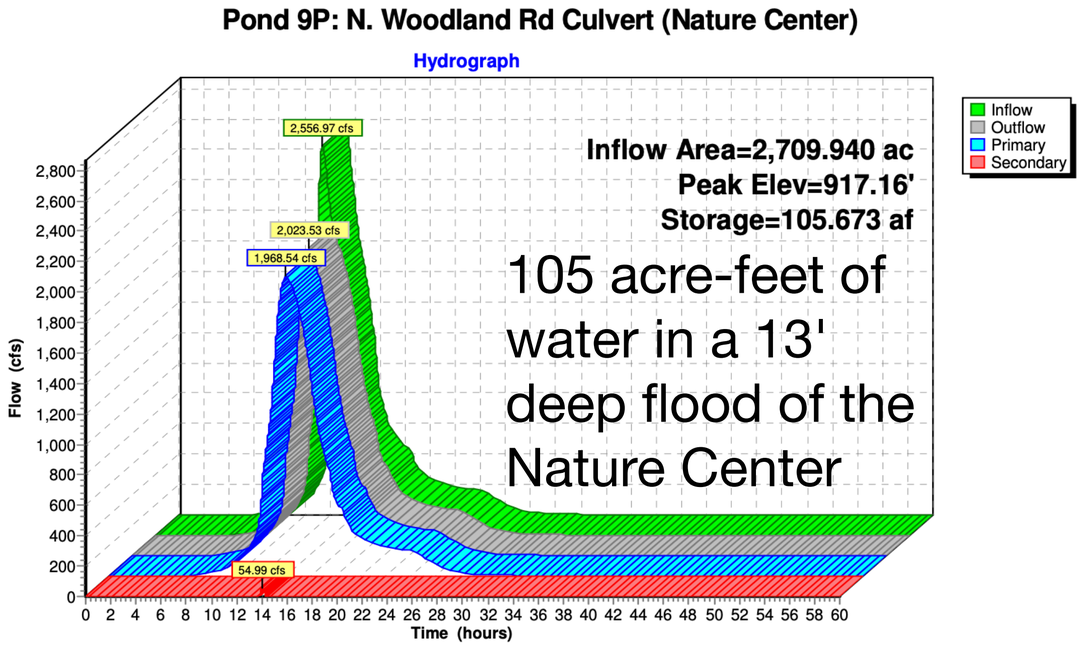
Highlights from AECOM model

100-year 5" storm plus dam breach



Let's look at this for a minute to understand the special hazard of dam breaches.

water in a 15' deep flood of Southerly Park



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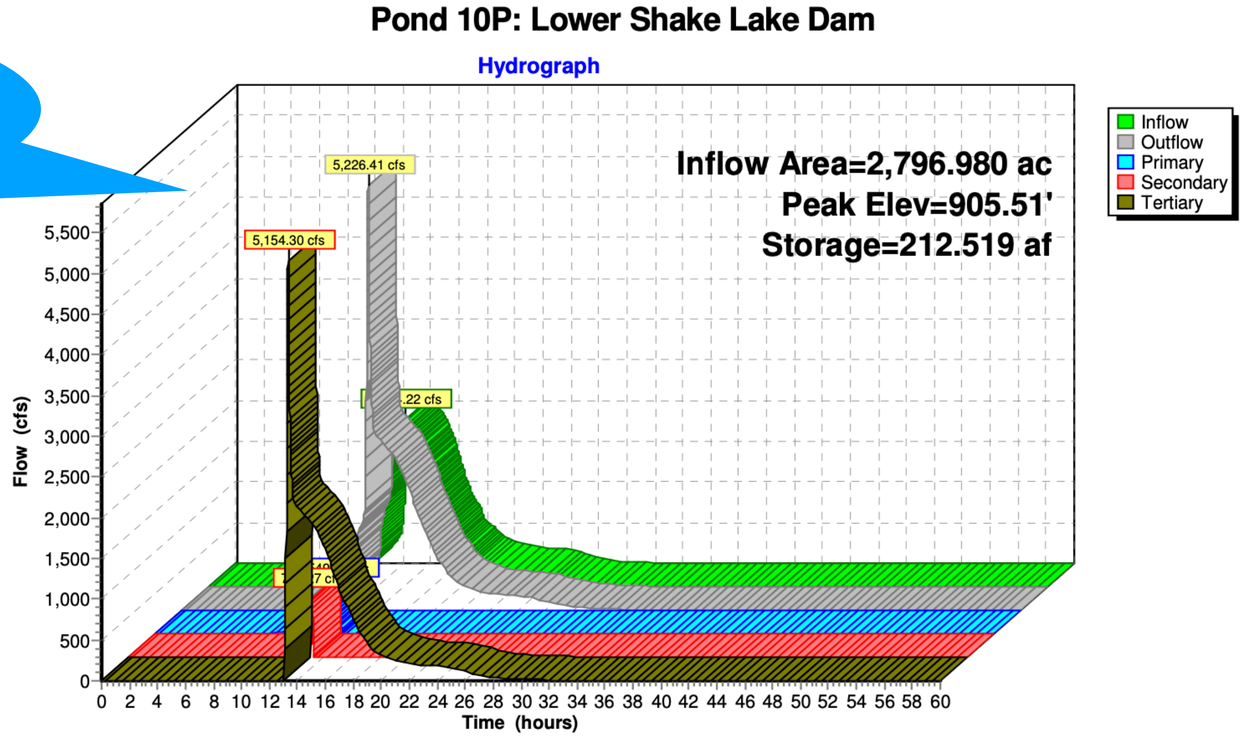

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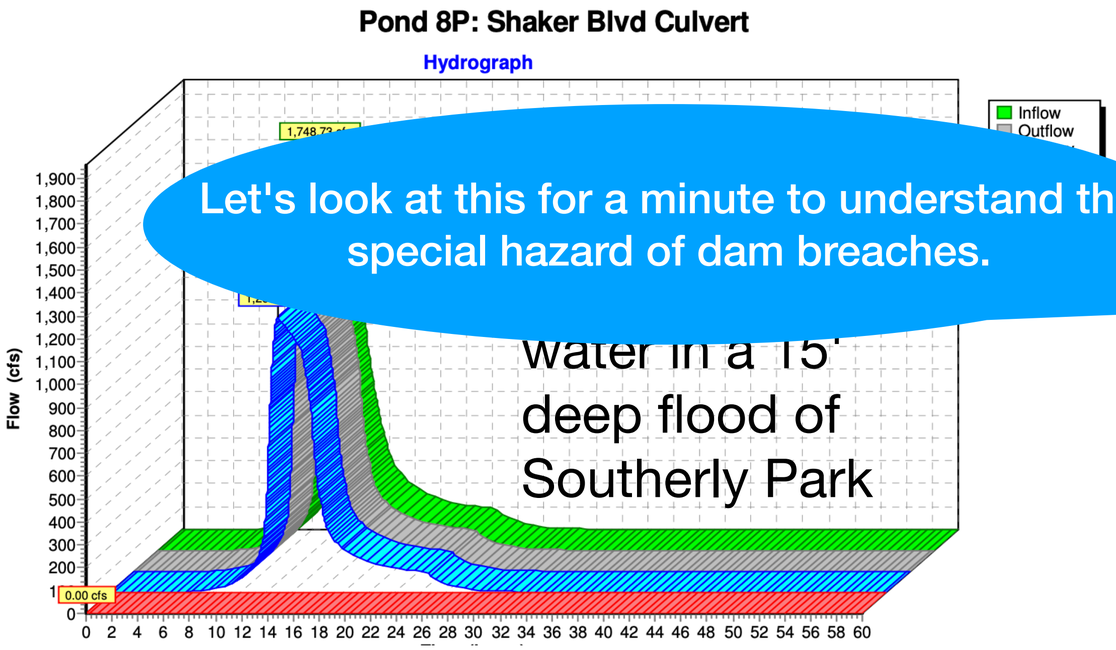

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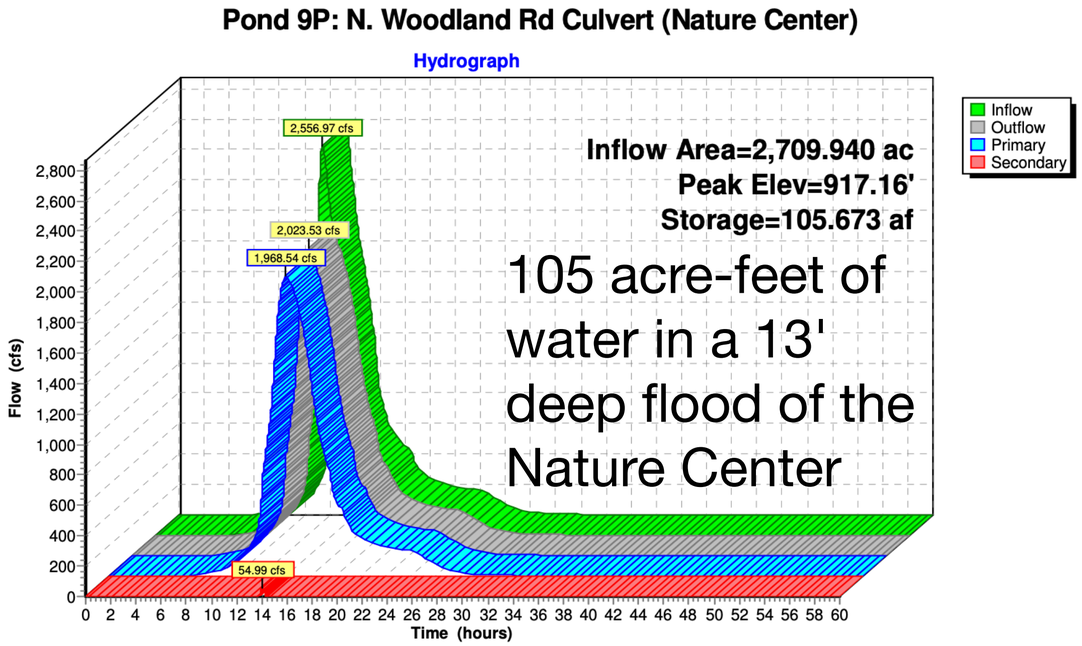

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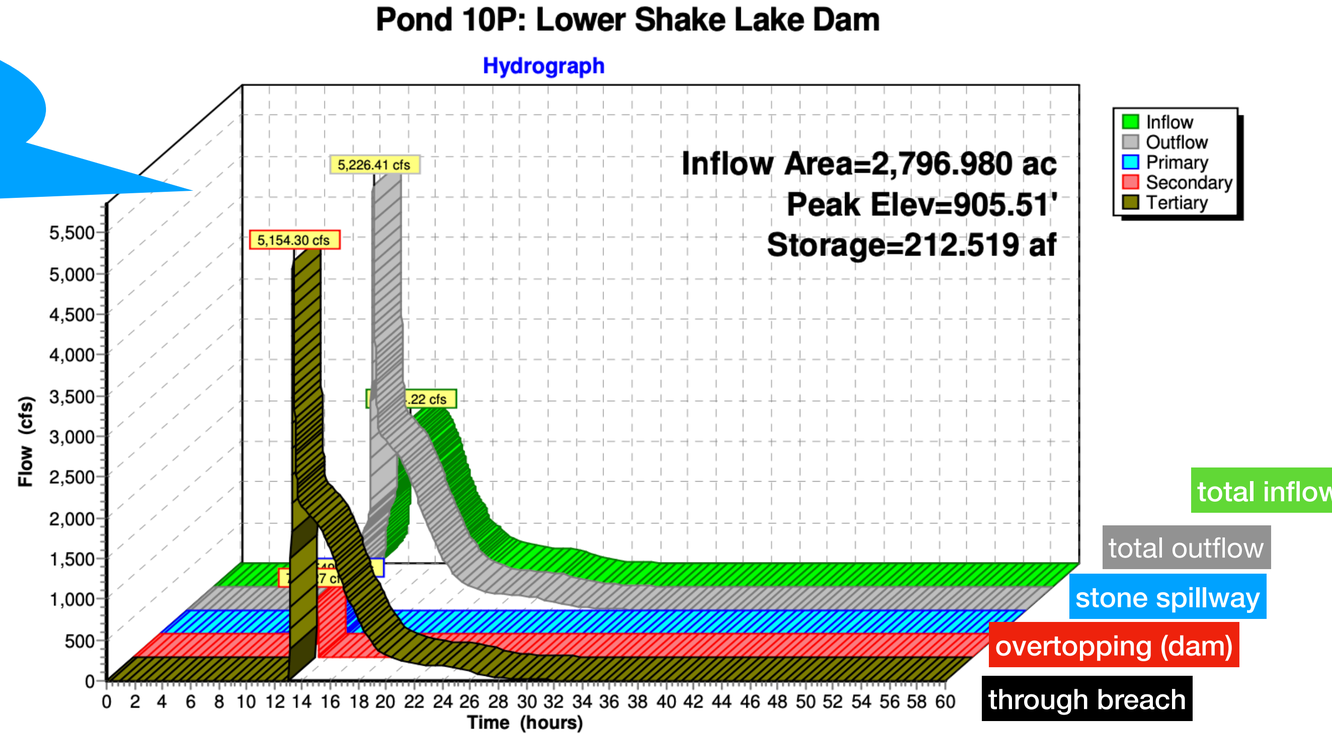

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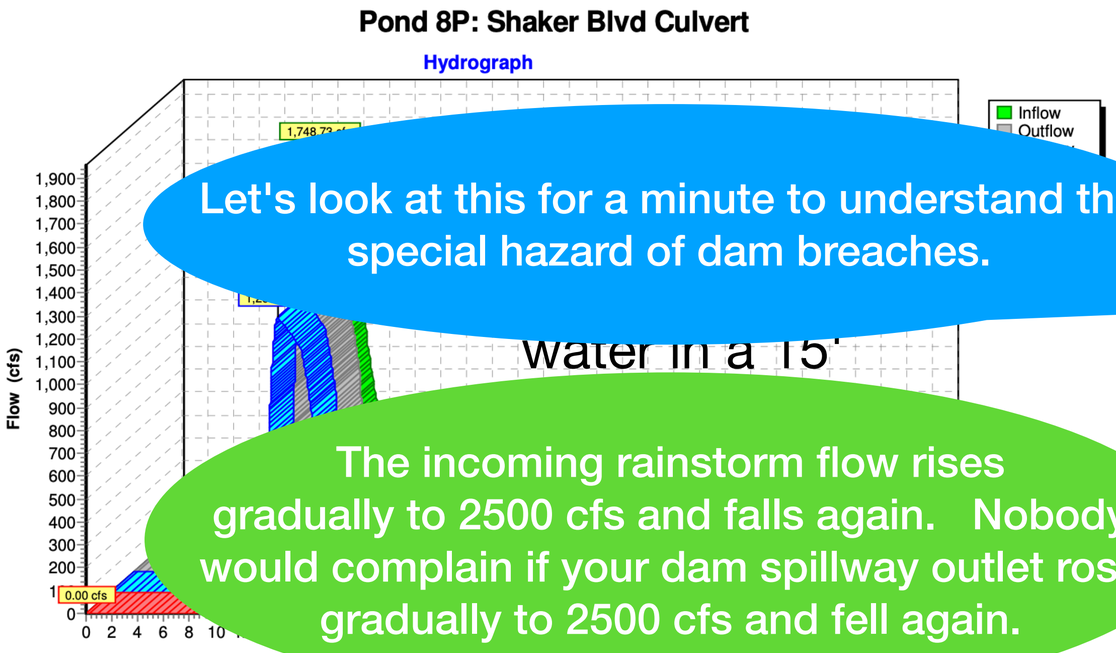

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water in a 15'

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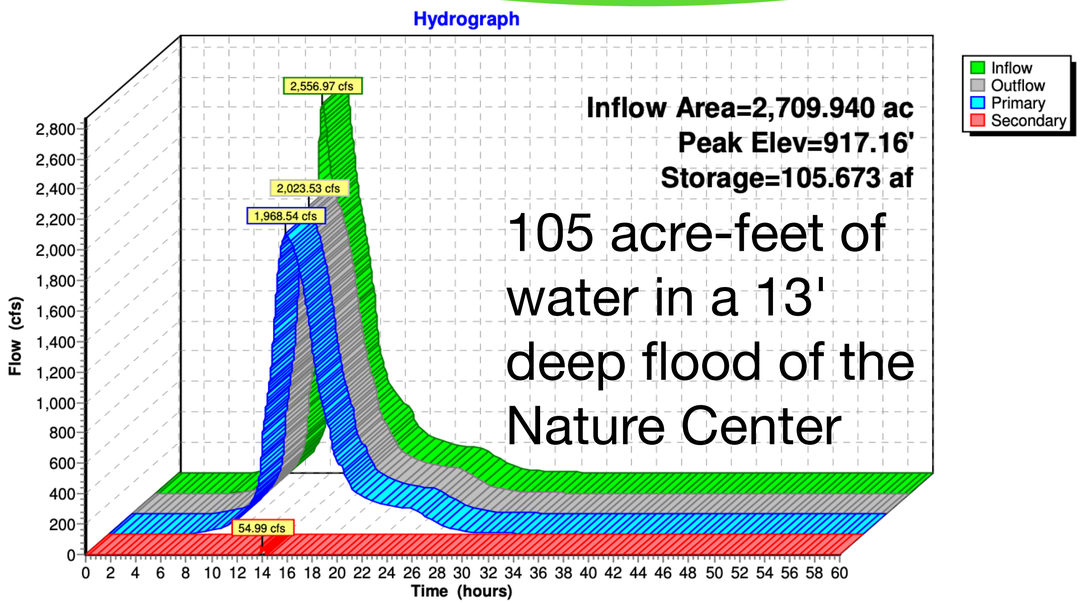

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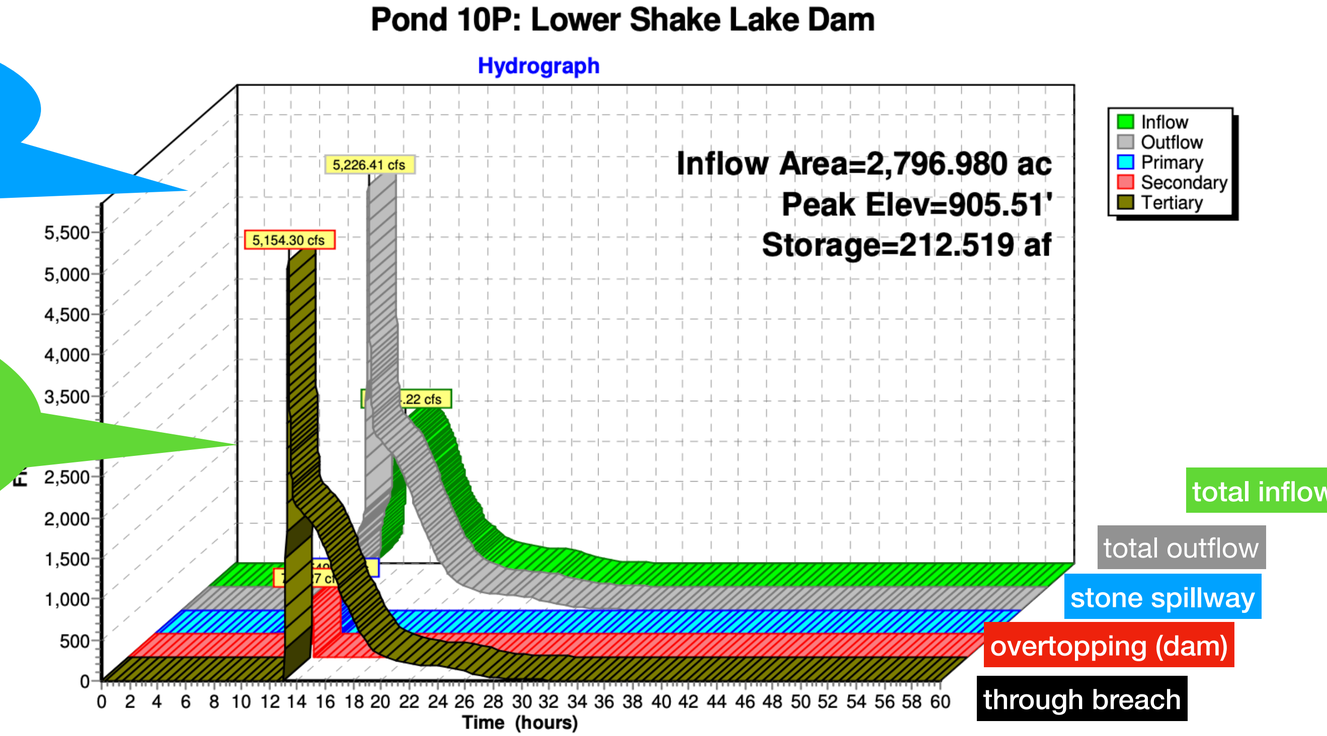

