Civil & Environmental Consultants, Inc.
325 Seaboard Lane | Suite 170 | Franklin, Tennessee 37067
Phone: (615) 333-7797 | Fax: (615) 333-7751

MEMORANDUM

Date: May 1, 2019
To: Mr. Paul Holzen, P.E., LEED AP, City of Franklin
From: Eric J. Gardner, P.E., CPESC, Jeffrey B. Shaver, P.E., CFM, CPESC
Subject: Ralston Creek at Liberty Hills – Feasibility Study Summary
CEC Project No. 153-050

1.0 INTRODUCTION

CEC has completed a hydrologic and hydraulic analysis of Ralston Creek to determine potential solutions to address flooding and streambank erosion in the Royal Oaks Subdivision. The study area also included the Liberty Hills Subdivision retention pond, located east of the subdivision entrance from Liberty Pike. This analysis has been performed according to the Professional Services Agreement (COF Contract No. 2015-0356) approved on November 19, 2015 and amended on September 12, 2017.

The second phase of the hydrologic and hydraulic analysis was to delineate the 100-yr floodplain for Ralston Creek in the Royal Oaks Subdivision and around the Liberty Hills Pond. In addition, once the 100-yr floodplain was delineated potential solutions would be evaluated to reduce flooding during the 100-yr event upstream of Liberty Hills Drive. The goal for the potential solutions was to decrease the flooding upstream of Liberty Hills Drive while not increasing the outflow from the Liberty Hills Pond when compared to the existing conditions. The results of the extended flood study were displayed at the Project Public Meeting, held on November 8, 2018 and are depicted on the attached Figure 1 “Preliminary Flood Study”.

Since this analysis had multiple phases with varying objectives, the approach and results for each analysis phase are presented separately.

2.0 EXECUTIVE SUMMARY

CEC analyzed fifteen potential solutions to reduce flooding along Ralston Creek and around the Liberty Hills Pond. The first phase analyzed eleven potential solutions that showed flooding along Ralston Creek due to the lower more frequent rainfall events could be reduced through modifications to the Liberty Hills Pond. However, in most instances a reduction in outflow from the pond resulted in an increase in the pond water elevation. Five of the potential solutions showed a reduction in both the pond outflow and pond water elevation, however they were either trending toward potential increases during larger rainfall events, provided minimal reductions in the pond outflow such that it would not provide a noticeable reduction in flooding along Ralston Creek, or were “extreme”

solutions that may not be acceptable. The "extreme" solutions would require the Liberty Hills Pond to be changed from a neighborhood amenity to an unsightly flood control facility (e.g. drain pond and construct walls around pond to increase storage volume). It was also determined that the cost-benefit ratio of the "extreme" solutions would provide little relief for a relatively large cost.

In simple terms, the analysis shows releasing stormwater from the pond at a slower rate requires additional storage volume for the pond, which has the potential of increased flooding for the properties adjacent to the Liberty Hills Pond. Subsequently, modifying the outlet structure to release stormwater quicker resulted in the potential for increased flooding downstream of the pond along Ralston Creek.

The second phase analyzed four additional potential solutions which showed there is not a solution that will lower the pond water elevation a measurable amount for the 100-yr event while not increasing the outflow from the pond. The extended flood study also indicated that the majority of the houses adjacent to the right descending bank of Ralston Creek downstream of Liberty Hills Drive are located in the base flood (100-year) floodplain in the existing condition.

CEC recommends that the City not make modifications to the Liberty Hills Pond outlet structure and storage capacity. The following information provide a detailed description of the existing conditions and each of the potential solutions that were evaluated. The following details describes the modifications that would be required with each option, a table with the results from the analysis, and CEC's reason for not recommending the option.

3.0 FLOODING AND STREAMBANK EROSION ANALYSIS

The initial phase of the analysis was to evaluate potential solutions for flooding due to the lower more frequent rainfall events downstream of the Liberty Hills Pond. The goal for the potential solutions is to decrease the outflow from the Liberty Hills Pond while not increasing the water elevation in the pond when compared to the existing conditions.

The analysis included measuring the Liberty Hills Pond's response to rainfall events by collecting rainfall depth, water level in the pond, and flow leaving the pond over a 21 month time period. The field data that was collected was used to calibrate a hydrologic computer model to simulate existing field conditions so potential solutions to address flooding and streambank erosion along Ralston Creek could be evaluated. The calibration of the hydrologic computer model also included use of a hydraulic computer model to evaluate flow depth measurements and photographs provided by a resident along Ralston Creek downstream of the Liberty Hills Pond. The resulting flows from this model were lower than the regression equations produced but are extrapolated from field measurements.

Since there was not a rainfall event during the field data collection period that equaled or exceeded the 1-yr, 24-hr rainfall depth, as defined by NOAA Atlas 14, this phase of the analysis was limited to the 1-yr through 10-yr rainfall events when evaluating potential solutions. Table 1 shows the rainfall depths used in the analysis; other than the observed maximum, the other design storm depths are from NOAA Atlas 14. The potential solutions which were evaluated included modifications to

the existing Liberty Hills Pond's outlet structure, modification to the Liberty Hills Pond's storage volume, and combinations of the outlet structure and storage volume modifications.

Table 1 - Rainfall Depths

Event	Rainfall Depth (in)
Observed (Max)	2.16
1-YR, 24-HR	3.09
2-YR, 24-HR	3.69
5-YR, 24-HR	4.49
10-YR, 24-HR	5.14

During the Project Public Meeting, held on November 8, 2018, attendees asked if the pond could be excavated deeper to create additional volume. It was explained that volume created below the outlet control structure would not create additional detention, as the pond would fill to the elevation of the outlet structure and remain at that level. This alternative was not analyzed in the hydrologic computer model since only additional storage excavated above the existing pond water elevation would be effective in reducing the pond water elevation during rainfall events.

3.1 Existing Outlet Structure

The existing outlet structure for the Liberty Hills Pond consists of two concrete elliptical culverts under Liberty Hills Drive with a weir box located on their upstream end. The weir box is a rectangular box with four smaller triangular weirs as shown on Figure EX-1, "Existing Outlet Structure". The invert of the triangular weirs are approximately 5 inches above the invert of the elliptical culverts. The normal pond depth for the existing condition is approximately 3'-2". Table 2 shows how flow is attenuated for the existing condition.

Table 2 - Existing Outlet Structure Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)
Observed (Max)	709.40	64.88	45.53	29.8
1-YR, 24-HR	709.52	74.29	49.09	33.9
2-YR, 24-HR	710.44	121.71	69.86	42.6
5-YR, 24-HR	712.48	235.25	101.41	56.9
10-YR, 24-HR	713.83	327.12	117.67	64.0

3.2 Modified Outlet Structure 1 (MOS-1)

Modified Outlet Structure 1 consists of replacing one of the existing triangular weirs with a 4-inch rectangular weir as shown on Figure MOS-1, "Modified Outlet Structure 1". The invert of the proposed 4-inch rectangular weir would be constructed at the same elevations as the invert of existing elliptical culverts. The remaining portions of the existing outlet structure would remain unchanged. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 3 shows how the flow is attenuated for this alternative.

Table 3 - Modified Outlet Structure 1 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.05	64.88	46.62	28.1	2.4	-0.35
1-YR, 24-HR	709.23	74.29	51.39	30.8	4.7	-0.29
2-YR, 24-HR	710.16	121.71	71.09	41.6	1.8	-0.28
5-YR, 24-HR	712.26	235.25	102.43	56.5	1.0	-0.22
10-YR, 24-HR	713.66	327.12	118.78	63.7	0.9	-0.17

Increase Decrease

This alternative when compared to the existing outlet structure would increase the outflow from the Liberty Hills Pond between 0.9% - 4.7% while lowering the pond water elevation. This alternative was not selected to move forward with additional analysis since it would increase flows with the potential to increase flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.3 Modified Outlet Structure 2 (MOS-2)

Modified Outlet Structure 2 consists of replacing one of the existing triangular weirs with a 6-inch rectangular weir as shown on Figure MOS-2, "Modified Outlet Structure 2". The invert of the proposed 6-inch rectangular weir would be constructed at the same elevations as the invert of existing elliptical culverts. The remaining portions of the existing outlet structure would remain unchanged. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 4 shows how the flow is attenuated for this alternative.

Table 4 - Modified Outlet Structure 2 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.03	64.88	47.09	27.4	3.4	-0.37
1-YR, 24-HR	709.20	74.29	51.83	30.2	5.6	-0.32
2-YR, 24-HR	710.12	121.71	71.96	40.9	3.0	-0.32
5-YR, 24-HR	712.21	235.25	104	55.8	2.6	-0.27
10-YR, 24-HR	713.61	327.12	120.73	63.1	2.6	-0.22

Increase Decrease

This alternative when compared to the existing outlet structure would increase the outflow from the Liberty Hills Pond between 2.6% - 5.6% while lowering the pond water elevation. This alternative was not selected to move forward with additional analysis since it would increase flows with the potential to increase flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.4 Modified Outlet Structure 3 (MOS-3)

Modified Outlet Structure 3 consists of replacing one of the existing triangular weirs with a 6-inch rectangular weir as shown on Figure MOS-3, "Modified Outlet Structure 3". The invert of the proposed 6-inch rectangular weir would be constructed at the same elevations as the invert of existing elliptical culverts. The remaining three existing triangular weirs would be filled (removed) from the weir box. The remaining portions of the existing outlet structure would remain unchanged. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 5 shows how the flow is attenuated for this alternative.

Table 5 - Modified Outlet Structure 3 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.18	64.88	43.48	33.0	-4.5	-0.22
1-YR, 24-HR	709.39	74.29	48.06	35.3	-2.1	-0.13
2-YR, 24-HR	710.37	121.71	65.55	46.1	-6.2	-0.07
5-YR, 24-HR	712.51	235.25	92.85	60.5	-8.4	0.03
10-YR, 24-HR	713.9	327.12	106.93	67.3	-9.1	0.07

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 2.1% - 9.1%. The pond water elevations would decrease for the 1-yr and 2-yr rainfall events and would increase for the 5-yr and 10-yr rainfall events. This alternative was not selected to move forward with additional analysis since has the potential to increase the pond water surface elevation for the higher rainfall events.

