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Consulting Engineers

MEMORANDUM

PROJECT:	Full Spectrum Detention Study Muller Project #13-058.01
TO:	Ted Christianson / City and County of Denver Ken MacKenzie / UDFCD
FROM:	Sam Rogers / Muller Engineering Company Jim Wulliman / Muller Engineering Company
DATE:	October 6, 2015
SUBJECT:	Full Spectrum Innovation and Implementation

Muller Engineering Company has completed an evaluation of several variations in the application of full spectrum detention basins (FSD) within two test watersheds. The study focuses on optimizing the use of FSD basins versus detention basins sized solely for the excess urban runoff volume (EURV) or water quality capture volume (WQCV) in various portions of actual and synthetic watersheds. The evaluation was accomplished by analyzing the peak 100-year flow rate at the outfall point for each watershed using CUHP version 1.4.3 and EPA SWMM 5 for various detention basin applications.

Two watersheds were examined in this study. The first is a synthetic watershed composed of ten identical 100 acre sub-watersheds modeled with hydrologic parameters typical of the Denver metropolitan area, herein known as the “Synthetic Denver Watershed”. The second is the 3.2 square mile Harvard Gulch watershed, located in south Denver. Three tasks requested by Denver were completed to address the scope of work for the project and are outlined in the sections that follow.

TASK 1: FULL SPECTRUM OPTIMIZATION

The first task evaluated various “beat the peak” scenarios. Earlier studies showed that in a fully-detained watershed, implementing FSD in the upper portions and basins that are sized solely for EURV in the downstream portions resulted in outflows from the watershed that were even lower than from FSD implemented throughout the watershed. The objective of this task was to further refine this analysis and find out if there was a consistent “sweet spot” in the ratio of upstream FSD to downstream EURV to yield the lowest outflows from a watershed. The benefit that EURV or WQCV basins provide is the option to construct a smaller detention basin and use less land area in relation to a FSD detention basin. These optimizations help to show the most effective ratio of upstream FSD to downstream EURV or WQCV basins.

Ratios of upstream FSD to downstream EURV from 100% FSD/0% EURV to 60% FSD/40% EURV were analyzed. For each ratio, a 100-year storm event was routed through each hydrologic model and the associated peak flow rate at the outfall was documented. The analysis was then repeated for downstream basins sized solely for the WQCV instead of EURV.

SYNTHETIC DENVER WATERSHED

Approach

Ten 100-acre sub-watersheds were assembled in CUHP and SWMM and modeled using 2-hour, 100-year design storms consistent with Denver-area rainfall based on the USDCM. Each sub-watershed was assigned an on-line detention basin that used the same depth versus area storage curve for each basin. Three different outlet rating curves were developed for the detention basins from tabular results for outflow versus headwater depth calculated through weir and orifice equations. The first rating curve was based on FSD only, consisting of an outlet box with four orifices and an outlet pipe. The second rating curve factors in an overflow spillway set at the EURV water surface for a 72-hour drain time, thus allowing for higher outflows in the upper stages. The third rating curve lowers the same spillway to the WQCV water surface for a 40-hour drain time, thus allowing for higher flows at stages lower than the second rating curve.

The SWMM model was first set up with all ten sub-watersheds utilizing the FSD rating curve to represent 100% FSD coverage. The hydraulic model was executed by routing all the basins with the kinematic wave equation and the resulting peak outflow at the watershed outfall point was recorded. Next, the rating curve for the downstream basin was changed to the EURV curve, thus shifting the ratio to 90% FSD and 10% EURV. The hydraulic model was executed again and the resulting peak outflow recorded. In this iterative manner, each basin just upstream from the previously changed basin was adjusted to the EURV curve, shifting the ratio by 10% each time and recording the outfall flow. Because having FSD in the middle of watersheds is critical to efficient watershed function, the analysis ended at a ratio of 60% upstream FSD to 40% downstream EURV. The same analysis was then performed for FSD / WQCV coverage by changing the outlet rating curves to the WQCV rating curves.

Results

The results from the Synthetic Denver Watershed optimization are shown in **Figure 1** and in **Table 1**. The analysis indicates an optimal ratio of 80% upstream FSD to 20% downstream EURV or WQCV. As a baseline, 100% FSD implementation yields a peak flow of 1231 cfs at the outfall, while at 80% FSD coverage, the model yields a peak flow of 1178 cfs using downstream EURV detention, and a slightly lower peak flow of 1169 cfs using downstream WQCV detention.