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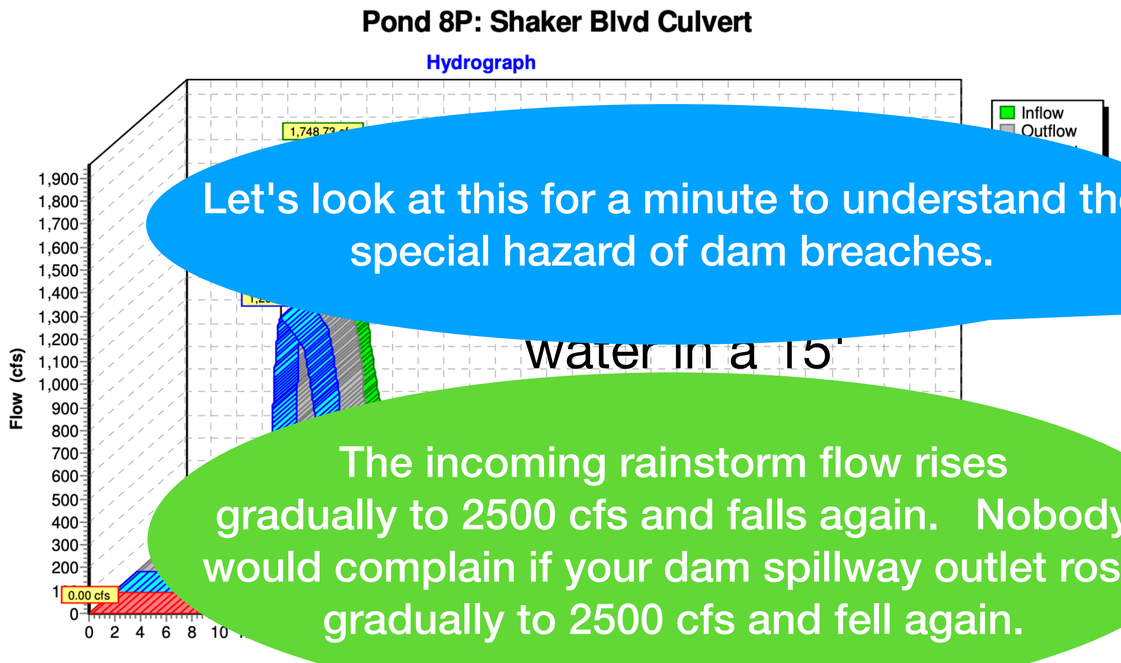

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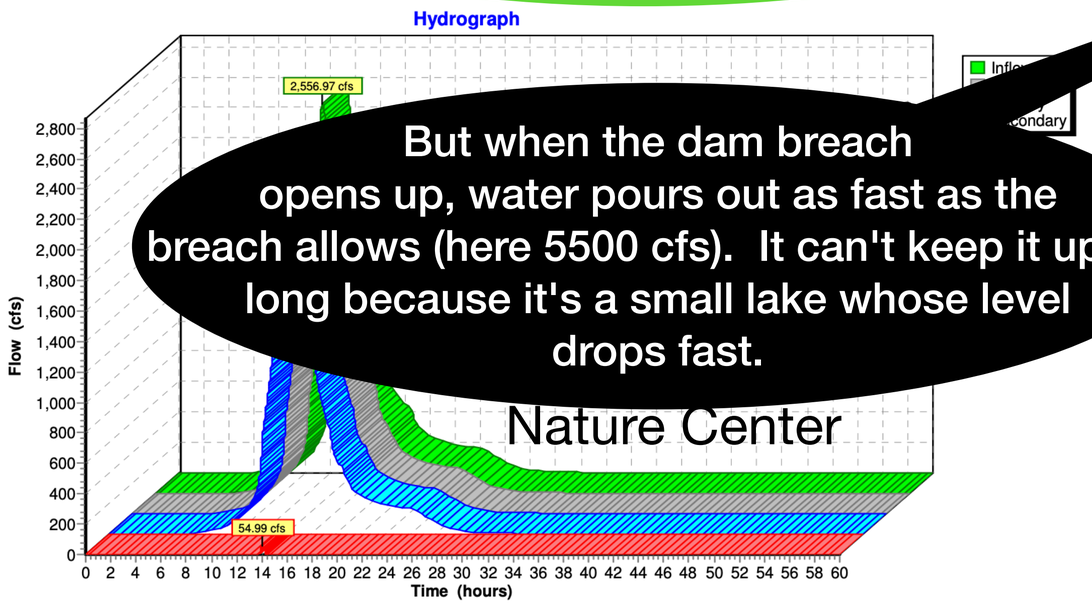
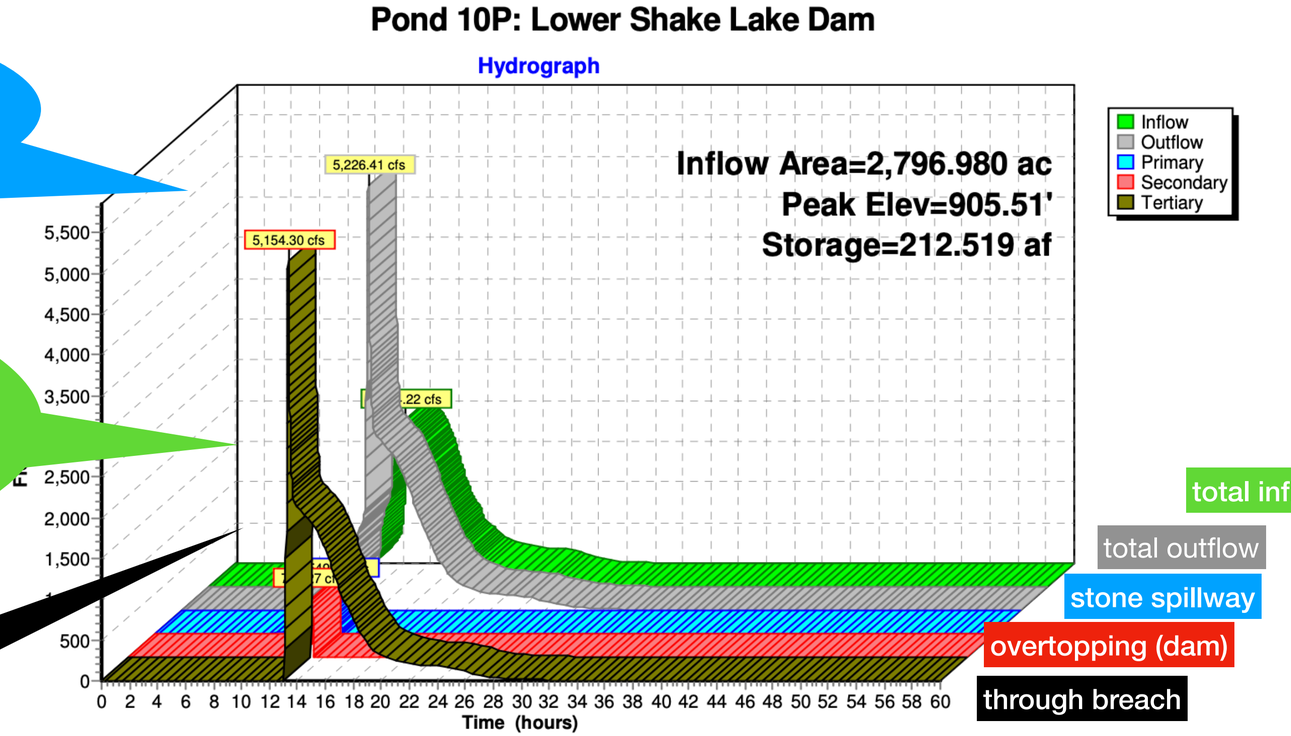


But when the dam breach opens up, water pours out as fast as the breach allows (here 5500 cfs). It can't keep it up for long because it's a small lake whose level drops fast.

Nature Center



total inflow

total outflow

stone spillway

overtopping (dam)

through breach

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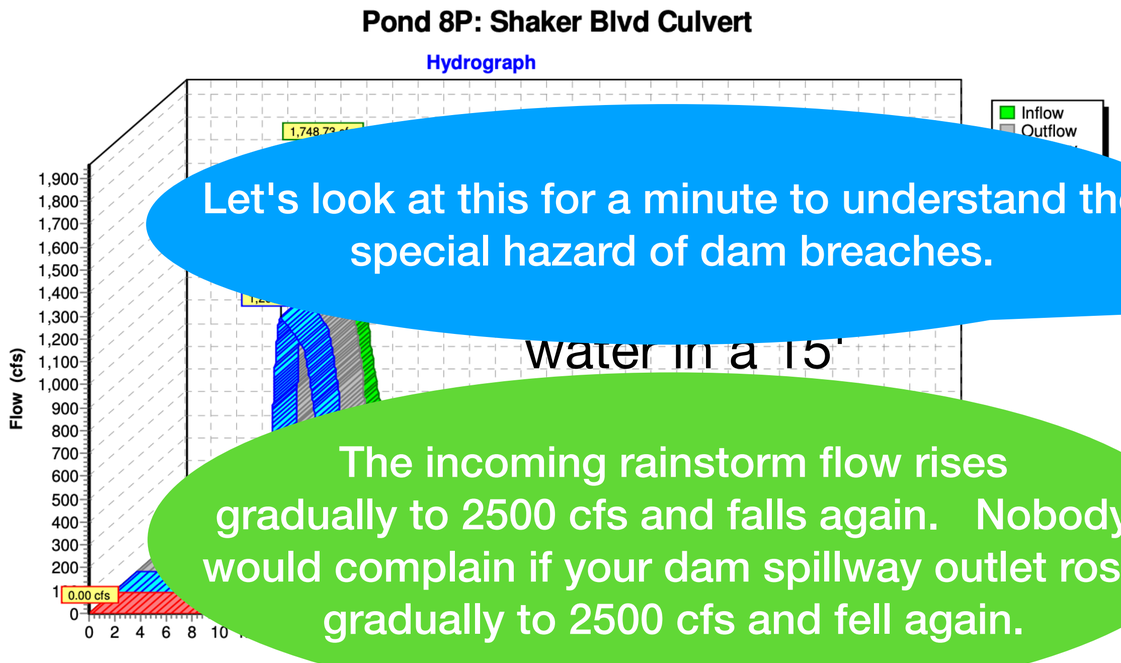
Let's look downstream.

Highlights from AECOM model

100-year 5" storm plus dam breach



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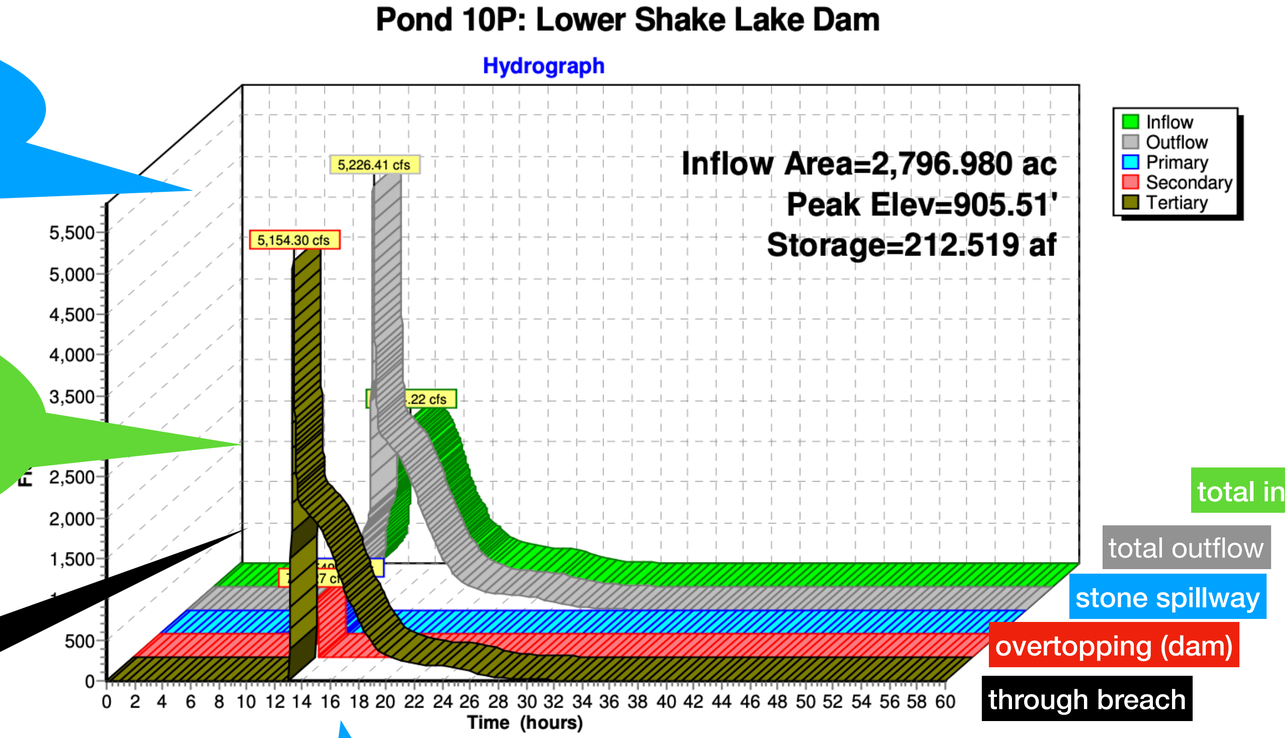

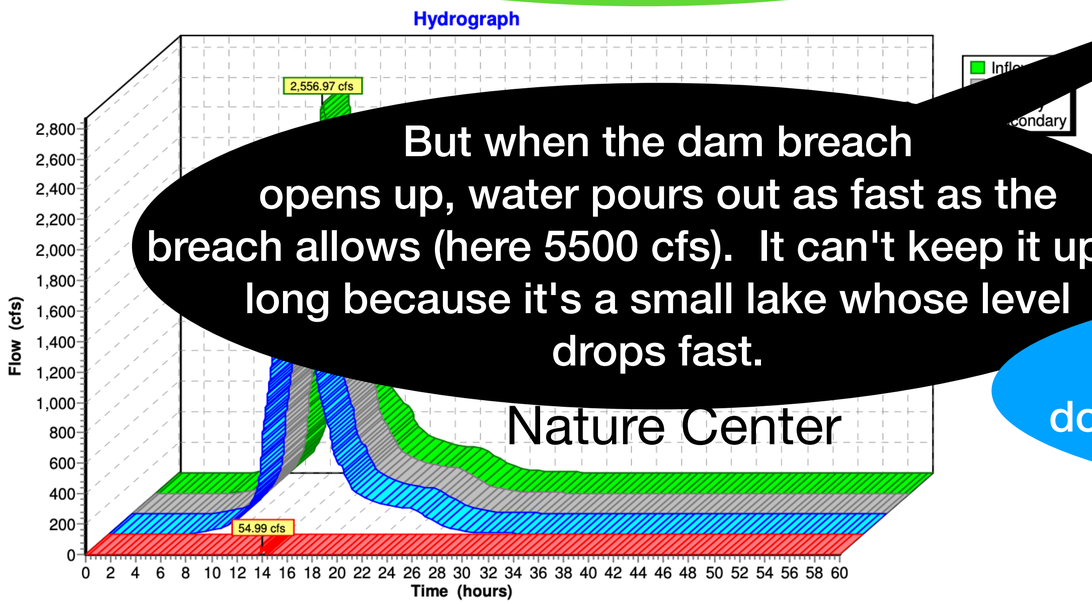

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"But does this cause a flood?" is a question about how stuff downstream responds to (a) large rates over (b) short times.

ration peak
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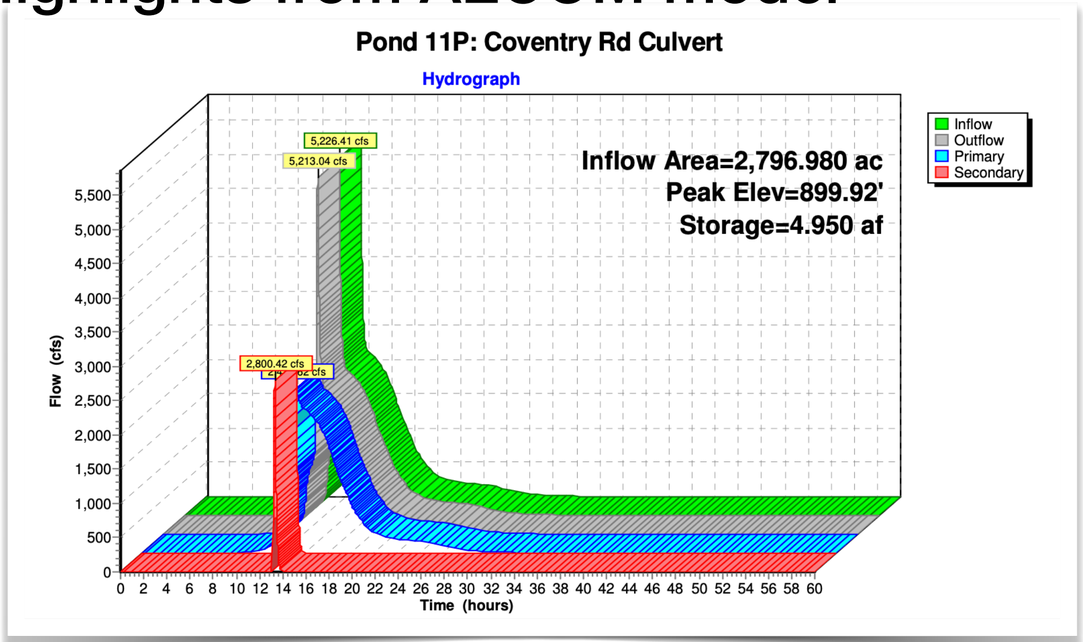
inflows.

Let's look downstream.