3.5 Modified Outlet Structure 4 (MOS-4)

Modified Outlet Structure 4 consists of removing the existing weir box that is located in front of the elliptical culverts under Liberty Hills Drive and removing one of the elliptical culverts under Liberty Hills Drive as shown on Figure MOS-4, "Modified Outlet Structure 4". The invert of the remaining elliptical culvert would remain at its current elevation. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 6 shows how the flow is attenuated for this alternative.

Table 6 - Modified Outlet Structure 4 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	708.84	64.88	47.13	27.4	3.5	-0.56
1-YR, 24-HR	708.91	74.29	50.2	32.4	2.3	-0.61
2-YR, 24-HR	709.66	121.71	83.13	31.7	19.0	-0.78
5-YR, 24-HR	711.21	235.25	151.67	35.5	49.6	-1.27
10-YR, 24-HR	712.43	327.12	188.02	42.5	59.8	-1.40

Increase Decrease

This alternative when compared to the existing outlet structure would increase the outflow from the Liberty Hills Pond between 2.3% - 59.8% while lowering the pond water elevation. This alternative was not selected to move forward with additional analysis since it would increase flows with the potential to increase flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.6 Modified Outlet Structure 5 (MOS-5)

Modified Outlet Structure 5 consists of removing the existing outlet structure completely and replacing it with one 48" reinforce concrete pipe as shown on Figure MOS-5, "Modified Outlet Structure 5". The invert of the proposed 48" RCP would set at the same invert elevation as the existing elliptical culverts. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 7 shows how the flow is attenuated for this alternative.

Table 7 - Modified Outlet Structure 5 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.12	64.88	40.73	37.2	-10.5	-0.28
1-YR, 24-HR	709.23	74.29	43.51	41.4	-11.4	-0.29
2-YR, 24-HR	710.13	121.71	69.30	43.1	-0.8	-0.31
5-YR, 24-HR	712.07	235.25	110.54	53.0	9.0	-0.41
10-YR, 24-HR	713.43	327.12	131.23	59.9	11.5	-0.40

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 0.8% - 11.4% for the 1-yr and 2-yr rainfall events and would increase the outflow from the Liberty Hills Pond between 9% - 11.5% for the 5-yr and 10-yr rainfall events. The pond water elevation would decrease with this alternative. This alternative was not selected to move forward with additional analysis since it would increase flows with the potential to increase flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.7 Modified Outlet Structure 6 (MOS-6)

Modified Outlet Structure 6 consists of removing the existing outlet structure completely and replacing it with a new weir box with a combination triangular and rectangular weir. The invert elevation is set at the existing pond bottom elevation. One of the existing elliptical culverts would be reinstalled under Liberty Hills Drive with an invert elevation set at the existing pond bottom elevation. Figure MOS-6, "Modified Outlet Structure 6" shows the proposed outlet structure configuration. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 8 shows how the flow is attenuated for this alternative.

Table 8 - Modified Outlet Structure 6 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	708.44	64.88	28.58	55.9	-37.2	-0.96
1-YR, 24-HR	708.73	74.29	32.86	55.8	-33.1	-0.79
2-YR, 24-HR	709.93	121.71	51.37	57.8	-26.5	-0.51
5-YR, 24-HR	712.24	235.25	83.22	64.6	-17.9	-0.24
10-YR, 24-HR	713.72	327.12	99.25	69.7	-15.7	-0.11

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 15.7% - 37.2% while also decreasing the pond water elevation. However, the decrease in outflow and water elevation is getting smaller as the rainfall depth increases for the larger events. This trend supports the assumption that by removing one of the elliptical culverts under Liberty Hills Drive the pond water elevation would increase for the larger rainfall events which were not included in this analysis. This alternative was not selected to move forward with additional analysis since it had the potential to increase the pond water surface elevation for the higher rainfall events.

3.8 Modified Pond Storage 1 (MPND-1)

Modified Pond Storage 1 consists of increasing the storage volume by excavating the area shown on Figure MPND-1, "Modified Pond Storage 1". The existing outlet structure would not be modified for this alternative. The normal pond depth for this alternative would remain the same as the existing conditions. Table 9 shows how the flow is attenuated for this alternative.

Table 9 - Modified Pond Storage 1 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.32	64.88	43.32	33.2	-4.9	-0.08
1-YR, 24-HR	709.44	74.29	46.81	37.0	-4.6	-0.08
2-YR, 24-HR	710.32	121.71	67.58	44.5	-3.3	-0.12
5-YR, 24-HR	712.35	235.25	99.78	57.6	-1.6	-0.13
10-YR, 24-HR	713.74	327.12	116.64	64.3	-0.9	-0.09

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 0.9% - 4.9% while also decreasing the pond water elevation. This alternative was not selected to move forward with additional analysis since the decrease in the outflow from the pond is not large enough to notice a reduction in flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.9 Modified Pond Storage 2 (MPND-2)

Modified Pond Storage 2 consists of increasing the storage volume by constructing a retaining wall around the pond and excavating the area shown on Figure MPND-2, “Modified Pond Storage 2”. The existing outlet structure would not be modified for this alternative. The normal pond depth for this alternative would remain the same as the existing conditions. Table 10 shows how the flow is attenuated for this alternative.

Table 10 - Modified Pond Storage 2 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.12	64.88	36.16	44.3	-20.6	-0.28
1-YR, 24-HR	709.19	74.29	38.93	47.6	-20.7	-0.33
2-YR, 24-HR	709.79	121.71	56.16	53.9	-19.6	-0.65
5-YR, 24-HR	711.33	235.25	85.24	63.8	-15.9	-1.15
10-YR, 24-HR	712.63	327.12	103.35	68.4	-12.2	-1.20

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 12.2% - 20.7% while also decreasing the pond water elevation. This alternative was analyzed as an “extreme” alternative to see the impacts of maximizing storage in the Liberty Hills Pond. This alternative was not selected to move forward with additional analysis due to the aesthetics of having a retaining wall surrounding the pond. The retaining wall would have the potential to limit access to the pond and affect adjacent property owners by having a drop off located

at their property line in lieu of a slope down to the pond. This alternative also had diminishing attenuation as the storm depths increased.

3.10 Combination Modifications 1 (COMB-1)

Combination Modifications 1 included modifying the existing outlet structure of Liberty Hills Pond as described above for Modified Outlet Structure 5 and modifying the pond storage as described above in Modified Pond Storage 1. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 11 shows how the flow is attenuated for this alternative.

Table 11 - Combination Modifications 1 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.03	64.88	38.35	40.9	-15.8	-0.37
1-YR, 24-HR	709.13	74.29	40.97	44.9	-16.5	-0.39
2-YR, 24-HR	710.01	121.71	65.77	46.0	-5.9	-0.43
5-YR, 24-HR	711.92	235.25	108.06	54.1	6.6	-0.56
10-YR, 24-HR	713.31	327.12	129.53	60.4	10.1	-0.52

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 5.9% - 16.5% for the 1-yr and 2-yr rainfall events and would increase the outflow from the Liberty Hills Pond between 6.6% - 10.1% for the 5-yr and 10-yr rainfall events. The pond water elevation would decrease with this alternative. This alternative was analyzed to evaluate if adding additional storage to the pond would work with Modified Outlet Structure 5 to decrease the outflow from the pond for the rainfall events used for this analysis while not increasing the water elevation in the pond. This alternative was not selected to move forward with additional analysis since it would increase flows with the potential to increase flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.11 Combination Modifications 2 (COMB-2)

Combination Modifications 2 included modify the existing outlet structure of Liberty Hills Pond as described above for Modified Outlet Structure 3 and modifying the pond storage as described above in Modified Pond Storage 1. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. Table 12 shows how the flow is attenuated for this alternative.

Table 12 - Combination Modifications 2 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	709.10	64.88	41.57	35.9	-8.7	-0.30
1-YR, 24-HR	709.32	74.29	46.5	37.4	-5.3	-0.20
2-YR, 24-HR	710.25	121.71	63.76	47.6	-8.7	-0.19
5-YR, 24-HR	712.38	235.25	91.42	61.1	-9.9	-0.10
10-YR, 24-HR	713.8	327.12	105.97	67.6	-9.9	-0.03

Increase Decrease

This alternative when compared to the existing outlet structure would decrease the outflow from the Liberty Hills Pond between 5.3% - 9.9%. The pond water elevation would decrease with this alternative. This alternative was analyzed to evaluate if adding additional storage to the pond would work with Modified Outlet Structure 3 to decrease the outflow from the pond for the rainfall events used for this analysis while not increasing the water elevation in the pond. This alternative was not selected to move forward with additional analysis since the decrease in the outflow from the pond is not considered large enough to notice a reduction in flooding and streambank erosion in Ralston Creek downstream of Liberty Hills Drive.

3.12 Combination Modifications 3 (COMB-3)

Combination Modifications 3 included modifying the existing outlet structure of Liberty Hills Pond as described above for Modified Outlet Structure 6 and modifying the pond storage as described above in Modified Pond Storage 2. This alternative would lower the permanent water surface of the Liberty Hills Pond approximately 5 inches. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 13 shows how the flow is attenuated for this alternative.

Table 13 - Combination Modifications 3 Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
Observed (Max)	708.37	64.88	27.62	57.4	-39.3	-1.03
1-YR, 24-HR	708.58	74.29	30.63	58.8	-37.6	-0.94
2-YR, 24-HR	709.33	121.71	42.15	65.4	-39.7	-1.11
5-YR, 24-HR	711.01	235.25	67.79	71.2	-33.2	-1.47
10-YR, 24-HR	712.37	327.12	84.75	74.1	-28.0	-1.46

Increase Decrease

This alternative when compared to the existing conditions would decrease the outflow from the Liberty Hills Pond between 28% - 39.7% while also decreasing the pond water elevation. This alternative was analyzed as an "extreme" alternative to see the impacts of maximizing storage in the Liberty Hills Pond by draining the pond and constructing a retaining wall to allow additional excavation. This alternative was not selected to move forward with additional analysis due to the aesthetics of having a retaining wall surrounding the pond area and the existing pond being drained. The retaining wall would have the potential to limit access to the pond area and affect adjacent property owners by having a drop off located at their property line in lieu of a slope down to the pond area. This alternative also had diminishing attenuation as the storm depths increased.