Table 1 - 100-year Storm Event, Synthetic Denver Watershed

Detention Ratio	Peak Flow (cfs)	% Reduction from full FSD
100% FSD	1231	0.0%
90% FSD : 10% EURV	1192	3.2%
80% FSD : 20% EURV	**1178**	**4.3%**
70% FSD : 30% EURV	1194	3.0%
60% FSD : 40% EURV	1231	0.0%
90% FSD : 10% WQCV	1186	3.7%
80% FSD : 20% WQCV	**1169**	**5.0%**
70% FSD : 30% WQCV	1177	4.4%
60% FSD : 40% WQCV	1213	1.5%

HARVARD GULCH WATERSHED

Approach

The evaluation for the Harvard Gulch watershed was similar to the analysis for the Synthetic Denver Watershed. Various ratios of upstream FSD to downstream EURV or WQCV were modeled using CUHP and SWMM based on actual sub-watershed sizes and parameters. In this case, the ratios did not comprise even 10% increments, but a representative range of ratios were modelled.

Results

The results from the Harvard Gulch Watershed modelling indicate an optimal ratio of approximately 80% upstream FSD to 20% downstream EURV or WQCV. This is essentially the same "sweet spot" as the Synthetic Watershed analysis. As a baseline, 100% FSD implementation yields a peak flow of 2392 at the outfall, while at 82.3% FSD coverage, the model yields a peak flow rate of 2367.4 cfs using EURV detention, and 2367.8 cfs using WQCV detention. Unlike the synthetic watershed, the downstream WQCV basins did not produce noticeably lower flows than the EURV basins.

Table 2 - 100-year Storm Event, Harvard Gulch Watershed

Detention Ratio	Peak Flow (cfs)	% Reduction from No Detention
No Detention	3095	0.0%
100% FSD	2392	22.7%
86% FSD : 14% EURV	2378	23.1%
82% FSD : 18% EURV	**2367**	**23.5%**
76% FSD : 24% EURV	2368	23.5%
71% FSD : 29% EURV	2420	21.8%
86% FSD : 14% WQCV	2380	23.1%
82% FSD : 18% WQCV	**2368**	**23.5%**
76% FSD : 24% WQCV	2368	23.5%
71% FSD : 29% WQCV	2421	21.8%

Results from the Harvard Gulch Watershed optimization are shown in **Table 2 and Figures 2 & 3**.

TASK 2: IMPROVING RESULTS OF DOWNSTREAM EURV BASIN WHEN NO DETENTION IS USED IN UPSTREAM WATERSHED

Task 2 focused on the Synthetic Denver Watershed model that featured 10% downstream EURV detention and all upstream sub-watersheds having no detention. It was found in prior modeling that a basin that drains the EURV in 72 hours results in a 100-year outflow of 2701 cfs, which is 1% greater than the watershed outflow with no detention (2685 cfs). Several approaches were used to assess whether an EURV basin in the downstream 10% of the watershed could achieve a peak watershed outflow equal to or less than the no-detention scenario.

The first approach used was to modify the drain time for the EURV from 72 hours to 52 hours, which is the minimum recommended drain time in the updated draft USDCM. Speeding up the drain time to 52 hours actually increases the outflow to 2706 cfs. **Figure 4** shows these results in comparison to the no-detention scenario and the results for a model with 10% FSD at the downstream end and the upstream 90% with no detention.

The second approach was to decrease the length of the spillway crest set at the EURV water surface. The results indicate that reducing the spillway crest length will decrease the peak flow at the downstream end of the watershed. A spillway sized for a head of 1.0 foot based on the undetained 100-year flow (length equal to the 100-year undetained flow divided by 3) will achieve the same watershed outflow as the scenario that has no detention in the entire watershed. Further decreasing the spillway length keeps reducing the watershed outflow rate to a point where it eventually equals the outflow rate for a FSD basin in the downstream 10% of the watershed. At that point, the 100-year water surface in the EURV detention basin with a shortened spillway equals the 100-year water surface in a FSD basin, making the two types of basins essentially equivalent in storage volume, area, and effect on watershed outflows. These results are indicated in **Figure 5**.

TASK 3: ORIFICE SIZE VARIATION

Task 3 assessed the impact of draining the EURV faster by placing an orifice at half the WQCV depth and checking the effect on watershed outflow rate associated with increasing the orifice size. Task 3 was modeled using the scenario of FSD in the upstream 90% of the watershed and EURV in the downstream 10% of the watershed. **Figure 6** indicates initial results. Substantially increasing the orifice discharge by lowering the orifice from the top of the WQCV to half the WQCV depth and further increasing the orifice size actually is shown to slightly increase the peak flow rate from the watershed. Since these results did not indicate a benefit associated with this approach, no further modeling was undertaken. Further modeling of Task 3 can be pursued if desired by Denver.

CONCLUSIONS

The full spectrum detention evaluation described above leads to several conclusions:

1. For a study area consisting of ten 100-acre sub-watersheds, the lowest 100-year peak discharge at the downstream end of the watershed was achieved with full-spectrum detention in the upstream 80 percent of the watershed and either WQCV or EURV basins in the downstream 20 percent of the watershed. WQCV basins in the downstream 20 percent of the watershed yielded slightly lower 100-year peak flows at the downstream end of the watershed than EURV basins.