Highlights from AECOM model

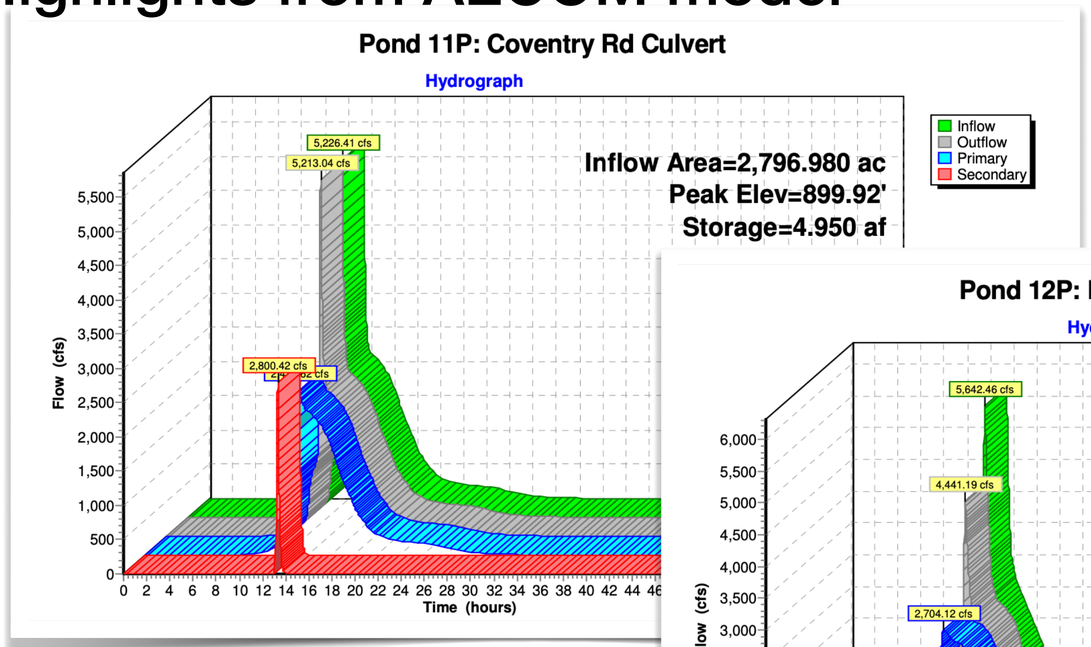
100-year 5" storm plus dam breach



The Coventry Rd. culvert fills up to 899.92', just barely overtopping (1' deep) but the overtopping flow carries the sharp peak.

Highlights from AECOM model

100-year 5" storm plus dam breach



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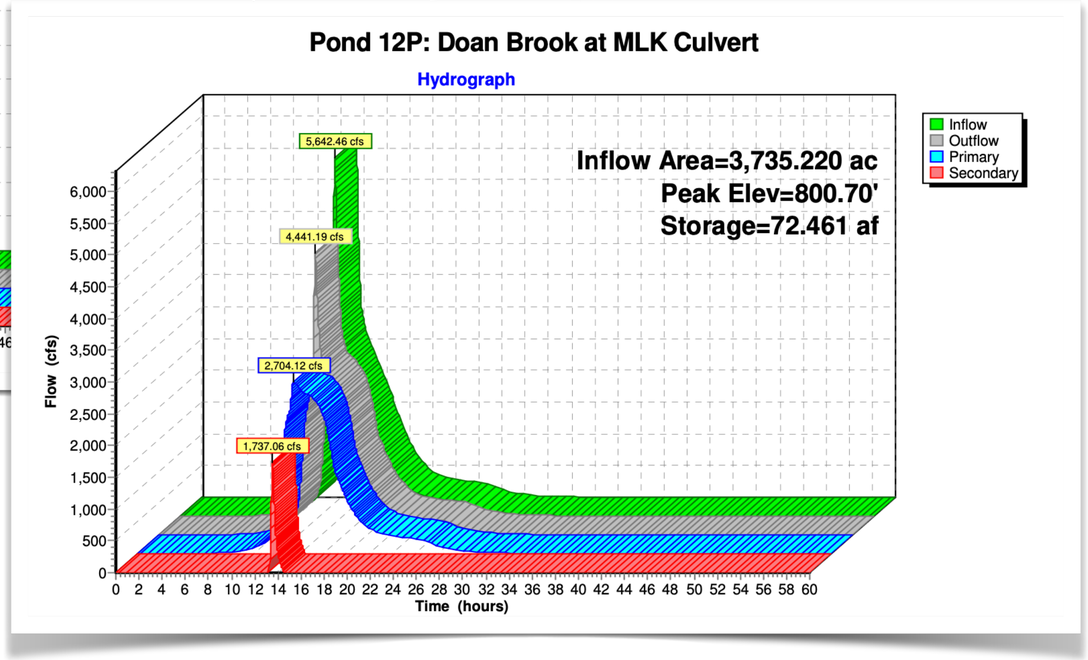
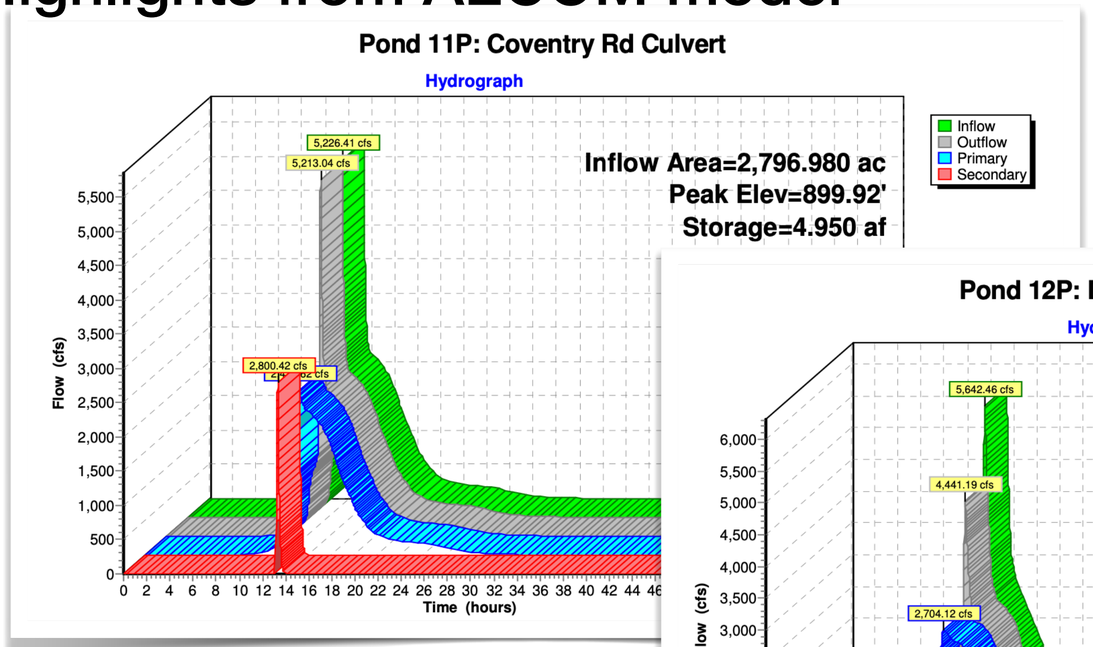


The MLK culvert barely overtops ("secondary" flow is 2' deep) and it slows the flood a lot by storing 72 a-f in the deep basin upstream. A peak of 4441 cfs is heading downstream ...

Highlights from AECOM model

100-y



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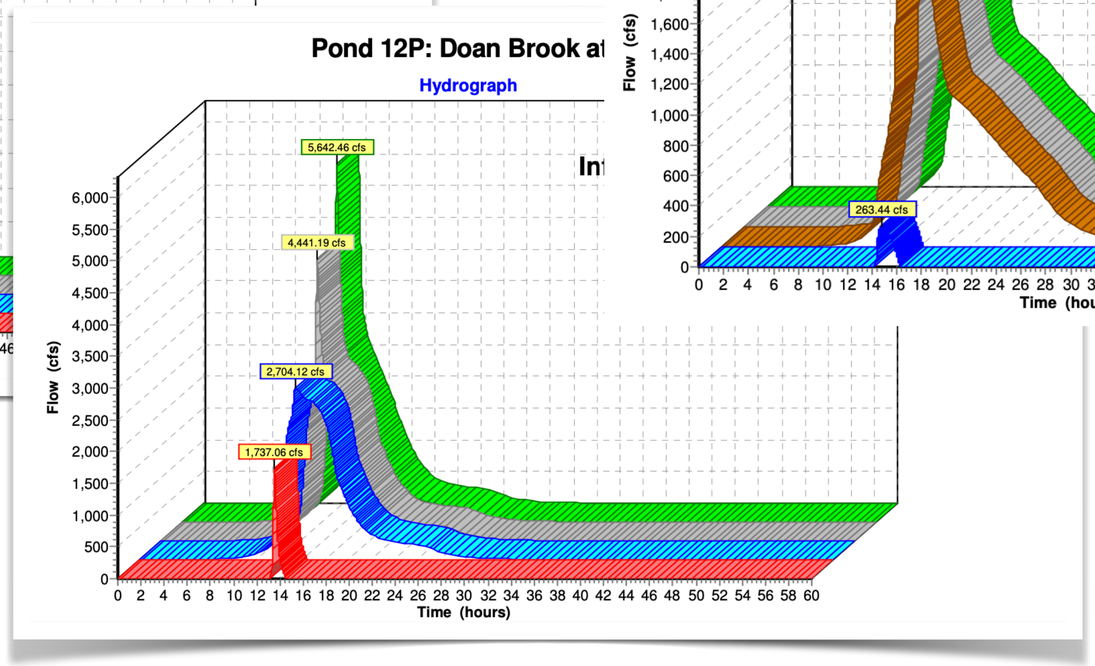

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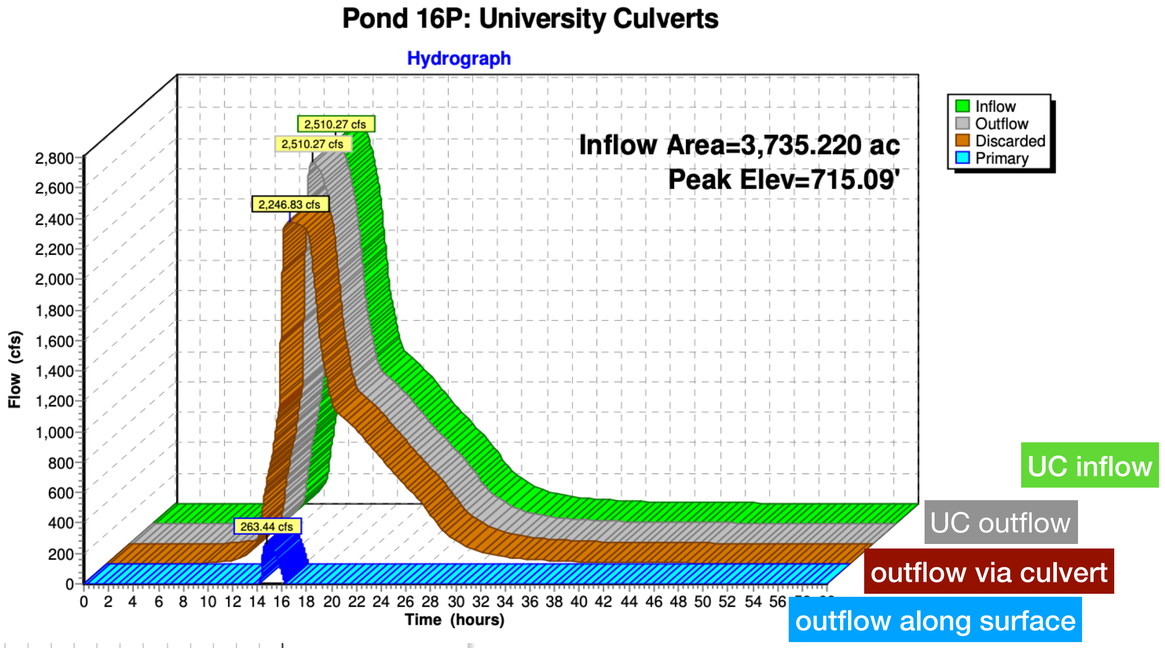

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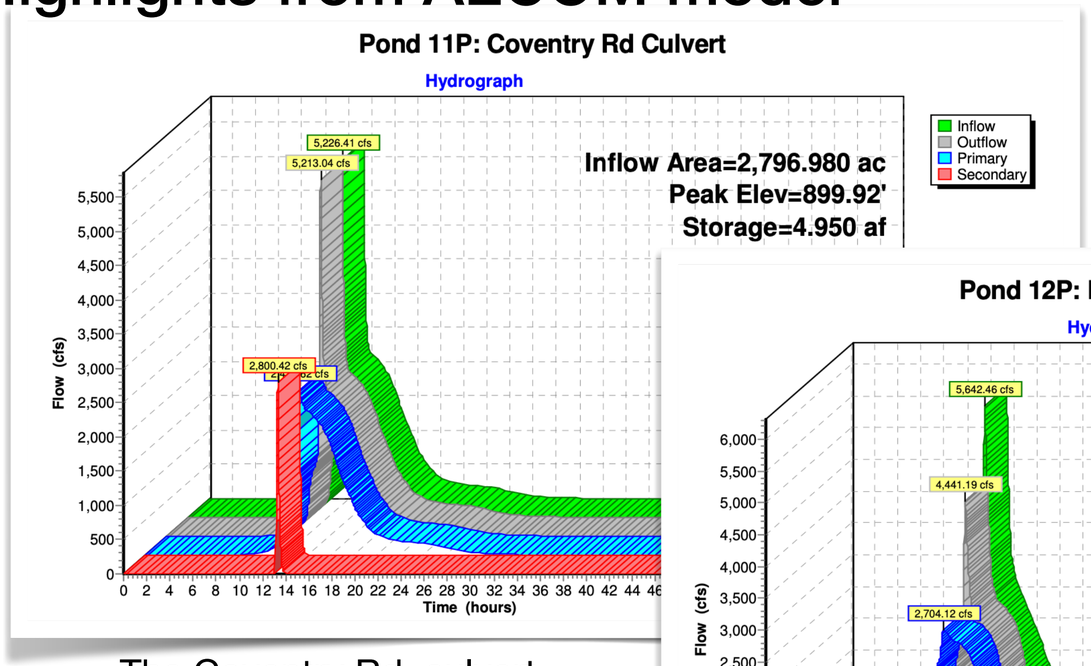

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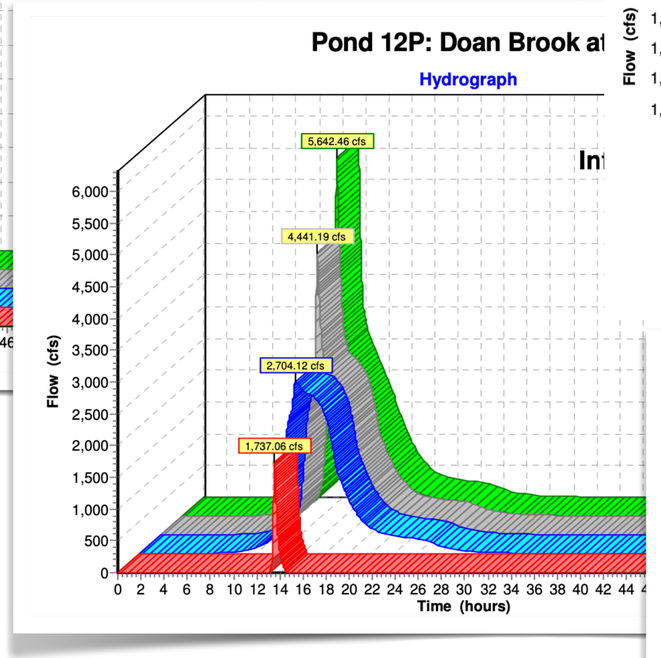

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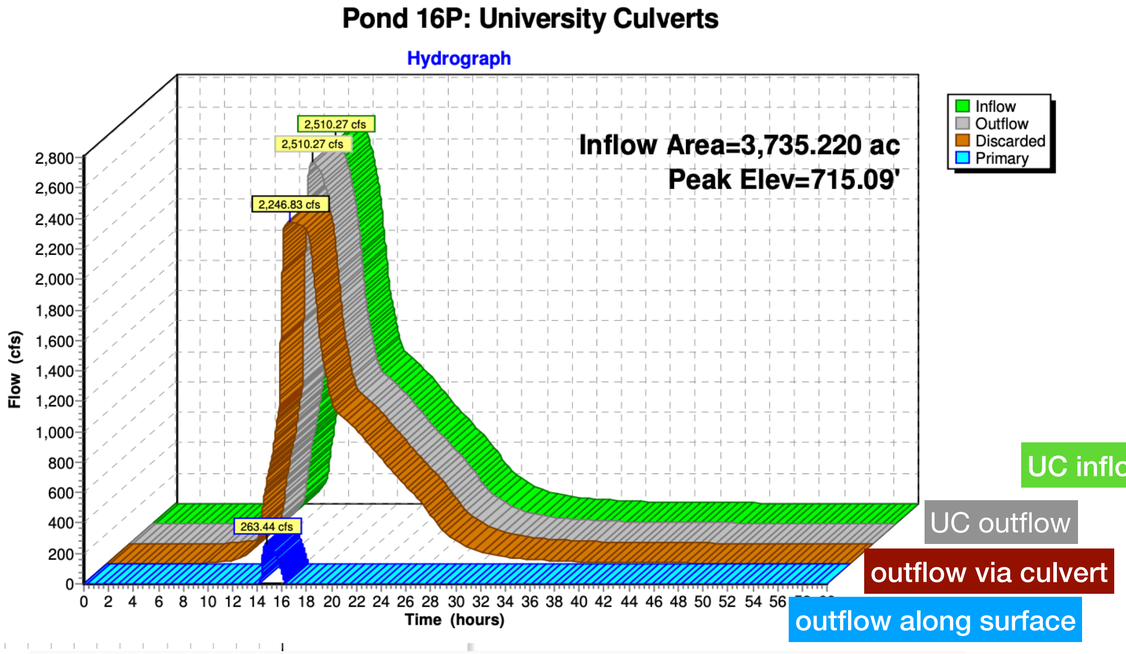
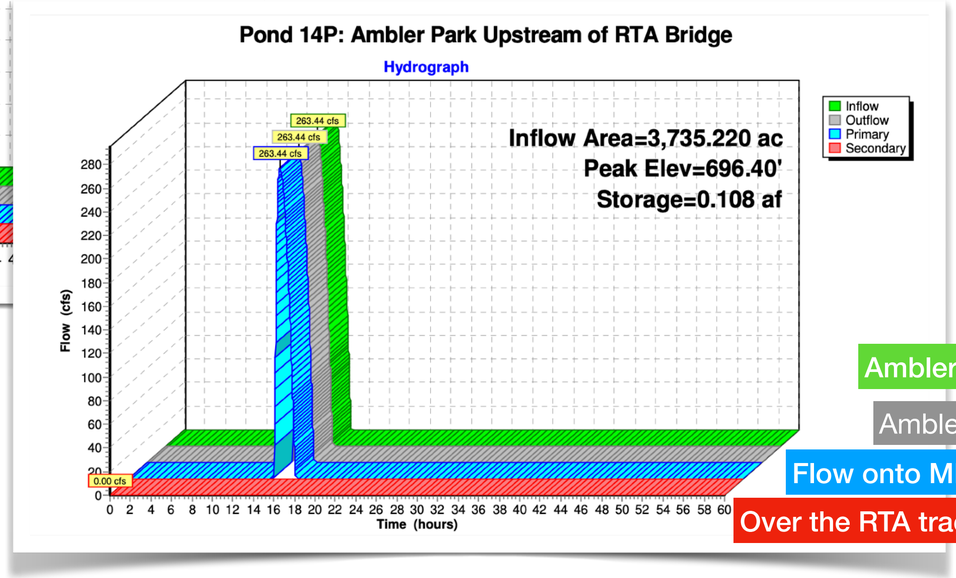


UC inflow

UC outflow

outflow via culvert

outflow along surface



Ambler Park surface inflow

Ambler Park total outflow

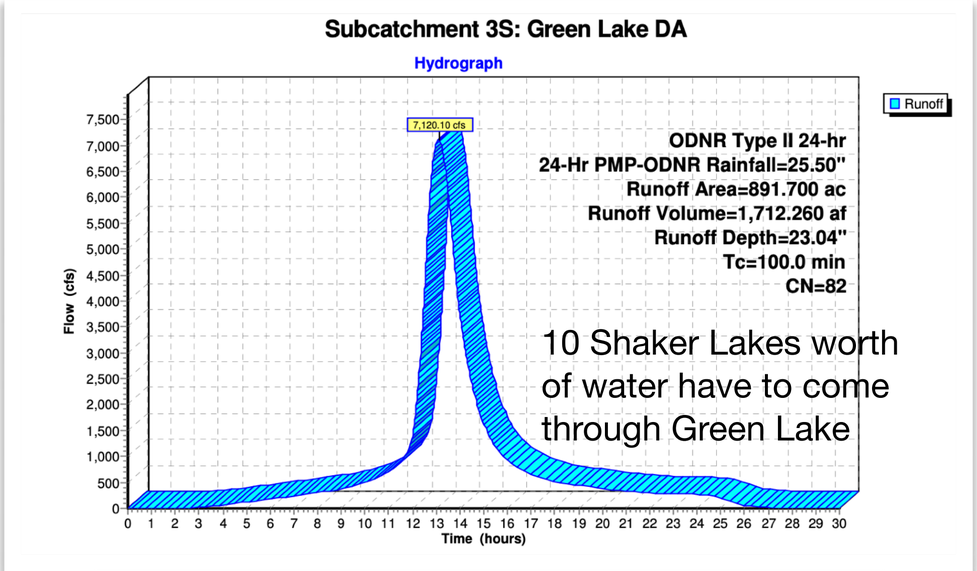
Flow onto MLK+Cedar

Over the RTA tracks (!)

