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16. Abstract

Permanent stormwater quality structures in developed urban areas require the use of smaller footprint or underground structures. This project investigated if an underground treatment structure made from off-the-shelf precast concrete sections would exhibit the required sediment removal efficiency and involve minimum maintenance. The project consisted of a literature review of small footprint and underground stormwater treatment devices, their cost, performance, and maintenance considerations; and a physical model study to test the principles to be employed and construction of a full-scale prototype for proving the concepts. Research results of conceptual models, physical models and part of the prototype are documented in the first project report entitled "The Development of Non-proprietary Underground Stormwater Quality Structures, Report Number FHWA/TX-07/0-4611-1." These results demonstrate that extended detention can be used to remove suspended solids from stormwater. It also shows that maintenance will be needed to sustain the overall level of performance (in terms of sediment removal). While the efficiency of the structure is around 75 percent removal, approximately 17 percent of the solids discharged can be attributed to resuspension. This report documents experiments conducted on the prototype in an attempt to optimize sediment removal efficiency by reducing sediment resuspension. Design and maintenance guidelines are included in this report. In summary, several refinements show promise in significantly reducing the resuspension loading, which could increase the overall efficiency to over 80 percent with maintenance intervals in excess of twelve months.

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UNDERGROUND STORMWATER QUALITY DETENTION BMP FOR SEDIMENT TRAPPING IN ULTRA-URBAN ENVIRONMENTS: FINAL RESULTS AND DESIGN GUIDELINES

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TABLE OF CONTENTS

Page

List of Figures ix

List of Tables x

Chapter 1: Introduction 1
Background 1
Objectives 1
Approach 1

Chapter 2: Methods and Materials 3
Experimental Design 3
  Sediment Delivery 3
  Inlet Configuration 4
  Sedimentation Basin 5
  Outlet Configuration 5
Data Acquisition 7
Data Processing 7
  Inflow and Outflow Rate Estimation 8
  Event Mean Concentration 8
  TSS Removal Ratio 8
Conducted Experiments 9
  Resuspension Determination 10
  Outlet Relocation Experiments 11
  Detention Experiments (with Closed Outlet) 12
  Additional Experiments 12

Chapter 3: Results and Discussion 15
Resuspension Determination 16
Outlet Relocation Experiments 17
  Fixed Outlet 17
  Floating Outlet 19
Detention Experiments (with Closed Outlet) 21
  Fixed Outlet 21
  Floating Outlet 22
Additional Experiments 23
  First and Second Experiment 23
  Third Experiment 25
Results Summary 26
  Event Mean Concentration 26
  TSS Removal Ratio 27

Chapter 4: Conclusions and Recommendations 29
Conclusions 29
  Conclusions from Resuspension Results 29
  Conclusions from Outlet Relocation Experiment Results 29

Conclusions from Detention Experiment Results 29
Conclusions from Additional Experiment Results 29
Recommendations 30
Recommendations for Prototype Improvement 30
Recommendations for Maintainance 30

References 33

Appendix A: Documentation of the Research Data 35

Appendix B: Design Guidance Document (Two Design Examples) 55

Appendix C: Standard Details for Structure and Specifications for Material and Construction 61

Appendix D: Maintainance Schedule and Documentation 71

LIST OF FIGURES

Page

Figure 2.1. A. Hydroseeder for Making Slurry. B. Point of Injection into Main Line. 4
Figure 2.2. A. Energy Dissipation at Inlet. B. Mixing Tank... 4
Figure 2.3. View of Sedimentation Tank Before Outlet Relocation.
A. From Upstream. B. From Downstream.. 5
Figure 2.4. View of Fixed and Floating Outlet. A. Outlets at End. B. Outlets in Middle. 6
Figure 2.5. A. Gate Valve and Butterfly Valve. B. Actuator Box and Solar Panel. 7
Figure 2.6. View of Sedimentation Tank After Outlet Relocation.
A. From Upstream. B. From Downstream.. 11
Figure 3.1. Summary of Tests Conducted on the Prototype. 15
Figure 3.2. Measured Concentrations at 6-minute Intervals for Initial 2:30 hrs........................... 16
Figure 3.3. Effect of Relocating Fixed Outlet on the Outflow Rate. 18
Figure 3.4. Reduction in TSS Observed at Outlet Due to Relocation of Fixed Outlet. 19
Figure 3.5. Effect of Relocating Floating Outlet on the Outflow Rate. 20
Figure 3.6. Reduction in TSS Observed at Outlet Due to Relocation of Floating Outlet............. 21
Figure 3.7. TSS Concentration vs. Time for Fixed Outlet with 0, 2, 3, and 6-hour Detention. ... 22
Figure 3.8. TSS Concentration vs. Time for Floating Outlet with 0, 1, 2, and 3-hour
Detention. 23
Figure 3.9. Effect of Outlet Location (at End, in Middle, and at Inlet) for Fixed Outlet. 24
Figure 3.10. TSS for Fixed Outlet Located at End with 6 inch Outlet Opening. 25

LIST OF TABLES

Page

Table 2.1. Summary of Testing Conducted in 2006–2007. 10
Table 3 1. Sediment Loss Due to Resuspension. 17
Table 3.2. Event Mean Concentrations in mg/L. 26
Table 3.3. TSS Removal Ratios. 27
Table A.1. Data from Resuspension Experiments for Fixed Outlet. 37
Table A.2. Data from Resuspension Experiments for Floating Outlet. 38
Table A.3. Data from Outlet Relocation Experiment for Fixed Outlet–Run 1. 39
Table A.4. Data from Outlet Relocation Experiment for Fixed Outlet–Run 2. 40
Table A.5. Data from Outlet Relocation Experiment for Fixed Outlet–Run 3. 41
Table A.6. Data from Outlet Relocation Experiment for Floating Outlet–Run 1 42
Table A.7. Data from Outlet Relocation Experiment for Floating Outlet–Run 2 43
Table A.8. Data from Outlet Relocation Experiment for Floating Outlet–Run 3 44
Table A.9. Data from Detention Experiment for Fixed Outlet–θ=2 Hours. 45
Table A.10. Data from Detention Experiment for Fixed Outlet–θ=3 Hours. 46
Table A.11. Data from Detention Experiment for Fixed Outlet–θ=6 Hours. 47
Table A.12. Data from Detention Experiment for Floating Outlet–θ=1 Hours. 48
Table A.13. Data from Detention Experiment for Floating Outlet–θ=2 Hours. 49
Table A.14. Data from Detention Experiment for Floating Outlet–θ=3 Hours. 50
Table A.15. Data from Additional Experiments–First Experiment. 51
Table A.16. Data from Additional Experiments–Second Experiment. 52
Table A.17. Data from Additional Experiments–Third Experiment. 53
Table B.1. TSS Removal Efficiency Corresponding to Different Designs. 57
Table B.2. Required Runoff to Be Detained Corresponding to Different
TSS Removal Efficiency of the Small Footprint BMP (for Edwards Aquifer). 58

CHAPTER 1: INTRODUCTION

BACKGROUND

Phase II rules of the National Pollutant Discharge Elimination System (NPDES/TPDES) requires that all new construction and reconstruction address issues of stormwater quality. In many cases, retrofitting of existing urban rights-of-way is necessary and requires acquisition of additional right-of-way that is cost prohibitive or would prove socially disruptive. In these situations, it will be necessary to resort to underground stormwater treatment structures.

The purpose of this project was to develop simple, effective stormwater quality treatment structures that are simple in design but effective in removing regulated stormwater pollutants for Texas Department of Transportation (TxDOT). The proposed underground stormwater best management practice (BMP) will be suited for ultra-urban conditions that require low head loss and highly efficient, low maintenance and cost effective stormwater quality treatment within limited rights-of-way.

OBJECTIVES

The objectives of the project were as follows:

- Develop a physical model to test the viability of using extended off-the-shelf precast concrete sections as a stormwater quality structure.
- Develop a prototype based on the physical model to prove the effectiveness of the concept.
- Develop design criteria and specifications for structures.
- Develop maintenance guidelines.

APPROACH

Researchers conducted the project in four phases over a period of four years.

1. Phase one consisted of an extensive literature review documenting small footprint technologies being used for stormwater quality treatment. This phase was completed in 2005.
2. Phase two ran concurrent with phase one and involved the development of a 1/5th scale physical model to test the potential effectiveness of a simple detention structure for stormwater treatment.
3. Phase three was the development of a prototype structure to verify the results of the physical modeling phase.
4. Phase four involved modifying the prototype operating characteristics to improve the performance of the prototype.

The TxDOT report "The Development of Non-proprietary Underground Stormwater Quality Structures" (Landphair et al., 2007) documents the first three phases of the project completed prior to 2007. This report documents the last phase of the project. In addition, the appendices to this report contain design guidelines, standard details of the proposed structure and maintenance specifications. This final report concludes the development of a small footprint stormwater BMP that began in 2003 and completed in 2007 in four major phases.

CHAPTER 2:
METHODS AND MATERIALS

Researchers maintained the same testing setup as the previous part of this study (Landphair et al., 2007). Landphair et al. (2007) provides a more detailed description of the prototype experiments). This chapter summarizes the prominent features of the setup and procedure used for the testing, along with the modifications to the testing procedure and experimental setup during the course of this project.

EXPERIMENTAL DESIGN

Sediment Delivery

Suspended solids used for the testing consisted of commercial silica sediment, having a density of 2.65 g/cm^3 and a particle size distribution with $D_{99} \leq 50$ micron. It should be noted that the sediment used was comparable to typical suspended solid particles found in highway runoff (Li et al., 2005).

Onsite personnel prepared concentrated slurry by mixing 50 lb of the silica sediment in 500 gallons of water in a hydroseeder (Figure 2.1 A). The slurry was maintained at a homogeneous sediment concentration of approximately 11,983 mg/L by continuous agitation. The slurry was then injected at a uniform rate (0.0223 cfs) into the main line which fed water to the mixing tank at a rate of 1 cfs (Figure 2.1 B). The resulting dilution ratio (equation 2.1) gives an inlet concentration of approximately 267 mg/L, which is typical of urban highway runoffs (Li, et al., 2006).

$$C = \frac{Q_1 \times C_1 + Q_2 \times C_2}{Q_1 + Q_2} = \frac{Q_1}{Q_1 + Q_2} \times C_1 = \frac{0.0223}{1} \times C_1 = 0.0223 \times C_1 \quad \text{..........................(2.1)}$$

$$\text{since } C_2 \text{ is} \cong 0$$

Figure 2.1. A. Hydroseeder for Making Slurry. B. Point of Injection into Main Line.

Inlet Configuration

A mixing tank connected to an 18-inch diameter inlet in the sedimentation tank (Figure 2.2 B), simulated a more realistic inflow regime. Before entering the sedimentation tank, the simulated runoff water dropped down in a free fall in the mixing tank, causing turbulence and preventing any sedimentation at the inlet.

Nine concrete blocks installed in a staggered fashion in two rows (Figure 2.2 A), approximately 1 ft from the inlet served as energy dissipaters. These blocks dispersed the momentum of the incoming water and reduced resuspension due to the shearing effect of water.

Figure 2.2. A. Energy Dissipation at Inlet. B. Mixing Tank.

Sedimentation Basin

The sedimentation basin had an effective runoff holding capacity of approximately 3600 ft^3. An 80 ft long, 10 ft wide and 6 ft high pre-cast concrete tank was assembled at the TTI/TxDOT Hydraulics, Sedimentation & Erosion Control Laboratory (HSECL) facility to serve as the sedimentation basin. A 4.5 ft high weir wall, installed close to the outlet end and serving as an overflow release mechanism, resulted in a sedimentation basin working volume of 3600 ft^3. The dimensions were set to fit in the right-of-way area along a highway. Figure 2.3 shows views of the sedimentation basin from upstream and downstream.

Figure 2.3. View of Sedimentation Tank Before Outlet Relocation.
A. From Upstream.
B. From Downstream.

Outlet Configuration

The prototype draining at an average outflow rate of 0.042 cfs resulted in a drainage time of approximately 24 hours. These outflow rate and drainage time values provided sufficient time for the sediment to settle and to reduce the scour downstream from the sedimentation basin.

However, due to changes in prototype configuration during the experiment, there was some departure from the drainage time.

$$Q = \frac{\forall}{\theta} = \frac{3630\,ft^3}{24hr} \times \frac{1\,hr}{3600\sec} \approx 0.042cfs$$

The two outlets tested included a fixed outlet connected to the hole at the bottom-right of the weir and a floating outlet connected to the hole at the bottom-center of the weir (Figure 2.4 A). Two independent gate valves situated outside the tank controlled the flow through each outlet. During the course of the experiments conducted during 2006–2007, there were two major changes to the outlet configuration. The first change included moving both outlets (fixed and floating) to the middle of the tank (Figure 2.4 B). The later part of this chapter will explain the "outlet relocation" experiments in further detail.

Figure 2.4. View of Fixed and Floating Outlet. A. Outlets at End. B. Outlets in Middle.

The second change included replacing the gate-valves with a butterfly valve (Figure 2.5 A) and actuator (controller) box powered by a solar panel (Figure 2.5 B) and batteries. This change in setup helped to control the opening and shutting of the butterfly valve and allowed the researchers to maintain a predetermined "detention" period for the testing. Researchers in University of Texas, Austin, developed, assembled and installed the setup on the prototype at the HSECL facility in riverside campus before commencing these experiments. Middleton et al. (2006) describe the working setup in detail. The later part of this chapter explains the detention experiments in further detail.

Figure 2.5. A. Gate Valve and Butterfly Valve. B. Actuator Box and Solar Panel.

DATA ACQUISITION

Researchers used an ISCO (Teledyne Isco, Lincoln, Nebraska) sampler (ISCO-6712) with a bubbler flowmeter (ISCO-730) to monitor the water level in the sedimentation basin and collect samples from the outlet end of the sedimentation tank. A bubbler flowmeter logged data, which was transferred to the computer using a rapid transfer device (ISCO 581). The FLOWLINK software enabled researchers to access the data on the computer. Data included water level readings at 15-second intervals, as well as the time of the sample acquisition. The level data provided an estimate of the outflow rate variation over the period of the test. Researchers transported samples to the laboratory and analyzed them for total suspended solids (TSS) in accordance with standard methods (APHA, 2005).

DATA PROCESSING

Researchers analyzed the flow rate and TSS data to interpret the significance of the testing results. The following subsections describe, in detail, the procedure involved in determining flow rates, event mean concentrations (EMC), and TSS.

Inflow and Outflow Rate Estimation

The rise or fall in the water level was obtained by subtracting consecutive water level readings at every one-hour interval from the commencement of the test. The first hour was ignored as water was flowing into the sedimentation tank, as well as flowing out of it. This fall in water level was then multiplied by the surface area of the tank to get the outflow rate:

$$Outflow\,Rate(\,cfs\,) = \frac{Fall\,in\,water\,level(\,ft\,)}{1(\,hr\,)} \times \frac{1(\,hr\,)}{3600(sec)} \times Surface\,area\,of\,\tan k(\,sq\;ft\,)$$

$$Outflow\,Rate(\,cfs\,) = \frac{Fall\,in\,water\,level(\,ft\,)}{1(\,hr\,)} \times \frac{1(\,hr\,)}{3600(sec)} \times 800(\,sq\;ft\,)$$

$$Outflow\,Rate(\,cfs\,) = 0.222 \times Fall\,in\,water\,level(\,ft\,)$$

Outflow rate was calculated for each hour interval from the time the water started draining from the tank. For the sake of simplicity, an outflow rate profile was developed for each outlet configuration by taking an average of the calculated outflows for runs with similar configurations. The experiments to determine resuspension lasted for approximately 150 minutes, and the time interval used for those experiments was six minutes.

Event Mean Concentration

Researchers used the flow and concentration measured for each time interval to calculate the EMC. The EMC can be used to characterize the quality of the water leaving the sedimentation basin in terms of suspended solids.

$$EMC = \frac{\sum_{i=1}^{24}\left(C_i \times Q_i\right)}{\sum_{i=1}^{24} Q_i}$$

TSS Removal Ratio

The TSS ratio, calculated according to the formula below, was an indicator of the performance of the sedimentation tank.

$$R = \frac{Mass_{in} - Mass_{out}}{Mass_{in}}$$

CONDUCTED EXPERIMENTS

Researchers subjected the prototype to various tests over a two-year period. The 14 tests conducted on the prototype during 2005–2006 (Landphair et al., 2007) were primarily to evaluate the performance of the prototype under different operating conditions. Researchers observed that the prototype displayed low TSS removal efficiency. The primary reason attributed to the under-performance of the prototype was lower efficiencies resulting from resuspension of settled sediment. Onsite personnel observed while filling the tank that the initial sheet of water displaced the settled sediment by shearing action and carried it to the region close to the weir where the outlets were located. As a result of this observation, researchers extended the project for another year to improve the performance of the prototype by manipulating the testing configuration to overcome this problem.

Researchers conducted a total of 21 tests on the prototype during 2006–2007 to study methods to improve the performance of the prototype and recommend the best operating configuration of the BMP (Table 2.1). The three main sets of experiments conducted were:

1. Resuspension Determination
2. Outlet Relocation
3. Detention (with Closed Outlet)

In addition to the above-mentioned sets of experiments, researchers also conducted three separate runs.

Table 2.1. Summary of Testing Conducted in 2006–2007.