2. For the Harvard Gulch watershed, the lowest 100-year peak discharge at the downstream end of the watershed was also achieved with full-spectrum detention in the upstream approximately 80 percent of the watershed and either WQCV or EURV basins in the downstream approximately 20 percent of the watershed. There wasn't a significant difference in 100-year peak flows between WQCV basins and EURV basins in the downstream 20 percent of the watershed.

3. For the study area consisting of ten 100-acre sub-watersheds with an EURV basin in the downstream sub-watershed, the most effective variable to achieve reduced 100-year peak flow rates at the downstream end of the watershed was the crest length of the spillway at the EURV water surface. Reducing the spillway length results in reduced 100-year peak flow rates. A crest length equal to the undetained 100-year flow rate divided by 3 (equivalent to a head of 1.0 foot for the undetained 100-year flow rate) or less yields 100-year peak flows at the downstream end of the watershed equal to or less than the peak flow rate with no detention.

4. For a watershed with FSD in the upstream 90% and EURV in the downstream 10%, no reduction in 100-year peak flows was achieved by increasing the discharge rate at half the WQCV depth. In fact, the larger the release rate at this elevation, the larger the overall downstream peak flow rate.

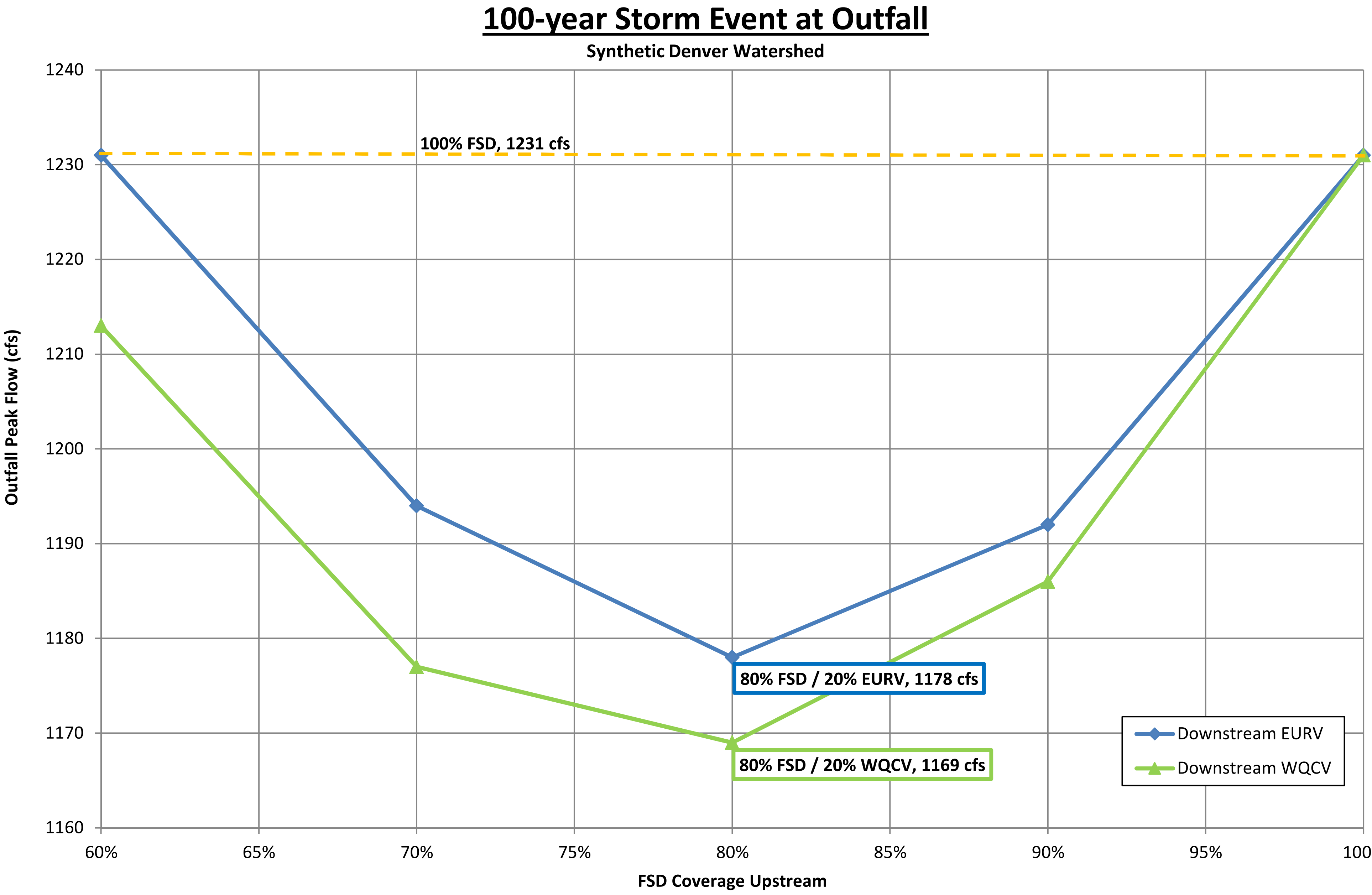

100-year Storm Event at Outfall
Synthetic Denver Watershed
Outfall Peak Flow (cfs)
1240
1230
1220
1210
1200
1190
1180
1170
1160
60%
65%
70%
75%
80%
85%
90%
95%
100%
FSD Coverage Upstream
100% FSD, 1231 cfs
80% FSD / 20% EURV, 1178 cfs
80% FSD / 20% WQCV, 1169 cfs
Downstream EURV
Downstream WQCV