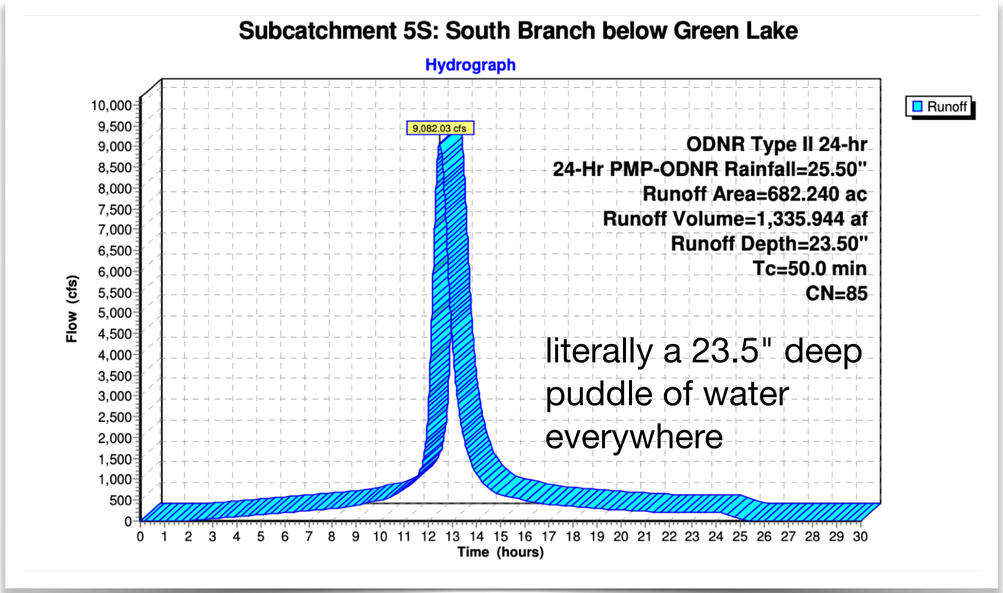
at peak 2246 enters the UC culvert and only a tiny amount (263 cfs) becomes a surface flow (1.5' deep) in Ambler Park. **This is a minor flood, not a major one.**

Highlights from AECOM model

Truly stupendous amounts of rainfall, mostly in a few hours



10 Shaker Lakes worth of water have to come through Green Lake

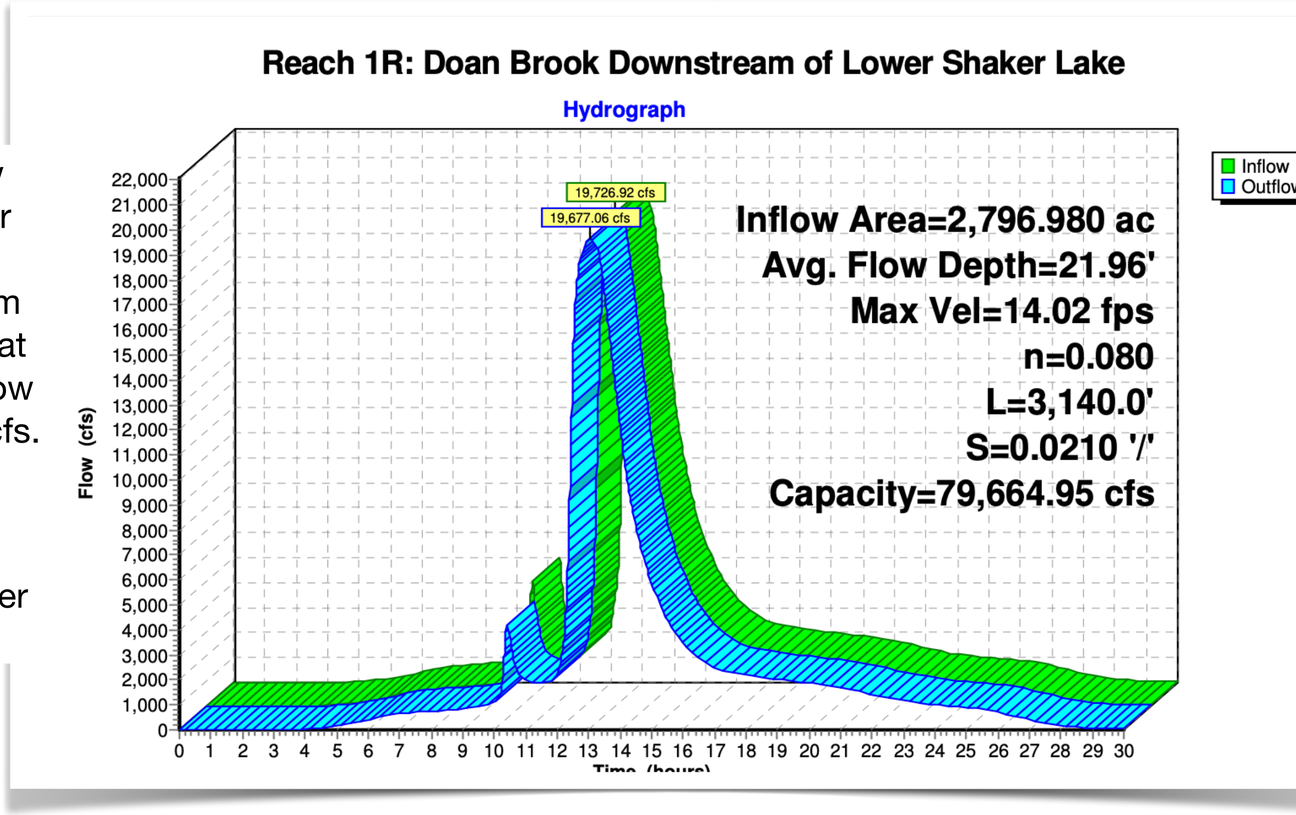


literally a 23.5" deep puddle of water everywhere

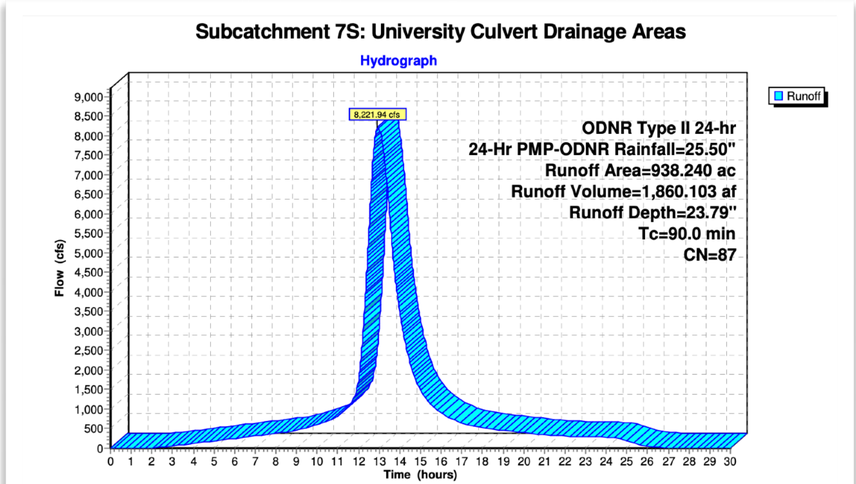
PMF 24" storm

Here's how much water has to get downstream somehow, at a peak inflow of 19,700 cfs.

That's 27 acre-feet per minute.



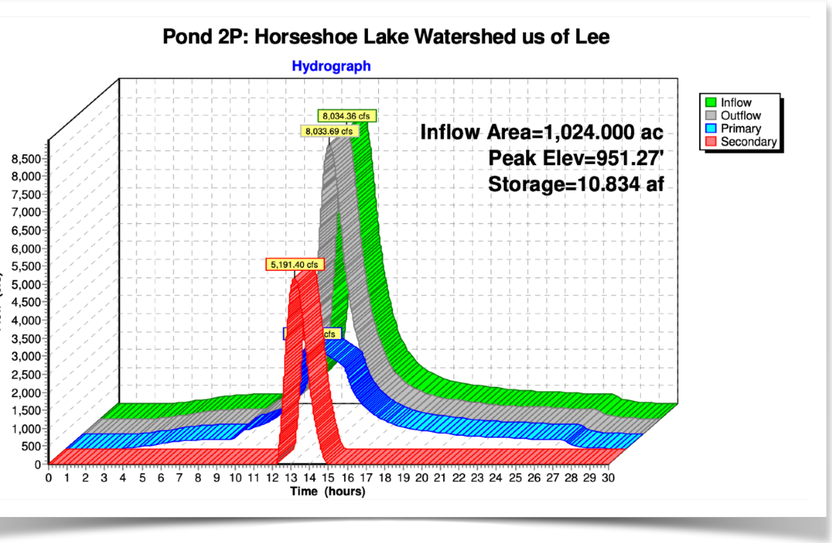
The flow from JUST rainwater *in the Ambler Heights culvert* is 400% of the Ambler Park culvert capacity and will flood University Circle by itself.



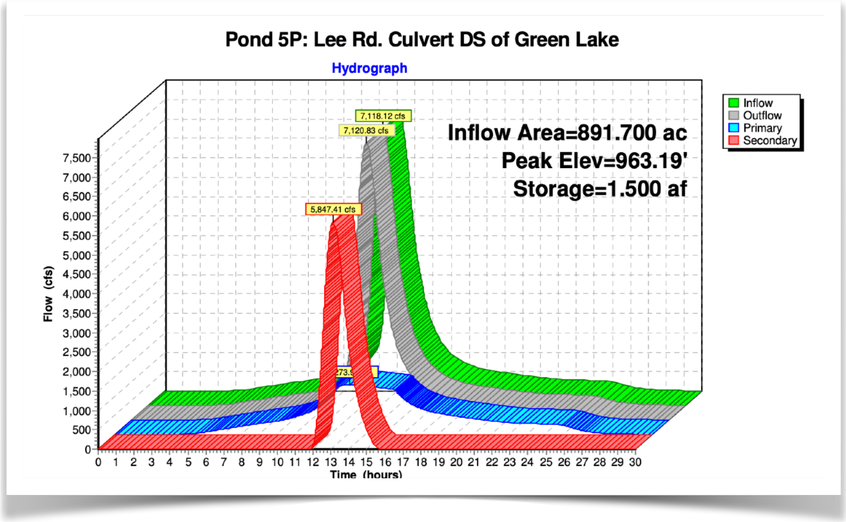
Highlights from AECOM model

PMF 24" storm

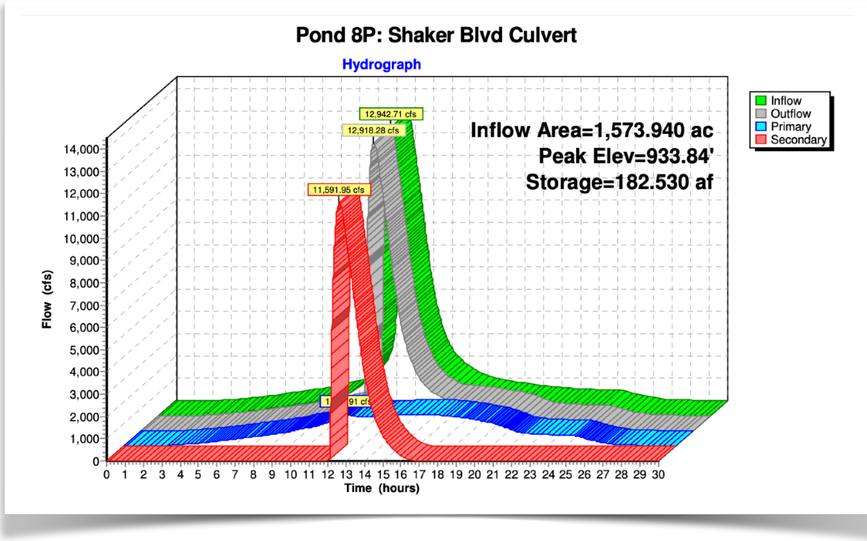
Lee Rd at Horseshoe



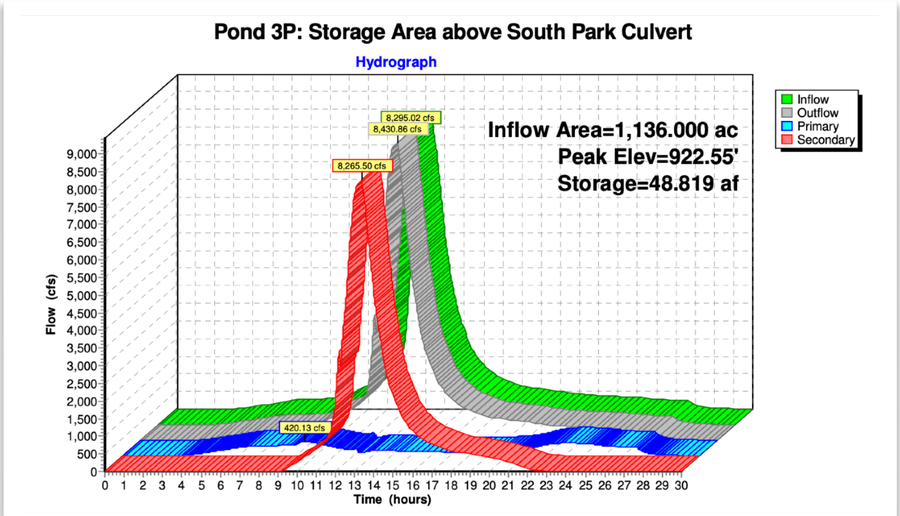
Lee Rd at Green Lake



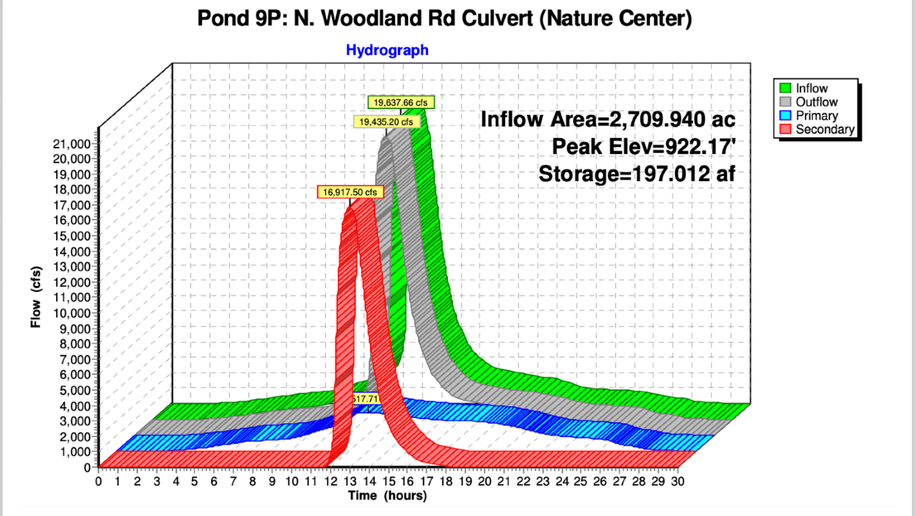
Shaker Blvd @ Southerly Park



South Park Blvd entering NCSL



S Woodland Rd entering Lower Lake



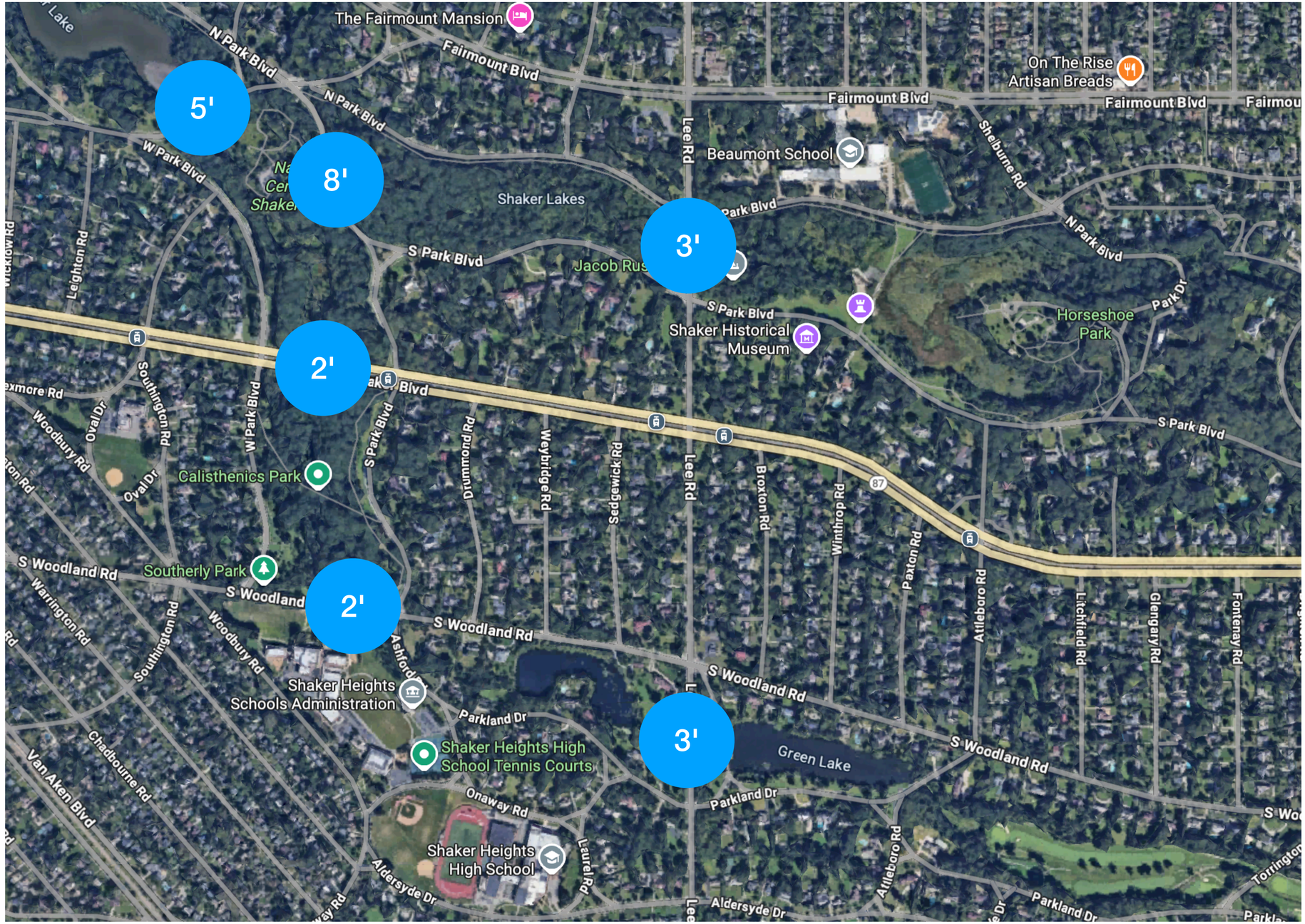
Highlights from AECOM model

Upstream of the lake:

Every road that crosses the brook is inundated.