4.0 EXTENDED FLOOD STUDY ANALYSIS

Since this analysis was to extend the existing hydraulic model which supports the Effective FEMA Flood Insurance Study (FIS) for Ralston Creek, the hydrologic method for calculating peak flow was not changed from that used in the FIS. The flows were calculated using the same regression equations used for the Effective FIS model. In addition, to evaluate the outflow from the Liberty Hills Pond for the potential solutions, a separate hydrologic computer model was developed and calibrated to the regression equation peak flows. Table 14 shows the peak flows used for the extended flood study.

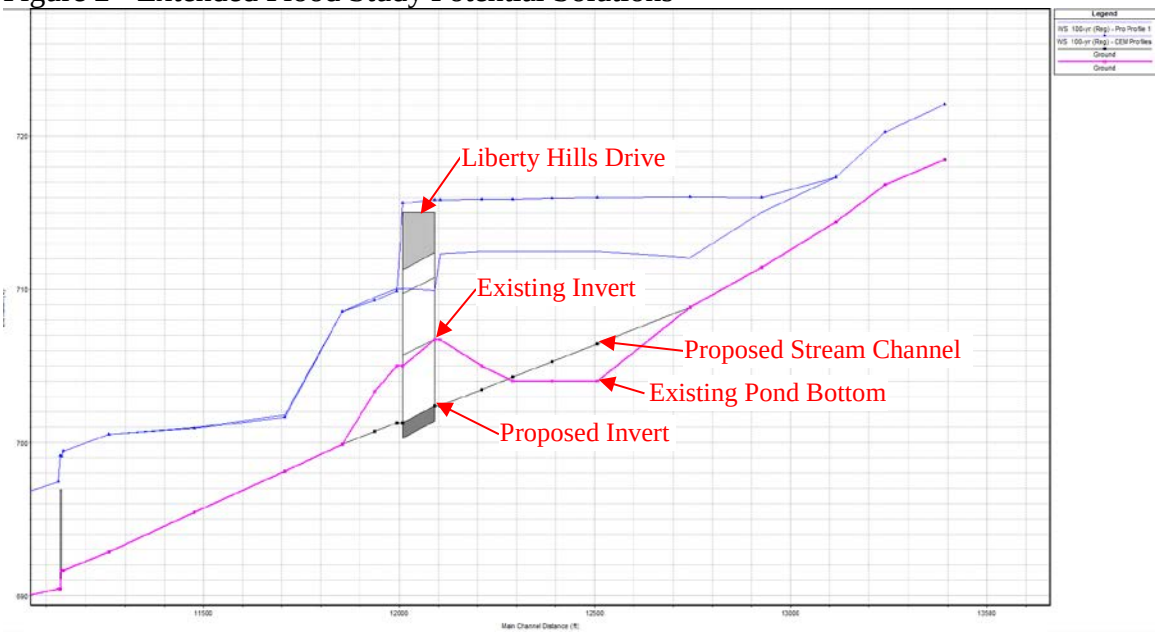
Table 14 - Extended Flood Study Regression Equation Peak Flows at Liberty Hills Drive

Event	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR
Peak Flow (cfs)	262	418	533	689	810	936	1239

The regression equations calculated larger hydrologic flows for the 2-yr, 5-yr, and 10-yr events than were calculated with the hydrologic computer model that was calibrated with the field data that was collected for the initial phase of the analysis. The difference in the flows is because the hydrologic computer model used in the initial analysis is specific to the study area, and the regression equations were developed to apply to a much larger region of Tennessee. However, when extending the existing flood study for Ralston Creek the flows calculated with the regression equations should be used.

The potential solutions evaluated for this phase of the analysis do not correspond to the initial phase of the hydrologic and hydraulic analysis since the purpose of the analyses are different, the hydrologic methods are different, and it was decided not to pursue any of the potential solutions evaluated in the initial analysis. The potential solutions evaluated for this phase included draining the Liberty Hills Pond by replacing the existing outlet structure and elliptical culverts under Liberty Hills Drive with a box culvert and a box culvert weir box combination with lower inverts. Figure 2 shows how the inverts of the culvert under Liberty Hills Drive were lowered for the potential solutions.

Figure 2 - Extended Flood Study Potential Solutions



4.1 Existing Conditions

The existing conditions hydraulic computer model for the extended flood study was developed based on field surveyed cross-sections of Ralston Creek between Victoria Court and Royal Oaks Blvd. The bridges between Victoria Court and Liberty Hills Drive were also included in the model. The existing elliptical culverts under Liberty Hills Drive were included in the model, but the weir box as part of the Liberty Hills Pond outlet structure was not included in the model. Based on the geometry of the existing outlet structure and observing flow over the weir box during the smaller storm events, it was determined the flow through the existing outlet pipes would not be impeded during the 100-yr event used for the flood study. Table 15 shows the results for the water elevation in the pond for the existing conditions.

Table 14 - Flood Study Existing Conditions Hydrologic Model Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)
2-YR	711.93	425.99	348.55	-18.2
5-YR	713.22	550.06	415.47	-24.5
10-YR	714.19	649.58	459.3	-29.3
25-YR	715.35	789.44	565.64	-28.3
50-YR	715.65	902.62	771.09	-14.6
100-YR	715.82	1,018.60	940.76	-7.6
500-YR	716.09	1,304.84	1,288.10	-1.3

The extended flood study indicated that the majority of the parcels adjacent to the right descending bank of Ralston Creek downstream of Liberty Hills Drive are located in the base flood (100-year)

flood plain in the existing condition. The results of the extended flood study were displayed at the Project Public Meeting, held on November 8, 2018 and are depicted on the attached Figure 1 "Preliminary Flood Study".

4.2 6'x5' Box Culvert

This potential solution included removing the existing outlet structure of the Liberty Hills Pond and replacing it with a 6'x5' reinforced concrete box culvert under Liberty Hills Drive with invert elevations as shown in Figure 2. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 15 shows how the flow is attenuated for this alternative.

Table 15 - 6'x5' Box Culvert Hydrologic Model Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
2-YR	710.22	425.99	330.66	-22.4	-5.1%	-1.71
5-YR	712.15	550.06	387.57	-29.5	-6.7%	-1.07
10-YR	713.5	649.58	422.54	-35	-8.0%	-0.69
25-YR	715.1	789.44	461.94	-41.5	-18.3%	-0.25
50-YR	715.61	902.62	691.61	-23.4	-10.3%	-0.04
100-YR	715.82	1,018.60	889.74	-12.7	-5.4%	0
500-YR	716.12	1,304.84	1272.24	-2.5	-1.2%	0.03

Increase Decrease

This alternative when compared to the existing conditions would not increase the outflow from the Liberty Hills Pond while also decreasing the pond water elevation for the 2-yr through 50-yr events. This alternative was not selected to move forward with additional analysis since there was no reduction in the 100-yr pond water elevation.

4.3 6'x5' Box Culvert with Weir

This potential solution included removing the existing outlet structure of the Liberty Hills Pond and replacing it with a 6'x5' reinforced concrete box culvert under Liberty Hills Drive with invert elevations as shown in Figure 2. A weir box would also be placed in front of the culvert. The weir box would be 7.5' tall with a 4.5' rectangular weir. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 16 shows how the flow is attenuated for this alternative.

Table 16 - 6'x5' Box Culvert with Weir Box Hydrologic Model Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
2-YR	710.52	425.99	340.25	-20.1	-2.4%	-1.41
5-YR	712.34	550.06	392.59	-28.6	-5.5%	-0.88
10-YR	713.64	649.58	426.03	-34.4	-7.2%	-0.55
25-YR	715.19	789.44	477.31	-39.5	-15.6%	-0.16
50-YR	715.63	902.62	708.84	-21.5	-8.1%	-0.02
100-YR	715.83	1,018.60	900.9	-11.6	-4.2%	0.01
500-YR	716.12	1,304.84	1276.87	-2.1	-0.9%	0.03

Increase Decrease

This alternative when compared to the existing conditions would not increase the outflow from the Liberty Hills Pond while also decreasing the pond water elevation for the 2-yr through 50-yr events. This alternative was not selected to move forward with additional analysis since there was only minor reduction in the 100-yr pond water elevation.

4.4 12'x10' Box Culvert

This potential solution included removing the existing outlet structure of the Liberty Hills Pond and replacing it with a 12'x10' reinforced concrete box culvert under Liberty Hills Drive with invert elevations as shown in Figure 2. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 17 shows how the flow is attenuated for this alternative.

Table 17 - 12'x10' Box Culvert Hydrologic Model Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
2-YR	707.22	425.99	410.39	-3.7	17.7%	-4.71
5-YR	708.14	550.06	523.57	-4.8	26.0%	-5.08
10-YR	708.88	649.58	613.77	-5.5	33.6%	-5.31
25-YR	709.87	789.44	740.36	-6.2	30.9%	-5.48
50-YR	710.62	902.62	841.85	-6.7	9.2%	-5.03
100-YR	711.36	1,018.60	944.16	-7.3	0.4%	-4.46
500-YR	712.98	1,304.84	1183.79	-9.3	-8.1%	-3.11

Increase Decrease

This alternative when compared to the existing conditions would increase the outflow from the Liberty Hills Pond while decreasing the pond water elevation. This alternative was not selected to move forward with additional analysis since there was is an increase in the outflow from the pond.

4.5 12'x10' Box Culvert with Weir

This potential solution included removing the existing outlet structure of the Liberty Hills Pond and replacing it with a 12'x10' reinforced concrete box culvert under Liberty Hills Drive with invert elevations as shown in Figure 2. A weir box would also be placed in front of the culvert. The weir box would be 12' tall with a 3.5' rectangular weir. This alternative would effectively remove the permanent pool from the Liberty Hills Pond. A natural stream channel would be constructed to convey the stormwater runoff from the pond inflow locations to the proposed outlet structure. Table 18 shows how the flow is attenuated for this alternative.