	OUTLET		DETENTION TIME [hrs]	LOADING [lbs]	№ of Runs
	TYPE	LOCATION			
RESUSPENSION DETERMINATION	Fixed	End	0	0	3
	Floating	End	0	0	3
OUTLET RELOCATION	Fixed	Middle	0	50	3
	Floating	Middle	0	50	3
DETENTION (WITH CLOSED OUTLET)	Fixed	Middle	2	50	1
	Fixed	Middle	3	50	1
	Fixed	Middle	6	50	1
	Floating	Middle	1	50	1
	Floating	Middle	2	50	1
	Floating	Middle	3	50	1
ADDITIONAL EXPERIMENTS	Fixed	End	3	50	1
	Fixed	Near Inlet	3	50	1
	Fixed*	End	3	50	1

* 6 inch outlet opening.

Resuspension Determination

The objective of this experiment was to establish the existence of resuspension and to determine the amount of resuspension. The testing included three repetitions using fixed outlet and three repetitions using floating outlet. The outlets were located near the weir wall, as shown in Figure 2.4 A. These experiments did not use sediment. However, accumulated sediment from previously conducted runs was present at the bottom of the tank. Water from the lake was pumped into the tank and samples were collected at six-minute intervals for two and half hours. The samples were analyzed for total suspended solids. Water level data were also collected for the duration of the test. The results from this experiment included the amount of sediment leaving the prototype in the initial two and half hours.

Outlet Relocation Experiments

The purpose of the relocation was to investigate the effect of moving the outlets away from the observed high sediment accumulation zone (near the weir). This zone was identified by visual observation during the experiments conducted previously (Landphair et al., 2007). As part of this experiment, three repetitions of the test using a fixed outlet and three repetitions using a floating outlet were conducted.

Before commencing the experiment, both the outlets were moved to the middle of the tank. The fixed outlet was relocated to the middle of the tank using a 1 inch internal diameter (I.D.) PVC pipe, while the floating outlet was relocated using a 2 inch I.D. PVC pipe (Figure 2.6 A&B). An inlet loading of 50 lbs was maintained using a hydroseeder. The test time started when the water began filling the tank. The outlets were left open for the entire duration of the test.

Figure 2.6. View of Sedimentation Tank After Outlet Relocation.
A. From Upstream.
B. From Downstream.

Detention Experiments (with Closed Outlet)

Researchers observed relatively high TSS concentration at the outlet for the first few hours of discharge from both the fixed and floating outlet. If the discharge were to be completely withheld during the first few hours by closing the outlet valve, the efficiency of the prototype could be improved. This "detention" of the water in the tank could help reduce the effect of resuspension by allowing ample time for the resuspended sediment to resettle. The purpose of the detention experiment was to observe the effect of holding the water for a certain period, before opening the valve and emptying the sedimentation tank, on the outlet concentration. Researchers conducted three runs using a fixed outlet with detention times of two, three, and six hours, respectively and three runs using a floating outlet with detention times of one, two, and three hours, respectively. It was initially decided to conduct one run each with detention times of one, two, and three hours for both fixed and floating outlet. However, after observing the results of the two-hour and three-hour detention for the fixed outlet, it was concluded that more useful information could be obtained by testing for six-hours detention instead of the one-hour detention. The gate valves were replaced by a 6 inch butterfly valve, which was controlled by an actuator and powered by a battery and solar panel. The location of the outlets was maintained at the same place as the outlet relocation experiment (the middle of the tank). Therefore, it should be noted that the results from these experiments express a combined effect of outlet relocation and detention.

Additional Experiments

During the course of the testing, researchers observed data from the experiments conducted and decided to perform three additional experiments. The three additional experiments conducted involved fixed outlet and a detention of three hours.

The first experiment included moving the fixed outlet back to the weir-end of the tank (Figure 2.4 A) and applying a detention of three hours. This experiment was conducted to observe the effect of detention without outlet relocation.

The second experiment included relocating the fixed outlet near the inlet to the tank (close to the mixing tank) and applying a detention of three hours. Researchers thought that keeping the inlet and outlet close together would result in a setup that would be easier for inspection and maintenance.

The third experiment included relocating the fixed outlet to the end of the tank, widening the outlet to 6 inch diameter size and applying a detention of three hours. This experiment was conducted to examine the effect of having a larger diameter outlet to prevent fouling by debris.

CHAPTER 3:
RESULTS AND DISCUSSION

Researchers conducted a total of 21 runs during the 2006–2007 period (Figure 3.1). The testing was conducted as part of a study to determine means to improve the performance of the prototype developed in the previous three-years work. The following sections discuss, in detail, the results of the prototype testing.

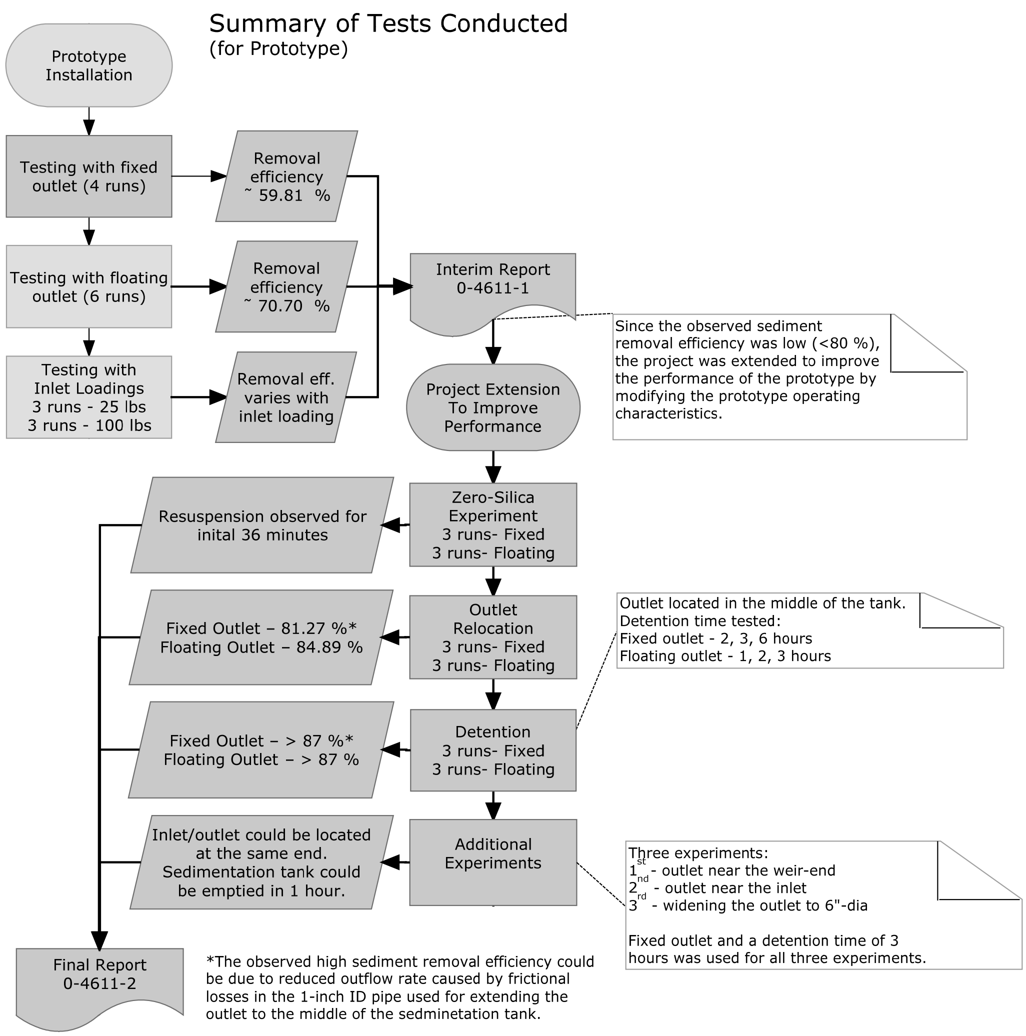

Figure 3.1. Summary of Tests Conducted on the Prototype.

RESUSPENSION DETERMINATION

The results of the testing to determine the amount of resuspension indicated significant resuspension with both fixed and floating outlet. The resuspension effect was observed for the first 30 minutes only. Figure 3.2 illustrates the average of three tests, each conducted with fixed and floating outlet.

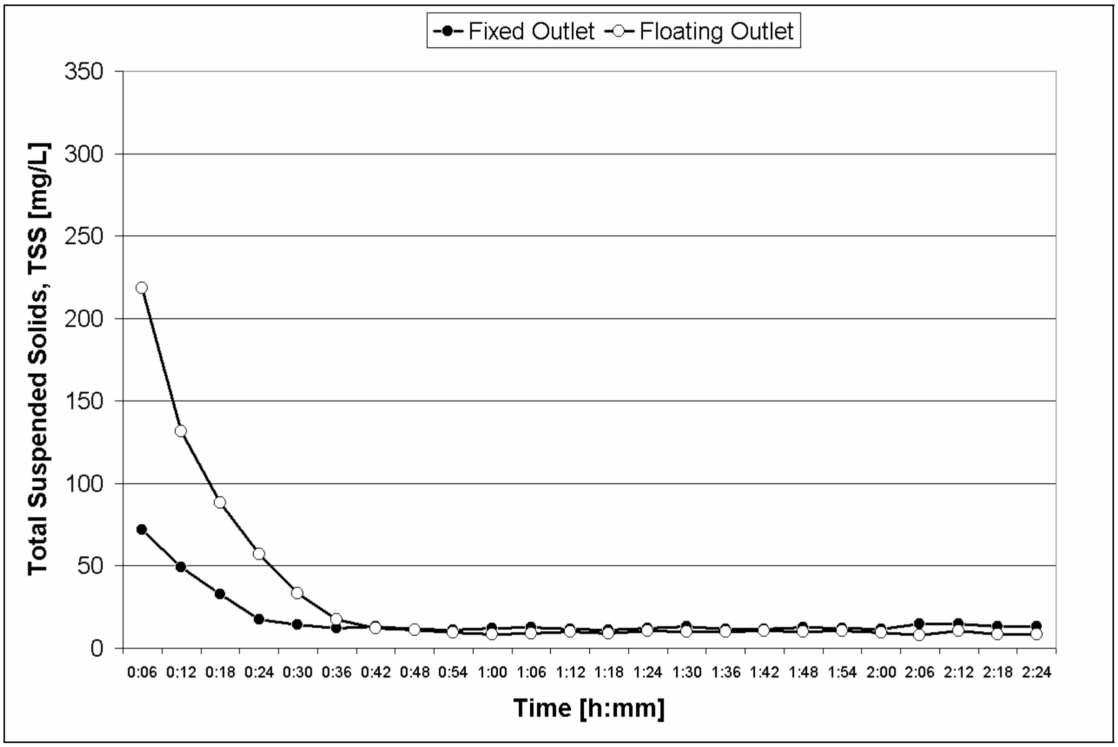

Figure 3.2. Measured Concentrations at 6-minute Intervals for Initial 2:30 hrs.

Higher resuspension was observed for the floating outlet, which is contrary to results observed in the 2005–2006 study. The researchers attribute this anomaly in the results to the movement of the floating outlet (skimmer) close to the bottom of the sedimentation tank while the tank was being filled, causing previously settled sediment to re-entrain. The level and concentration data, along with relevant calculations, have been presented in a tabular form in Appendix A. Table A-1 provides the data for fixed outlet, while Table A-2 provides data for floating outlet. The calculated amount of sediment resuspended and transported out of the sedimentation tank is presented in Table 3.1. The sediment lost due to resuspension for the fixed outlet (0.56 lbs) is higher than that for the floating outlet (0.42 lbs), even though the total suspended concentrations for the fixed outlet are relatively lower than the floating outlet. This is due to the lower outflow rates observed in the case of floating outlet. The researchers believe that in reality the resuspension will be even more pronounced when there is sediment present in the influent water. When the influent water has sediment present, the resuspended particles will take a longer time to settle. This will make the resuspension effect persist for more than 30 minutes.

Table 3 1. Sediment Loss Due to Resuspension.

OUTLET TYPE	$\sum C_i \times Q_i$ [lb]	AVG $\sum C_i \times Q_i$ [lb]
Fixed	0.48	0.56
	0.64	
	0.55	
Floating	0.50	0.42
	0.34	
	0.41	

OUTLET RELOCATION EXPERIMENTS

In this section, results from both the fixed and floating outlet are described and a comparison is made with results from last year to show the effect of relocating the outlets.

Fixed Outlet

This extension of the fixed outlet significantly reduced the flow rate observed at the outlet. The sedimentation tank took about 36 hours to empty with this reduced outflow rate. The reduction in outflow rate due to relocating the outlet to the middle was due to frictional losses in the 40 ft long pipe. Figure 3.3 shows the graph of outflow rate vs. time before and after relocating the fixed outlet.

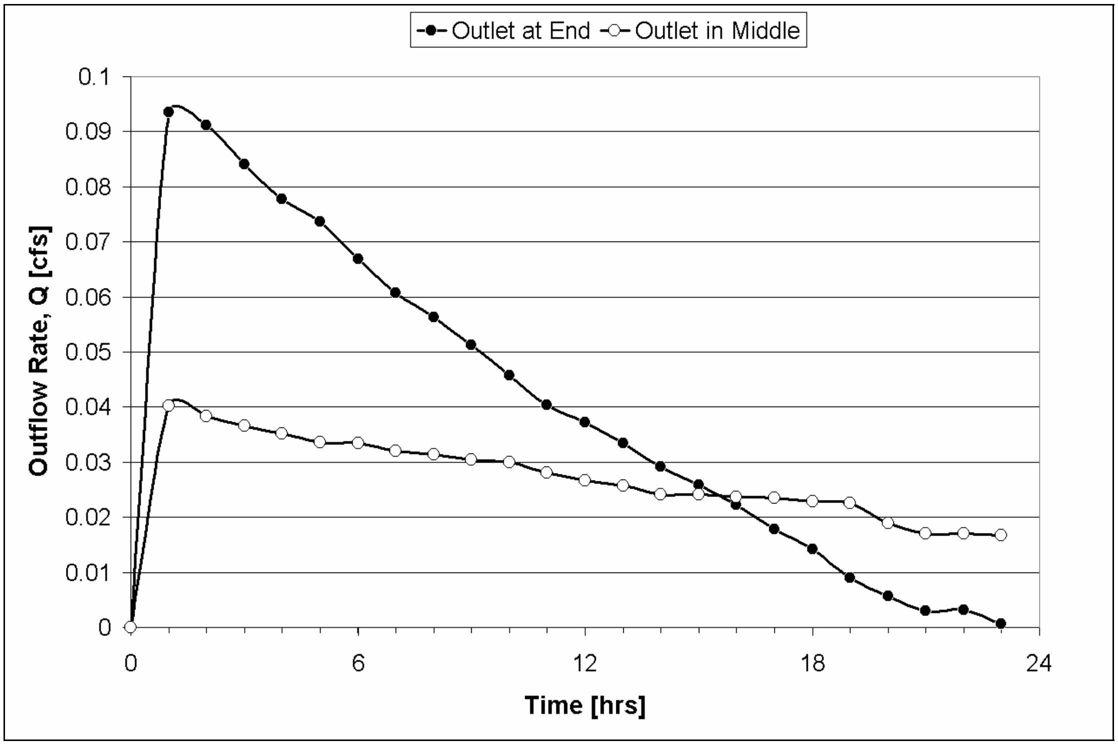

Figure 3.3. Effect of Relocating Fixed Outlet on the Outflow Rate.

A small decrease was also observed in the outlet concentration of total suspended solids. Figure 3.4 shows the graph of total suspended solids at outlet vs. time before and after relocating the outlet to the middle of the tank. The plots are an average of three runs for outlet in middle and four runs for outlet at end. The data points for the outlet at end were derived from the 0-4611-1 report (Landphair et al., 2007). Appendix A presents the tabulated data for the individual tests for the outlet located in the middle of the tank (Tables A-3, A-4, and A-5). The average EMC calculated for the runs was 63 mg/L. The average efficiency calculated was 81 percent. The average EMC calculated for the runs with outlet in middle of the tank (63 mg/L) was significantly lower than average EMC with outlet at end (91 mg/L). Consequently, the average efficiency calculated (81 percent) was higher than with outlet at end (60 percent). Researchers understand that the large increase in efficiencies may be due to the reduced outflow rate.

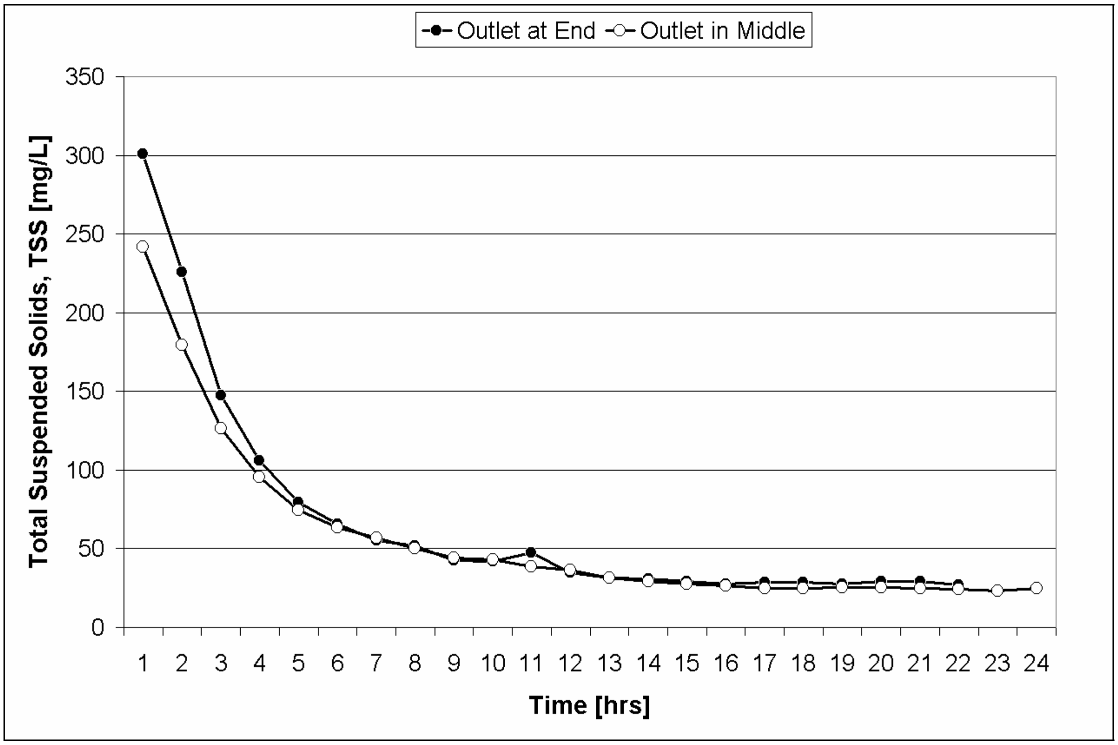

Figure 3.4. Reduction in TSS Observed at Outlet Due to Relocation of Fixed Outlet.