Water speeds of of 4-6 feet per second.

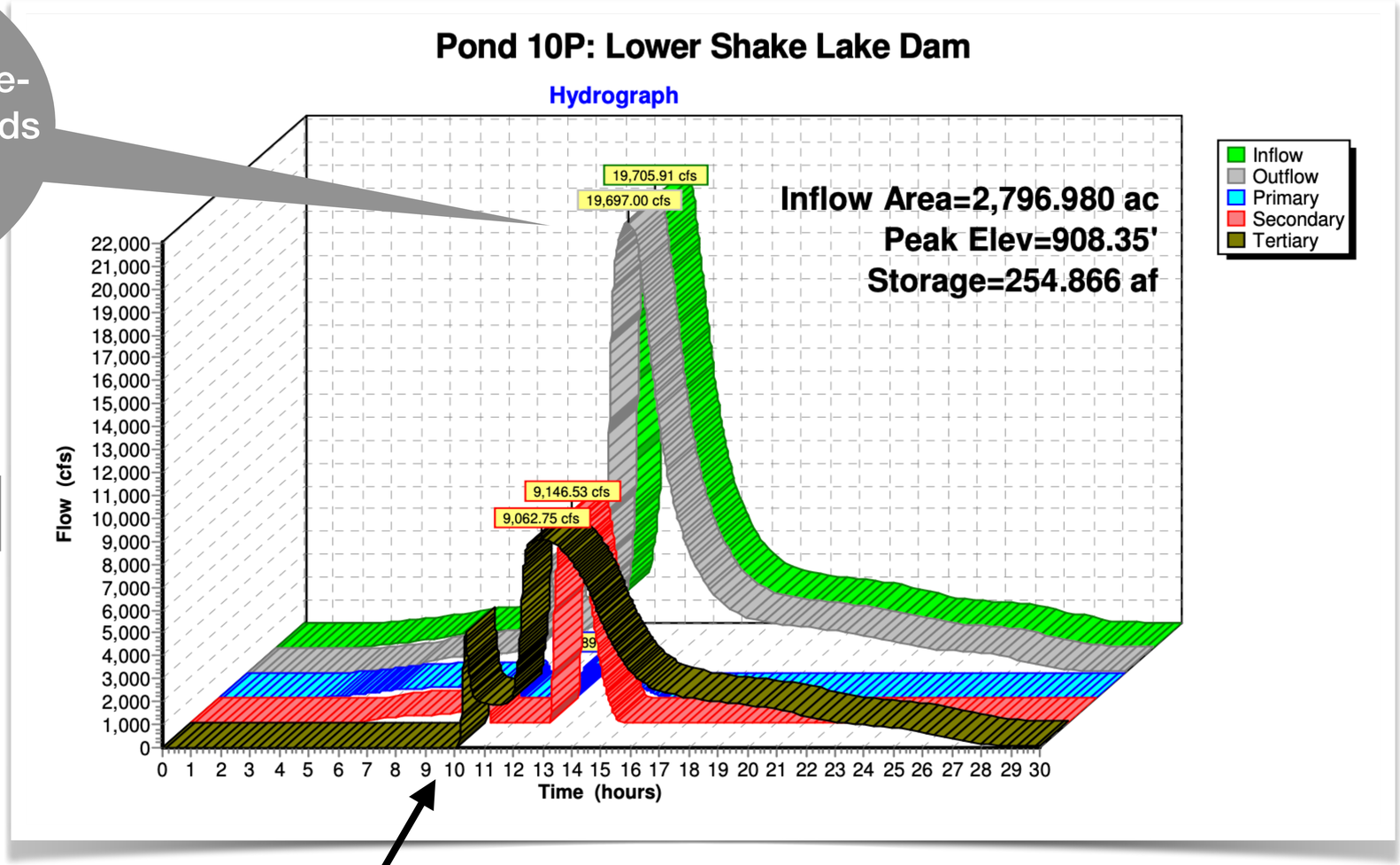
PMF 24" storm



Highlights from AECOM model

PMF 24" storm plus dam breach

outflow as high as 19,000 cfs = one acre-foot every two seconds = 178 a-f every 5 minutes