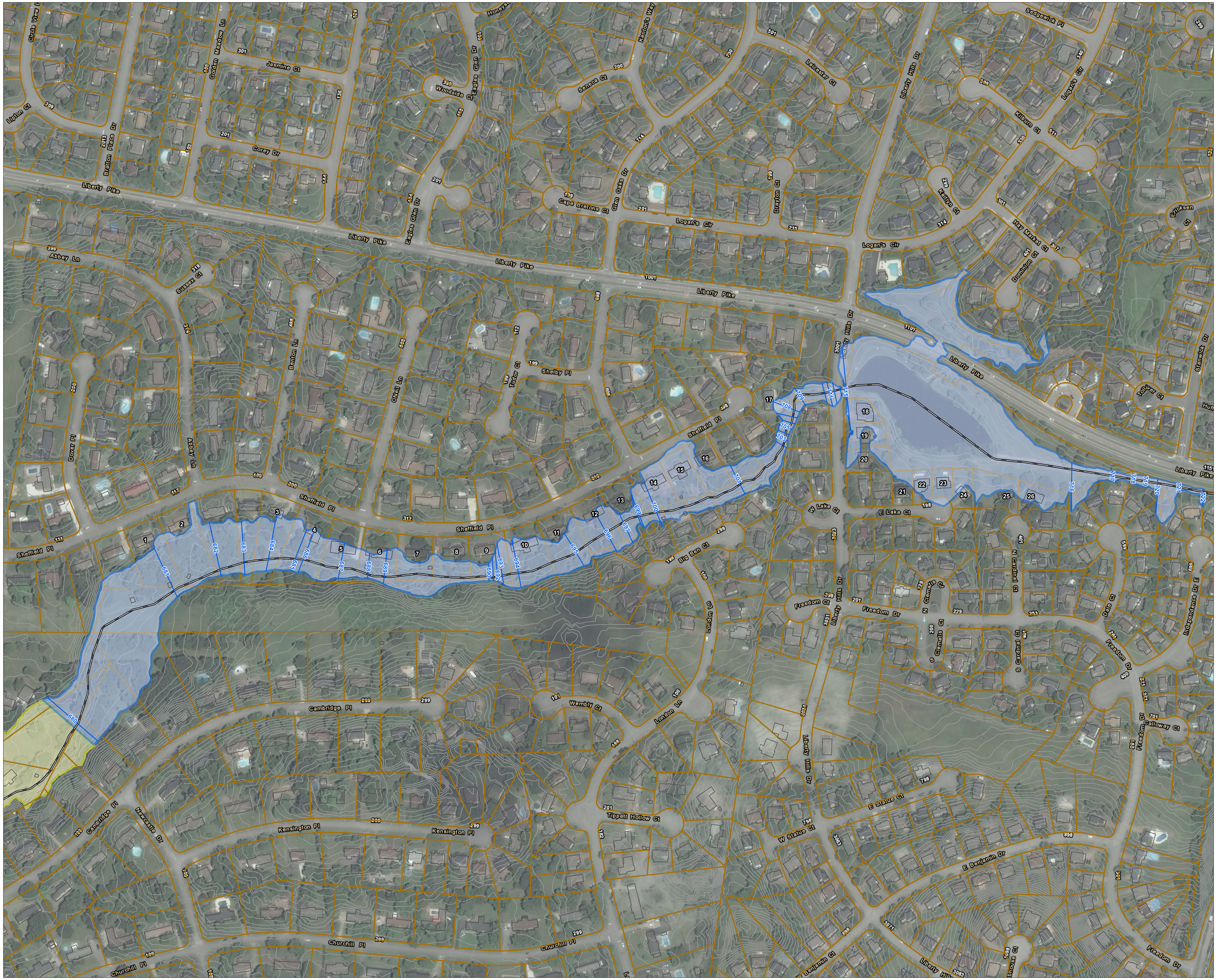
Table 18 - 12'x10' Box Culvert with Weir Box Hydrologic Model Results

Event	Pond Water Elevation (ft)	Pond Inflow (cfs)	Pond Outflow (cfs)	Flow Attenuation IN vs OUT (%)	Outflow Change vs Existing (%)	Water Elevation Change vs Existing (ft)
2-YR	711.52	425.99	316.74	-25.6	-9.1%	-0.41
5-YR	712.96	550.06	394.58	-28.3	-5.0%	-0.26
10-YR	713.95	649.58	450.99	-30.6	-1.8%	-0.24
25-YR	715.01	789.44	567.32	-28.1	0.3%	-0.34
50-YR	715.42	902.62	748.55	-17.1	-2.9%	-0.23
100-YR	715.62	1,018.60	926.99	-9	-1.5%	-0.2
500-YR	715.91	1,304.84	1282.9	-1.7	-0.4%	-0.18

Increase Decrease

This alternative when compared to the existing conditions would increase the outflow from the Liberty Hills Pond for the 25-yr event while also decreasing the pond water elevation. This alternative was not selected to move forward with additional analysis since there was an increase in the pond outflow for the 25-yr event and only a minor reduction in the 100-yr pond water elevation.

Enclosures
Figure 1 – "Preliminary Flood Study"
Figure EX-1 – "Existing Outlet Structure"
Figure MOS-1 – "Modified Outlet Structure 1"
Figure MOS-2 – "Modified Outlet Structure 2"
Figure MOS-3 – "Modified Outlet Structure 3"
Figure MOS-4 – "Modified Outlet Structure 4"
Figure MOS-5 – "Modified Outlet Structure 5"
Figure MOS-6 – "Modified Outlet Structure 6"
Figure MPND-1 – "Modified Pond Storage 1"
Figure MPND-2 – "Modified Pond Storage 2"



	Address	FFE (FT)	BFE (FT)
1	116 Sheffield Place	686.6	681.1
2	118 Sheffield Place	684.7	681.7
3	120 Sheffield Place	693.3	684.0
4	202 Sheffield Place	688.0	686.3
5	204 Sheffield Place	688.5	687.5
6	301 Sheffield Place	690.5	689.4
7	303 Sheffield Place	692.8	689.7
8	305 Sheffield Place	694.0	689.7
9	307 Sheffield Place	694.4	692.3
10	309 Sheffield Place	697.8	694.5
11	311 Sheffield Place	697.9	695.3
12	313 Sheffield Place	698.5	696.6
13	315 Sheffield Place	700.8	697.4
14	401 Sheffield Place	703.1	700.6
15	317 Sheffield Place	702.6	700.7
16	319 Sheffield Place	704.6	700.9
17	325 Sheffield Place	712.3	709.0
18	3008 Liberty Hills Drive	716.6	715.9
19	3012 Liberty Hills Drive	717.3	715.9
20	3016 Liberty Hills Drive	718.2	715.9
21	120 E Lake Court	719.8	716.0
22	124 E Lake Court	719.2	716.0
23	128 E Lake Court	719.5	716.0
24	132 E Lake Court	718.6	716.0
25	405 N Cardinal Court	720.4	716.0
26	404 N Cardinal Court	720.8	716.0

LEGEND

- Topography
- Base Flood Elevations
- Building Footprints
- Ralston Creek
- Estimated 100 YR Floodplain
- Parcels
- Flood Hazard Boundary (FEMA)

REFERENCE

ESRI WORLD IMAGERY / ARCGIS MAP SERVICE: HTTP://GOTO.ARCGISONLINE.COM/MAPS/WORLD_IMAGERY, ACCESSED 9/17/2018, IMAGERY DATE: 2017.

SCALE IN FEET

0 150 300 450 600

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FRANKLIN, WILLIAMSON COUNTY, TN

DRAWN BY:	JMB	CHECKED BY:	JBS	APPROVED BY:	SEC
DATE:	9/17/2018	SCALE:	1 " = 150 '	PROJECT NO:	153-050.0008

PRELIMINARY FLOOD STUDY

FIGURE NO: 1

SHEET 1 OF 1

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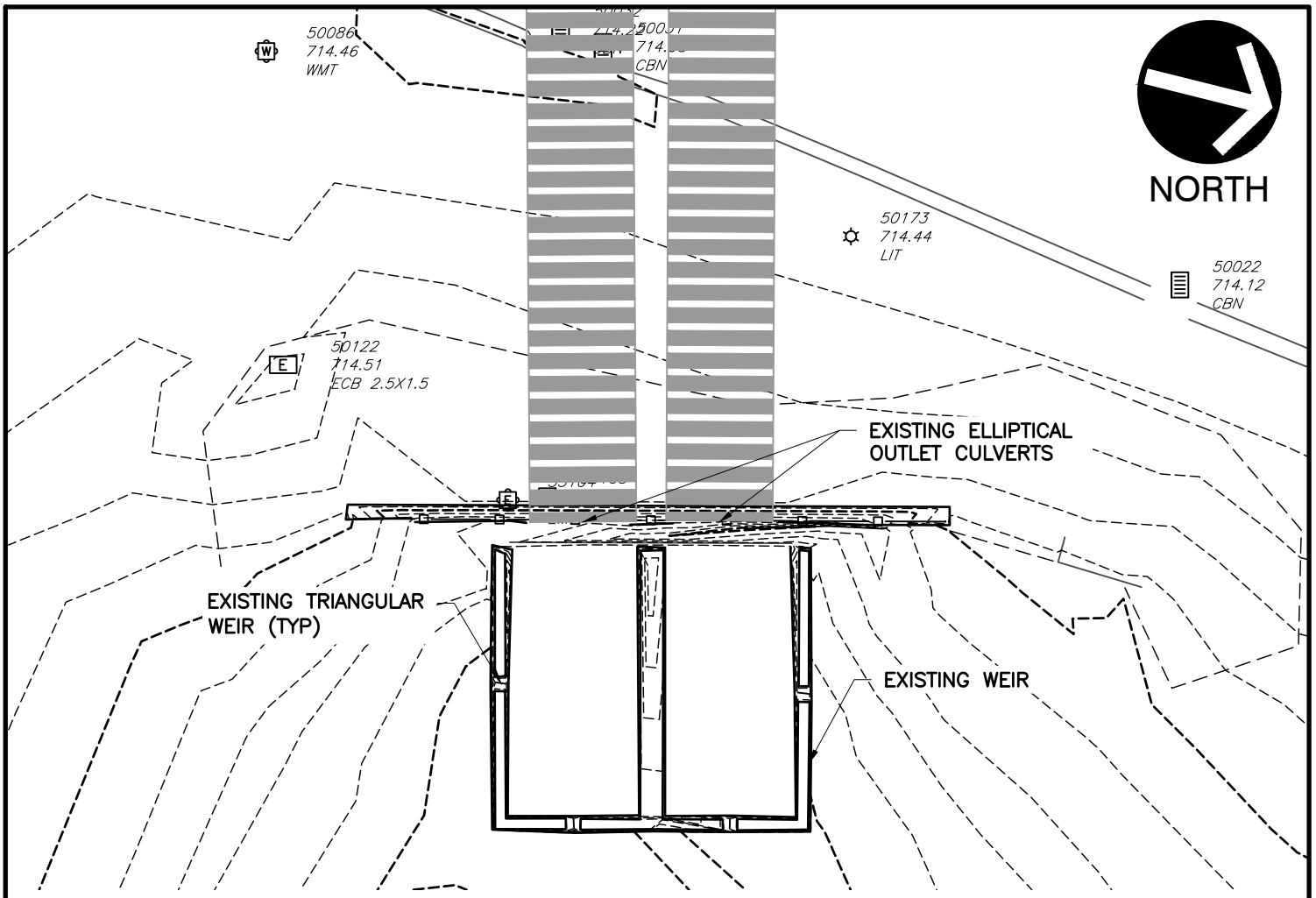