Floating Outlet

This extension of the floating outlet did not have significant influence on the flow rate observed at the outlet. The sedimentation tank took about 24 hours to empty with this new outflow rate. Figure 3.5 shows the graph of outflow rate vs. time before and after relocating the fixed outlet.

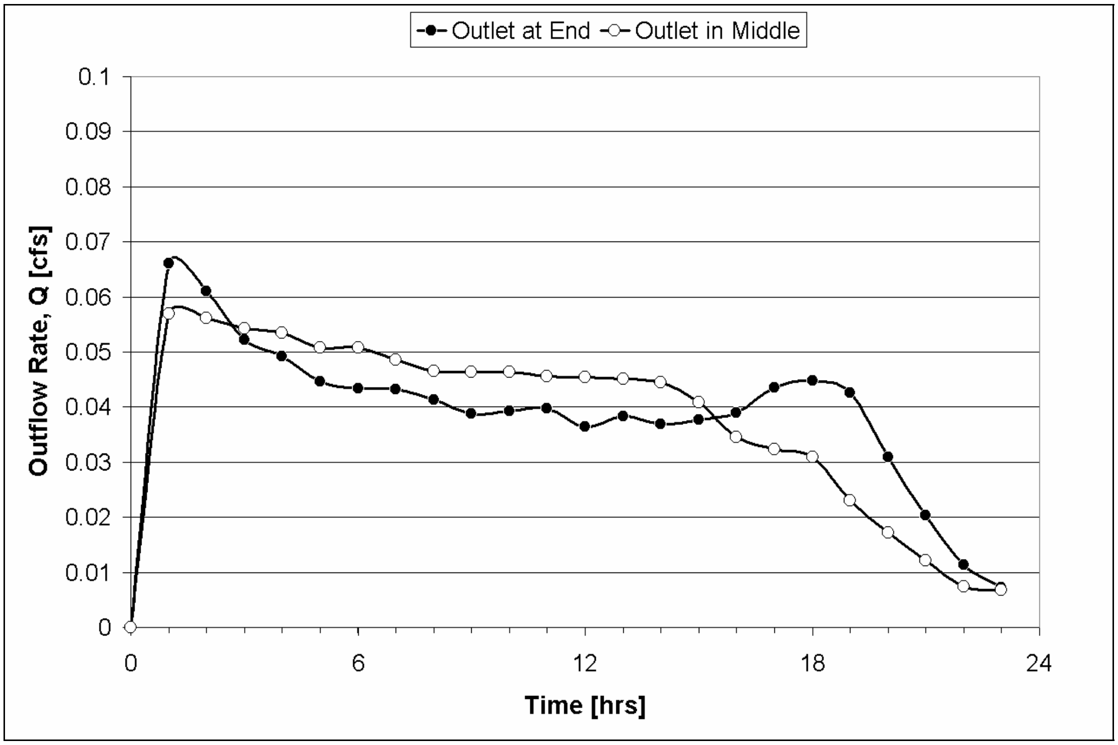

Figure 3.5. Effect of Relocating Floating Outlet on the Outflow Rate.

A significant decrease in the total suspended solids concentration was observed at the outlet. The average total suspended solids concentration at outlet vs. time graph, both before and after relocating the outlet to the middle of the tank for the floating outlet, are presented in Figure 3.6. The plots are an average of three runs for outlet in middle and six runs for outlet at end. The data points for the outlet at end were derived from the 0-4611-1 report (Landphair et al., 2007). The tabulated data for the individual tests for the outlet located in the middle of the tank are presented in Appendix A (Tables A-6, A-7, and A-8). The average EMC calculated for the runs with outlet in middle of the tank (36 mg/L) was much lower than average EMC with outlet at end (68 mg/L), and the average efficiency calculated (85 percent) was significantly higher than with outlet at end (71 percent).

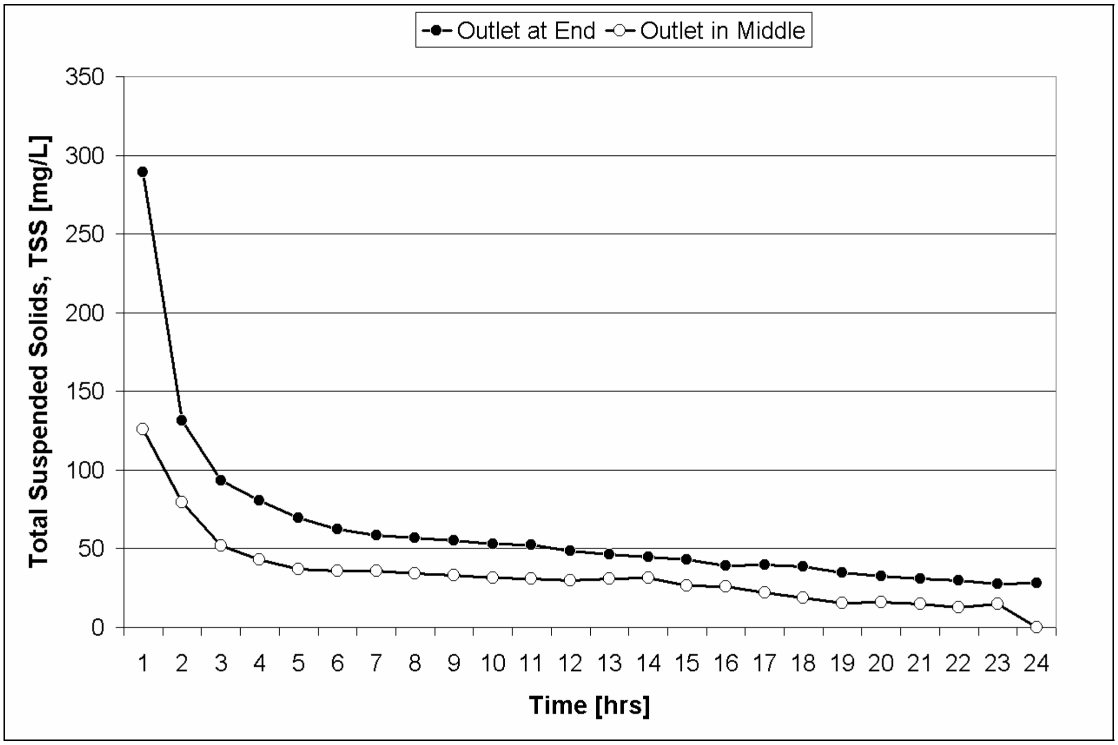

Figure 3.6. Reduction in TSS Observed at Outlet Due to Relocation of Floating Outlet.

DETENTION EXPERIMENTS (WITH CLOSED OUTLET)

The tests conducted on the small footprint Best Management Practices (BMP) prototype included:

Fixed Outlet

This experiment examined three detention times, two, three, and six hours respectively. Figure 3.7 shows the graph of total suspended solid concentration at outlet vs. time (for each of these detention times along with that for no detention) The data points for the 0-hour (no closed-outlet detention) were an average of the three runs and were derived from the outlet relocation experiments discussed previously. Results show a trend of decreasing total suspended solids concentration at outlet with increasing detention time. Comparing the graph of three-hour detention with that of six-hour detention seems to indicate that the beneficial effects of detention beyond three hour are negligible. Appendix A (Tables A-9, A-10, and A-11) contains the tabulated data for the individual tests for the two, three, and six-hour detention, respectively. The EMCs calculated for the runs with two, three, and six-hour detention (42, 38, and 31 mg/L, respectively) were much lower than average EMC with 0-hour detention (63 mg/L), and the removal efficiencies calculated for the two, three, and six-hour detention (88, 89, and 91 percent, respectively) were reasonably higher than with 0-hour detention (81 percent).

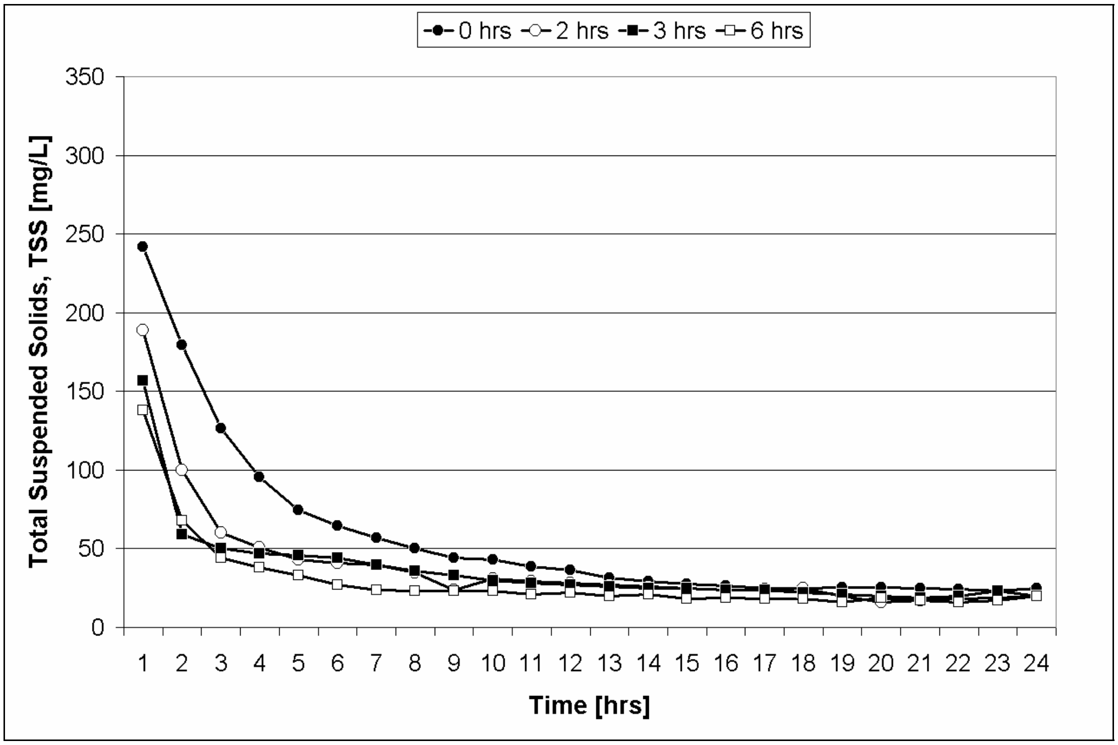

Figure 3.7. TSS Concentration vs. Time for Fixed Outlet with 0, 2, 3, and 6-hour Detention.

Floating Outlet

Three detention times were examined for this experiment: one, two, and three hours. Figure 3.8 shows the graph of total suspended solid concentration at outlet vs. time graph (for each of these detention times along with that for no detention). The data points for the 0-hour (no detention) were an average of the three runs and were derived from the outlet relocation experiments discussed previously. Results show a trend of decreasing total suspended solids concentration at outlet with increasing detention time. The results show that after three hours of detention, the total suspended solids concentration at the outlet remains constant for the entire duration of the experiment. This may be the lowest achievable concentration with the sediment used in the experiment. The tabulated data for the individual tests for the one, two, and three-hour detention are presented in Appendix A (Tables A-12, A-13, and A-14, respectively). The

EMCs calculated for the runs with one, two, and three-hour detention (29, 25, and 20 mg/L, respectively) were lower than average EMC with 0-hour detention (36 mg/L). The removal efficiencies calculated for the one, two, and three-hour detentions (88, 90, and 92 percent, respectively) were higher than with 0-hour detention (85 percent).

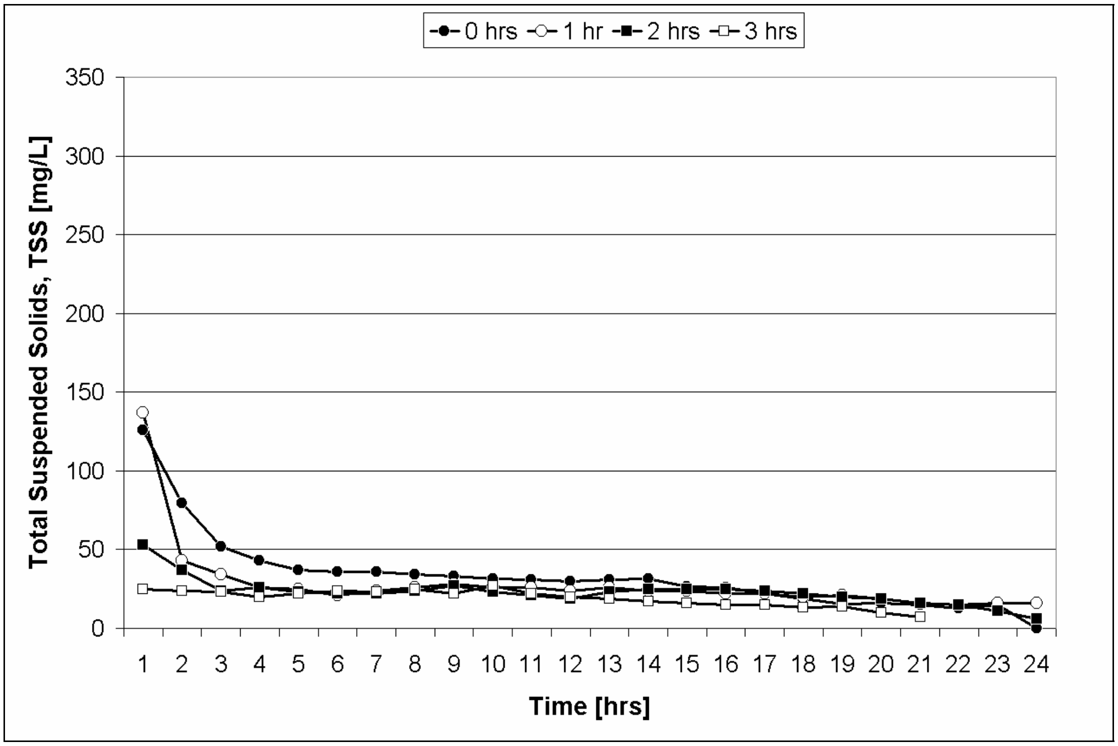

Figure 3.8. TSS Concentration vs. Time for Floating Outlet with 0, 1, 2, and 3-hour Detention.

ADDITIONAL EXPERIMENTS

Researchers conducted three additional experiments. The first and second experiments were conducted to obtain comparable data for outlet location and are discussed together in one sub-section. The third experiment was conducted to determine the effect of having a larger outlet size (diameter).

First and Second Experiment

Two outlet locations were examined for this experiment: at end (near weir wall) and near inlet. The total suspended solid concentration at outlet vs. time graph (for each of these outlet locations, along with that for outlet in middle) are presented in Figure 3.9. The data points for the outlet in middle were an average of the three runs and were derived from the outlet relocation experiments discussed previously. The emptying time for the run with the outlet at end (near weir wall) and for the run with outlet near inlet were both approximately 24 hours.

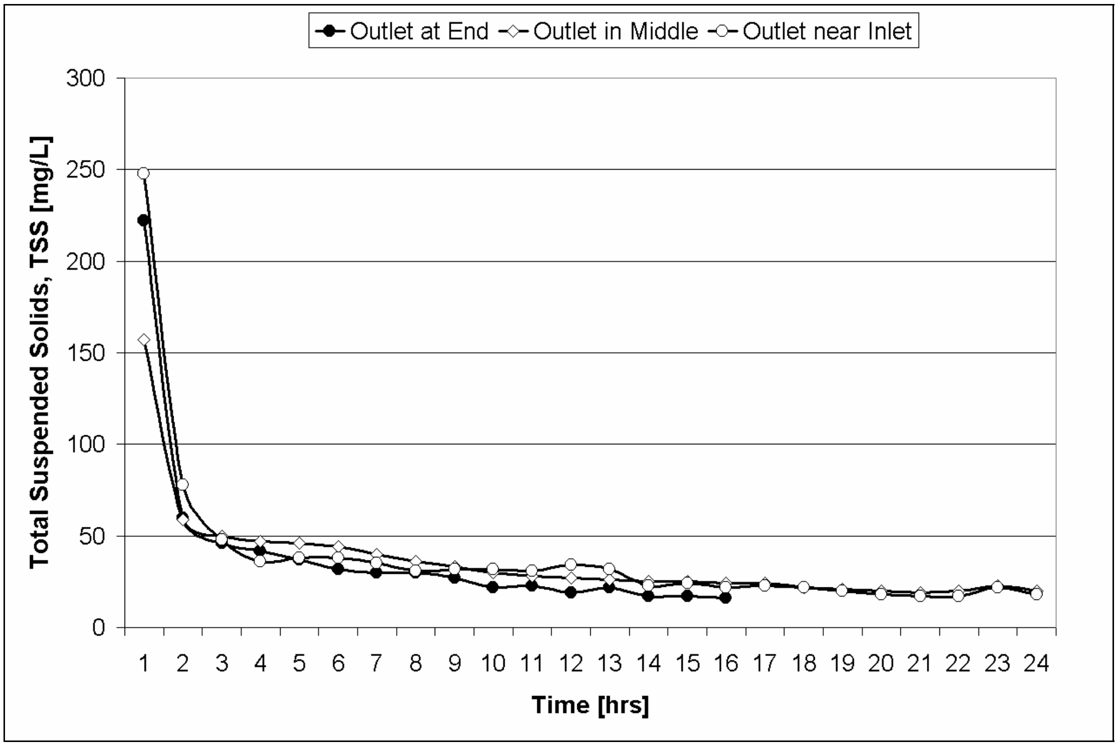

Figure 3.9. Effect of Outlet Location (at End, in Middle, and at Inlet) for Fixed Outlet.

