

# **Evaluation of the Storm Water Sediment Control Forebay at Anchorage Canal, South Bethany, DE**

**Robert W. Scarborough, Ph.D.  
&  
Michael G. Mensinger**

**Delaware Department of Natural Resources and  
Environmental Control  
Division of Soil and Water Conservation  
Delaware Coastal Programs  
89 Kings Highway  
Dover, DE 19901**

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## Background

When State Route 1 (SR1) was improved through the Township of South Bethany, DE a storm water drainage network was installed to direct storm water runoff into the canal system of the town. Most canals that terminate at SR1 receive runoff from approximately 76 m (250 ft) of roadway frontage and a corresponding drainage area of roughly 1 ha (2.5 ac) on the easterly side of SR1 to Ocean Drive. Anchorage Canal, which is the northern most canal, receives storm water runoff from approximately 900 m (3000 ft) of SR 1, along with residential and commercial properties totaling 25.3 ha (62.5 ac). The drainage area includes the condominiums of Sea Colony along with several businesses and associated parking lots. (Martin, et al., 2001). Anchorage Canal is unique in the South Bethany canal system because the terminal end is approximately three times as wide, at 45 m, (150 ft), as the other canals. This extra width extends westerly approximately 45 m (150 ft) at which point the canal returns to the nominal width of 15 m (50 ft).

Figure 1 shows Anchorage Canal and a visible sediment inflow in the spring of 2002. To minimize the amount of sediment that is deposited into the canal by storm water runoff the Delaware Department of Transportation (DelDOT) installed a storm water sediment control forebay at the easterly end of the canal in early 2004. The forebay is 18.75 m (61.5 ft) by 7.6 m (25 ft) with inflow from a 0.9 m (36 in) pipe with an invert elevation of -0.5 m (-1.67 ft). The forebay contains a timber weir located 7.6 m (25 ft) into the forebay with a top elevation of 0.0 m. Outflow is through a 3.6 m (12 ft) wide spillway at elevation of 0.3 m (1 ft) above sea level at the far end of the forebay. The Delaware Coastal Programs of DNREC was requested to evaluate the performance of the forebay by DelDOT.



*Figure 1. Anchorage Canal with visible sediment inflow.*



*Figure 2. Sediment forebay installed at Anchorage Canal.*

## **Sampling Design**

The design characteristics of the drainage network posed problems for efficient sampling. The final two storm water inflow catch basins have bottom elevations below sea level and thus have tidal movement of the water in the pipe. A sampling location up basin, above sea level, would not capture all the storm runoff and could affect the results. It was determined the best method would be to sample after the final catch basin and base sampling on a critical flow velocity. It is also difficult to accurately measure sediments in the water column if both suspended sediments and bed load are present. The site chosen for sampling had no deposited sediments in the pipe, as compared to sites farther up the drainage network. Due to the turbulent high flow velocity near the sampling location most sediment would be suspended in the pipe and an acceptable value of total sediment concentrations could be obtained from sampling the water column.

An automated ISCO Model 6712 storm water sampler was used to collect water samples. The sampler used a pressure sensor for water depth and a Doppler velocity sensor to calculate water movement in the pipe. Velocity and depth readings were recorded every five minutes. The sampler intake manifold was mounted near the bottom of the pipe adjacent to the Doppler unit. The sampler was triggered to sample when a critical velocity of 0.15 meters/second (0.5 fps) was exceeded. The sampling could not be triggered on flow because of the positive and negative flow values attributed to the tidal

movement. Water sample collection began at triggering and every 141 cubic meters (5000 cubic feet) of flow afterward. Data output was analyzed after each event to discard any sampling that might have occurred post storm, due to tidal flux.

Installed at the site was an ISCO 674 gauge to record precipitation data every five minutes of all storm events. Both the water sampler and precipitation gauge were battery operated with solar panel recharge.

## Methods

After each storm event, the collected water samples were transported to the Delaware National Estuarine Research Reserve laboratory, the sampler data was downloaded and the sampling trigger reset. At the laboratory the samples were composited for each storm event and then analyzed for total solids based on ATM Methods D 3977-97 "*Standard Methods for Determining Sediment Concentration in Water Samples*" Test Method B – Filtration. After the samples were filtered, the residue was dried at 102°C for 24 hours and weighed to determine the dry weight per sample volume collected of the sediments. The samples were then ashed at 500°C for 24 hours to determine the volatile and non-volatile components of the sediment.