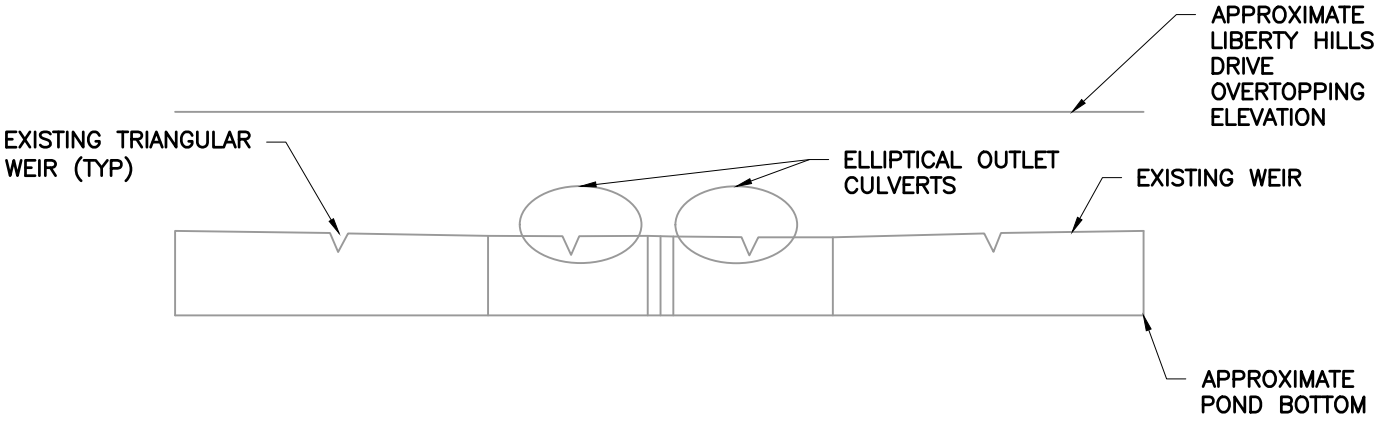

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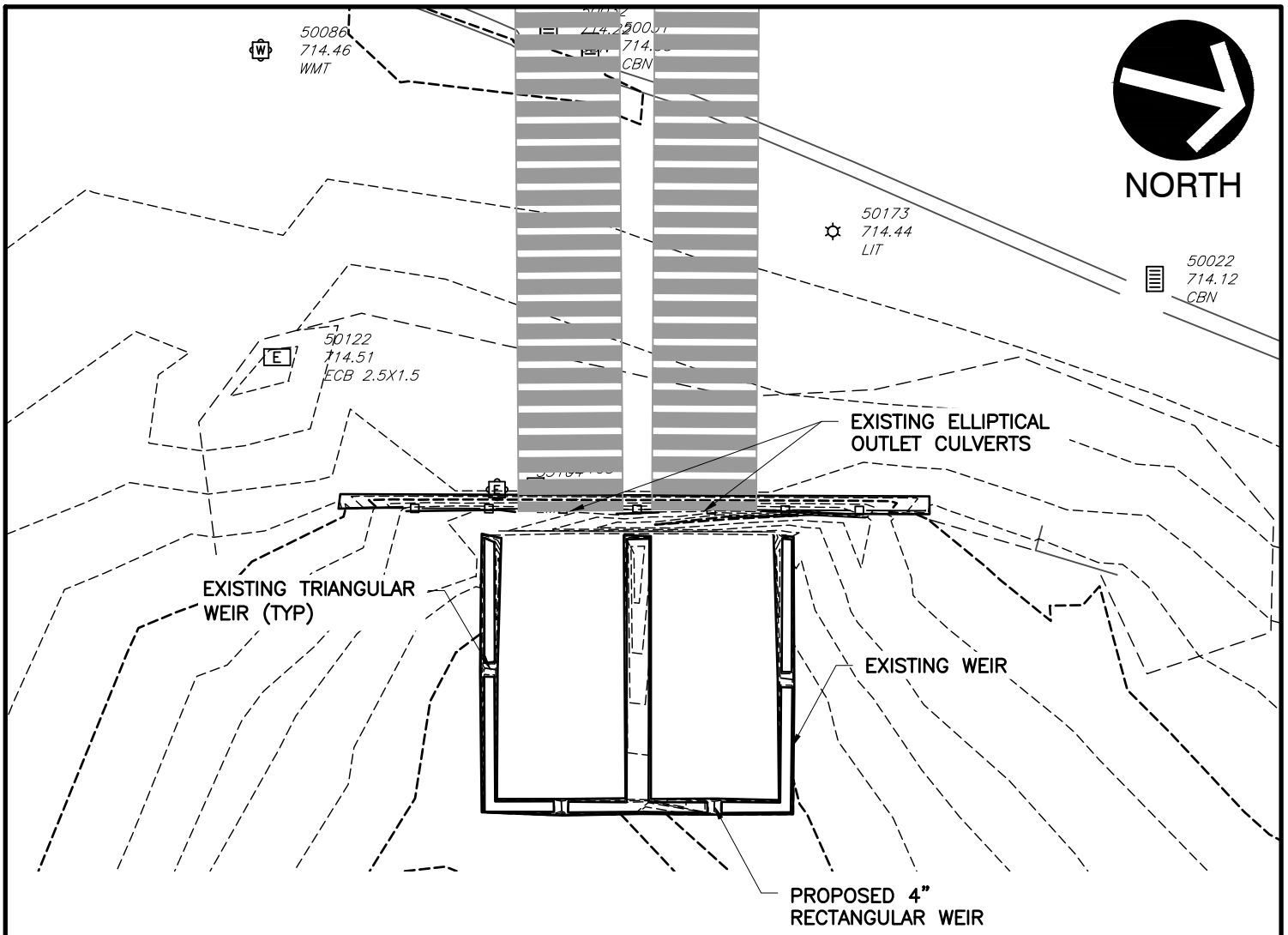
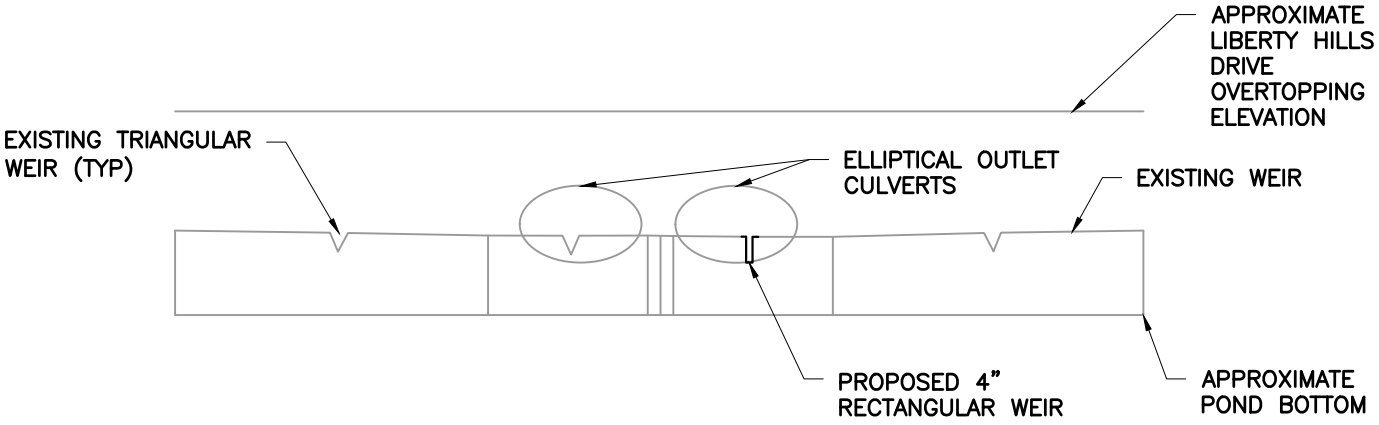
EXISTING OUTLET STRUCTURE

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**EX-1**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		

P:\2015\153-050\-CADD\Dwg\XRef\HECRAS\153050XR-CV01-Outlet_Detail.dwg{FIGURE NO. EX-1} LS:(4/23/2019 - jshaver) - LP: 4/30/2019 2:55 PM