The results show that outlet concentration was much higher for both these outlet locations compared to the outlet in the middle of the tank. However, as discussed previously, the lower concentrations for the outlet in the middle may be due to the lower outflow rate. The tabulated data for the individual tests for the outlet at end and outlet near inlet are presented in Appendix A (Tables A-15 and A-16, respectively). The EMC calculated for the outlet at end (near weir wall) was 60 mg/L, and the EMC for the outlet near inlet was 47 mg/L. The removal efficiency calculated for the outlet at end (near weir wall) was 75 percent, and the removal efficiency for the outlet near inlet was 81 percent. Considering all the factors (concentration, EMC, removal efficiency, and outflow rate), it is evident that there seems to be significant benefit to locating the outlet and inlet at the same side of the sedimentation tank.

Third Experiment

This experiment consisted of a single run with fixed outlet, three-hour detention and the outlet located at the end (near the weir). The only difference in this run was that the outlet diameter was increased to 6 inches. A detailed graph of outflow and total suspended solids concentration at the outlet (on separate axes) vs. time is presented in Figure 3.10. The results show a surprisingly low total suspended solids concentration at outlet. The initial spike in total suspended solids concentration observed in all the previous runs is not evident in this run. Researchers believe that this anomalous behavior may be because the rapidly falling water level in the tank might actually serve to accelerate the sediment particle and facilitate the settling process. The tabulated data for this experiment is presented in Appendix A (Table A-17). The EMC and removal efficiency calculated for this run were 47 mg/L and 81 percent, respectively.

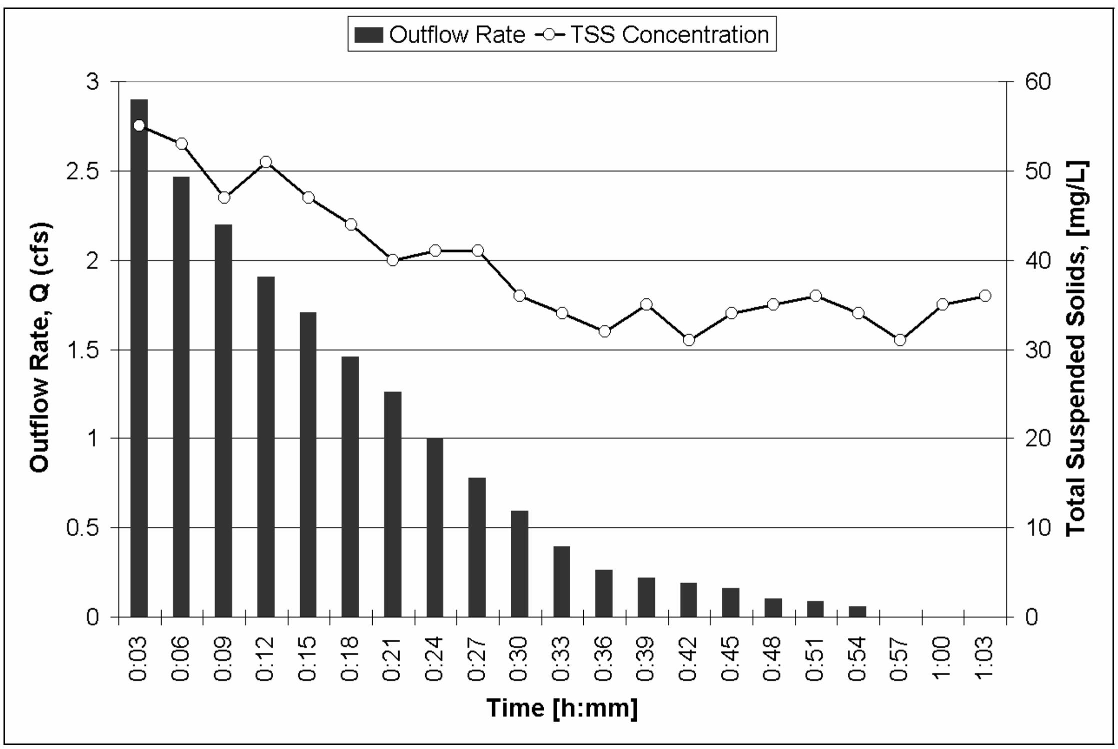

Figure 3.10. TSS for Fixed Outlet Located at End with 6 inch Outlet Opening.

RESULTS SUMMARY

The tests conducted on the small footprint BMP prototype included:

Event Mean Concentration

Detailed calculations of the event mean concentrations are presented in Table 3.2.

Table 3.2. Event Mean Concentrations in mg/L.

OUTLET		θ	LOADING [lbs]	$\sum C_i \times Q_i$	$\sum Q_i$	EMC	AVG. EMC
TYPE	LOCATION						
Fixed	End	0	0	21.57	1.810	11.92	14
Fixed	End	0	0	28.46	1.810	15.72	
Fixed	End	0	0	24.47	1.810	13.52	
Floating	End	0	0	22.16	1.254	17.67	15
Floating	End	0	0	15.04	1.254	11.99	
Floating	End	0	0	18.21	1.254	14.52	
Fixed	Middle	0	50	9.29	0.657	62.91	63
Fixed	Middle	0	50	9.64	0.657	65.28	
Fixed	Middle	0	50	9.16	0.657	62.03	
Floating	Middle	0	50	8.81	0.925	42.37	36
Floating	Middle	0	50	5.69	0.925	27.37	
Floating	Middle	0	50	8.17	0.925	39.29	
Fixed	Middle	2	50	6.17	0.657	41.78	42
Fixed	Middle	3	50	5.63	0.657	38.12	38
Fixed	Middle	6	50	4.58	0.657	31.01	31
Floating	Middle	1	50	6.03	0.925	29.00	29
Floating	Middle	2	50	5.10	0.925	24.53	25
Floating	Middle	3	50	4.12	0.925	19.82	20
Fixed	End	3	50	12.64	0.932	60.34	60
Fixed	Near Inlet	3	50	9.51	0.906	46.70	47
Fixed*	End	3	50	9.32	17.738	46.75	47

θ Detention Time in hours.
* 6 inch outlet opening.

The low EMCs for the fixed outlets with outlet located in the middle of the sedimentation tank may be misleading. As mentioned previously, the results might be affected by the low outflow rate for these experiments. The results of the floating outlet are unaffected by outflow rate and display a significant reduction in the EMC of the water flowing out of the sedimentation tank. The additional experiments conducted provided useful insights into the working of the prototype and provided valuable information to the researchers. The second and third of the additional experiments displayed relatively low EMCs. These results suggest that the outlet could be located close to the inlet and completely drained within one hour without significantly affecting the performance of the prototype.

TSS Removal Ratio

Detailed calculations of the removal ratios are presented in Table 3.3.

Table 3.3. TSS Removal Ratios.

OUTLET		θ	$MASS_{IN}$	$MASS_{OUT}$	REMOVAL RATIO	AVG. REMOVAL RATIO
TYPE	LOCATION					
Fixed	Middle	0	50	9.29	0.8142	0.813
Fixed	Middle	0	50	9.64	0.8072	
Fixed	Middle	0	50	9.16	0.8168	
Floating	Middle	0	50	8.81	0.8238	0.849
Floating	Middle	0	50	5.69	0.8862	
Floating	Middle	0	50	8.17	0.8366	
Fixed	Middle	2	50	6.17	0.8766	0.877
Fixed	Middle	3	50	5.63	0.8874	0.887
Fixed	Middle	6	50	4.58	0.9084	0.908
Floating	Middle	1	50	6.03	0.8794	0.879
Floating	Middle	2	50	5.10	0.8980	0.898
Floating	Middle	3	50	4.12	0.9176	0.918
Fixed	End	3	50	12.64	0.7472	0.747
Fixed	Near Inlet	3	50	9.51	0.8098	0.810
Fixed	End*	3	50	9.32	0.8136	0.814

θ Detention Time in hours.
* 6 inch outlet opening.

All the experiments except the first of the additional experiments had a removal ratio greater than 80 percent. The experiments wil the floating outlet achieved the highest removal ratio (0.9176. These removal ratios are much higher than the target removal ratios the researchers set out to achieve. The other interesting results were the second and third of the additional experiments, which displayed removal ratios above 0.8.

CHAPTER 4:
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Conclusions from Resuspension Results

The results of the resuspension experiment indicate that the problem of resuspension is significant. The resuspension effect is observed for the first 30 minutes when the tank is filling. However, the resuspension effect may be magnified when sediment-laden water enters the sedimentation tank. If this resuspension is reduced, significant improvement could be observed in the performance of the prototype.

Conclusions from Outlet Relocation Experiment Results

The results of outlet relocation experiments seem to show that significant benefit can be derived by moving the outlet closer to the inlet. The results for the fixed outlet may be misleading because the researchers could not conclude whether the improvement in performance was due to the new location of the outlet or because of the lower outflow rate. The 1 inch ID pipe used to extend the fixed outlet to the middle of the tank resulted in increased frictional losses that might have contributed to an increased settling and, therefore, a lower outlet TSS concentration.

Conclusions from Detention Experiment Results

The benefit of detaining the sediment-laden water prior to discharging is evident from the results of these experiments. For both fixed and floating outlet, the optimum detention time seems to be three hours. One concern that the researchers have about the results with the fixed outlet is that the effect of relocation of the outlet and detaining the sediment-laden water cannot be separated from the results of these experiments.

Conclusions from Additional Experiment Results

Even though no repetitions were conducted for these experiments, the results provided researchers with useful information. The main conclusions derived from these experiments were:

- to locate the inlet and outlet close to each other, and
- to empty the sedimentation tank in about one hour after closed-valve detention (three hours).

These actions could be carried out without adversely affecting the performance of the prototype. These results corroborate the researchers recommendations, discussed in the next chapter, for providing a flow-control chamber (FCC) and having a common inlet and outlet for the sedimentation tank.

RECOMMENDATIONS

Recommendations for Prototype Improvement

Based on the results of the study conducted in 2006–2007 and discussed in this report, the researchers recommend the following actions to improve performance of the prototype:

- A common inlet and outlet for the sedimentation basin with a flow-control chamber (FCC) would simplify inspection and maintenance of the BMP. A FCC prototype is provided with detailed design and dimension in Appendix C.
- A detention time of approximately three hours is sufficient to achieve desired sediment removal efficiency (>80%).
- One hour for emptying the water from the sedimentation tank (through the FCC) can be used for areas with high frequency, short duration storm events without compromising much sediment removal efficiency. This would allow the BMP to be available for the next storm event in approximately four hours.
- Using a floating outlet can improve the sediment removal efficiency. However, maintenance associated with a floating outlet, such as failure on the pivot joint or the flexible hose, or loss of buoyancy, may become a serious concern.

Recommendations for Maintainance

Based on the results of the study conducted in 2006–2007 and discussed in this report, the researchers recommend the following actions to improve performance of the prototype:

- The FCC should be inspected after every large storm (>0.5 inch) for the first year after installation.
- The FCC should be inspected annually following the first year after installation.

- Grab samples should be collected from the FCC outlet approximately three hours after the end of the storm event and analyzed for total suspended solids.
- A cleanup for the sedimentation tank should be performed, if the total suspended solids concentration of the grabbed samples from the FCC exceeds 50 mg/L.
- Ball valves have less clogging concerns than butterfly valves (based on field observations), and, therefore, are recommended for the outlet flow control.

Appendix D provides a flowchart of the maintenance schedule and a maintenance checklist.

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APPENDIX A:
DOCUMENTATION OF THE RESEARCH DATA

Table A.1. Data from Resuspension Experiments for Fixed Outlet.

Time Interval [hr]	Flow Rate Q_i [cfs]	Run 1		Run 2		Run 3	
		TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]
0:00–0:06	0.010[2]	66	0.01	78	0.02	72	0.02
0:06–0:12	0.020[2]	44	0.02	49	0.02	55	0.02
0:12–0:18	0.030[2]	27	0.02	37	0.02	34	0.02
0:18–0:24	0.040[2]	10	0.01	24	0.02	18	0.02
0:24–0:30	0.050[2]	13	0.01	16	0.02	14	0.02
0:30–0:36	0.060[2]	8	0.01	15	0.02	13	0.02
0:36–0:42	0.070[2]	12	0.02	15	0.02	13	0.02
0:42–0:48	0.080[2]	9	0.02	14	0.03	12	0.02
0:48–0:54	0.090[2]	11	0.02	12	0.02	10	0.02
0:54–1:00	0.100[2]	11	0.02	15	0.03	10	0.02
1:00–1:06	0.090[2]	13	0.03	14	0.03	11	0.02
1:06–1:12	0.090[2]	10	0.02	14	0.03	11	0.02
1:12–1:18	0.090[2]	10	0.02	11	0.02	13	0.03
1:18–1:24	0.090[2]	11	0.02	13	0.03	13	0.03
1:24–1:30	0.090[2]	16	0.03	11	0.02	13	0.03
1:30–1:36	0.090[2]	9	0.02	14	0.03	12	0.02
1:36–1:42	0.090[2]	9	0.02	14	0.03	12	0.02
1:42–1:48	0.090[2]	10	0.02	16	0.03	12	0.02
1:48–1:54	0.090[2]	11	0.02	14	0.03	12	0.02
1:54–2:00	0.090[2]	11	0.02	13	0.03	11	0.02
2:00–2:06	0.090[2]	10	0.02	18	0.04	16	0.03
2:06–2:12	0.090[2]	10	0.02	20	0.04	14	0.03
2:12–2:18	0.090[2]	10	0.02	18	0.04	12	0.02
2:18–2:24	0.090[2]	16	0.03	12	0.02	12	0.02
		$\sum C_i \times Q_i =$	0.48	$\sum C_i \times Q_i =$	0.64	$\sum C_i \times Q_i =$	0.55

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.2. Data from Resuspension Experiments for Floating Outlet.

Time Interval [hr]	Flow Rate Q_i [cfs]	Run 1		Run 2		Run 3	
		TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]
0:00–0:06	0.006[2]	235	0.03	216	0.03	204	0.03
0:06–0:12	0.012[2]	143	0.04	120	0.03	132	0.04
0:12–0:18	0.018[2]	95	0.04	82	0.03	88	0.04
0:18–0:24	0.024[2]	60	0.03	54	0.03	57	0.03
0:24–0:30	0.030[2]	35	0.02	33	0.02	31	0.02
0:30–0:36	0.036[2]	14	0.01	18	0.01	20	0.02
0:36–0:42	0.042[2]	12	0.01	9	0.01	15	0.01
0:42–0:48	0.048[2]	15	0.02	6	0.01	12	0.01
0:48–0:54	0.054[2]	13	0.02	6	0.01	10	0.01
0:54–1:00	0.060[2]	12	0.02	5	0.01	9	0.01
1:00–1:06	0.066[2]	10	0.01	8	0.01	9	0.01
1:06–1:12	0.066[2]	12	0.02	8	0.01	10	0.01
1:12–1:18	0.066[2]	11	0.02	7	0.01	9	0.01
1:18–1:24	0.066[2]	14	0.02	7	0.01	11	0.02
1:24–1:30	0.066[2]	12	0.02	8	0.01	10	0.01
1:30–1:36	0.066[2]	12	0.02	8	0.01	10	0.01
1:36–1:42	0.066[2]	16	0.02	6	0.01	10	0.01
1:42–1:48	0.066[2]	14	0.02	6	0.01	10	0.01
1:48–1:54	0.066[2]	13	0.02	9	0.01	10	0.01
1:54–2:00	0.066[2]	13	0.02	7	0.01	9	0.01
2:00–2:06	0.066[2]	11	0.02	6	0.01	7	0.01
2:06–2:12	0.066[2]	15	0.02	8	0.01	8	0.01
2:12–2:18	0.066[2]	12	0.02	6	0.01	8	0.01
2:18–2:24	0.066[2]	12	0.02	6	0.01	8	0.01
		$\sum C_i \times Q_i =$	0.50	$\sum C_i \times Q_i =$	0.34	$\sum C_i \times Q_i =$	0.41

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.3. Data from Outlet Relocation Experiment for Fixed Outlet–Run 1.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	219	1.23	0.13	0.13
1–2	0.040	192	1.73	0.19	0.32
2–3	0.038	127	1.10	0.12	0.44
3–4	0.037	95	0.78	0.08	0.52
4–5	0.035	76	0.60	0.06	0.59
5–6	0.034	63	0.48	0.05	0.64
6–7	0.033	55	0.41	0.04	0.68
7–8	0.032	49	0.35	0.04	0.72
8–9	0.031	46	0.32	0.03	0.75
9–10	0.030	43	0.29	0.03	0.79
10–11	0.030	39	0.26	0.03	0.81
11–12	0.028	36	0.23	0.02	0.84
12–13	0.027	30	0.18	0.02	0.86
13–14	0.026	27	0.16	0.02	0.88
14–15	0.024	25	0.14	0.01	0.89
15–16	0.024	26	0.14	0.02	0.90
16–17	0.024	25	0.13	0.01	0.92
17–18	0.024	24	0.13	0.01	0.93
18–19	0.023	23	0.12	0.01	0.95
19–20	0.023	23	0.12	0.01	0.96
20–21	0.019	25	0.11	0.01	0.97
21–22	0.017	26	0.10	0.01	0.98
22–23	0.017	24	0.09	0.01	0.99
23–24	0.017	24	0.09	0.01	1.00
$\sum Q_i =$	0.657	$\sum C_i \times Q_i =$	9.29		