After a year of storm water sampling the amount of sediment deposition in the forebay was calculated. The area of the forebay before the weir was divided into 55 equal sized sections and the post weir section into 84 equal sized sections. In each section four readings were taken to determine the average depth of the sediments in that section. Fifteen sediment samples were taken from the forebay using a petite ponar grab sampler. These samples were matched with the depth values of the surrounding area. The grab samples were analyzed with the identical methods as the storm water samples. To correlate volume (depth of deposited sediments in the forebay) to weight (inflow concentration per volume of storm water) two different bulk density values were used. For the non-volatile sediments, primarily sand and silt, a bulk density of 1200 kg/m<sup>3</sup> (75 lbs/ft<sup>3</sup>) was used, for the volatile sediments, a combination of leaves, pine needles, and other miscellaneous fine and coarse organics, a bulk density of 300 kg/m<sup>3</sup> (19 lbs/ft<sup>3</sup>) was used. By calculating the inflow amounts versus the amount captured in the forebay, the efficiency of the forebay was determined.

## Results

Storm water sampling began on April 10, 2004, shortly after the completion of the forebay. The last storm event sampled was April 1, 2005 with the forebay sediment load measured on April 16, 2005. Twenty-eight storms were sampled over the course of the year. In addition, 4 storm events had precipitation and flow values recorded, but no water samples were taken due to equipment malfunction; another three events only had precipitation amounts recorded. There were also four periods of total equipment failure

where it was determined, based on meteorological data from Ocean City, MD, that four storm events were missed.

To determine the amount of runoff from the storm events that were not captured the recorded precipitation vs. flow values were statistically analyzed and plotted as shown in Figure 3. The precipitation amount highly correlated ( $r^2=0.89$ ) with storm water runoff volume for events up to the maximum recorded amount of 7.59 cm (3.0 in.) The equation of  $y = 202.69x^2 + 902.29x - 703.31$  was used to estimate flow from the 7 missed storm water flow events. Based on the flow data and confirmed from the regression analysis storm events of less than 0.75 cm (0.3 inches) did not produce significant storm water runoff into the forebay

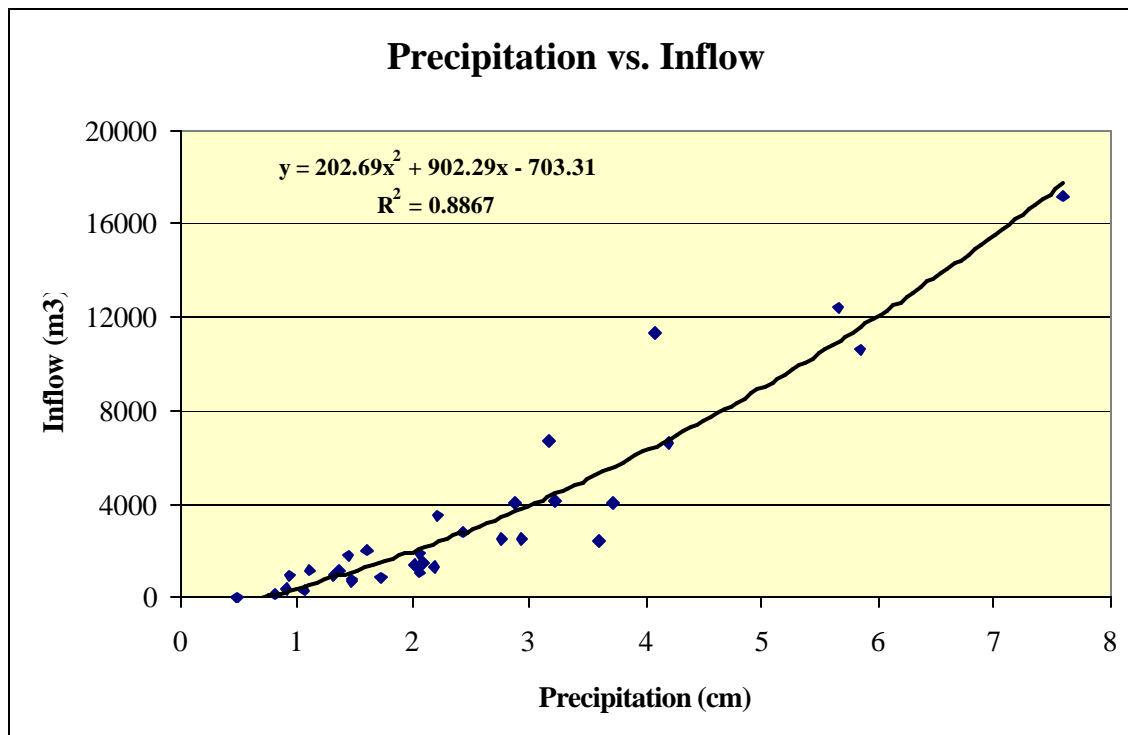


Figure 3. Precipitation vs. inflow to forebay.