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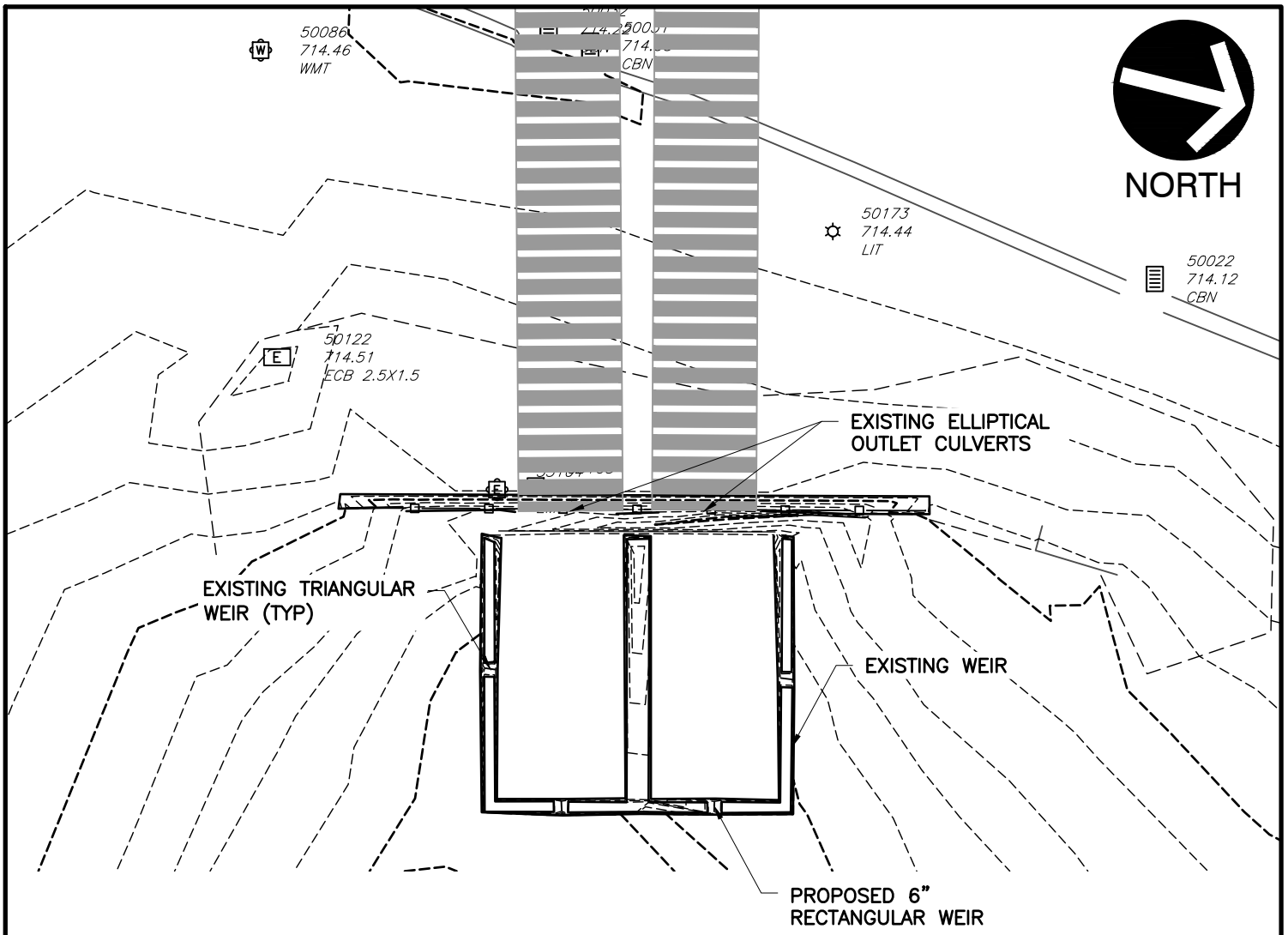
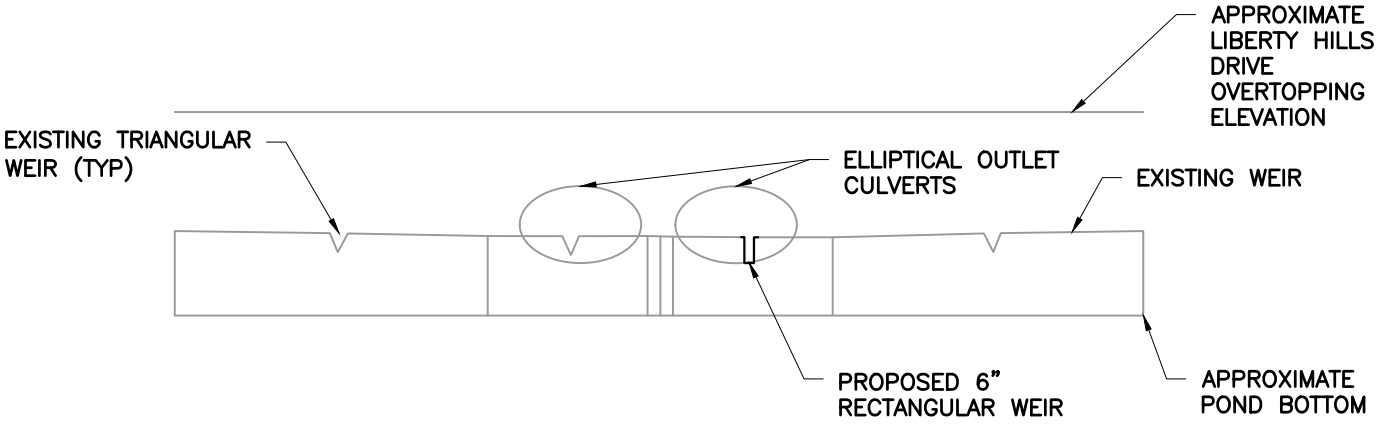
MODIFIED OUTLET STRUCTURE 1

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-1**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		

P:\2015\153-050\-CADD\Dwg\XRef\HECRAS\153050XR-CV01-Outlet_Detail.dwg{FIGURE NO. MOS-1} LS:(4/23/2019 - jshaver) - LP: 4/30/2019 2:55 PM





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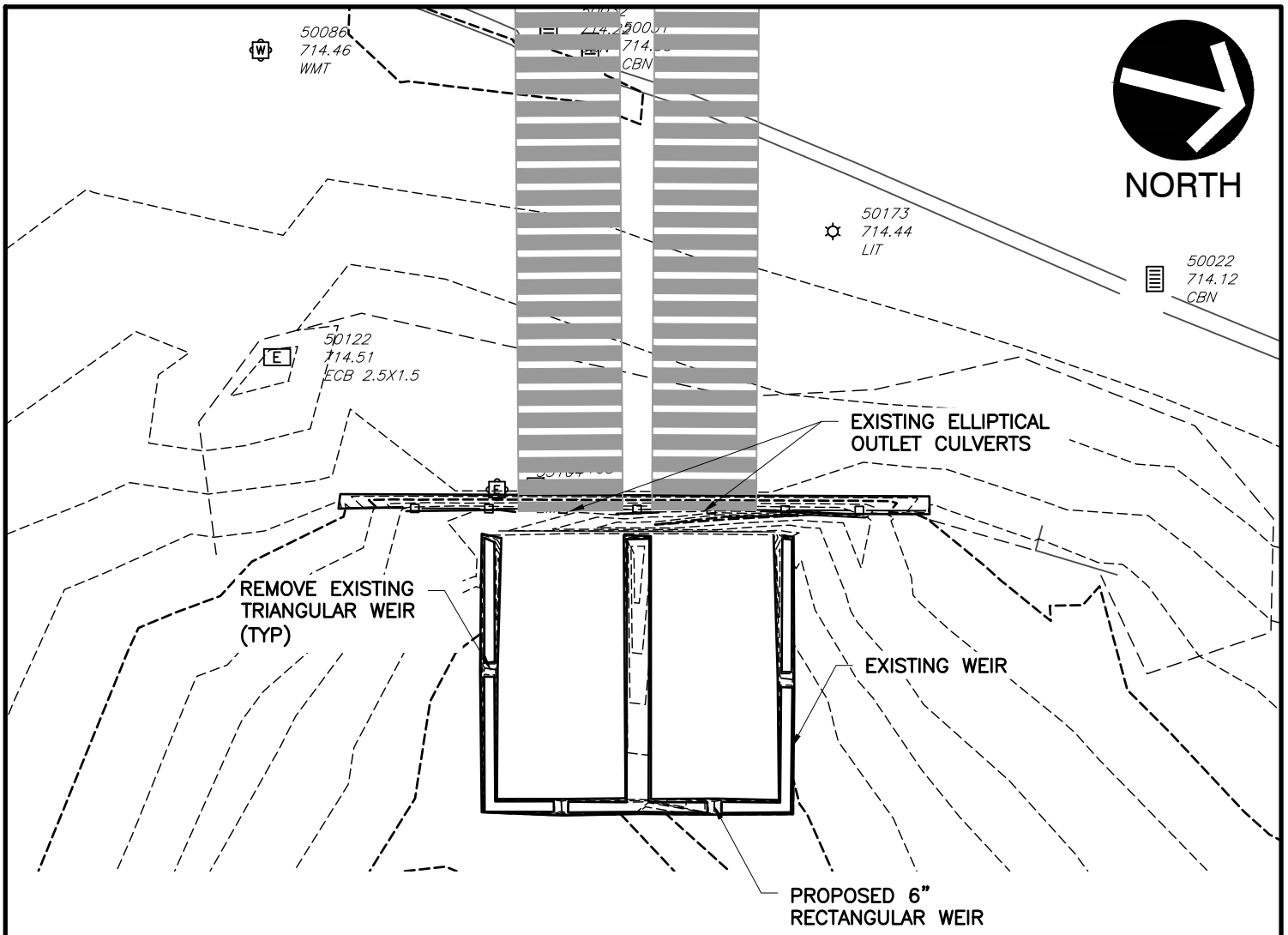
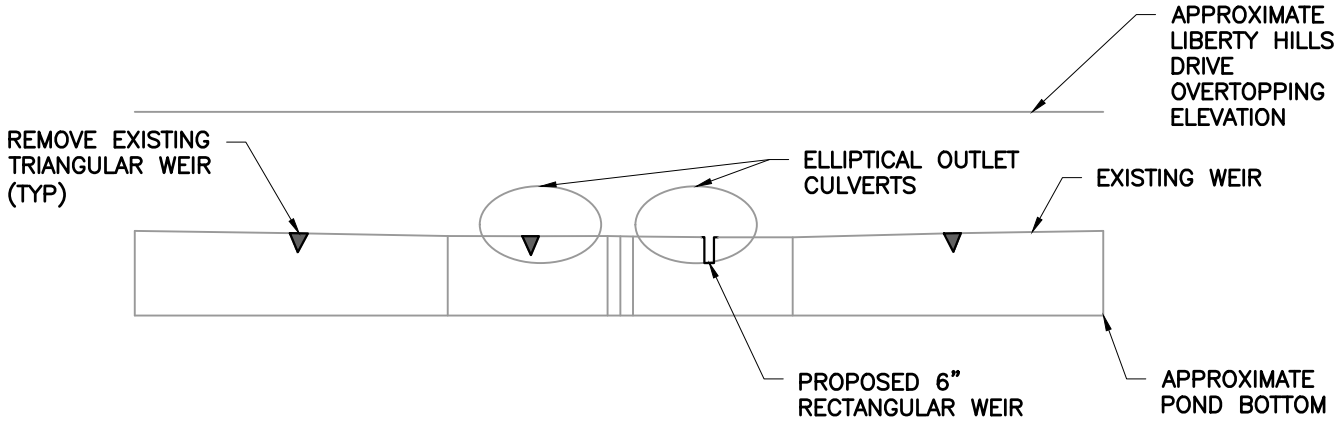
MODIFIED OUTLET STRUCTURE 2