[1] *Could not be assessed due to tank filling*
[2] *Estimated average*
[3] *No sample collected due to low/no outflow*

Table A.4. Data from Outlet Relocation Experiment for Fixed Outlet–Run 2.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	268	1.51	0.16	0.16
1–2	0.040	148	1.34	0.14	0.29
2–3	0.038	122	1.05	0.11	0.40
3–4	0.037	92	0.76	0.08	0.48
4–5	0.035	78	0.62	0.06	0.55
5–6	0.034	66	0.50	0.05	0.60
6–7	0.033	63	0.47	0.05	0.65
7–8	0.032	56	0.40	0.04	0.69
8–9	0.031	52	0.37	0.04	0.73
9–10	0.030	52	0.35	0.04	0.76
10–11	0.030	46	0.31	0.03	0.80
11–12	0.028	40	0.25	0.03	0.82
12–13	0.027	35	0.21	0.02	0.84
13–14	0.026	32	0.18	0.02	0.86
14–15	0.024	31	0.17	0.02	0.88
15–16	0.024	29	0.16	0.02	0.90
16–17	0.024	27	0.14	0.01	0.91
17–18	0.024	27	0.14	0.01	0.93
18–19	0.023	30	0.15	0.02	0.94
19–20	0.023	29	0.15	0.02	0.96
20–21	0.019	28	0.12	0.01	0.97
21–22	0.017	24	0.09	0.01	0.98
22–23	0.017	23	0.09	0.01	0.99
23–24	0.017	27	0.10	0.01	1.00
$\sum Q_i =$	0.657	$\sum C_i \times Q_i =$	9.64		

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.5. Data from Outlet Relocation Experiment for Fixed Outlet–Run 3.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	238	1.34	0.15	0.15
1–2	0.040	198	1.79	0.20	0.34
2–3	0.038	130	1.12	0.12	0.46
3–4	0.037	100	0.82	0.09	0.55
4–5	0.035	69	0.55	0.06	0.61
5–6	0.034	61	0.46	0.05	0.66
6–7	0.033	53	0.40	0.04	0.71
7–8	0.032	46	0.33	0.04	0.74
8–9	0.031	35	0.25	0.03	0.77
9–10	0.030	35	0.24	0.03	0.80
10–11	0.030	31	0.21	0.02	0.82
11–12	0.028	33	0.21	0.02	0.84
12–13	0.027	30	0.18	0.02	0.86
13–14	0.026	28	0.16	0.02	0.88
14–15	0.024	27	0.15	0.02	0.89
15–16	0.024	24	0.13	0.01	0.91
16–17	0.024	22	0.12	0.01	0.92
17–18	0.024	24	0.13	0.01	0.94
18–19	0.023	23	0.12	0.01	0.95
19–20	0.023	24	0.12	0.01	0.96
20–21	0.019	22	0.09	0.01	0.97
21–22	0.017	23	0.09	0.01	0.98
22–23	0.017	22	0.08	0.01	0.99
23–24	0.017	23	0.09	0.01	1.00
$\sum Q_i =$	0.657	$\sum C_i \times Q_i =$	9.16		

[1] *Could not be assessed due to tank filling*
[2] *Estimated average*
[3] *No sample collected due to low/no outflow*

Table A.6. Data from Outlet Relocation Experiment for Floating Outlet–Run 1.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	103	0.67	0.08	0.08
1–2	0.057	75	0.96	0.11	0.18
2–3	0.056	65	0.82	0.09	0.28
3–4	0.054	58	0.71	0.08	0.36
4–5	0.053	49	0.59	0.07	0.42
5–6	0.051	48	0.55	0.06	0.49
6–7	0.051	46	0.53	0.06	0.55
7–8	0.049	46	0.50	0.06	0.60
8–9	0.047	41	0.43	0.05	0.65
9–10	0.046	41	0.43	0.05	0.70
10–11	0.046	41	0.43	0.05	0.75
11–12	0.046	40	0.41	0.05	0.80
12–13	0.045	42	0.43	0.05	0.84
13–14	0.045	44	0.45	0.05	0.90
14–15	0.045	39	0.39	0.04	0.94
15–16	0.041	36	0.33	0.04	0.98
16–17	0.035	26	0.20	0.02	1.00
17–18	0.032	---[3]	0.00	0.00	1.00
18–19	0.031	---[3]	0.00	0.00	1.00
19–20	0.023	---[3]	0.00	0.00	1.00
20–21	0.017	---[3]	0.00	0.00	1.00
21–22	0.012	---[3]	0.00	0.00	1.00
22–23	0.007	---[3]	0.00	0.00	1.00
23–24	0.007	---[3]	0.00	0.00	1.00
$\sum Q_i$ =	0.925	$\sum C_i \times Q_i$ =	8.81		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

Table A.7. Data from Outlet Relocation Experiment for Floating Outlet–Run 2.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	71	0.46	0.08	0.08
1–2	0.057	44	0.56	0.10	0.18
2–3	0.056	43	0.54	0.10	0.28
3–4	0.054	33	0.40	0.07	0.35
4–5	0.053	27	0.32	0.06	0.40
5–6	0.051	24	0.27	0.05	0.45
6–7	0.051	29	0.33	0.06	0.51
7–8	0.049	29	0.32	0.06	0.56
8–9	0.047	27	0.28	0.05	0.61
9–10	0.046	23	0.24	0.04	0.66
10–11	0.046	22	0.23	0.04	0.70
11–12	0.046	23	0.24	0.04	0.74
12–13	0.045	25	0.26	0.04	0.78
13–14	0.045	26	0.26	0.05	0.83
14–15	0.045	19	0.19	0.03	0.86
15–16	0.041	19	0.17	0.03	0.89
16–17	0.035	21	0.16	0.03	0.92
17–18	0.032	18	0.13	0.02	0.95
18–19	0.031	16	0.11	0.02	0.96
19–20	0.023	15	0.08	0.01	0.98
20–21	0.017	17	0.07	0.01	0.99
21–22	0.012	12	0.03	0.01	1.00
22–23	0.007	15	0.03	0.00	1.00
23–24	0.007	---[3]	0.00	0.00	1.00
$\sum Q_i$ =	0.925	$\sum C_i \times Q_i$ =	5.69		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

Table A.8. Data from Outlet Relocation Experiment for Floating Outlet–Run 3.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	203	1.32	0.16	0.16
1–2	0.057	120	1.53	0.19	0.35
2–3	0.056	48	0.61	0.07	0.42
3–4	0.054	39	0.48	0.06	0.48
4–5	0.053	35	0.42	0.05	0.53
5–6	0.051	35	0.40	0.05	0.58
6–7	0.051	33	0.38	0.05	0.63
7–8	0.049	27	0.29	0.04	0.66
8–9	0.047	31	0.32	0.04	0.70
9–10	0.046	31	0.32	0.04	0.74
10–11	0.046	29	0.30	0.04	0.78
11–12	0.046	27	0.28	0.03	0.82
12–13	0.045	25	0.26	0.03	0.85
13–14	0.045	25	0.25	0.03	0.88
14–15	0.045	22	0.22	0.03	0.90
15–16	0.041	23	0.21	0.03	0.93
16–17	0.035	19	0.15	0.02	0.95
17–18	0.032	20	0.15	0.02	0.97
18–19	0.031	15	0.10	0.01	0.98
19–20	0.023	17	0.09	0.01	0.99
20–21	0.017	13	0.05	0.01	1.00
21–22	0.012	13	0.04	0.00	1.00
22–23	0.007	---[3]	0.00	0.00	1.00
23–24	0.007	---[3]	0.00	0.00	1.00
$\sum Q_i =$	0.925	$\sum C_i \times Q_i =$	8.17		

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.9. Data from Detention Experiment for Fixed Outlet–θ=2 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	189	1.06	0.17	0.17
1–2	0.040	100	0.90	0.15	0.32
2–3	0.038	60	0.52	0.08	0.40
3–4	0.037	51	0.42	0.07	0.47
4–5	0.035	43	0.34	0.06	0.53
5–6	0.034	41	0.31	0.05	0.58
6–7	0.033	40	0.30	0.05	0.62
7–8	0.032	35	0.25	0.04	0.67
8–9	0.031	24	0.17	0.03	0.69
9–10	0.030	31	0.21	0.03	0.73
10–11	0.030	29	0.20	0.03	0.76
11–12	0.028	28	0.18	0.03	0.79
12–13	0.027	27	0.16	0.03	0.81
13–14	0.026	26	0.15	0.02	0.84
14–15	0.024	25	0.14	0.02	0.86
15–16	0.024	24	0.13	0.02	0.88
16–17	0.024	24	0.13	0.02	0.90
17–18	0.024	25	0.13	0.02	0.92
18–19	0.023	20	0.10	0.02	0.94
19–20	0.023	16	0.08	0.01	0.95
20–21	0.019	17	0.07	0.01	0.96
21–22	0.017	18	0.07	0.01	0.98
22–23	0.017	19	0.07	0.01	0.99
23–24	0.017	20	0.08	0.01	1.00
$\sum Q_i$ =	0.657	$\sum C_i \times Q_i$ =	6.17		

[1] *Could not be assessed due to tank filling*
[2] *Estimated average*
[3] *No sample collected due to low/no outflow*

Table A.10. Data from Detention Experiment for Fixed Outlet–θ=3 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	157	0.88	0.16	0.16
1–2	0.040	59	0.53	0.09	0.25
2–3	0.038	50	0.43	0.08	0.33
3–4	0.037	47	0.39	0.07	0.40
4–5	0.035	46	0.36	0.06	0.46
5–6	0.034	44	0.33	0.06	0.52
6–7	0.033	40	0.30	0.05	0.57
7–8	0.032	36	0.26	0.05	0.62
8–9	0.031	33	0.23	0.04	0.66
9–10	0.030	30	0.20	0.04	0.70
10–11	0.030	28	0.19	0.03	0.73
11–12	0.028	27	0.17	0.03	0.76
12–13	0.027	26	0.16	0.03	0.79
13–14	0.026	25	0.14	0.03	0.82
14–15	0.024	25	0.14	0.02	0.84
15–16	0.024	24	0.13	0.02	0.86
16–17	0.024	24	0.13	0.02	0.89
17–18	0.024	22	0.12	0.02	0.91
18–19	0.023	21	0.11	0.02	0.92
19–20	0.023	20	0.10	0.02	0.94
20–21	0.019	19	0.08	0.01	0.96
21–22	0.017	20	0.08	0.01	0.97
22–23	0.017	23	0.09	0.02	0.99
23–24	0.017	20	0.08	0.01	1.00
$\sum Q_i =$	0.657	$\sum C_i \times Q_i =$	5.63		

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.11. Data from Detention Experiment for Fixed Outlet–θ=6 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.020[2]	138	0.78	0.17	0.17
1–2	0.040	68	0.61	0.13	0.30
2–3	0.038	44	0.38	0.08	0.39
3–4	0.037	38	0.31	0.07	0.45
4–5	0.035	33	0.26	0.06	0.51
5–6	0.034	27	0.20	0.04	0.56
6–7	0.033	24	0.18	0.04	0.60
7–8	0.032	23	0.17	0.04	0.63
8–9	0.031	23	0.16	0.04	0.67
9–10	0.030	23	0.16	0.03	0.70
10–11	0.030	21	0.14	0.03	0.73
11–12	0.028	22	0.14	0.03	0.76
12–13	0.027	20	0.12	0.03	0.79
13–14	0.026	21	0.12	0.03	0.82
14–15	0.024	18	0.10	0.02	0.84
15–16	0.024	19	0.10	0.02	0.86
16–17	0.024	18	0.10	0.02	0.88
17–18	0.024	18	0.10	0.02	0.90
18–19	0.023	16	0.08	0.02	0.92
19–20	0.023	19	0.10	0.02	0.94
20–21	0.019	17	0.07	0.02	0.96
21–22	0.017	16	0.06	0.01	0.97
22–23	0.017	17	0.06	0.01	0.98
23–24	0.017	20	0.08	0.02	1.00
$\sum Q_i$ =	0.657	$\sum C_i \times Q_i$ =	4.58		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

Table A.12. Data from Detention Experiment for Floating Outlet–θ=1 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	137	0.89	0.15	0.15
1–2	0.057	43	0.55	0.09	0.24
2–3	0.056	34	0.43	0.07	0.31
3–4	0.054	26	0.32	0.05	0.36
4–5	0.053	25	0.30	0.05	0.41
5–6	0.051	21	0.24	0.04	0.45
6–7	0.051	24	0.27	0.05	0.50
7–8	0.049	26	0.28	0.05	0.54
8–9	0.047	28	0.29	0.05	0.59
9–10	0.046	26	0.27	0.04	0.64
10–11	0.046	26	0.27	0.04	0.68
11–12	0.046	24	0.25	0.04	0.72
12–13	0.045	26	0.27	0.04	0.77
13–14	0.045	24	0.24	0.04	0.81
14–15	0.045	24	0.24	0.04	0.85
15–16	0.041	22	0.20	0.03	0.88
16–17	0.035	22	0.17	0.03	0.91
17–18	0.032	20	0.15	0.02	0.93
18–19	0.031	21	0.15	0.02	0.96
19–20	0.023	19	0.10	0.02	0.97
20–21	0.017	16	0.06	0.01	0.98
21–22	0.012	15	0.04	0.01	0.99
22–23	0.007	16	0.03	0.00	1.00
23–24	0.007	16	0.02	0.00	1.00
$\sum Q_i$ =	0.925	$\sum C_i \times Q_i$ =	6.03		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

Table A.13. Data from Detention Experiment for Floating Outlet–θ=2 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	53	0.35	0.07	0.07
1–2	0.057	37	0.47	0.09	0.16
2–3	0.056	24	0.30	0.06	0.22
3–4	0.054	26	0.32	0.06	0.28
4–5	0.053	23	0.28	0.05	0.34
5–6	0.051	22	0.25	0.05	0.39
6–7	0.051	22	0.25	0.05	0.43
7–8	0.049	24	0.26	0.05	0.49
8–9	0.047	27	0.28	0.06	0.54
9–10	0.046	23	0.24	0.05	0.59
10–11	0.046	21	0.22	0.04	0.63
11–12	0.046	19	0.19	0.04	0.67
12–13	0.045	23	0.23	0.05	0.72
13–14	0.045	25	0.25	0.05	0.77
14–15	0.045	25	0.25	0.05	0.81
15–16	0.041	25	0.23	0.05	0.86
16–17	0.035	24	0.19	0.04	0.90
17–18	0.032	22	0.16	0.03	0.93
18–19	0.031	20	0.14	0.03	0.96
19–20	0.023	19	0.10	0.02	0.97
20–21	0.017	16	0.06	0.01	0.99
21–22	0.012	15	0.04	0.01	0.99
22–23	0.007	11	0.02	0.00	1.00
23–24	0.007	6	0.01	0.00	1.00
$\sum Q_i$ =	0.925	$\sum C_i \times Q_i$ =	5.10		

1 *Could not be assessed due to tank filling*
2 *Estimated average*
3 *No sample collected due to low/no outflow*

Table A.14. Data from Detention Experiment for Floating Outlet–θ=3 Hours.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.029[2]	25	0.16	0.04	0.04
1–2	0.057	24	0.31	0.07	0.11
2–3	0.056	23	0.29	0.07	0.18
3–4	0.054	20	0.24	0.06	0.24
4–5	0.053	22	0.26	0.06	0.31
5–6	0.051	24	0.27	0.07	0.37
6–7	0.051	23	0.26	0.06	0.44
7–8	0.049	25	0.27	0.07	0.50
8–9	0.047	22	0.23	0.06	0.56
9–10	0.046	27	0.28	0.07	0.63
10–11	0.046	22	0.23	0.06	0.68
11–12	0.046	20	0.21	0.05	0.73
12–13	0.045	19	0.19	0.05	0.78
13–14	0.045	17	0.17	0.04	0.82
14–15	0.045	16	0.16	0.04	0.86
15–16	0.041	15	0.14	0.03	0.90
16–17	0.035	15	0.12	0.03	0.92
17–18	0.032	13	0.09	0.02	0.95
18–19	0.031	14	0.10	0.02	0.97
19–20	0.023	10	0.05	0.01	0.98
20–21	0.017	7	0.03	0.01	0.99
21–22	0.012	7	0.02	0.00	0.99
22–23	0.007	7	0.01	0.00	1.00
23–24	0.007	7	0.01	0.00	1.00
$\sum Q_i =$	0.925	$\sum C_i \times Q_i =$	4.12		

[1] *Could not be assessed due to tank filling*
[2] *Estimated average*
[3] *No sample collected due to low/no outflow*

Table A.15. Data from Additional Experiments–First Experiment.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.121	222	6.04	0.48	0.48
1–2	0.115	60	1.55	0.12	0.60
2–3	0.104	46	1.07	0.08	0.69
3–4	0.096	42	0.90	0.07	0.76
4–5	0.085	37	0.70	0.06	0.81
5–6	0.076	32	0.55	0.04	0.86
6–7	0.068	30	0.46	0.04	0.89
7–8	0.058	30	0.39	0.03	0.92
8–9	0.050	27	0.31	0.02	0.95
9–10	0.043	22	0.21	0.02	0.96
10–11	0.034	23	0.18	0.01	0.98
11–12	0.025	19	0.11	0.01	0.99
12–13	0.018	22	0.09	0.01	0.99
13–14	0.010	17	0.04	0.00	1.00
14–15	0.006	17	0.02	0.00	1.00
15–16	0.005	16	0.02	0.00	1.00
16–17	0.004	---[3]	0.00	0.00	1.00
17–18	0.003	---[3]	0.00	0.00	1.00
18–19	0.004	---[3]	0.00	0.00	1.00
19–20	0.002	---[3]	0.00	0.00	1.00
20–21	0.001	---[3]	0.00	0.00	1.00
21–22	0.002	---[3]	0.00	0.00	1.00
22–23	0.000	---[3]	0.00	0.00	1.00
23–24	0.003	---[3]	0.00	0.00	1.00
$\sum Q_i$ =	0.932	$\sum C_i \times Q_i$ =	12.64		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

Table A.16. Data from Additional Experiments–Second Experiment.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0–1	0.056	248	3.13	0.33	0.33
1–2	0.055	78	0.97	0.10	0.43
2–3	0.055	48	0.59	0.06	0.49
3–4	0.054	36	0.44	0.05	0.54
4–5	0.053	38	0.46	0.05	0.59
5–6	0.047	38	0.40	0.04	0.63
6–7	0.047	35	0.37	0.04	0.67
7–8	0.046	31	0.32	0.03	0.70
8–9	0.045	32	0.33	0.03	0.74
9–10	0.044	32	0.31	0.03	0.77
10–11	0.039	31	0.27	0.03	0.80
11–12	0.037	34	0.28	0.03	0.83
12–13	0.036	32	0.26	0.03	0.86
13–14	0.035	23	0.18	0.02	0.87
14–15	0.033	24	0.18	0.02	0.89
15–16	0.031	22	0.15	0.02	0.91
16–17	0.030	23	0.16	0.02	0.93
17–18	0.027	22	0.13	0.01	0.94
18–19	0.026	20	0.12	0.01	0.95
19–20	0.026	18	0.10	0.01	0.96
20–21	0.024	17	0.09	0.01	0.97
21–22	0.022	17	0.08	0.01	0.98
22–23	0.021	22	0.11	0.01	0.99
23–24	0.016	18	0.06	0.01	1.00
$\sum Q_i$ =	0.906	$\sum C_i \times Q_i$ =	9.51		

[1] *Could not be assessed due to tank filling*

[2] *Estimated average*

[3] *No sample collected due to low/no outflow*

Table A.17. Data from Additional Experiments–Third Experiment.