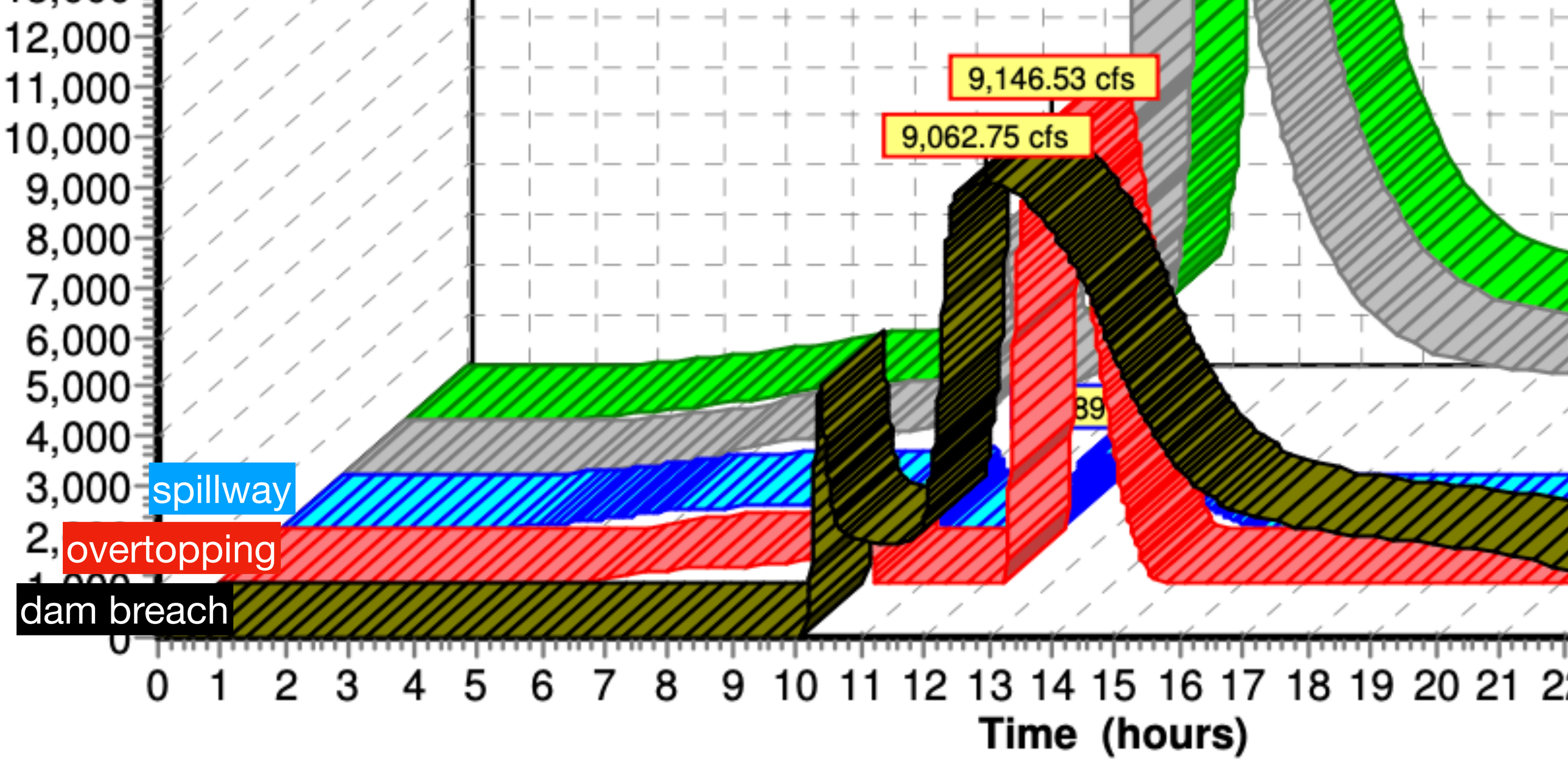
total

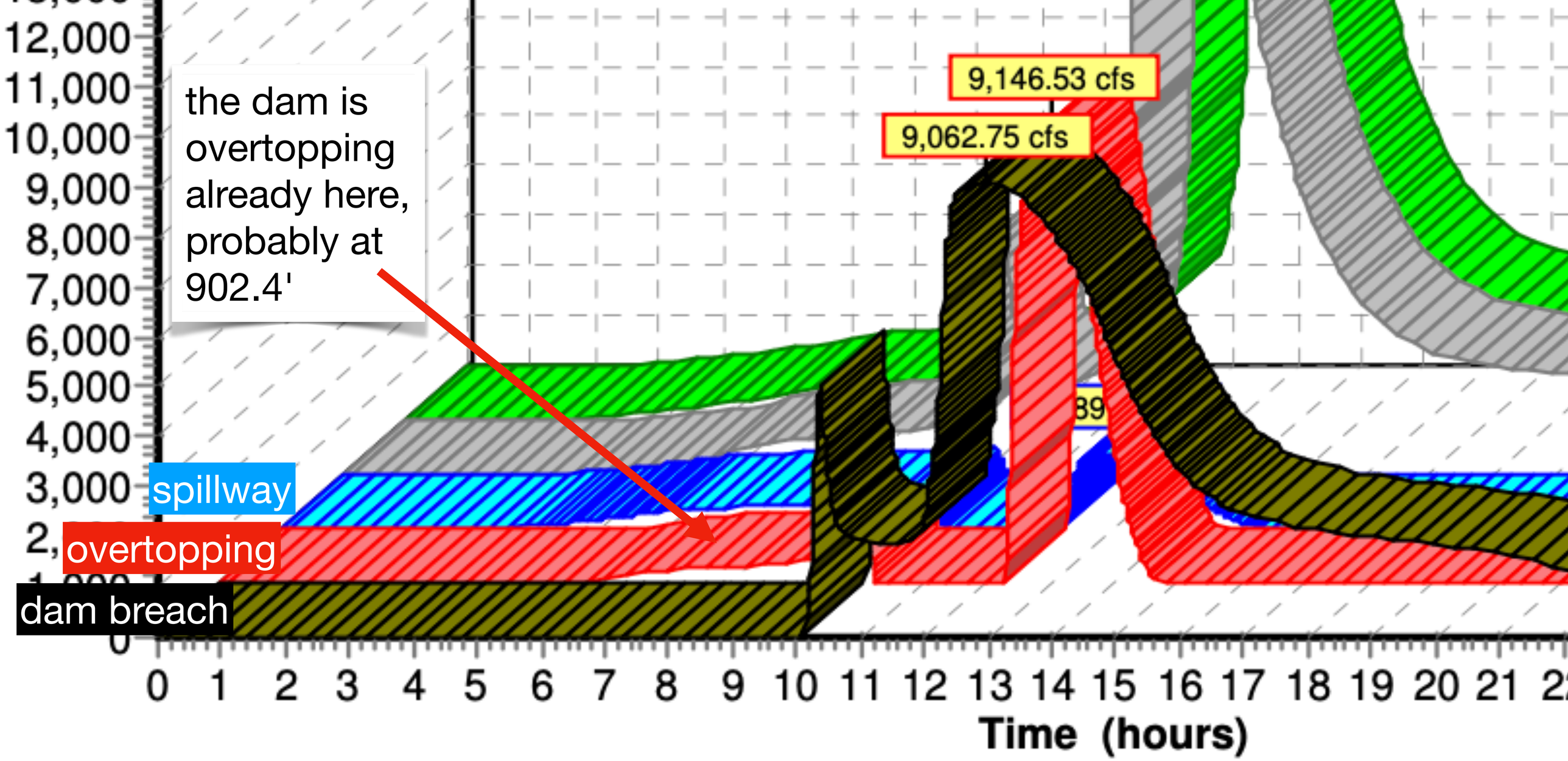
spillway

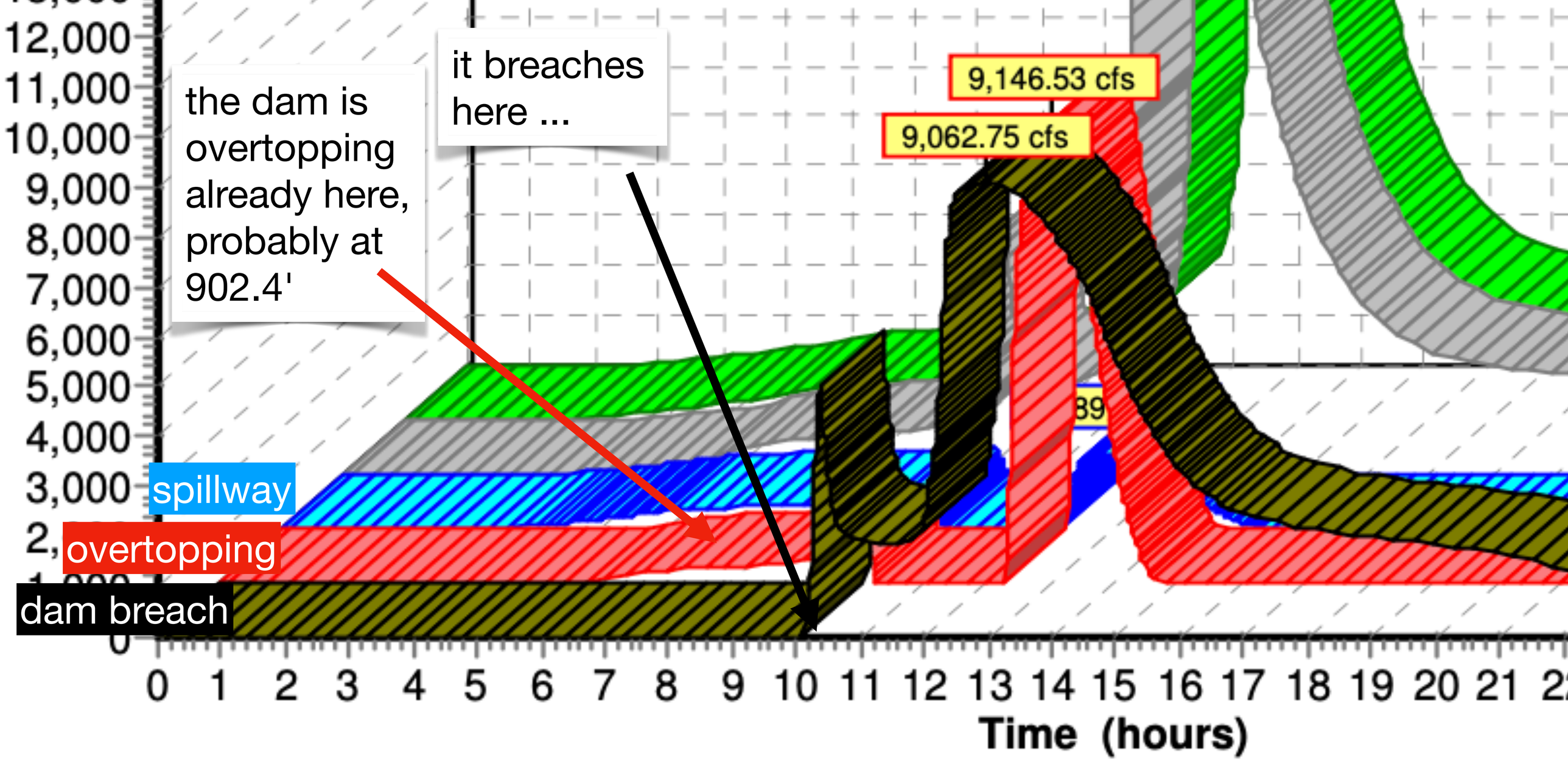
overtopping

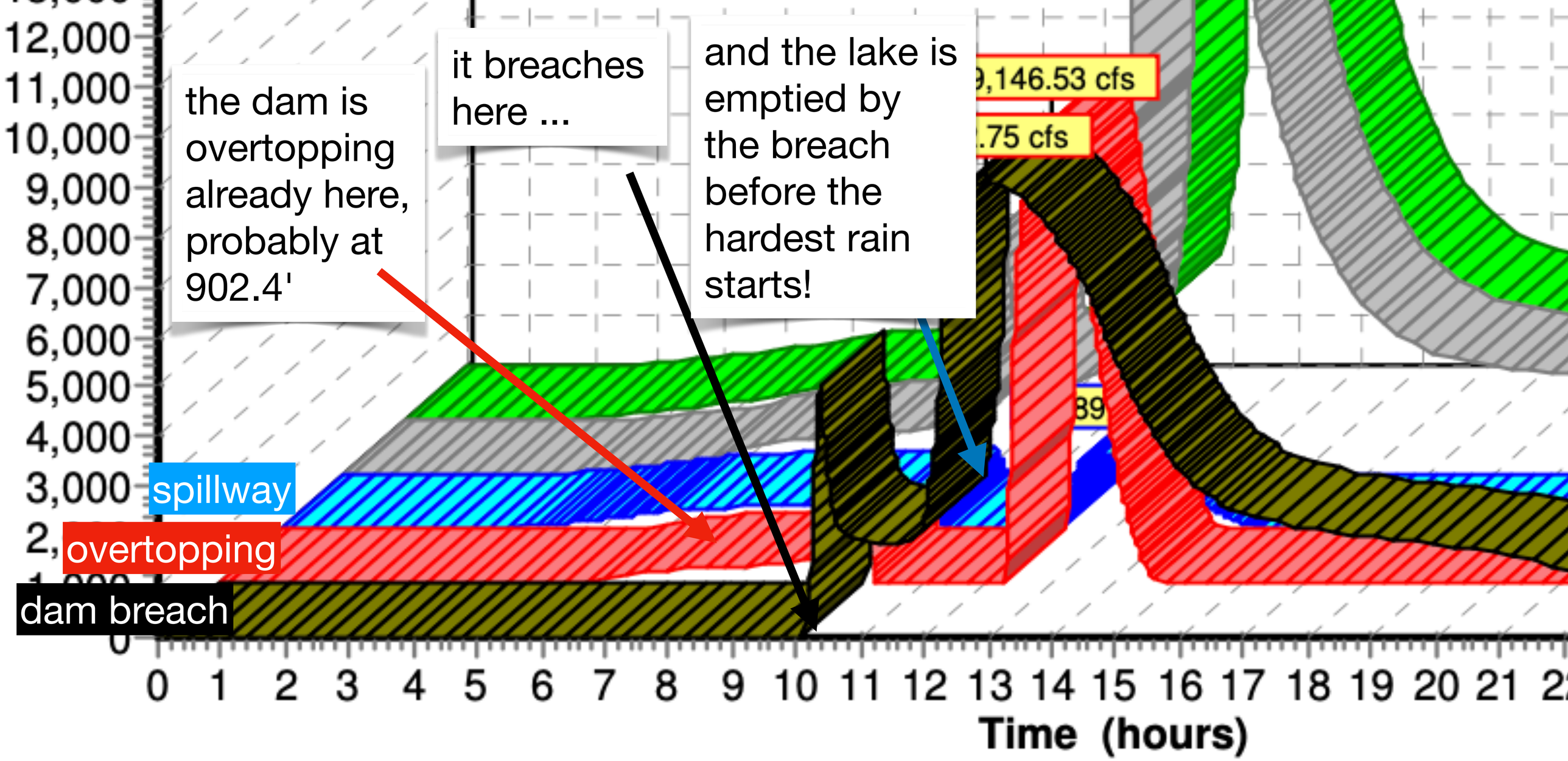
dam breach

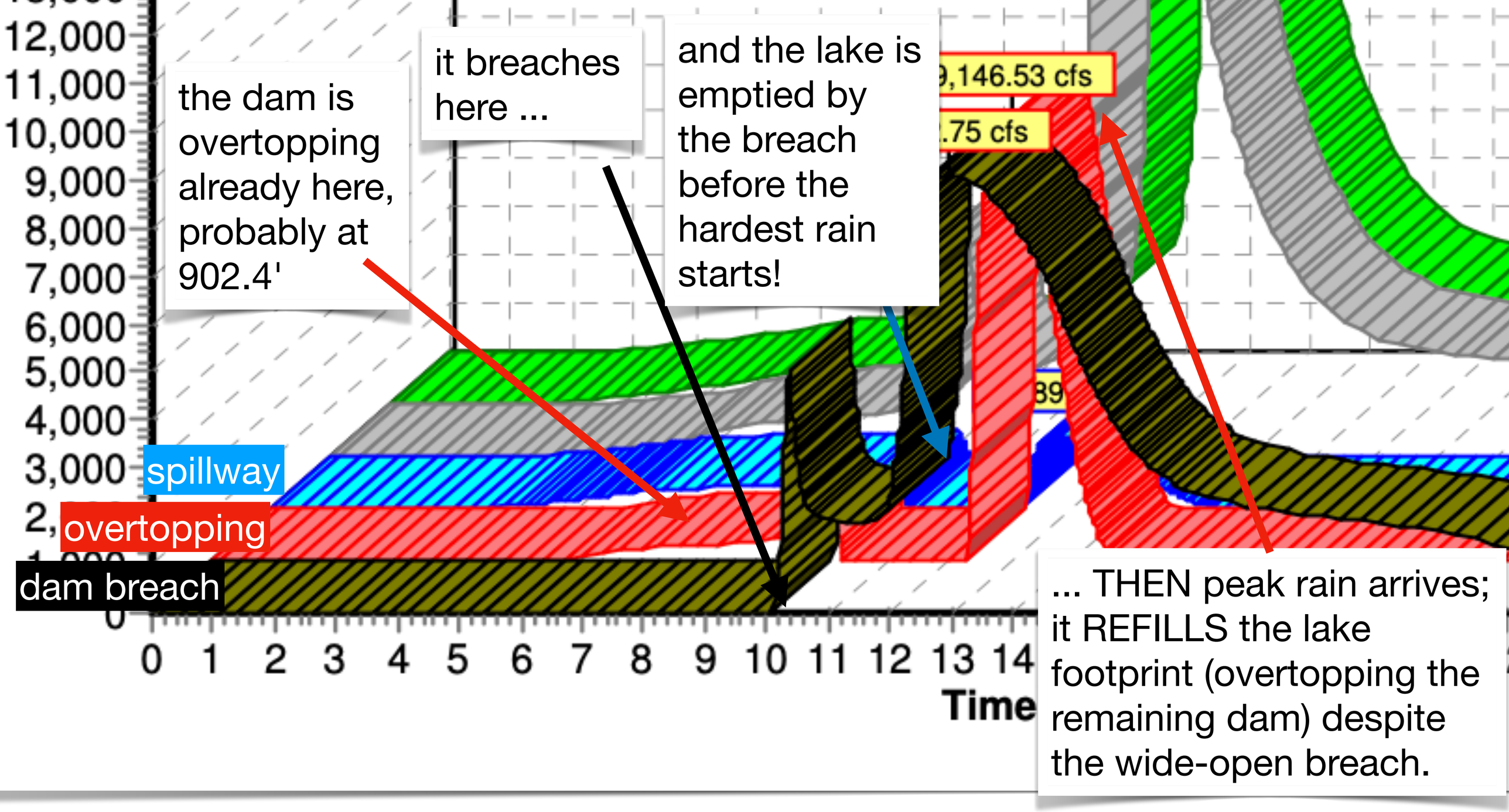
what's this sharp peak?


9,146.53 cfs
9,062.75 cfs
spillway
overtopping
dam breach
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time (hours)


the dam is overtopping already here, probably at 902.4'
9,146.53 cfs
9,062.75 cfs
spillway
overtopping
dam breach
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time (hours)


the dam is overtopping already here, probably at 902.4'
it breaches here ...
9,146.53 cfs
9,062.75 cfs
spillway
overtopping
dam breach
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time (hours)


the dam is overtopping already here, probably at 902.4'
it breaches here ...
and the lake is emptied by the breach before the hardest rain starts!
9,146.53 cfs
.75 cfs
89
spillway
overtopping
dam breach
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time (hours)

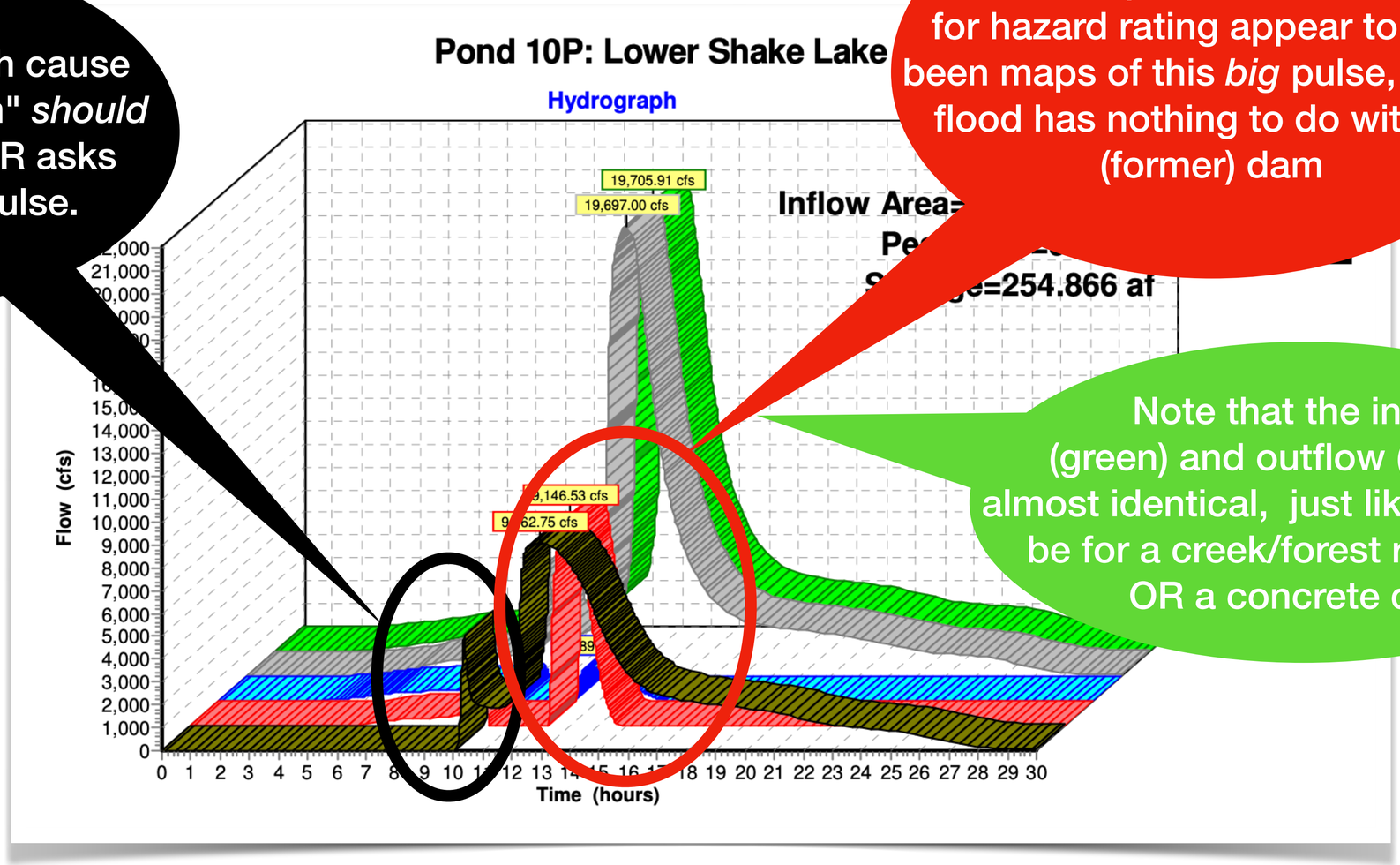

the dam is overtopping already here, probably at 902.4'
it breaches here ...
and the lake is emptied by the breach before the hardest rain starts!
... THEN peak rain arrives; it REFILLS the lake footprint (overtopping the remaining dam) despite the wide-open breach.
spillway
overtopping
dam breach
,146.53 cfs
.75 cfs
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time

Highlights from AECOM model

PMF 24" storm plus dam breach

"Did the dam breach cause flooding downstream" *should be* a question ODNR asks about this *little* pulse.

Flood maps that ODNR used for hazard rating appear to have been maps of this *big* pulse, whose flood has nothing to do with the (former) dam



Note that the inflow (green) and outflow (grey) are almost identical, just like they would be for a creek/forest restoration OR a concrete dam.

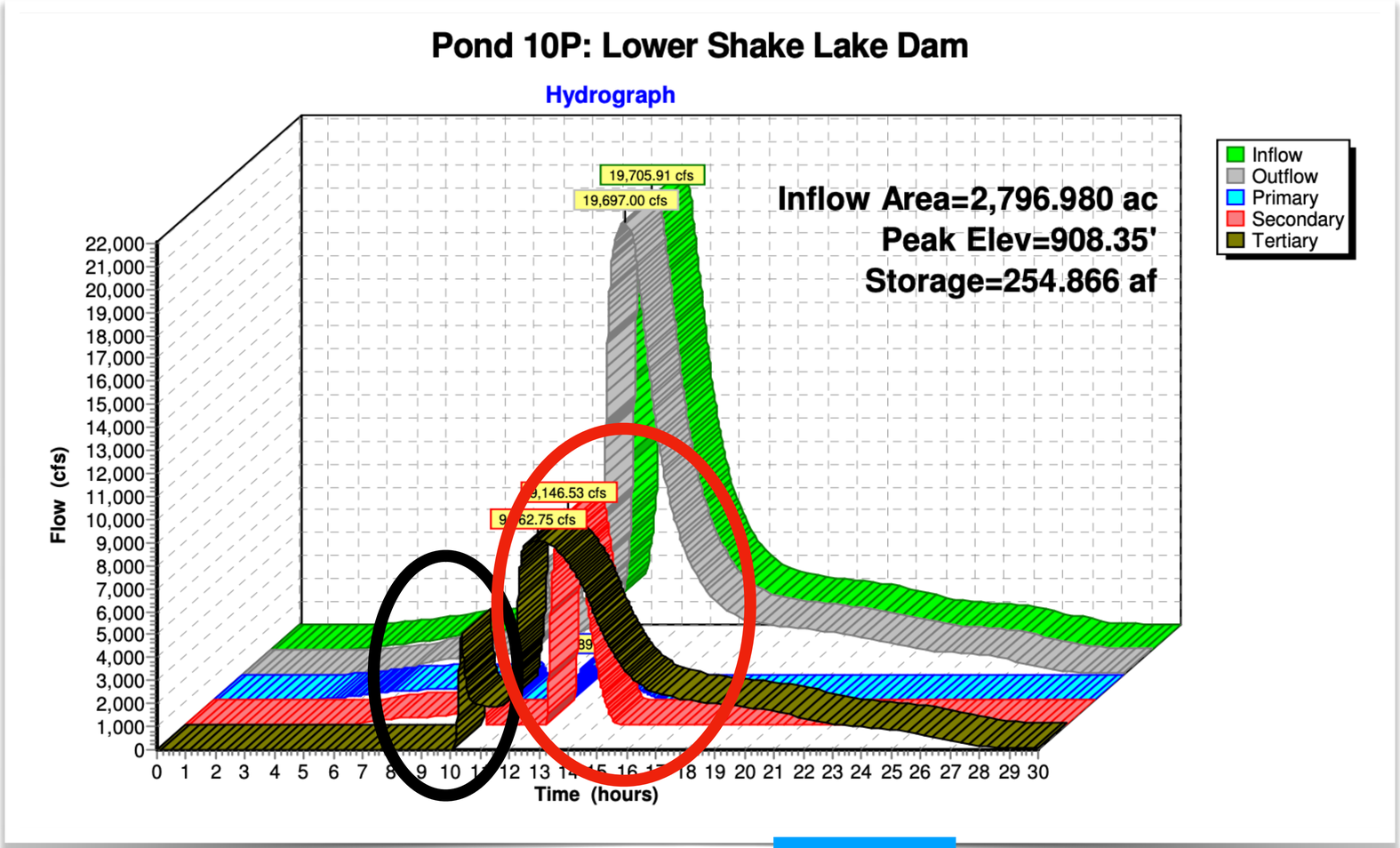
spillway

overtopping

dam breach

Highlights from AECOM model

PMF 24" storm plus dam breach



spillway

overtopping

dam breach

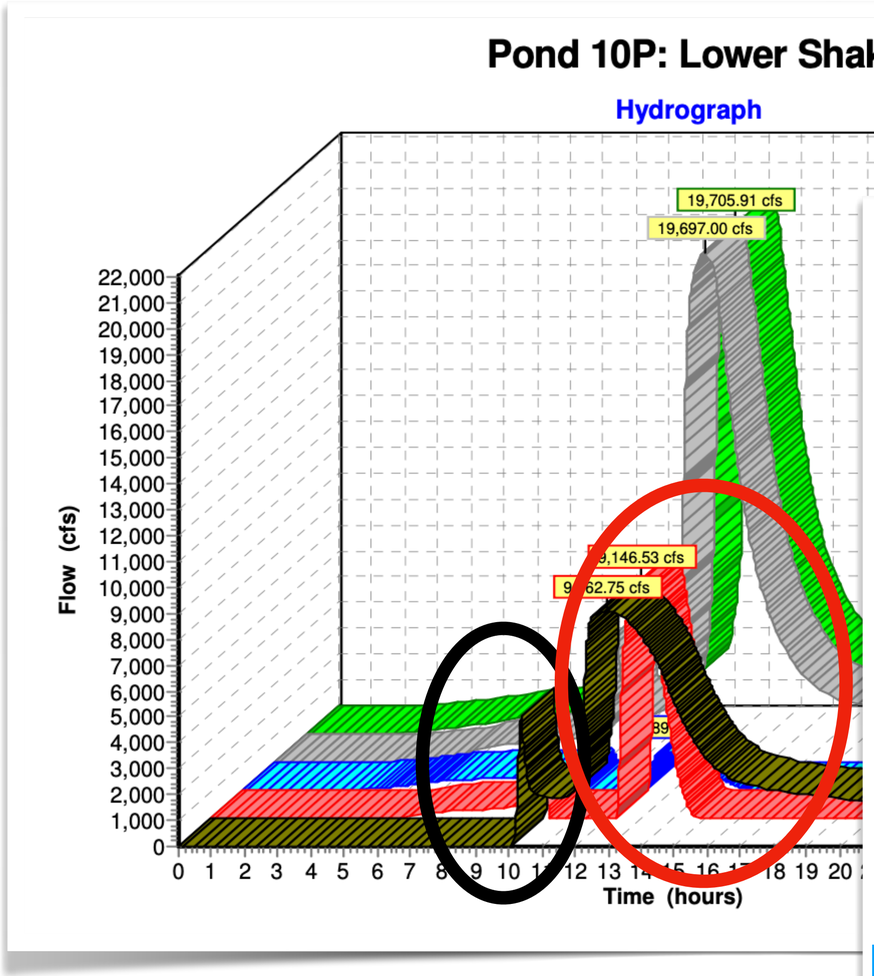
culvert

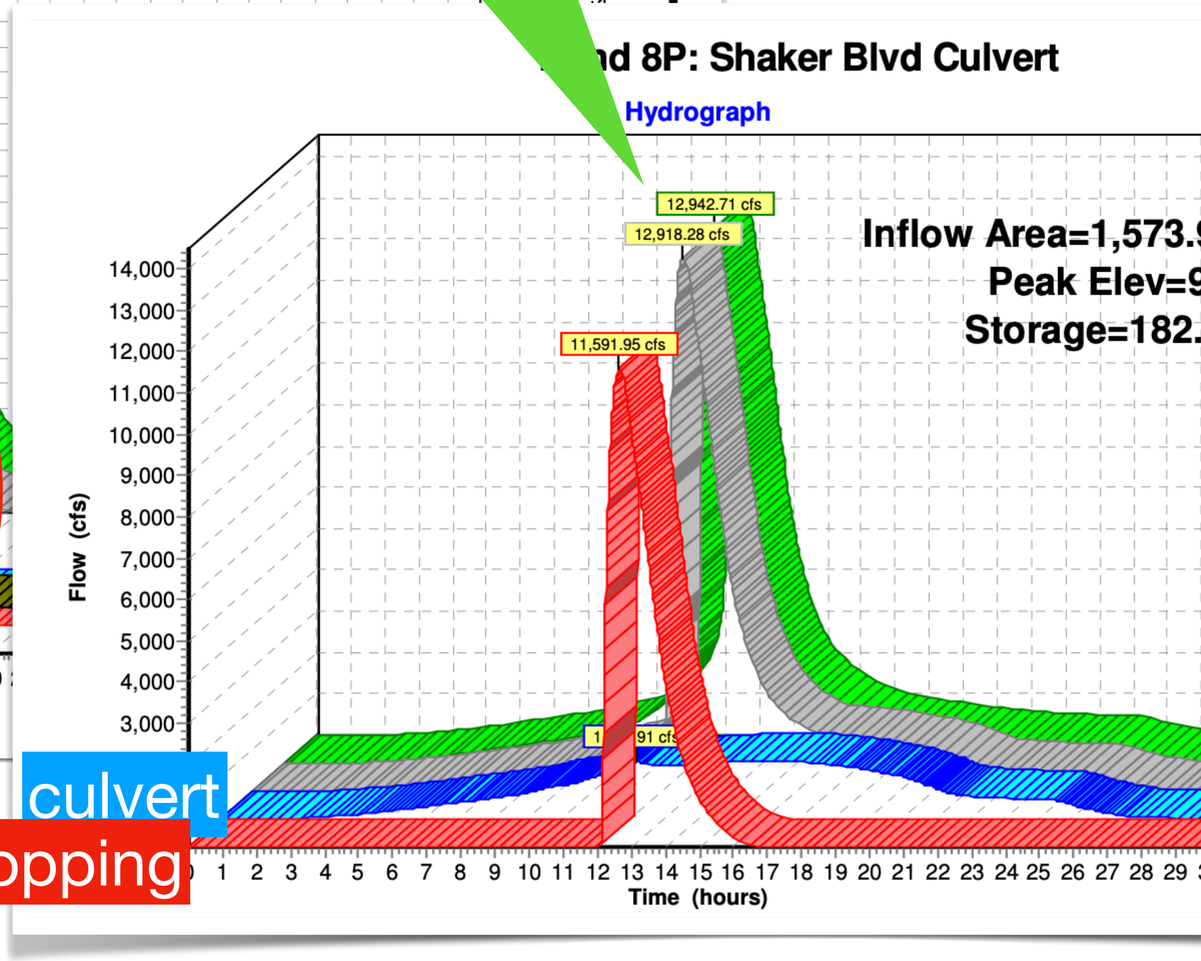
overtopping

Highlights from AECOM model

PMF 24" storm plus dam breach

For comparison here is a "dam" (Shaker Blvd embankment @ Southerly Park) *not* breaching. outflow (grey) = inflow (green) throughout the storm.