Figure 1

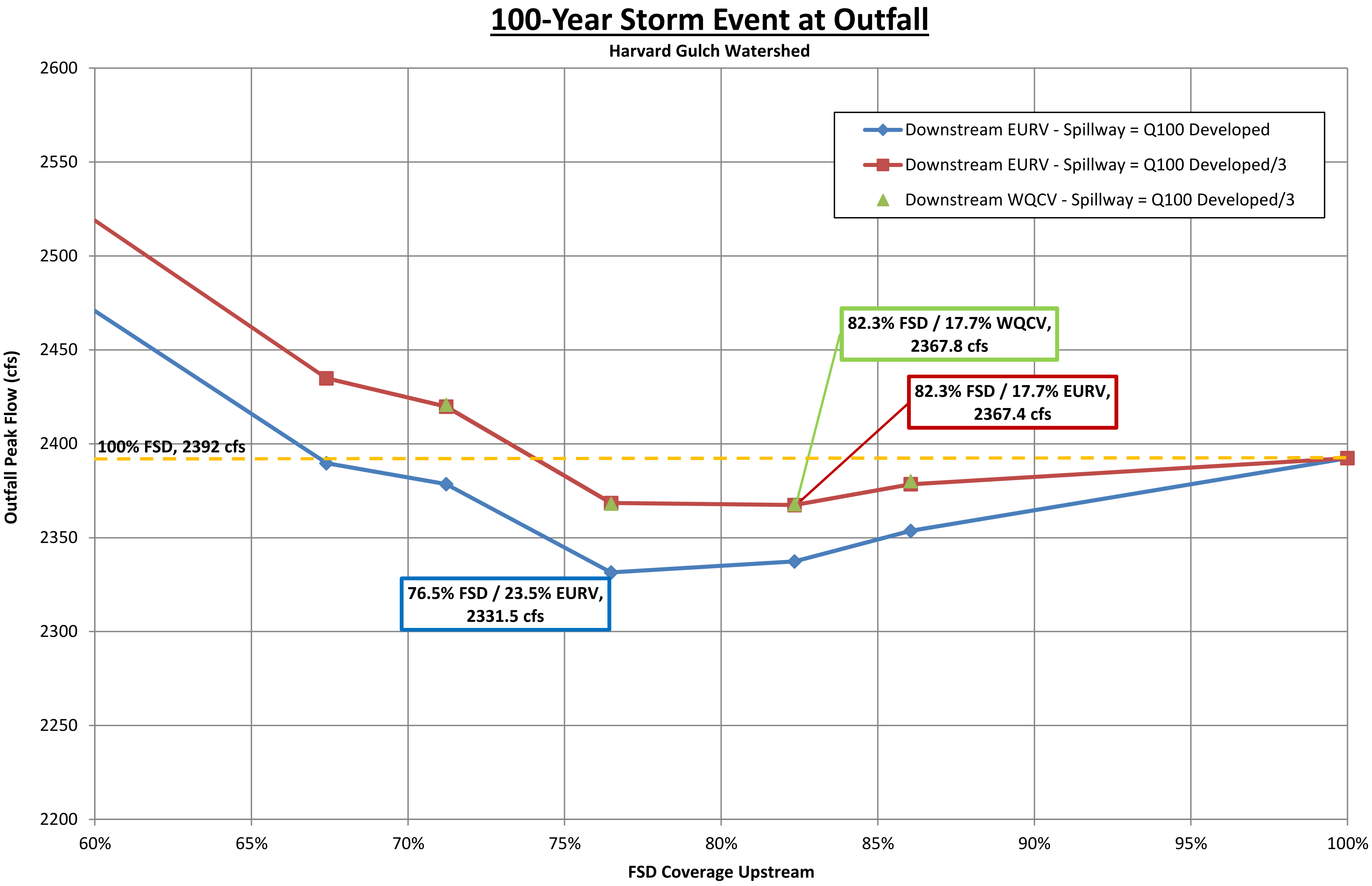

100-Year Storm Event at Outfall
Harvard Gulch Watershed
2600
2550
2500
2450
2400
2350
2300
2250
2200
Outfall Peak Flow (cfs)
60%
65%
70%
75%
80%
85%
90%
95%
100%
FSD Coverage Upstream
Downstream EURV - Spillway = Q100 Developed
Downstream EURV - Spillway = Q100 Developed/3
Downstream WQCV - Spillway = Q100 Developed/3
100% FSD, 2392 cfs
82.3% FSD / 17.7% WQCV, 2367.8 cfs
82.3% FSD / 17.7% EURV, 2367.4 cfs
76.5% FSD / 23.5% EURV, 2331.5 cfs