Time Interval [hr]	Flow Rate Q_i [cfs]	TSS C_i [mg/L]	$Mass_{OUT}$ $C_i \times Q_i$ [lb]	Mass Fraction $\frac{C_i \times Q_i}{\sum C_i \times Q_i}$	Mass Fraction Cumulative
0:00–0:03	2.898	55	1.79	0.19	0.19
0:03–0:03	2.467	53	1.47	0.16	0.35
0:06–0:03	2.196	47	1.16	0.12	0.47
0:09–0:03	1.904	51	1.09	0.12	0.59
0:12–0:03	1.708	47	0.90	0.10	0.69
0:15–0:03	1.458	44	0.72	0.08	0.77
0:18–0:03	1.258	40	0.57	0.06	0.83
0:21–0:03	1.001	41	0.46	0.05	0.88
0:24–0:03	0.780	41	0.36	0.04	0.91
0:27–0:03	0.596	36	0.24	0.03	0.94
0:30–0:03	0.396	34	0.15	0.02	0.96
0:00–0:03	0.262	32	0.09	0.01	0.97
0:00–0:03	0.218	35	0.09	0.01	0.98
0:00–0:03	0.191	31	0.07	0.01	0.98
0:00–0:03	0.160	34	0.06	0.01	0.99
0:00–0:03	0.102	35	0.04	0.00	0.99
0:00–0:03	0.087	36	0.04	0.00	1.00
0:00–0:03	0.058	34	0.02	0.00	1.00
18–19	---[3]	31	---[3]	---[3]	---[3]
19–20	---[3]	35	---[3]	---[3]	---[3]
20–21	---[3]	36	---[3]	---[3]	---[3]
21–22	---[3]	---[3]	---[3]	---[3]	---[3]
22–23	---[3]	---[3]	---[3]	---[3]	---[3]
23–24	---[3]	---[3]	---[3]	---[3]	---[3]
$\sum Q_i$ =	17.738	$\sum C_i \times Q_i$ =	9.32		

1 *Could not be assessed due to tank filling*

2 *Estimated average*

3 *No sample collected due to low/no outflow*

APPENDIX B:
DESIGN GUIDANCE DOCUMENT (TWO DESIGN EXAMPLES)

Example 1. Regulated Environmental Sensitive Areas (such as Edwards Aquifer)

A three-mile, four-lane undivided highway in an east-west orientation is being designed for Edwards Aquifer recharge zone located in Travis County, Texas. The recharge zone regulations require that new construction shall provide stormwater BMPs to remove 80 percent of the annual TSS from runoff. The planned highway is space-constrained and does not have enough land for surface type of BMPs such as extended detention basins. The area is gently sloped. Given the information, how many small footprint underground BMPs should be installed?

Additional information for design consideration includes:

- Pavement: conventional reinforced concrete
- Lane width: 12' for driving lane and 8' for shoulder

The prototype has a dimension of 80 ft length, 10 ft width, and 4.67 ft depth. Using the prototype design developed from this project, the following steps explain the design procedure.

Step 1. Choose a prototype design.

This project tested several design configurations. The TSS removal efficiency varies from design to design, which can be seen in the following table.

Table B.1. TSS Removal Efficiency Corresponding to Different Designs.

Design Configurations	TSS Removal Efficiency (%)
Fixed outlet with free outflow design	60
Floating outlet with free outflow design	71
Fixed outlet with 2-hour detention	82
Fixed outlet with 3-hour detention	84
Fixed outlet with 6-hour detention	86
Floating outlet with 1-hour detention	87
Floating outlet with 2-hour detention	95
Floating outlet with 3-hour detention	96

Assuming the design of “fixed outlet with 6-hour detention” is chosen and its expected TSS removal efficiency is 86 percent we go to step 2.

Step 2. Find the required runoff depth to be detained.

The following table presents required runoff depths to be detained based on the TSS removal performance of the selected design for removing 80 percent of the annual TSS from the recharge zone. Therefore, a storage volume for detaining 2 inches of runoff is necessary.

Table B.2. Required Runoff to Be Detained Corresponding to Different TSS Removal Efficiency of the Small Footprint BMP (for Edwards Aquifer).[1]

TSS Removal Efficiency (%)	Required Runoff Depth to Be Detained (inches)
80	4
86	2
90	1.6
96	1.2

1 provided by author (Dr. Michael E. Barrett)

Step 3. Calculate the number of small footprint BMP.

Assuming that the crown of the pavement separates runoff generated from each bound and the small footprint BMPs will be installed on both bounds of shoulders, the drainage area includes two 12 ft lanes and an 8 ft shoulder. Hence, required storage volume per linear foot of highway is calculated as:

Required storage volume per linear foot of highway = $(2 \cdot 12' + 1 \cdot 8') \cdot \frac{2"}{12} = 5.3\,\text{ft}^3/\text{ft}$

Then,

Number of 80 ft tank per mile of highway

$$= \frac{\text{Required storage volume per mile}}{\text{Storage volume per unit of BMP}}$$

$$= \frac{5280 \cdot 5.3\,\text{ft}^3}{80' \cdot 10' \cdot 4.67'} = 8 \text{ units/mile}$$

Therefore,

Total number of units on both east and west bounds of the three-mile highway will need 8×3×2 = 48 units.

Example 2. General Ultra-urban Application

A three-mile, four-lane undivided highway in an east-west orientation is being designed for Harris County, Texas. The planned highway is space-constrained and does not have enough lands for surface type of BMPs such as extended detention basins. Due to flooding concerns, extended detention BMPs are recommended to completely drain within 24 hours. The area is gently sloped. Given the information, how many small footprint underground BMPs should be installed?

Additional information for design consideration includes:

- Pavement: conventional reinforced concrete
- Lane width: 12' for driving lane and 8' for shoulder

Step 1. Choose a prototype design.

Because there is no regulatory requirement in Harris County in terms of annual TSS removal, all designs listed in Table B.1 can be chosen. For comparison purposes, the design of "fixed outlet with 6-hour detention" is chosen. Thus, the expected removal efficiency is still 86 percent.

Step 2. Find the required runoff depth to be detained.

It is suggested that design engineers use Asquith et al.'s (2006) data to estimate required storage volume. In this case, 90-percentile rainfalls of six-hour duration are used. According to Asquith et al. (2006), the average rainfall depth of six-hour duration is 0.554 inch. By multiplying 0.554 with a frequency factor, the designed rainfall depth in terms of the percentile the rainfall is associated can be estimated. Because Asquith et al. (2006) only provide frequency factors for 24-hour and 48-hour duration rainfalls (both are 2.5), it is assumed that the frequency factor for six-hour rainfalls is 2.5. Therefore, a 90-percentile rainfall depth can be calculated by $0.554 \times 2.5 = 1.39$ inches.

Step 3. Calculate the number of small footprint BMP.

Assuming that the crown of the pavement separates runoff generated from each bound and the small footprint BMPs will be installed on both bounds of shoulders. The drainage area includes two 12 ft lanes and an 8 ft shoulder. Hence, required storage volume per linear foot of highway is calculated as:

Required storage volume per linear foot of highway = $(2\cdot 12' + 1\cdot 8')\cdot\frac{1.39''}{12} = 3.7\ \text{ft}^3/\text{ft}$

Then,

Number of 80 ft tank per mile of highway

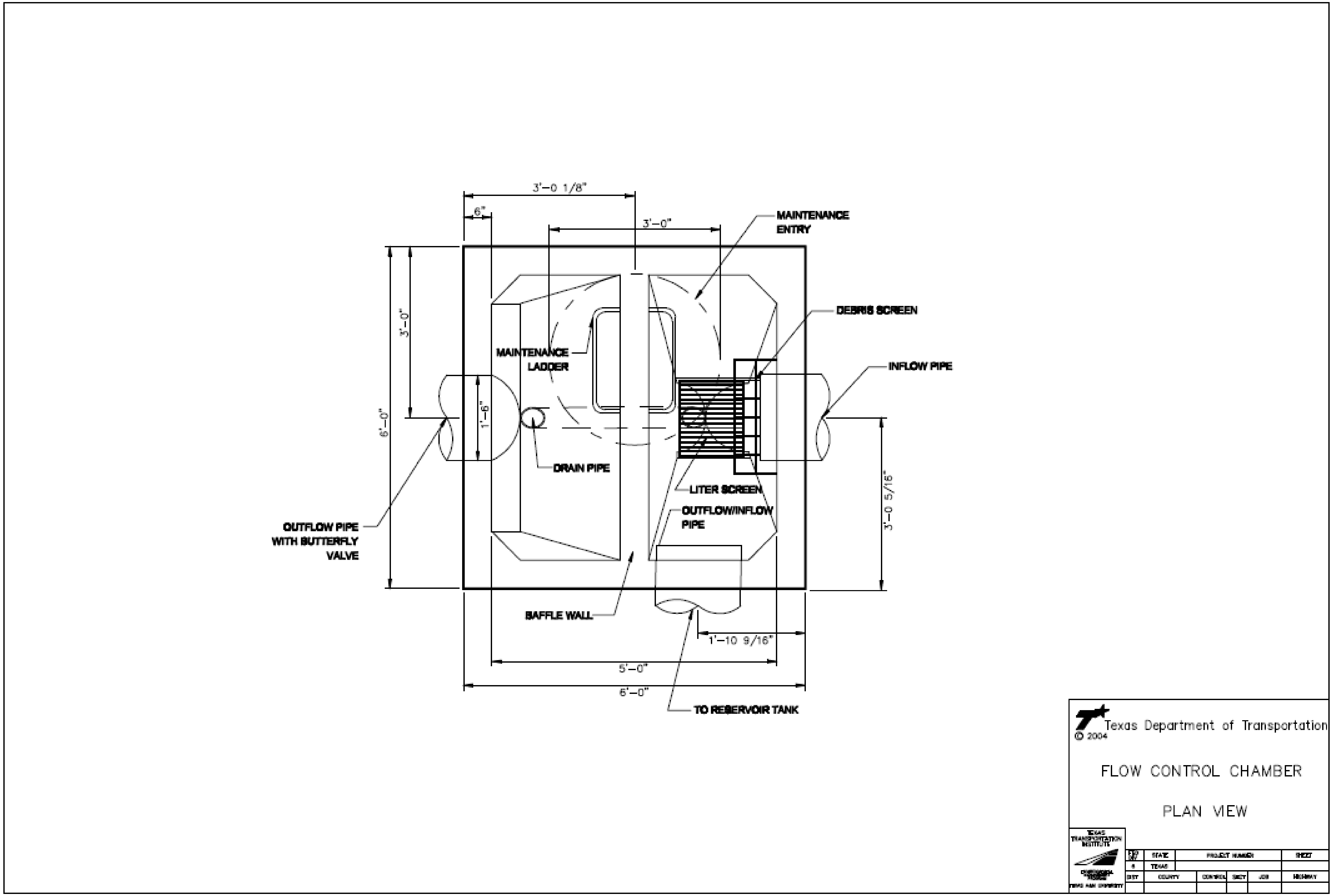
$$= \frac{\text{Required storage volume per mile}}{\text{Storage volume per unit of BMP}}$$

$$= \frac{5280\cdot 3.7\ \text{ft}^3}{80'\cdot 10'\cdot 4.67'} \approx 5\ \text{units/mile}$$