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-2**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		





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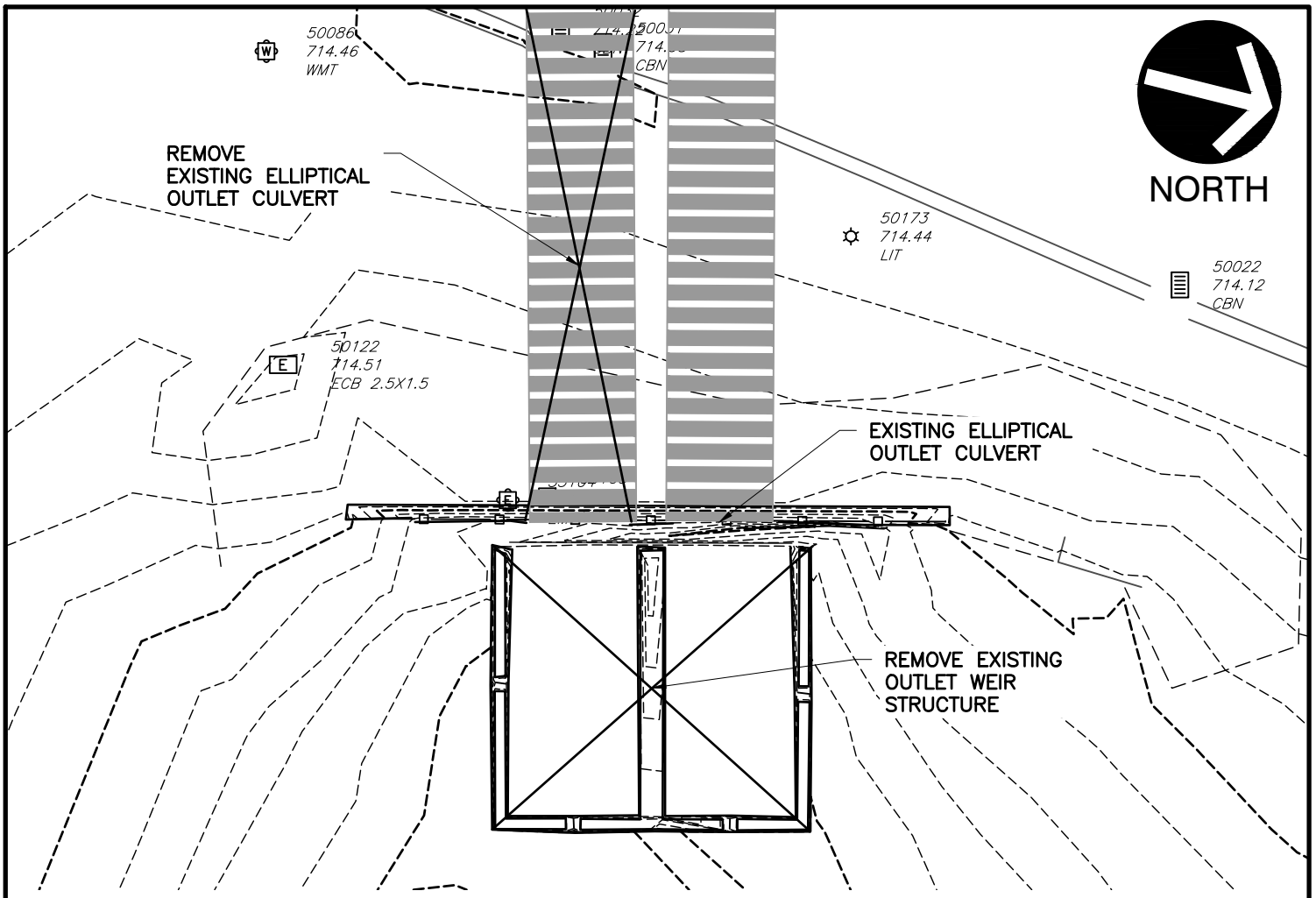
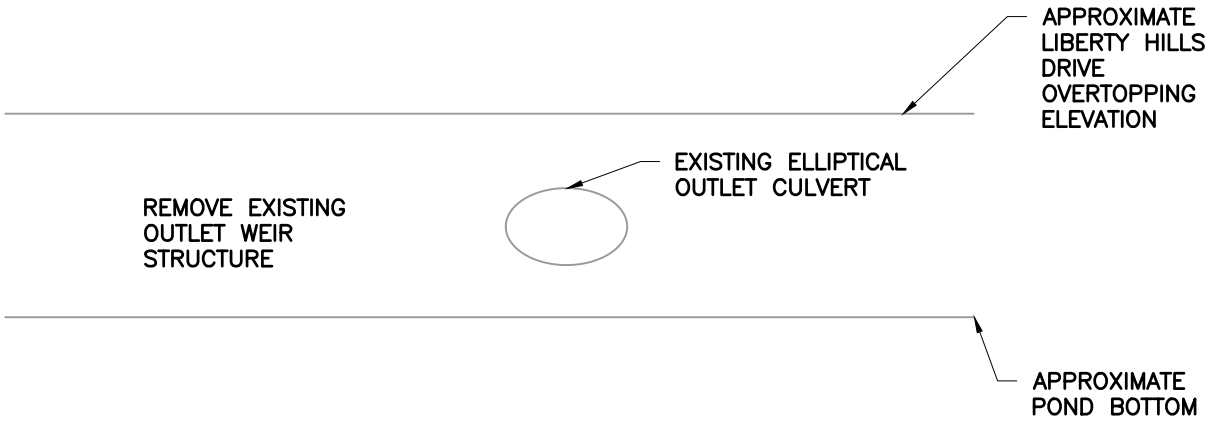
MODIFIED OUTLET STRUCTURE 3

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-3**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		