Figure 2

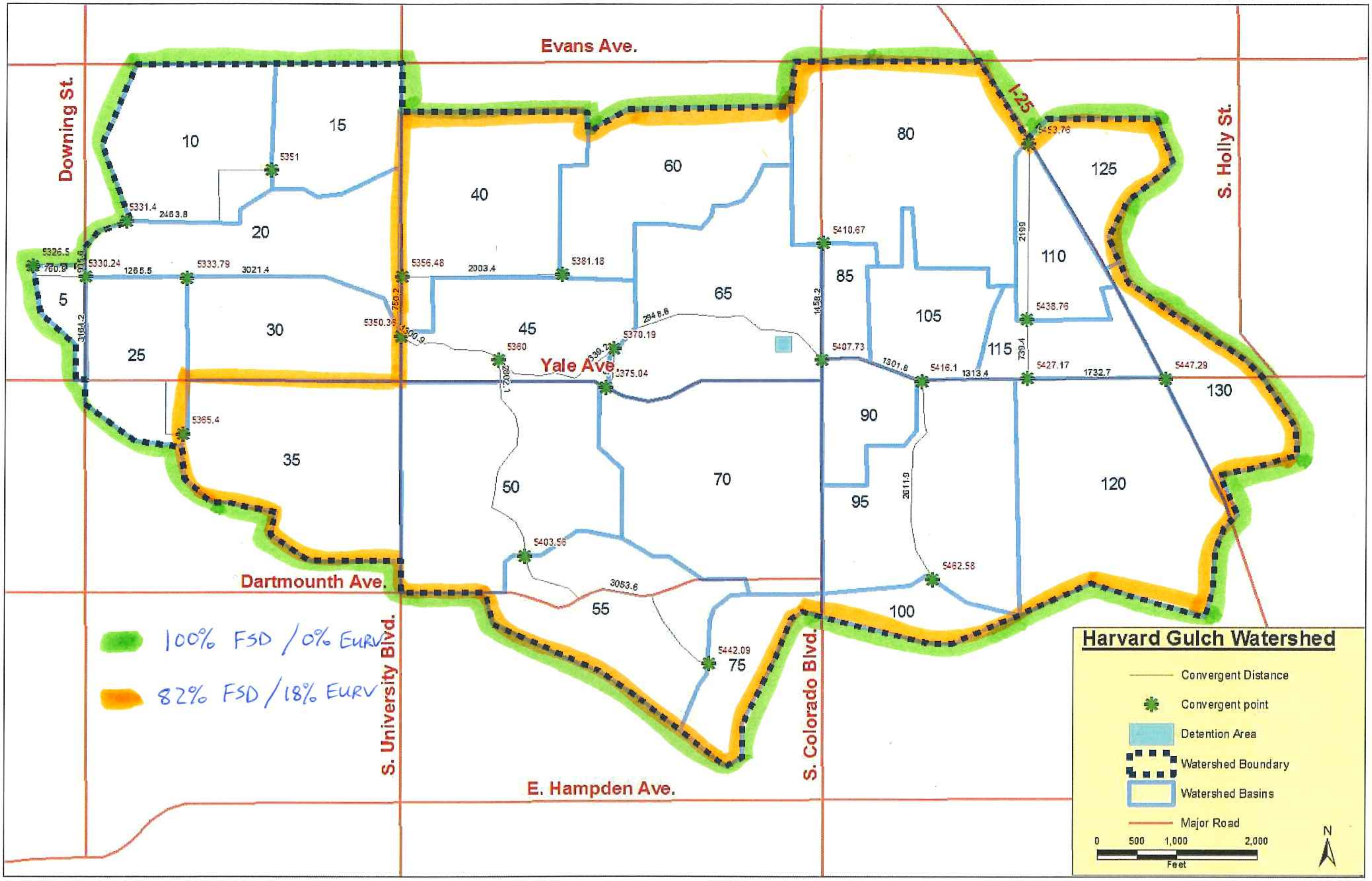
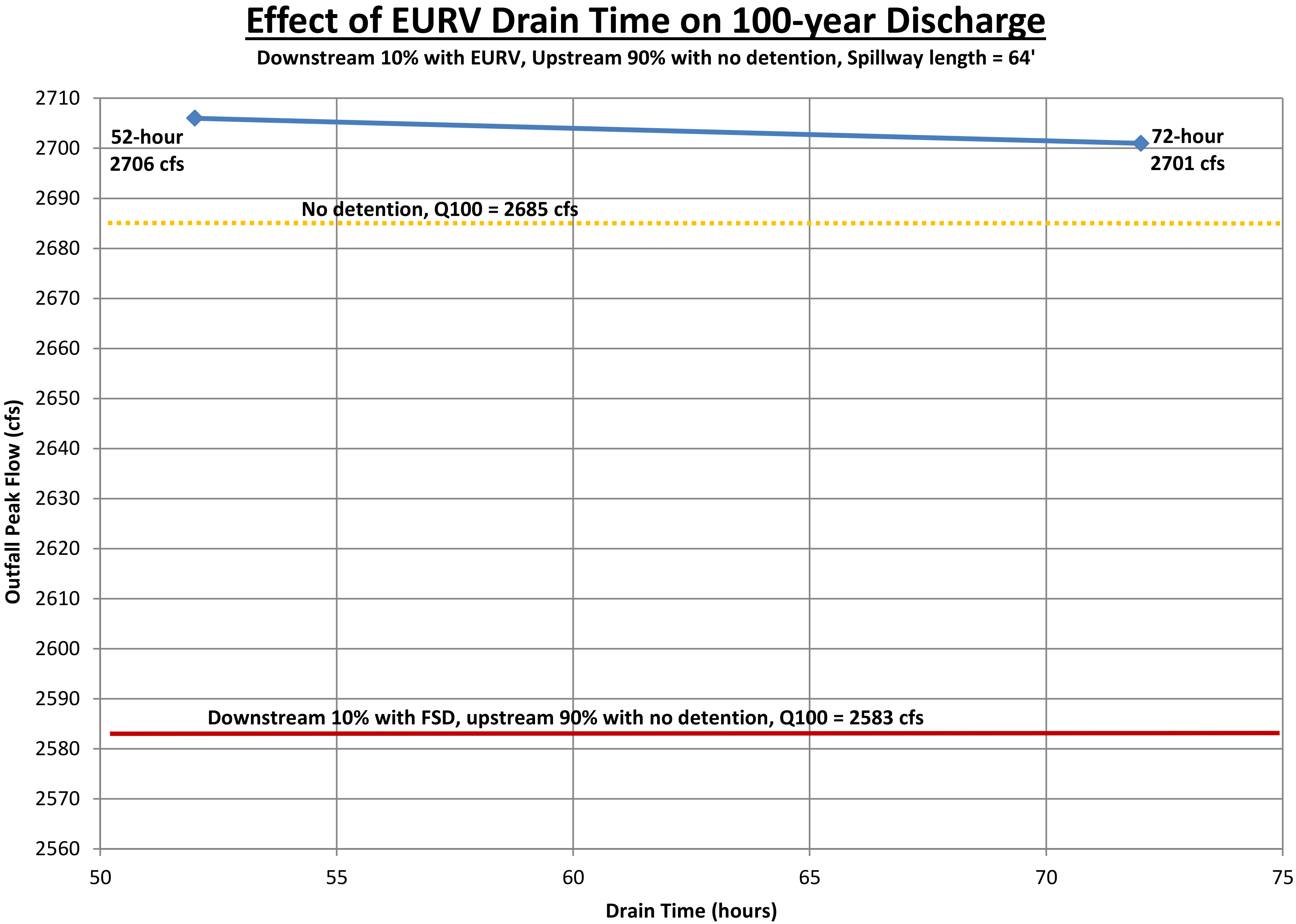

Harvard Gulch Watershed
Evans Ave.
Yale Ave.
Dartmouth Ave.
E. Hampden Ave.
Downing St.
S. University Blvd.
S. Colorado Blvd.
S. Holly St.
I-25
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
5351
5331.4
2463.8
5326.5
760.9
935.8
5330.24
1265.5
5333.79
3021.4
3184.2
5350.36
750.2
5356.48
2003.4
5361.18
5360
2802.1
5370.19
2948.6
5375.04
5365.4
5403.56
3053.6
5442.09
5410.67
1458.2
5407.73
7301.8
5416.1
1313.4
2611.9
5462.58
5453.76
2199
5438.76
739.4
5427.17
1732.7
5447.29
Convergent Distance
Convergent point
Detention Area
Watershed Boundary
Watershed Basins
Major Road
0
500
1,000
2,000
Feet
N
🟩 100% FSD / 0% EURV
🟧 82% FSD / 18% EURV