spillway

overtopping

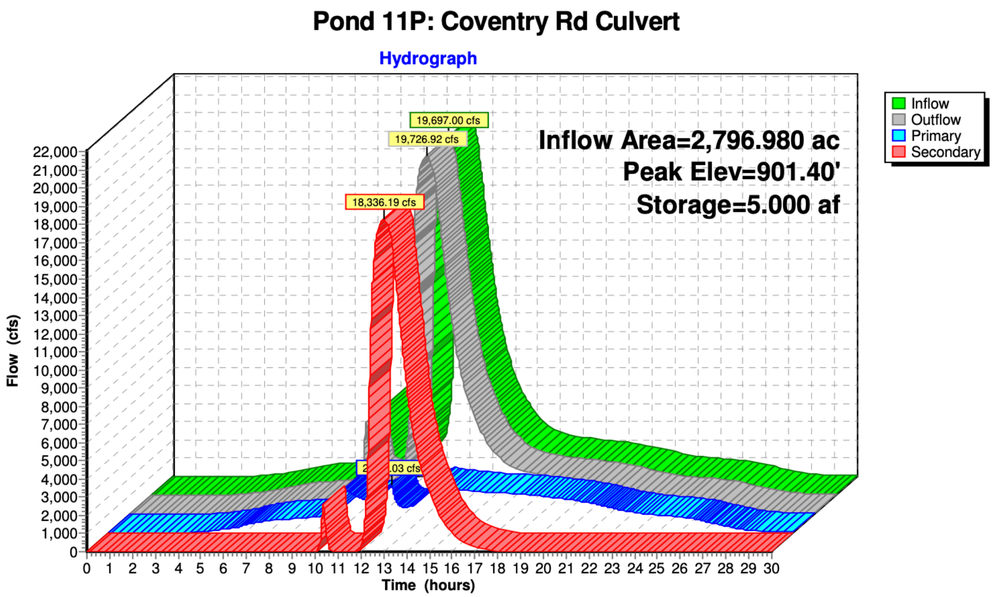
dam breach

culvert

overtopping

Highlights from AECOM model

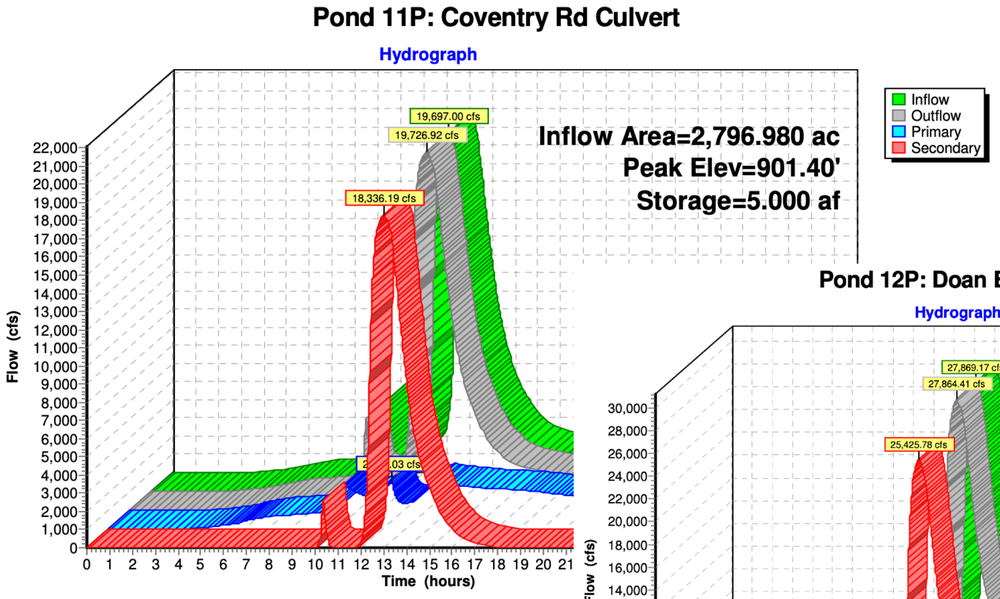
PMF 24" storm plus dam breach



Coventry Rd. overtopping is 3' deep in main flood (dam-breach mini-peak is 1' deep, same as the 100y flood)

Highlights from AECOM model

PMF 24" storm plus dam breach



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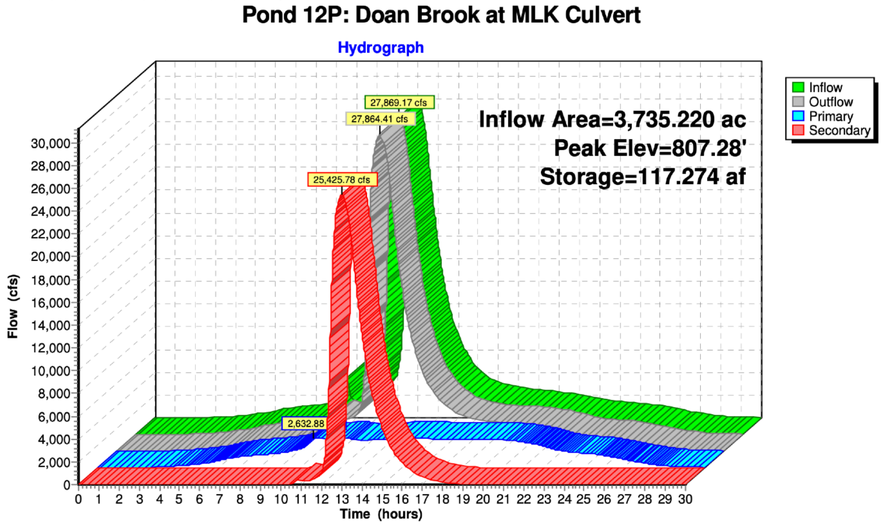
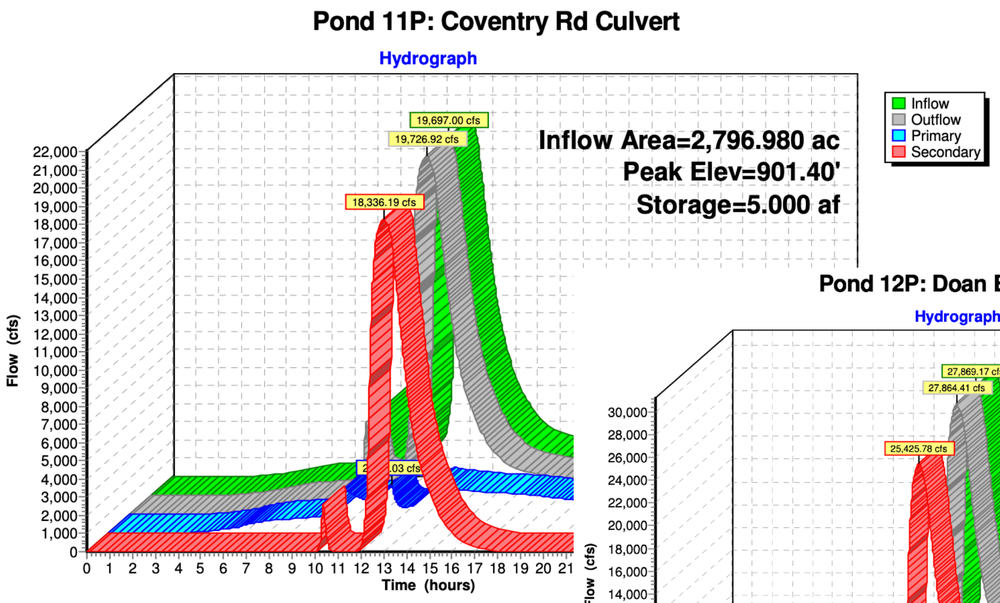


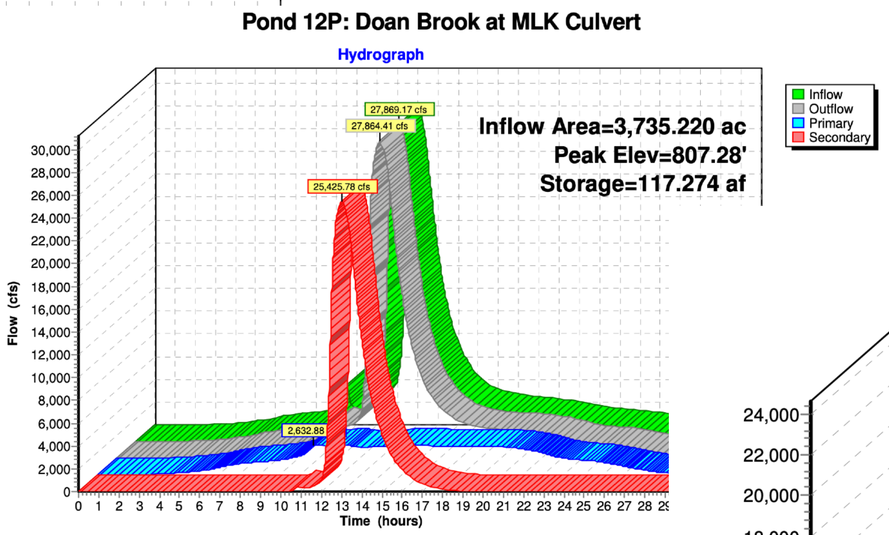
MLK is overtopped by 9' in main flood (dam-breach mini-peak is same as 100y flood)

Highlights from AECOM model

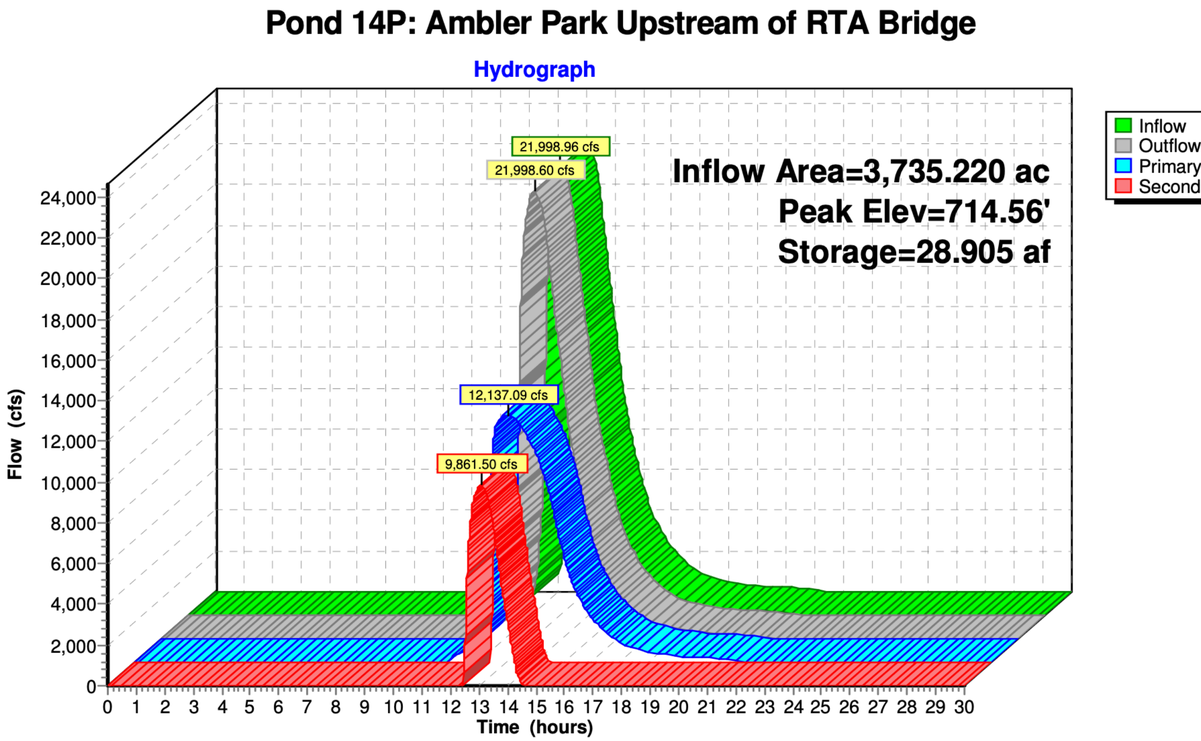
PMF 24" storm plus dam breach



Coventry Rd. overtopping is 3' deep in main flood (dam-breach mini-peak is 1' deep, same as the 100y flood)

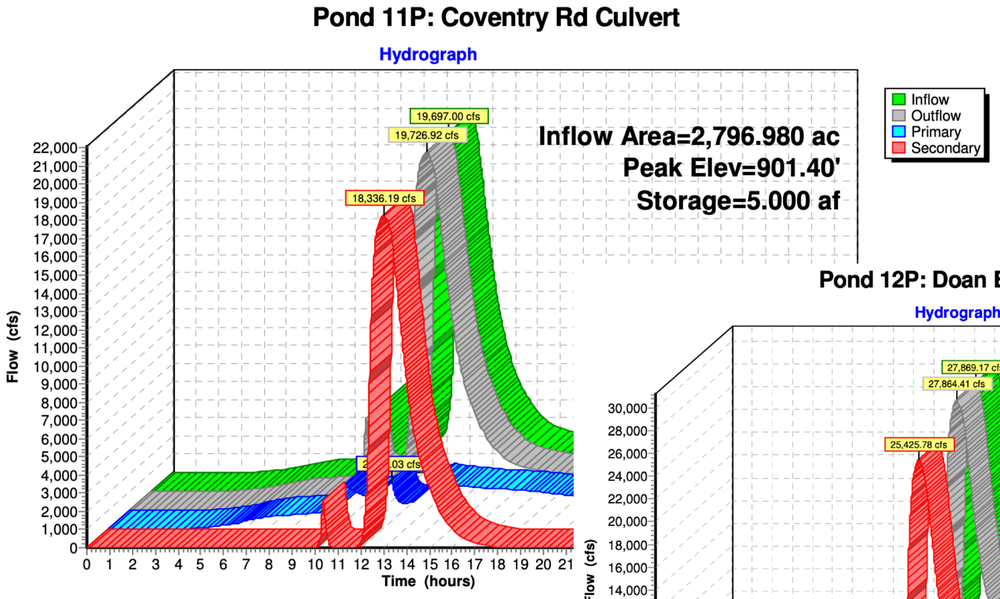


MLK is overtopped by 9' in main flood (dam-breach mini-peak is same as 100y flood)

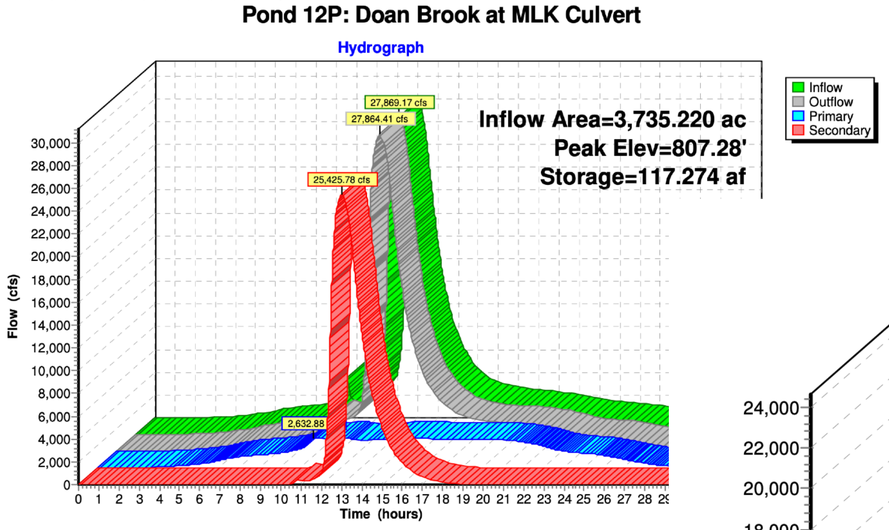


Highlights from AECOM model

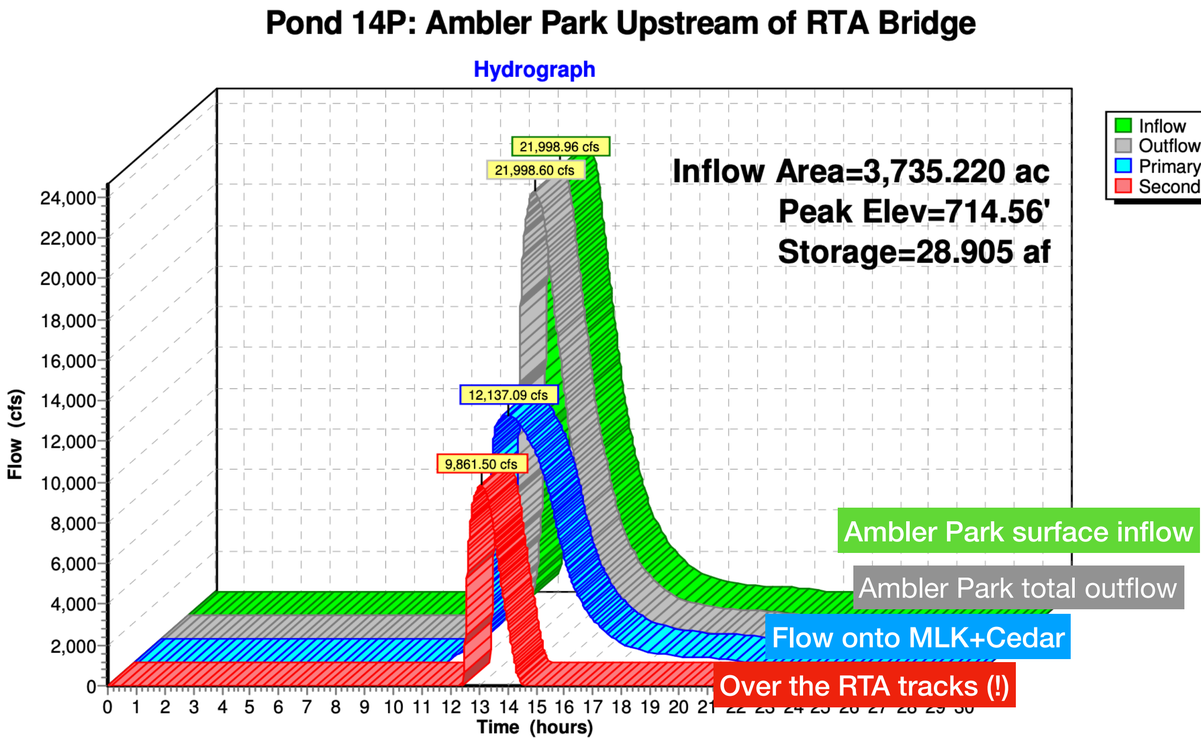
PMF 24" storm plus dam breach



Coventry Rd. overtopping is 3' deep in main flood (dam-breach mini-peak is 1' deep, same as the 100y flood)

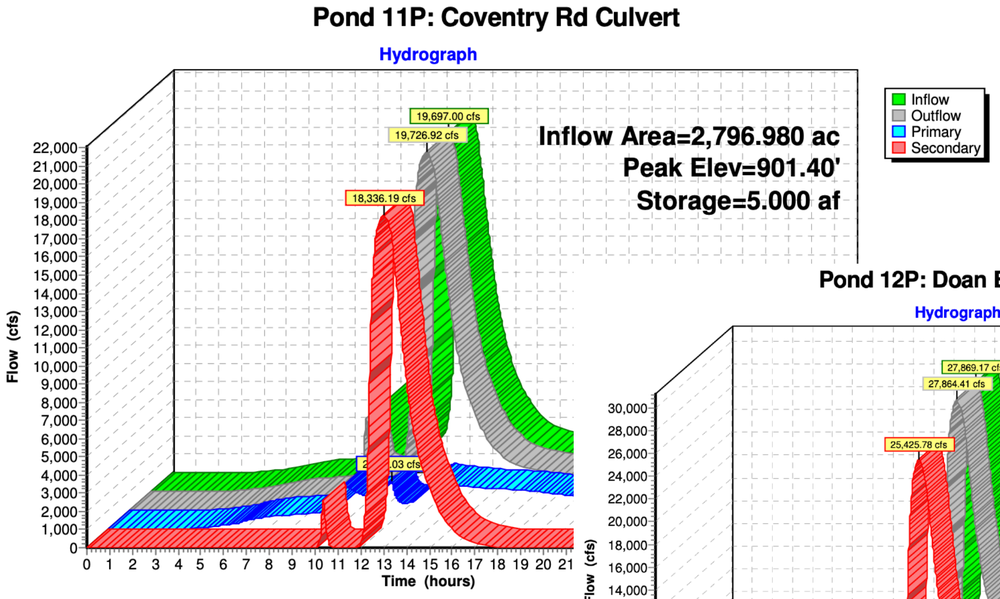


MLK is overtopped by 9' in main flood (dam-breach mini-peak is same as 100y flood)