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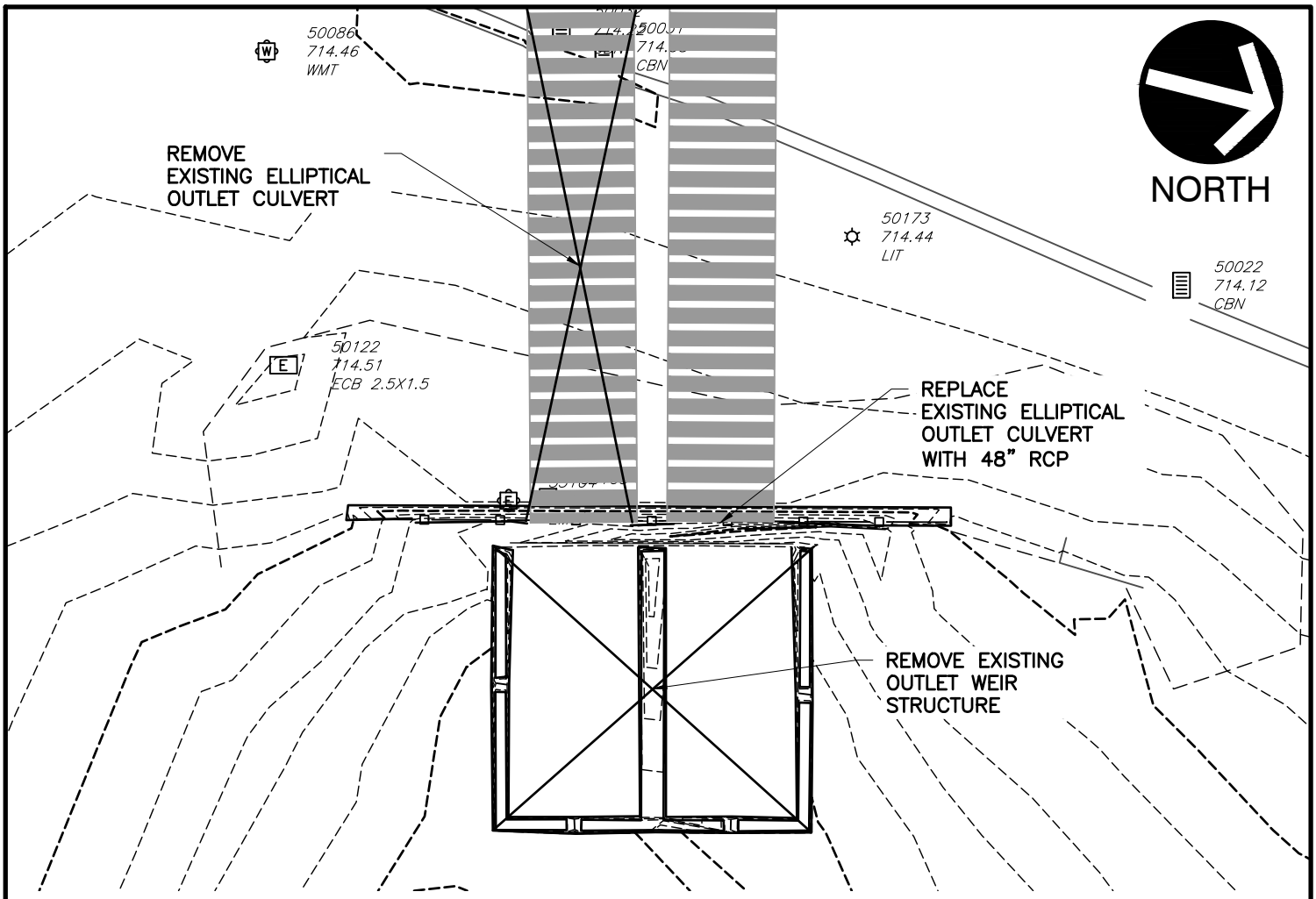
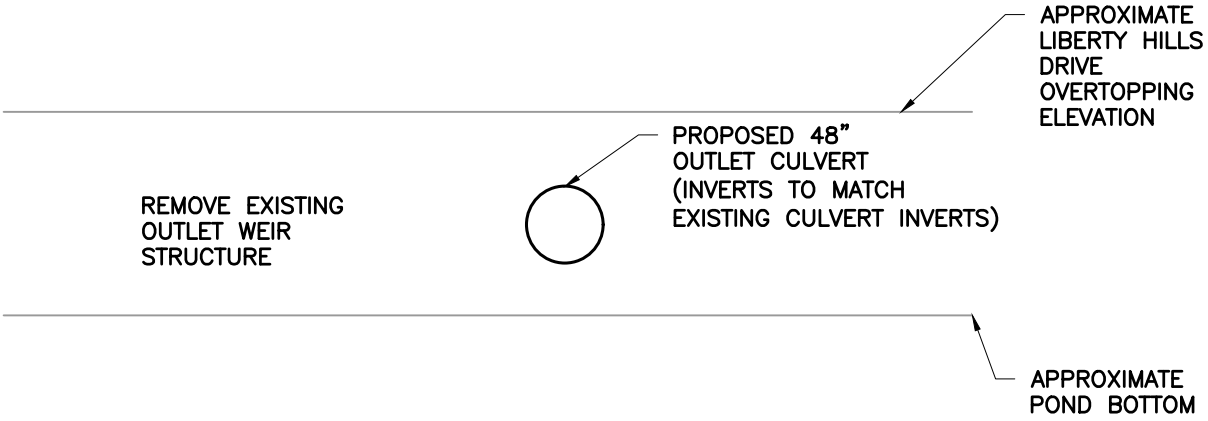
MODIFIED OUTLET STRUCTURE 4

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-4**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		





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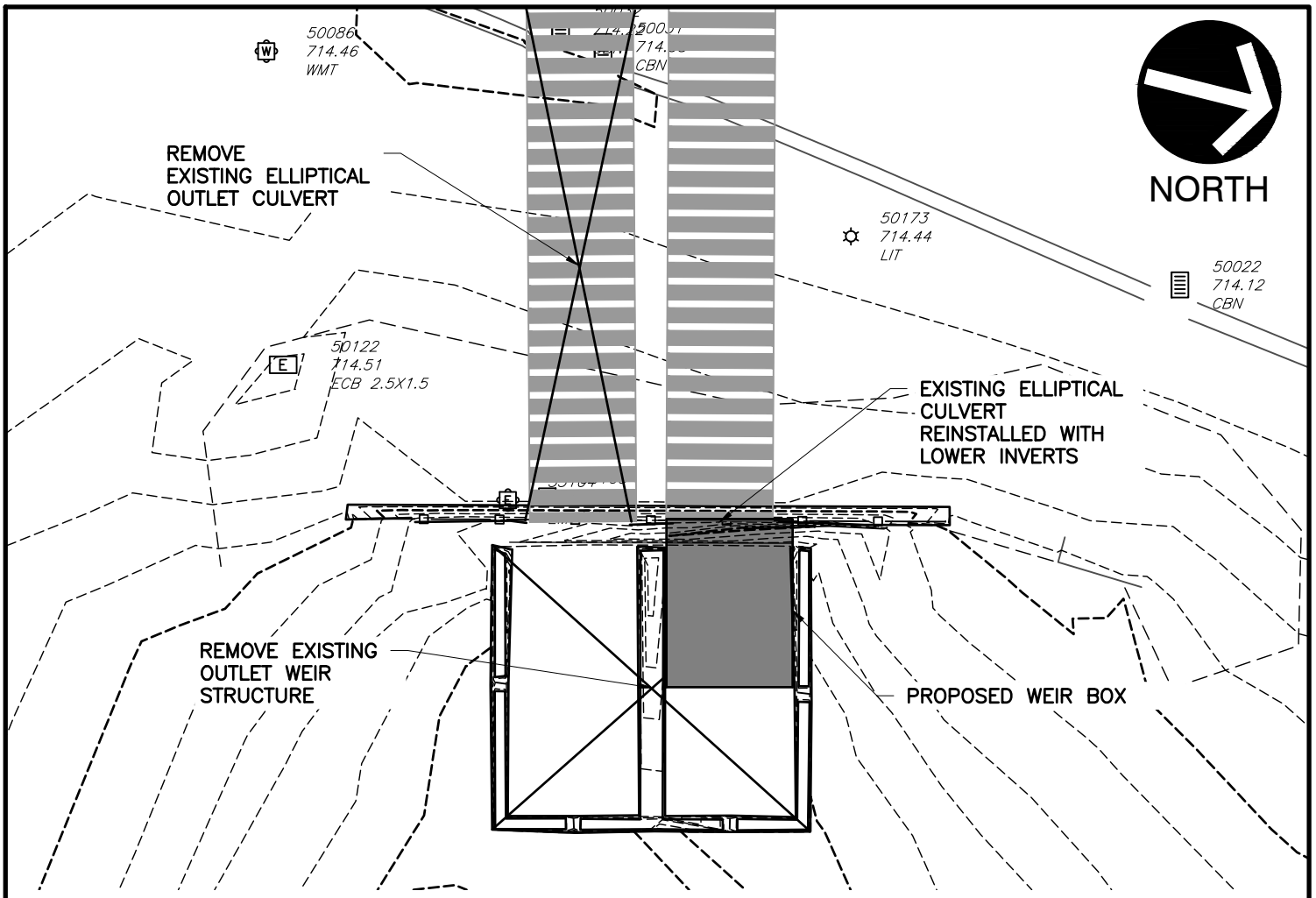
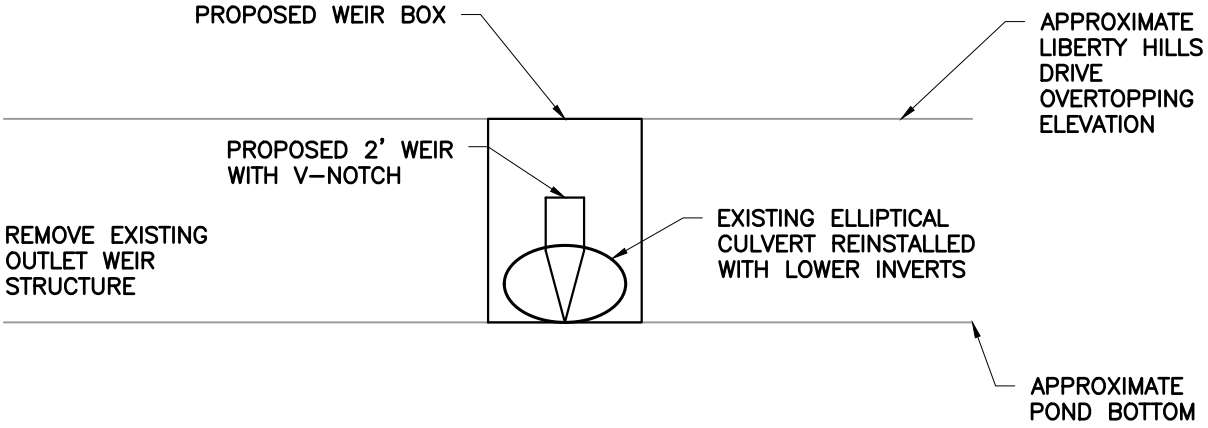
MODIFIED OUTLET STRUCTURE 5

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-5**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		





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MODIFIED OUTLET STRUCTURE 6

DRAWN BY:	JBS	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO.:	**MOS-6**
DATE:	JUNE 2017	DWG SCALE:	NTS	PROJECT NO:	153-050		

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REFERENCE

ESRI WORLD IMAGERY / ARCGIS MAP SERVICE:
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ACCESSED 4/30/2019, IMAGERY DATE: 2014.

LEGEND

Property Boundary

Area to be Excavated for Additional Storage

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MODIFIED POND STORAGE 1

DRAWN BY:	DR	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO:	**MPND-1**
DATE:	4/30/2019	SCALE:	1 " = 100 '	PROJECT NO:	153-050		

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NORTH

SCALE IN FEET

0 300

LEGEND

- Property Boundary
- Retaining Wall
- Area to be Excavated for Additional Storage

REFERENCE

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HTTP://GOTO.ARCGISONLINE.COM/MAPS/WORLD_IMAGERY,
ACCESSED 4/30/2019, IMAGERY DATE: 2014.

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MODIFIED POND STORAGE 2

DRAWN BY:	DR	CHECKED BY:	JBS	APPROVED BY:	EJG	FIGURE NO:	**MPND-2**
DATE:	4/30/2019	SCALE:	1 " = 100 '	PROJECT NO:	153-050		

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