Figure 3



Effect of EURV Drain Time on 100-year Discharge

Downstream 10% with EURV, Upstream 90% with no detention, Spillway length = 64'

Figure 4

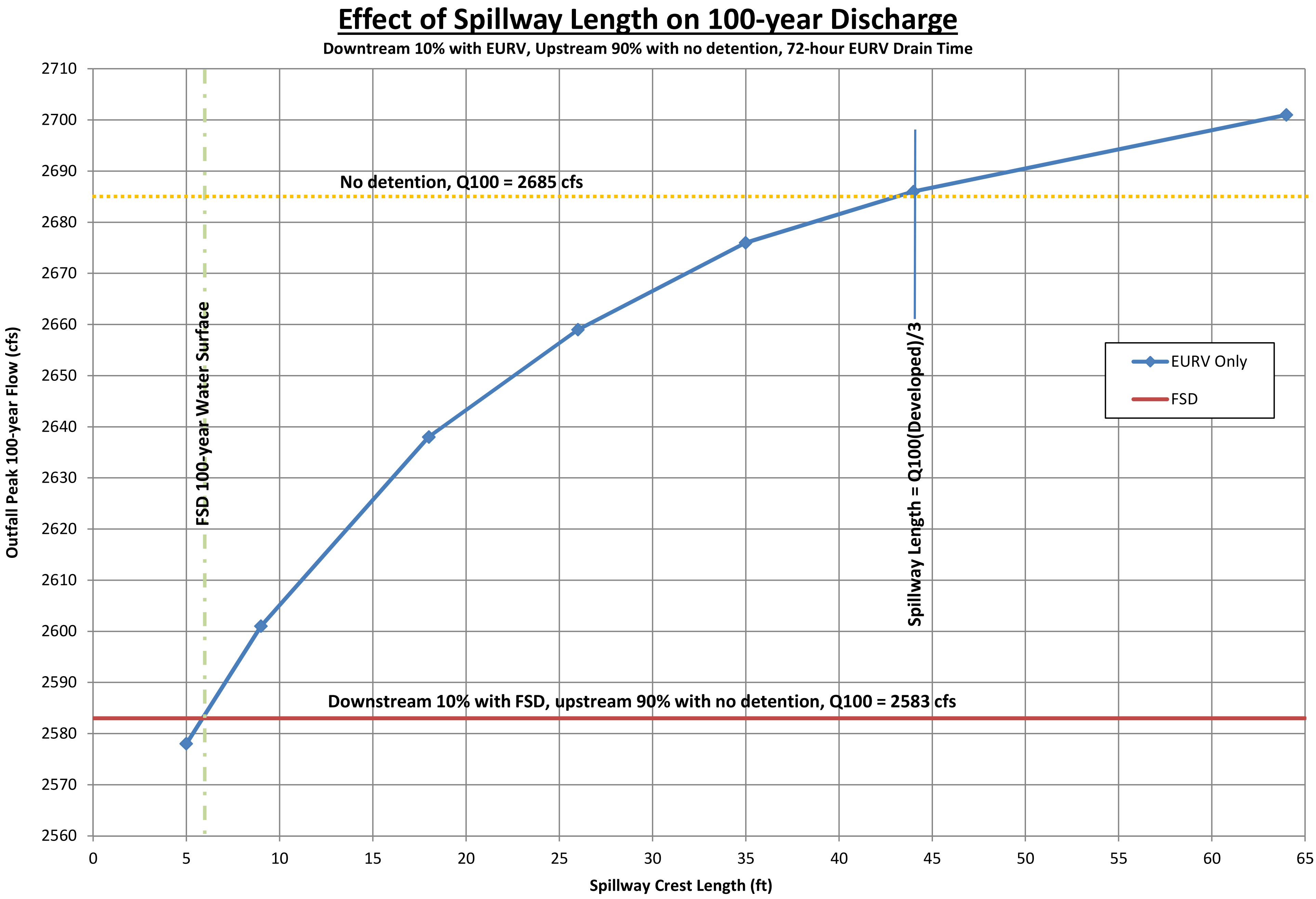

Effect of Spillway Length on 100-year Discharge
Downtream 10% with EURV, Upstream 90% with no detention, 72-hour EURV Drain Time
Outfall Peak 100-year Flow (cfs)
2710
2700
2690
2680
2670
2660
2650
2640
2630
2620
2610
2600
2590
2580
2570
2560
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Spillway Crest Length (ft)
No detention, Q100 = 2685 cfs
FSD 100-year Water Surface
Spillway Length = Q100(Developed)/3
Downstream 10% with FSD, upstream 90% with no detention, Q100 = 2583 cfs
EURV Only
FSD