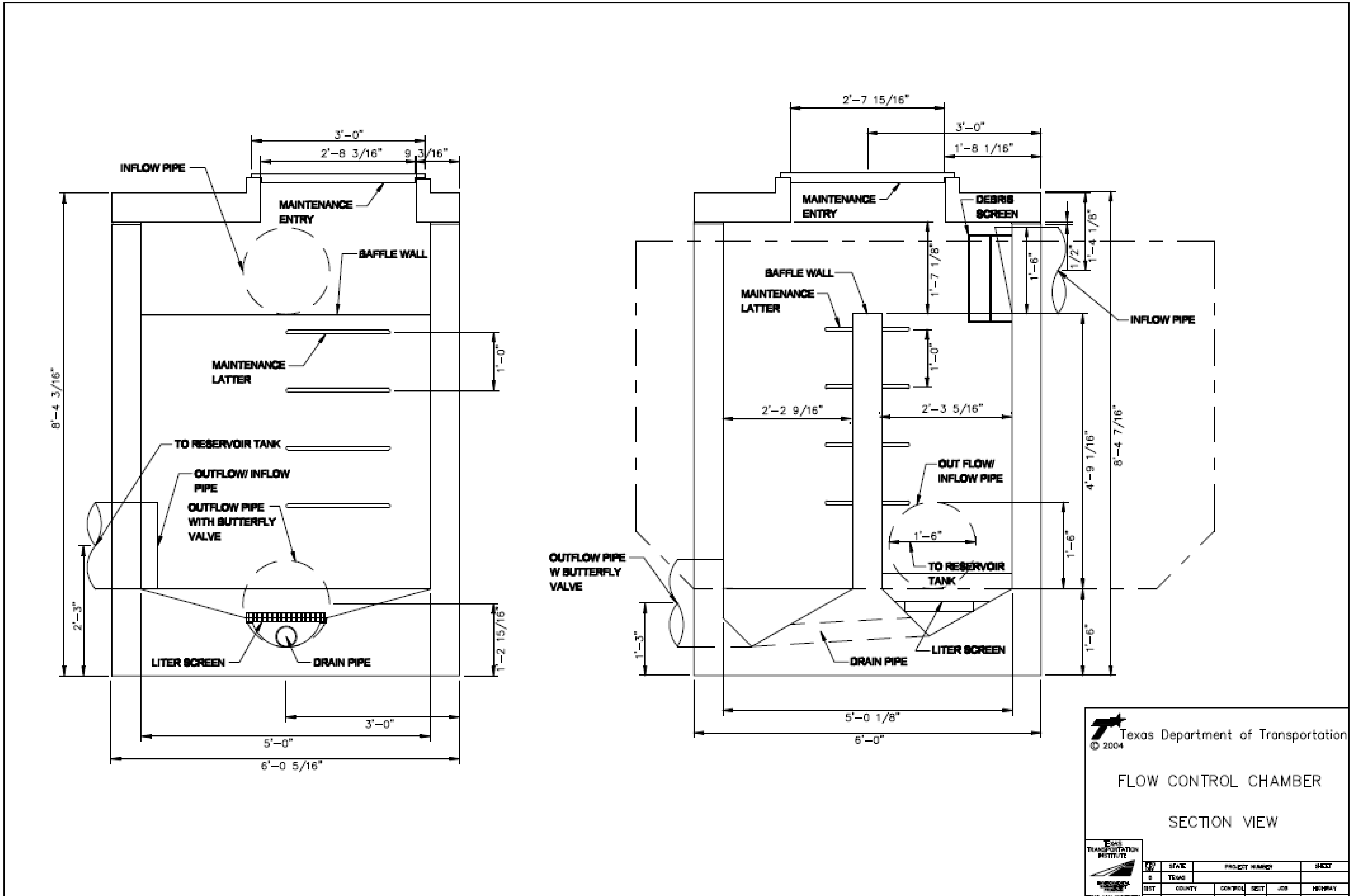
Therefore,

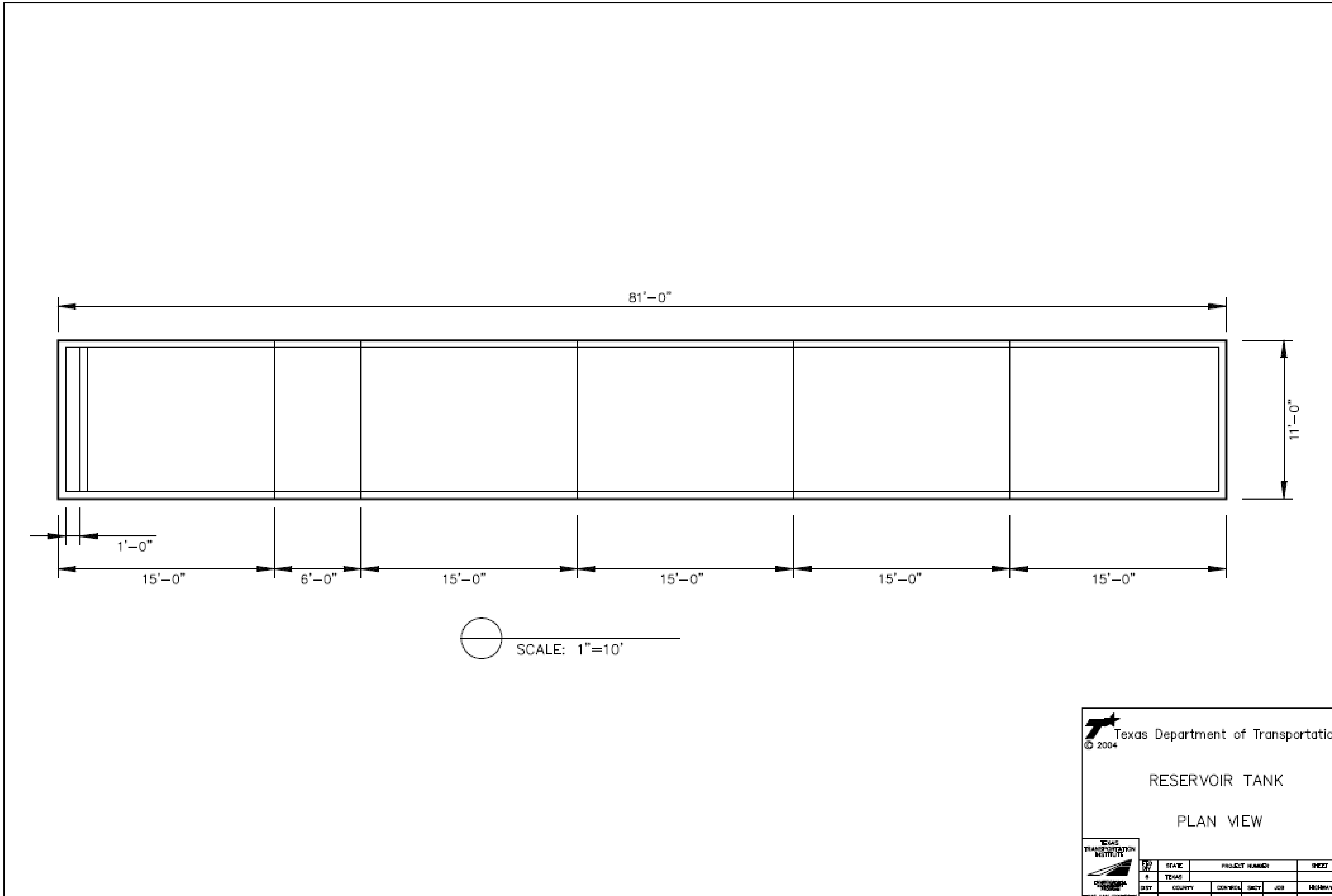
Total number of units on both east and west bounds of the three-mile highway will need 5×3×2 = 30 units.

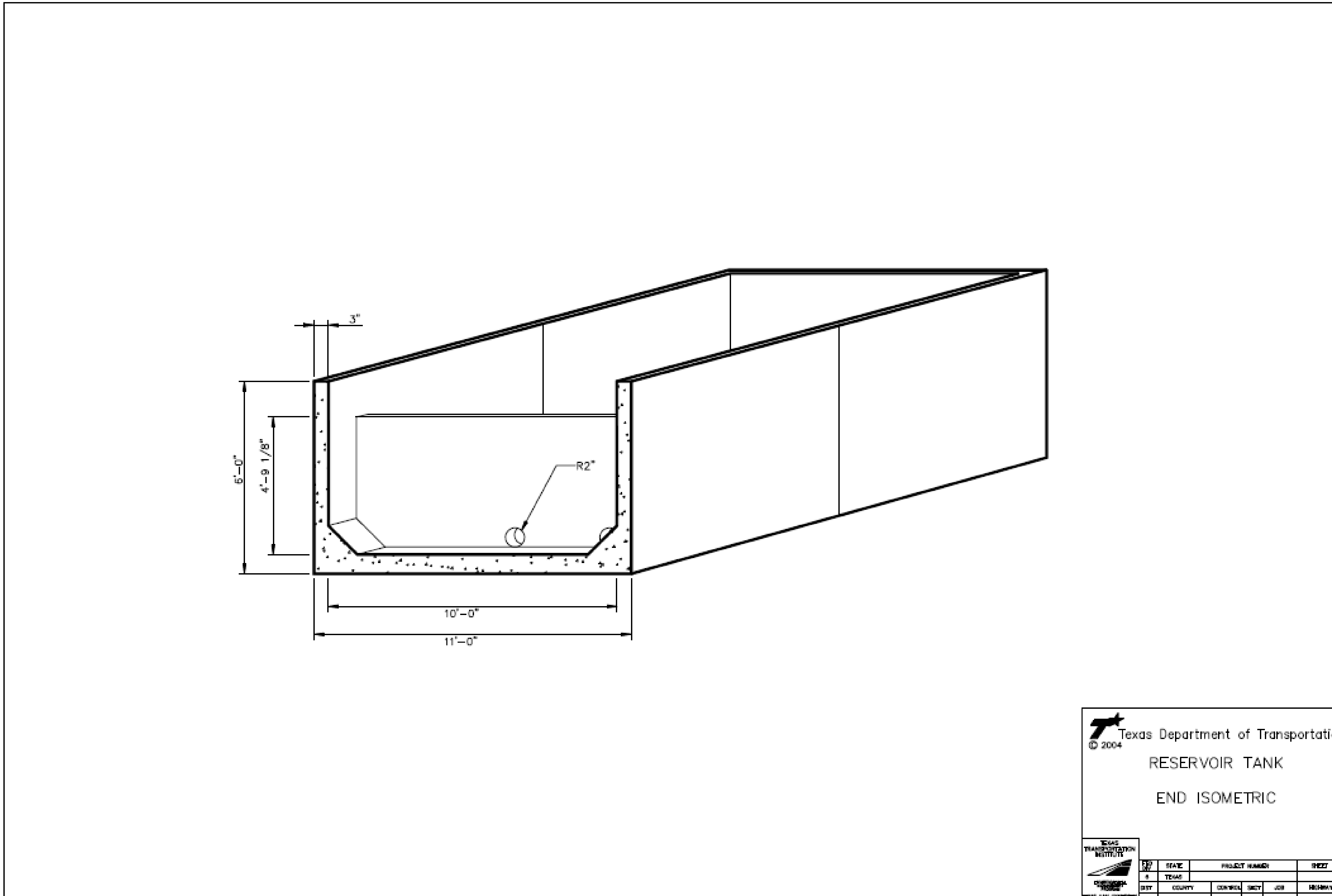
APPENDIX C:
STANDARD DETAILS FOR STRUCTURE AND SPECIFICATIONS FOR MATERIAL AND CONSTRUCTION

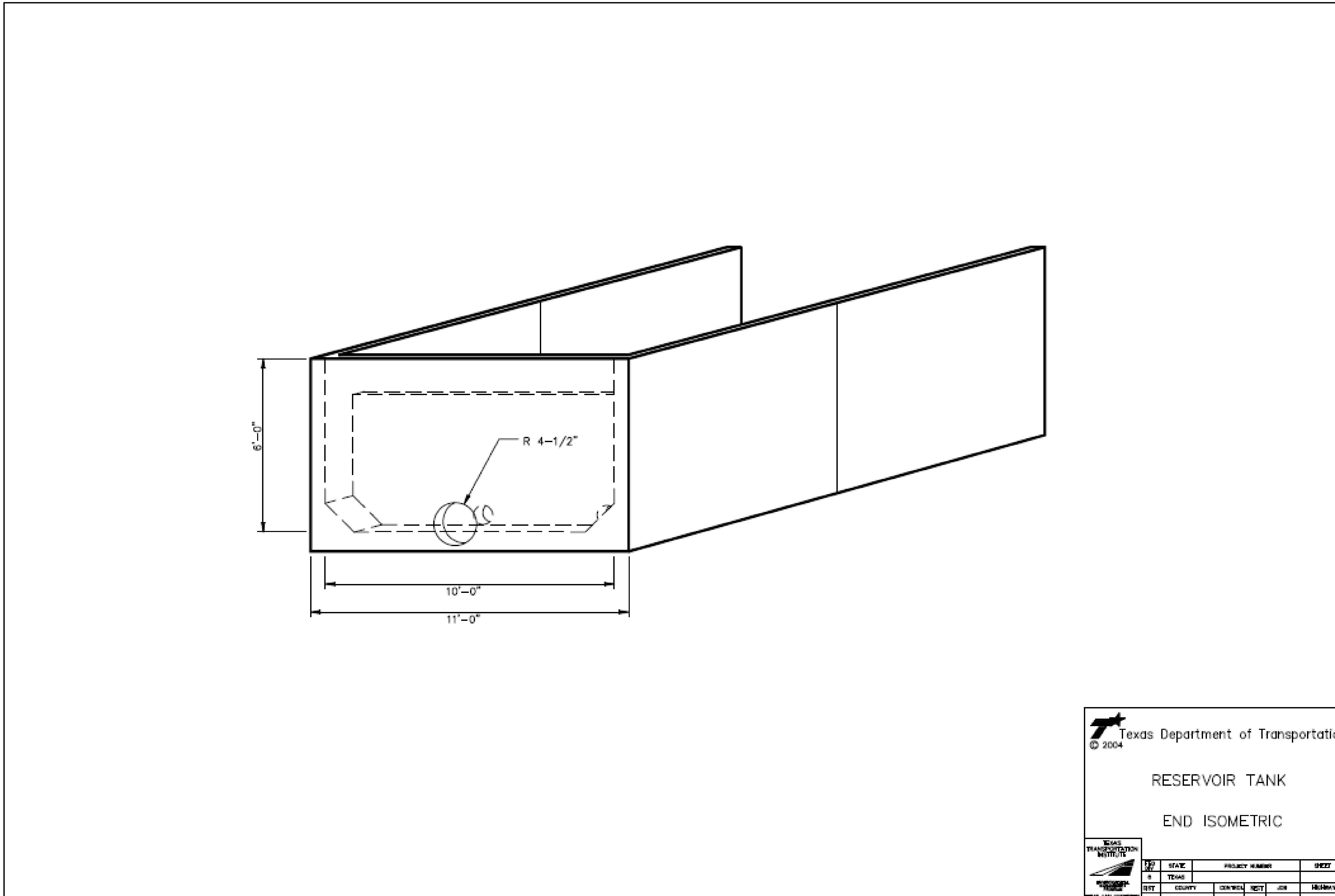


3'-0 1/8"
6"
3'-0"
MAINTENANCE ENTRY
DEBRIS SCREEN
INFLOW PIPE
3'-0"
6'-0"
1'-6"
MAINTENANCE LADDER
DRAIN PIPE
LITER SCREEN
OUTFLOW/INFLOW PIPE
OUTFLOW PIPE WITH BUTTERFLY VALVE
3'-0 5/16"
BAFFLE WALL
1'-10 9/16"
5'-0"
6'-0"
TO RESERVOIR TANK
Texas Department of Transportation
© 2004
FLOW CONTROL CHAMBER
PLAN VIEW

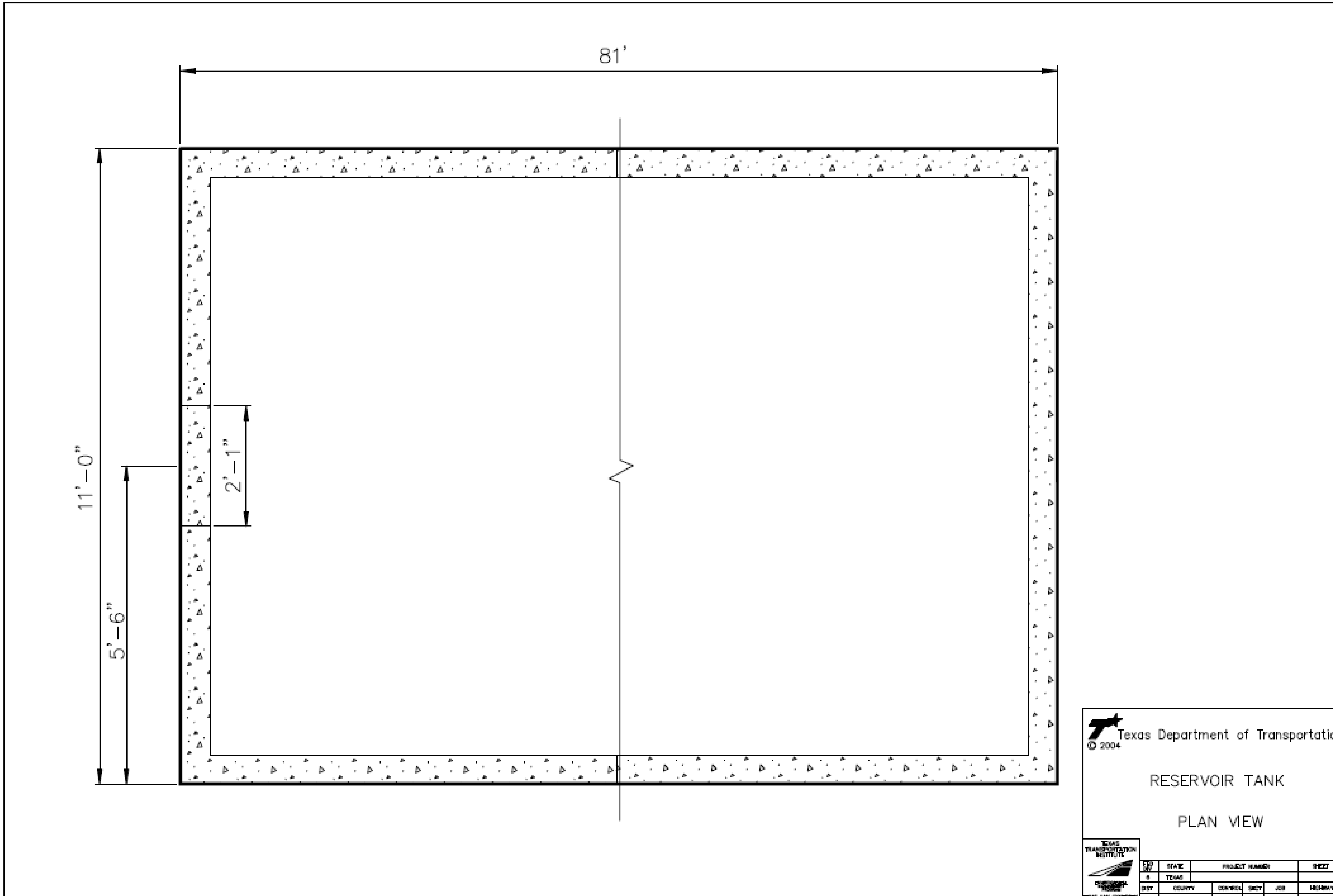

3'-0"
2'-8 3/16"
9 3/16"
INFLOW PIPE
MAINTENANCE ENTRY
BAFFLE WALL
MAINTENANCE LATTER
1'-0"
8'-4 3/16"
TO RESERVOIR TANK
OUTFLOW/ INFLOW PIPE
OUTFLOW PIPE WITH BUTTERFLY VALVE
2'-3"
1'-2 15/16"
LITER SCREEN
DRAIN PIPE
3'-0"
5'-0"
6'-0 5/16"
2'-7 15/16"
3'-0"
1'-8 1/16"
MAINTENANCE ENTRY
DEBRIS SCREEN
1'-7 1/8"
1'-6"
1/2"
1'-4 1/8"
INFLOW PIPE
BAFFLE WALL
MAINTENANCE LATTER
1'-0"
2'-2 9/16"
2'-3 5/16"
4'-9 1/16"
8'-4 7/16"
OUT FLOW/ INFLOW PIPE
1'-6"
1'-6"
TO RESERVOIR TANK
OUTFLOW PIPE W BUTTERFLY VALVE
1'-3"
1'-6"
LITER SCREEN
DRAIN PIPE
5'-0 1/8"
6'-0"
Texas Department of Transportation
© 2004
FLOW CONTROL CHAMBER
SECTION VIEW
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
STATE
PROJECT NUMBER
SHEET
TEXAS
DIST
COUNTY
CONTROL
SECT
JOB
HIGHWAY