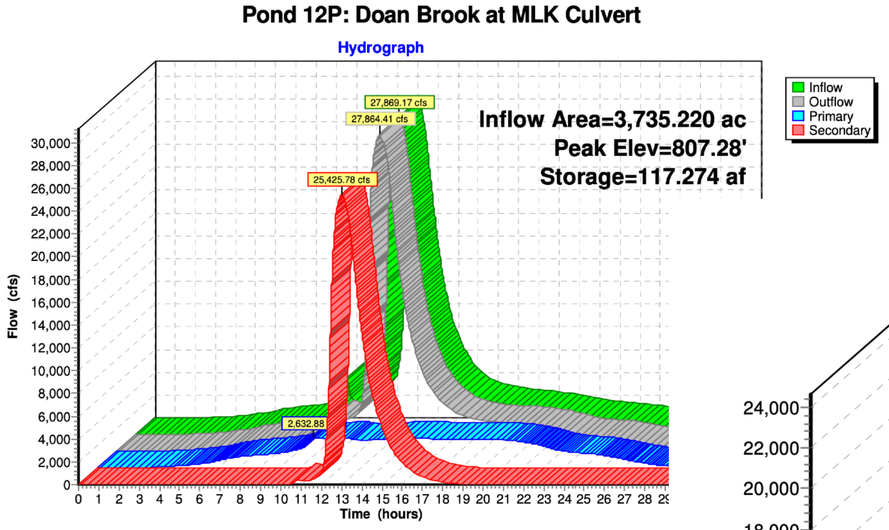


Highlights from AECOM model

PMF 24" storm plus dam breach

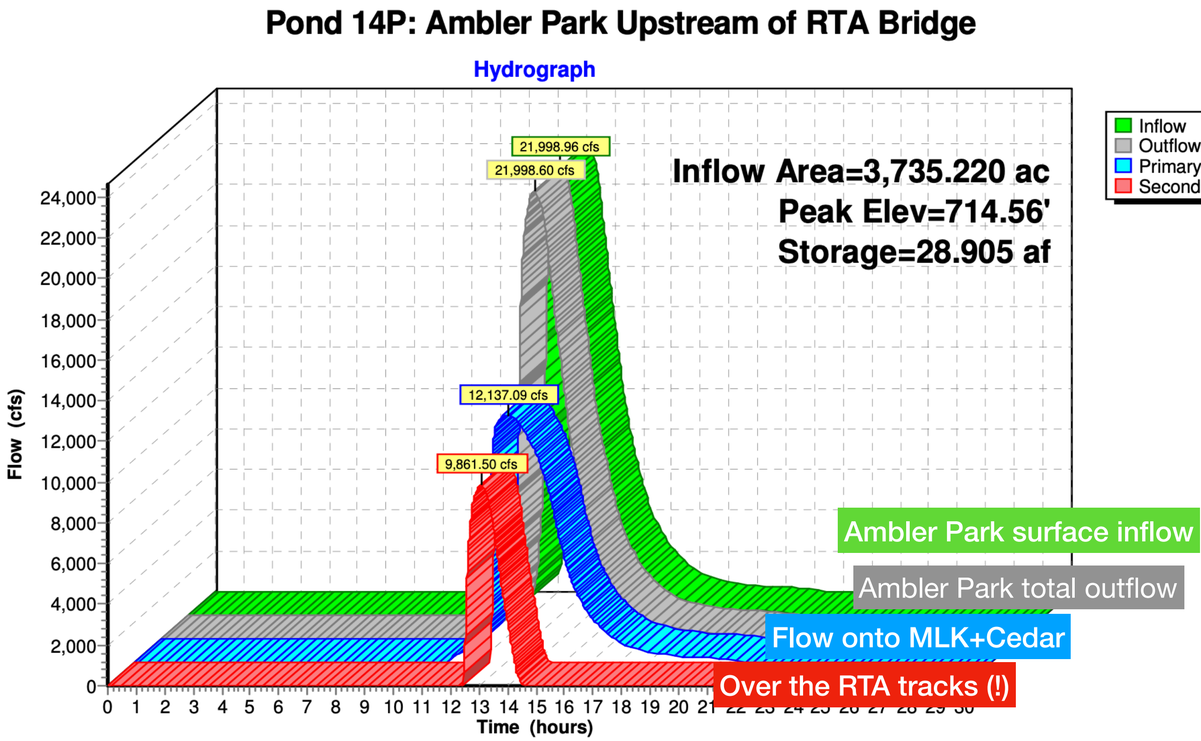


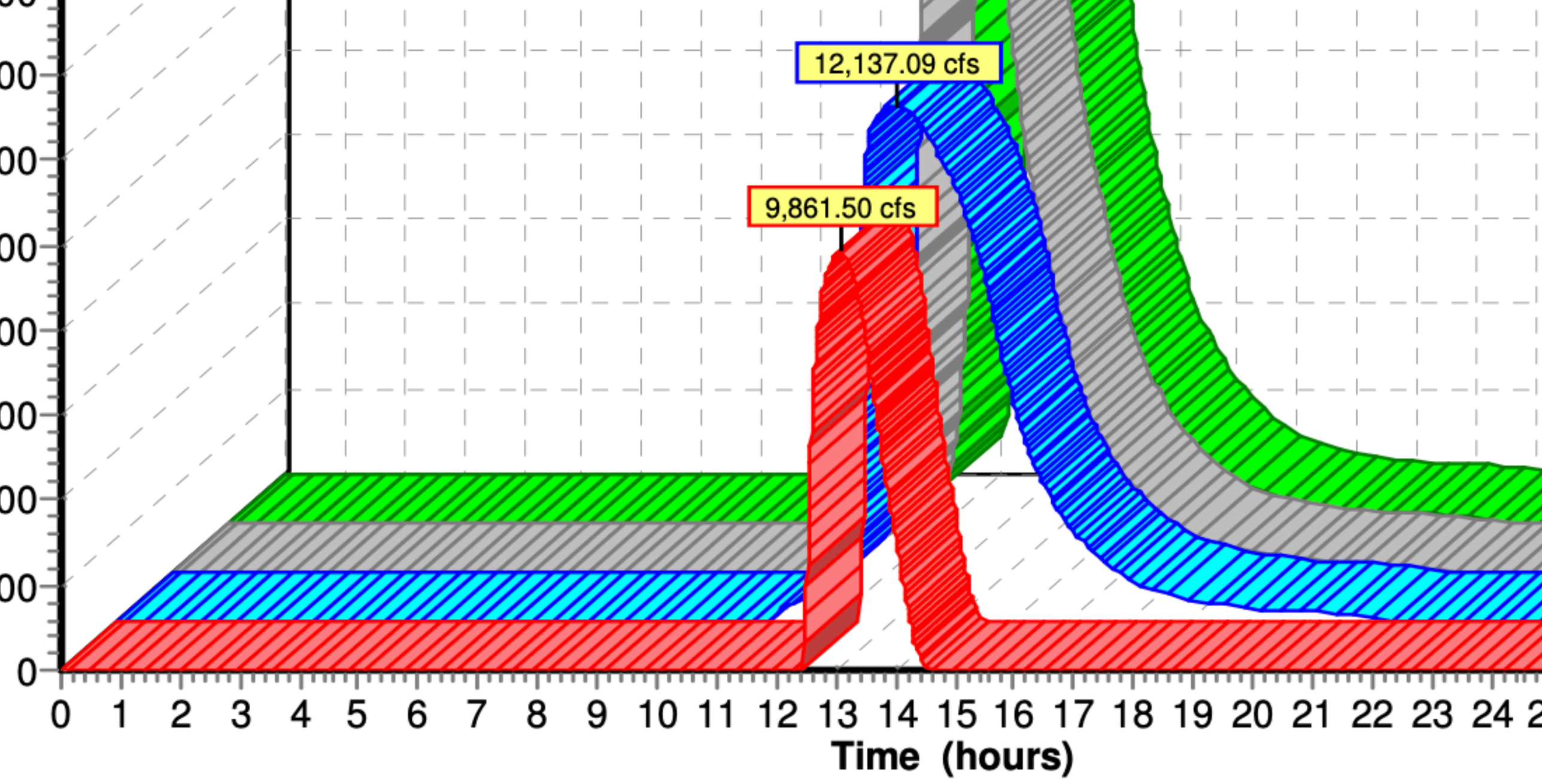
Coventry Rd. overtopping is 3' deep in main flood (dam-breach mini-peak is 1' deep, same as the 100y flood)

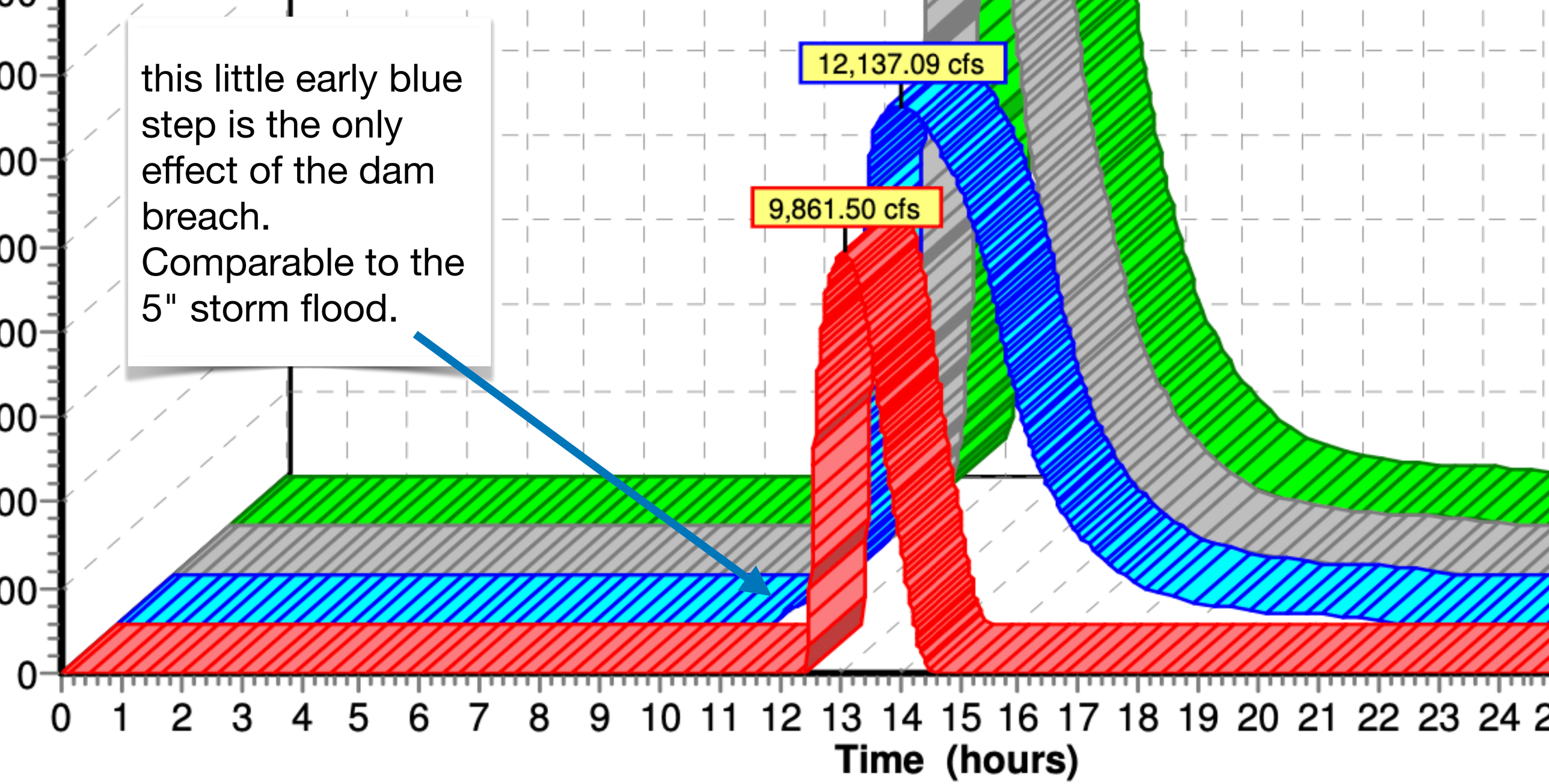


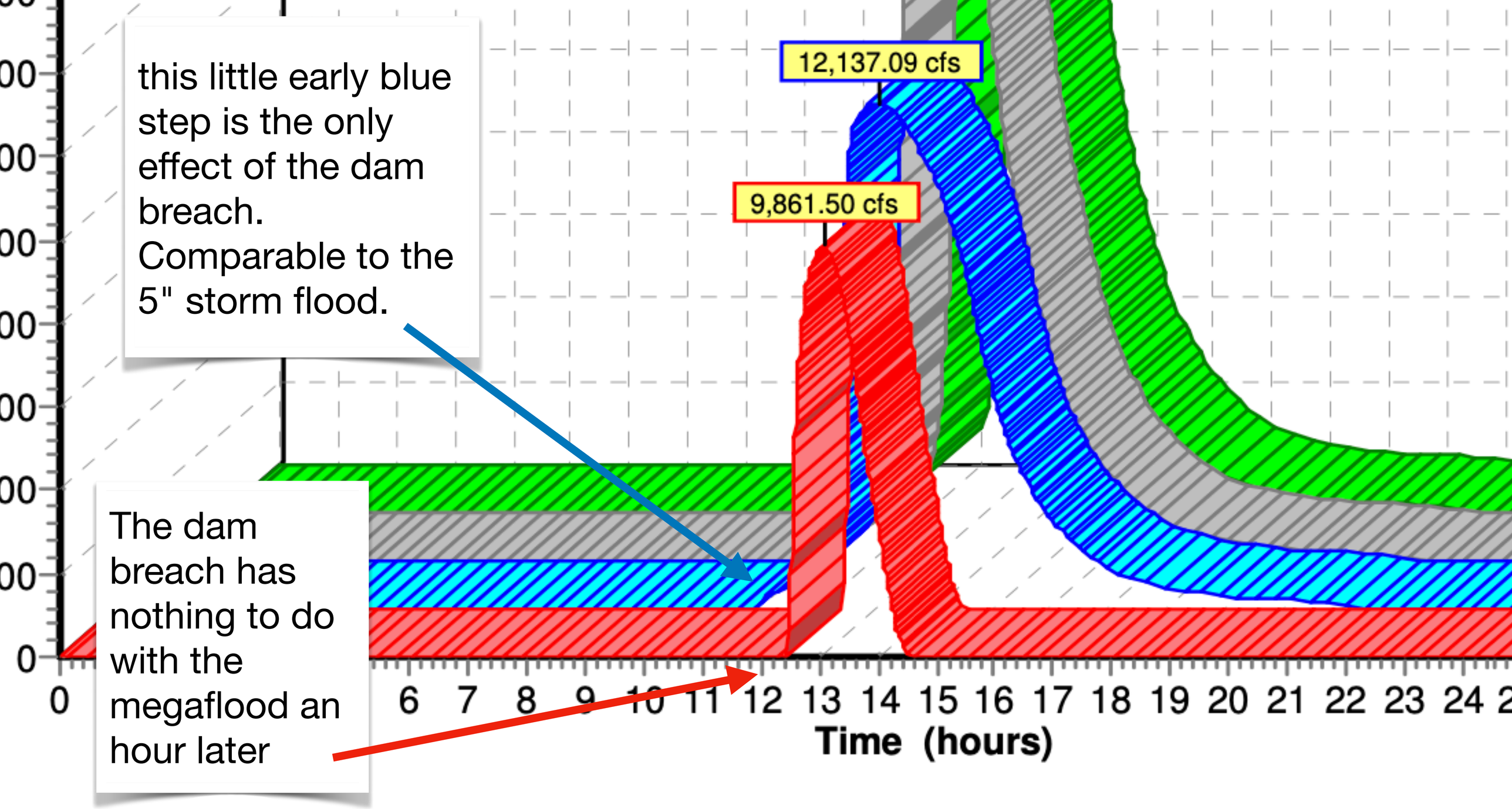
MLK is overtopped by 9' in main flood (dam-breach mini-peak is same as 100y flood)

Only 15% of this storm flow fits down the Ambler Park culvert; the rest goes over the surface as a flood. At peak flow water is going BOTH UNDER AND OVER the RTA bridge.




12,137.09 cfs
9,861.50 cfs
0
00
00
00
00
00
00
00
00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)


this little early blue step is the only effect of the dam breach. Comparable to the 5" storm flood.
12,137.09 cfs
9,861.50 cfs
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)


this little early blue step is the only effect of the dam breach. Comparable to the 5" storm flood.
The dam breach has nothing to do with the megaflood an hour later
12,137.09 cfs
9,861.50 cfs
0
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)

Cross Section ID	Road/Bridge Name	W.S. Elev (ft)	Min Ch El (ft)	Water Depth (ft)	Travel Time (hrs)
3080.263	Martin Luther King Jr. Dr.	801.57	759.4	42.17	0.25
343.4128	CSX Bridge	696.47	693.68	2.79	0.31

Cross Section ID	Road/Bridge Name	W.S. Elev (ft)	Min Ch El (ft)	Water Depth (ft)	Travel Time (hrs)
3080.263	Martin Luther King Jr. Dr.	816.93	759.4	57.53	0.15
343.4128	CSX Bridge	699.79	693.68	5.81	0.2

100 Year Dam Failure Limits
PMF Dam Failure Limits
River Centerline
Critical Cross Section
Critical Structure - PMF Dam Failure
Proposed Road Blocks
10' Contours
1% Annual Change (100 yr); Floodplain

NOTES:
1. 100-YEAR FLOOD LIMITS OBTAINED FROM CUYAHOGA COUNTY FLOOD INSURANCE STUDY (STUDY NO. 39035CV001A, DATED DECEMBER 3, 2010)
2. POTENTIAL AFFECTED AREAS SHOWN ARE A COMPOSITE OF 100-YEAR AND PROBABLE MAXIMUM FLOOD (PMF) FAILURES. EVACUATION FOR 100-YEAR FAILURE IS THE SAME FOR THE SUNNY DAY FAILURE. ONLY THE 100-YEAR FLOOD AND PROBABLE MAXIMUM FLOOD FAILURE LIMITS ARE SHOWN FOR CLARITY.
3. BECAUSE OF THE METHOD, PROCEDURES, AND ASSUMPTIONS USED TO DEVELOP THE FLOODED AREAS, THE LIMITS OF FLOODING SHOWN ARE APPROXIMATE AND SHOULD BE USED ONLY AS A GUIDELINE FOR ESTABLISHING EVACUATION ZONES. ACTUAL AREAS INUNDATED WILL DEPEND ON ACTUAL FAILURE CONDITIONS, DEBRIS JAMS, AND OTHER FACTORS AND MAY DIFFER FROM AREAS SHOWN ON MAPS.
4. TIMES TO PEAK FOR 100-YEAR AND PMF ARE FOR FLOODWAVE PEAK ARRIVAL TIMES. AREAS OF INUNDATION WILL EXPERIENCE FLOODING PRIOR TO THE FLOOD WAVE PEAK.

0 37.5 75 150 Meters

0 125 250 500 Feet

Main Dike Failure

NEORSD
Lower Shaker Lake Dam
Dam Break Analysis
Shaker Heights, OH

AECOM

Figure D
Failure Inundation Map 2

My opinion:

- ODNR documents state clearly that Lower Lake's "Class I" status was driven entirely by having University Circle in the floodplain
- AECOM's Emergency Action Plan modeling provides much more detail about how floodwater gets into University Circle.
    - The current dam does NOT cause Class I hazards from the "sunny-day failure" scenario
    - The PMF is definitely a flood but it does NOT seem to be worsened if the dam failure. (FEMA guidance seems to suggests this should matter but I don't know if ODNR agrees.)
    - In between: the 5" storm is very informative about how far to scale down the new dam/lake in pursuit of Class II reclassification.