Figure 5

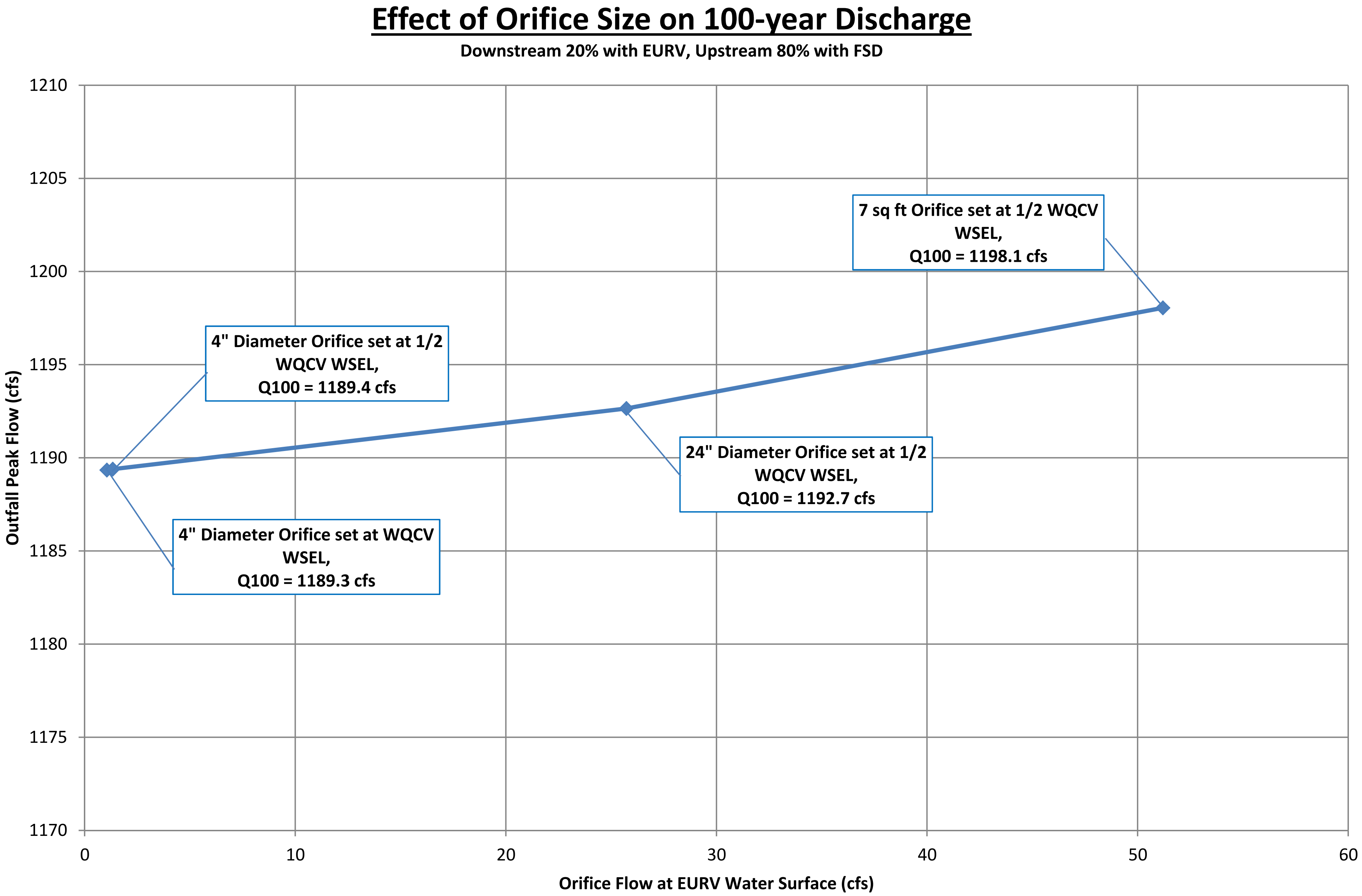

Effect of Orifice Size on 100-year Discharge
Downstream 20% with EURV, Upstream 80% with FSD
Outfall Peak Flow (cfs)
1210
1205
1200
1195
1190
1185
1180
1175
1170
0
10
20
30
40
50
60
Orifice Flow at EURV Water Surface (cfs)
7 sq ft Orifice set at 1/2 WQCV WSEL, Q100 = 1198.1 cfs
4" Diameter Orifice set at 1/2 WQCV WSEL, Q100 = 1189.4 cfs
24" Diameter Orifice set at 1/2 WQCV WSEL, Q100 = 1192.7 cfs
4" Diameter Orifice set at WQCV WSEL, Q100 = 1189.3 cfs

Figure 6