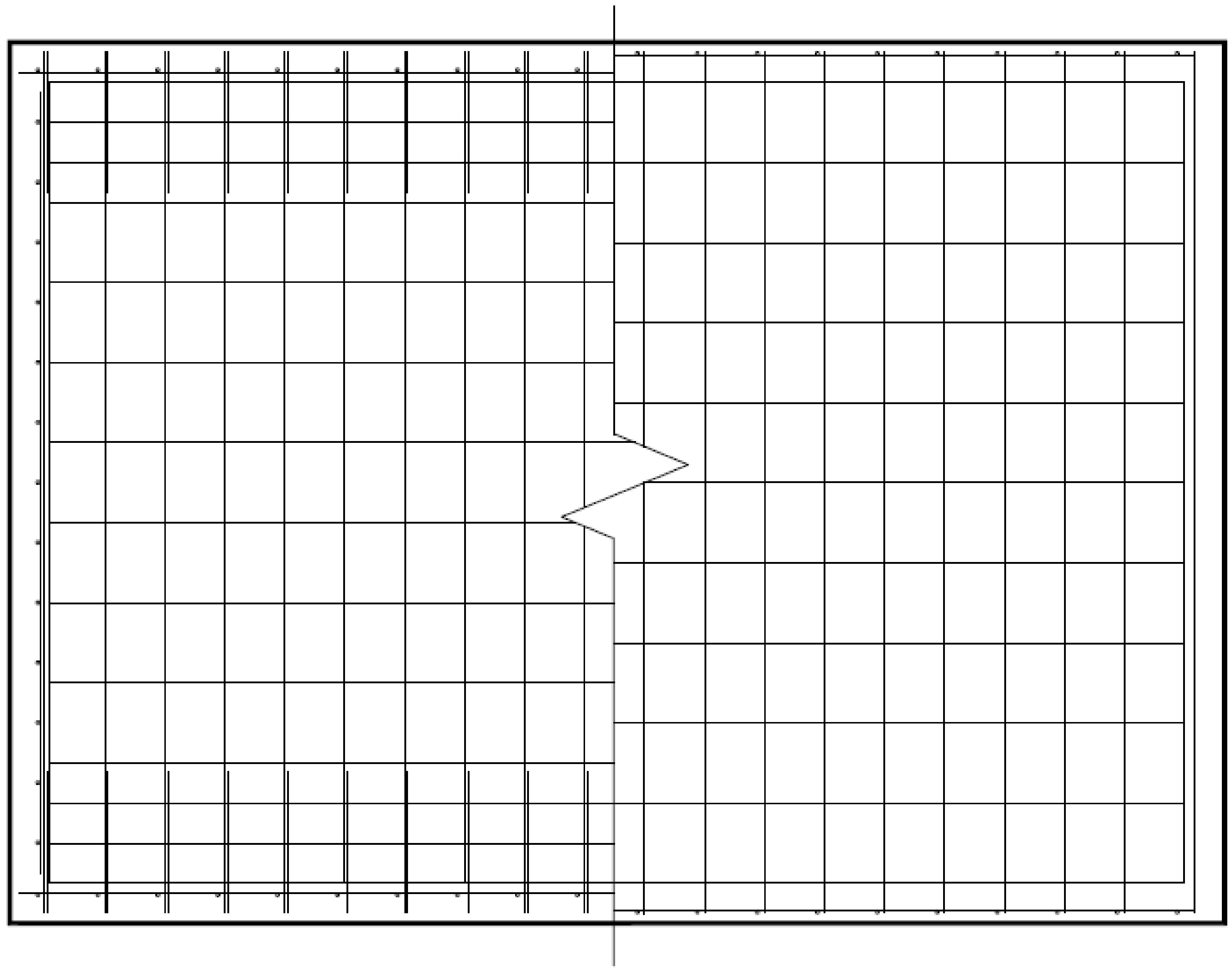

81'–0"
11'–0"
1'–0"
15'–0"
6'–0"
15'–0"
15'–0"
15'–0"
15'–0"
SCALE: 1"=10'
Texas Department of Transportation
© 2004
RESERVOIR TANK
PLAN VIEW


3"
6'-0"
4'-9 1/8"
R2"
10'-0"
11'-0"
Texas Department of Transportation
© 2004
RESERVOIR TANK
END ISOMETRIC
TEXAS TRANSPORTATION INSTITUTE
STATE
PROJECT NUMBER
SHEET
TEXAS
COUNTY
CONTROL
SECT
JOB
HIGHWAY



6'-0"
R 4-1/2"
10'-0"
11'-0"
Texas Department of Transportation
© 2004
RESERVOIR TANK
END ISOMETRIC


81'
11'-0"
5'-6"
2'-1"
Texas Department of Transportation
© 2004
RESERVOIR TANK
PLAN VIEW



Note:

Rebars shown are for surface hydraulics experiments only. For field underground application, rebars shall be designed and reviewed by structural and geotechnical engineers.

Texas Department of Transportation

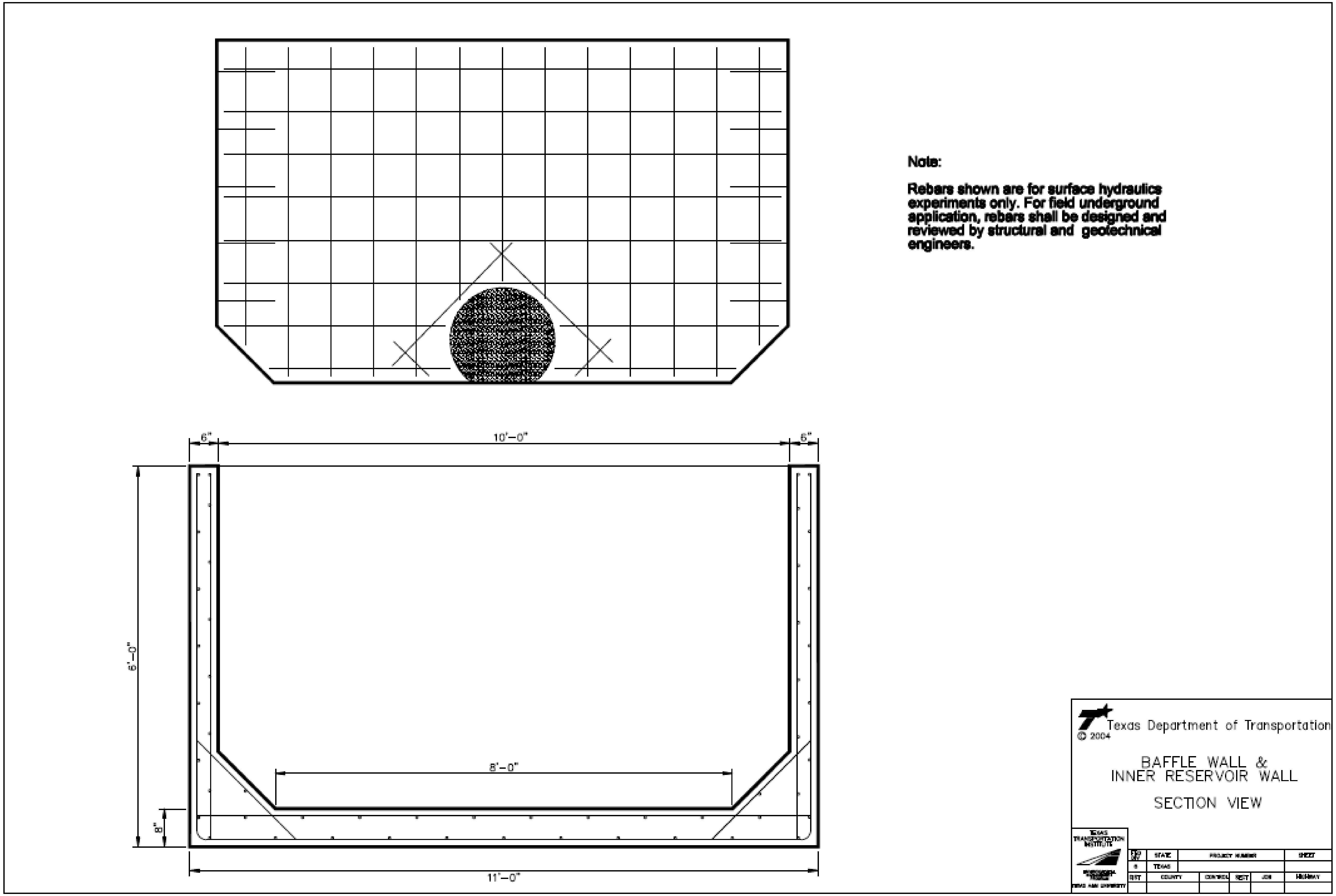
RESERVOIR REBAR SCHEDULE

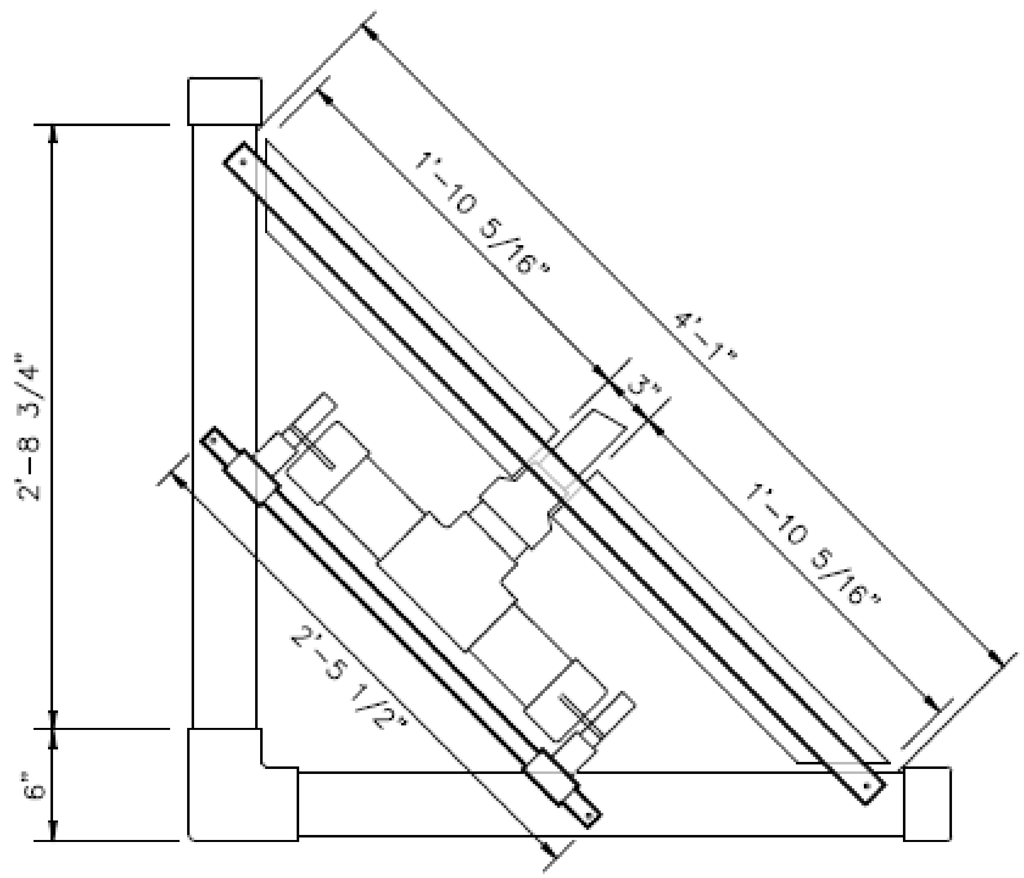
PLAN VIEW

TEXAS TRANSPORTATION INSTITUTE

TEXAS A&M UNIVERSITY

FED RD DIV	STATE	PROJECT NUMBER			SHEET
6	TEXAS				
DIST	COUNTY	CONTROL	SECT	JOB	HIGHWAY


Note:
Rebars shown are for surface hydraulics experiments only. For field underground application, rebars shall be designed and reviewed by structural and geotechnical engineers.
6"
10'-0"
6"
6'-0"
8"
8'-0"
11'-0"
Texas Department of Transportation
© 2004
BAFFLE WALL &
INNER RESERVOIR WALL
SECTION VIEW
TEXAS TRANSPORTATION INSTITUTE
STATE
PROJECT NUMBER
SHEET
TEXAS
COUNTY
CONTROL
SECT
JOB
HIGHWAY



Note: All the components to the floating outlet are PVC.

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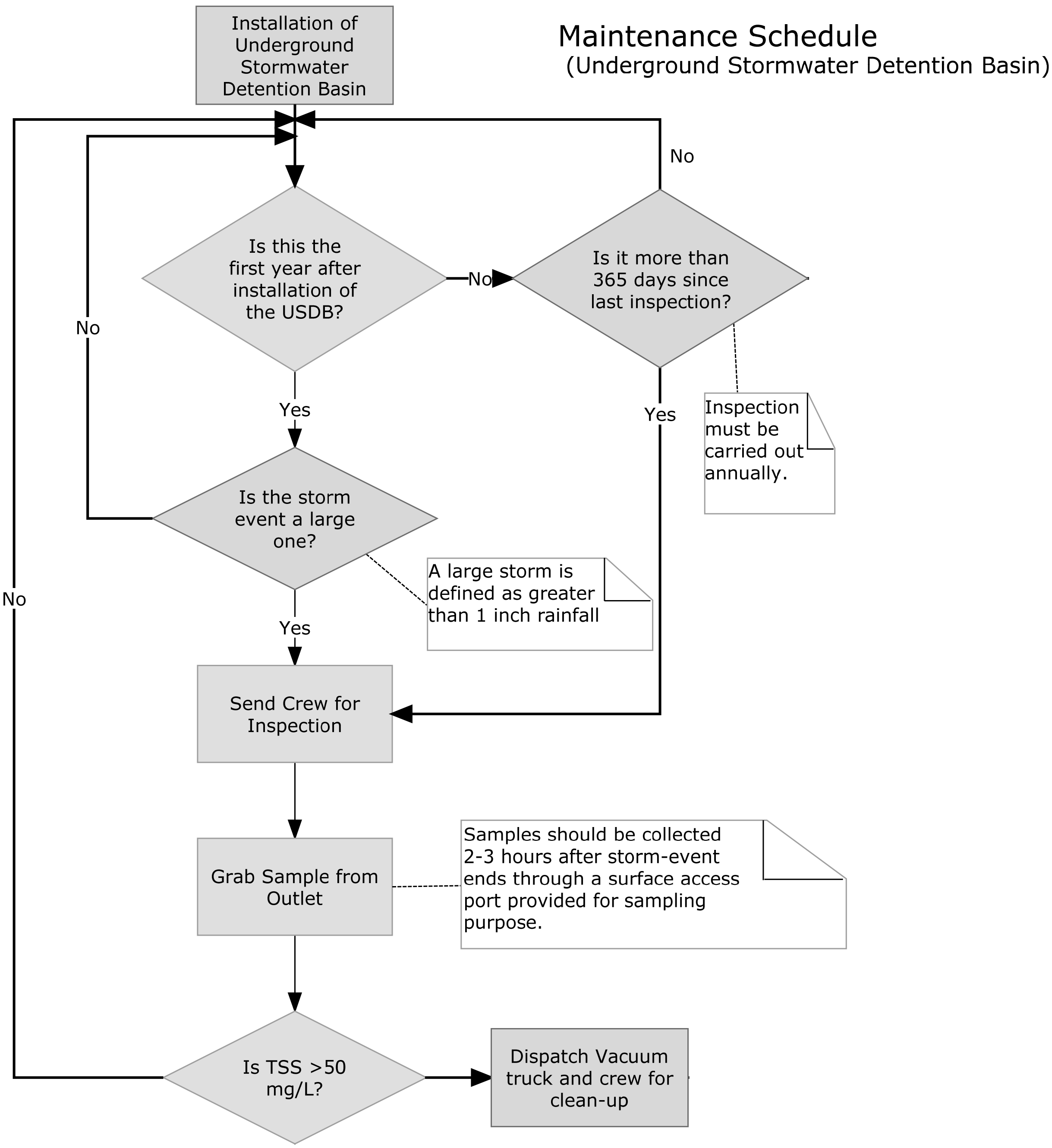
FLOATING
OUTLET

PLAN VIEW

APPENDIX D:
MAINTAINANCE SCHEDULE AND DOCUMENTATION


Installation of Underground Stormwater Detention Basin
Maintenance Schedule
(Underground Stormwater Detention Basin)
No
Is this the first year after installation of the USDB?
No
Is it more than 365 days since last inspection?
No
Yes
Yes
Inspection must be carried out annually.
Is the storm event a large one?
No
A large storm is defined as greater than 1 inch rainfall
Yes
Send Crew for Inspection
Grab Sample from Outlet
Samples should be collected 2-3 hours after storm-event ends through a surface access port provided for sampling purpose.
Is TSS >50 mg/L?
Dispatch Vacuum truck and crew for clean-up

Checklist for Maintenance

- ☐ Flow Control Chamber (FCC)
  - ☐ Butterfly Valve

    Instructions:
    Open/Close the butterfly valve with the switch located in the actuator box. Check to see if there is debris blocking the operation valve and remove any debris if present.

  - ☐ Actuator Box

    Instructions:
    Open the Actuator. Check the charge on the batteries. Check the fuses.

  - ☐ Outlet Mesh

    Instructions:
    Visually inspect outlet mesh for debris. If debris is present, remove the debris in a separate bag and carry out of the FCC.

  - ☐ Inlet

    Instructions:
    Visually inspect inlet for debris.

  - ☐ Samples from Outlet

    Instructions:
    Only consider after a rainfall event. Grab sample from FCC through surface port 2-3 hours after stop of rainfall. Analyze samples for total suspended solids.

- ☐ Sedimentation Tank
  - ☐ Silts

    Instructions:
    If total suspended solids concentration in sample from outlet exceeded 50 mg/L, then schedule a vacuum truck for cleaning the sedimentation tank.

  - ☐ Tank

    Instructions:
    Visually inspect tank for crack or any other form of fatigue. If cracks are observed, identify if they are major or minor. If cracks are minor, fix them with sealant.