To estimate the sediment load of the eleven missed storms an event mean concentration (EMC) of sediment was determined based on the log-transformed data (James, 1994). The EMC for the non-volatile sediments (NVS) had a high level of confidence as shown by a low coefficient of skewness (-0.35) of the log-transformed data. The volatile sediments (VS) had a lower (-0.55), but acceptable confidence value. The event mean concentrations for the non-volatile and volatile sediments were  $44 \text{ g/m}^3$  and  $17 \text{ g/m}^3$ , respectively. These EMC's were then multiplied by the measured or calculated flows of the missed storms to determine the sediment input to the forebay from each event. Table 1 shows the precipitation, inflow and sediment loads for all storm events that had measurable inflow during the sampling period.

**Actual Precipitation, Flow and Sediment Load**

Date	Precip (cm)	Flow (m3)	NVS (g/m3)	VS (g/m3)	NVS (kg)	VS (kg)
4/10/04	2.18	1360	61	37	83	51
4/12/04	7.59	17166	106	18	1828	312
4/23/04	1.12	1168	47	27	55	31
4/26/04	1.60	1992	98	28	194	56
5/25/04	2.01	1411	115	32	162	45
5/28/04	0.81	171	0	4	0	1
6/10/04	1.73	836	73	25	61	21
6/25/04	0.48	36	39	16	1	1
6/30/04	3.61	2389	166	0	396	0
7/12/04	2.06	1125	75	38	85	43
7/18/04	2.77	2533	32	45	81	114
7/25/04	1.32	953	37	22	35	21
7/27/04	4.19	6609	110	16	724	104
8/5/04	1.37	1137	10	7	11	7
8/13/04	3.73	4058	28	12	115	47
8/15/04	3.18	6692	17	5	116	32
8/30/04	1.47	709	71	31	50	22
9/15/04	2.95	2526	39	19	97	47
11/12/04	5.84	10597	31	15	330	159
11/27/04	2.06	1840	18	8	33	15
12/7/04	0.94	953	50	29	48	28
12/10/04	2.87	4077	20	11	83	44
1/14/05	3.23	4177	61	28	256	119
1/22/05	2.44	2822	8	7	23	19
2/14/05	2.08	1516	34	12	51	18
2/21/05	1.45	1829	26	12	47	22
3/8/05	2.21	3479	131	32	456	111
4/1/05	4.09	11351	46	12	524	136

**Actual Precipitation and Flow, Calculated Sediment Load**

Date	Precip (cm)	Flow (m3)	NVS (g/m3)	VS (g/m3)	NVS (kg)	VS (kg)
6/5/04	1.07	288	44	17	13	5
9/28/04	1.47	749	44	17	33	13
10/2/04	0.91	382	44	17	17	6
03/23/05	5.66	12427	44	17	551	208

**Actual Precipitation, Calculated Flow and Sediment Load**

Date	Precip (cm)	Flow (m3)	NVS (g/m3)	VS (g/m3)	NVS (kg)	VS (kg)
5/2/04	1.63	1299	44	17	58	22
9/18/04	0.79	133	44	17	6	2
9/29/04	1.73	1460	44	17	65	24

**Ocean City, MD Precip, Calculated Flow and Sediment Load**

Date	Precip (cm)	Flow (m3)	NVS (g/m3)	VS (g/m3)	NVS (kg)	VS (kg)
03/31/04	1.45	1028	44	17	46	17
03/07/04	1.12	558	44	17	25	9
05/31/04	2.57	2945	44	17	131	49
11/04/05	2.54	2896	44	17	128	49

**Totals**

Date	Precip (cm)	Flow (m3)	NVS (g/m3)	VS (g/m3)	NVS (kg)	VS (kg)
	92.29	119679			7019	2030

*Table 1. Precipitation, flow and sediment load values.*

The analysis of the captured sediments in the forebay after a year of sampling showed a higher deposition in the pre-weir section of the forebay (Table 2). A higher percentage of non-volatile sediments were captured in both sections based on weight; post-weir volumes of volatile and non-volatile sediments were similar.

	Pre-Weir		Post-Weir		Total	
	Non-volatile	Volatile	Non-volatile	Volatile	Non-volatile	Volatile
Weight (kg)	1596	249	840	183	2436	435
% Weight	87 %	13 %	82 %	18 %	85 %	15 %
Volume (m <sup>3</sup> )	1.33	0.83	0.70	0.61	2.03	1.45
% Volume	62 %	38 %	53 %	47 %	58 %	42 %

*Table 2. Weight and volume of sediment captured.*

The sediment inflow to Anchorage Canal from the storm water drainage network from April 10, 2004 through April 16, 2005 was estimated to be 9032 kg (19910 lbs) or 12.6 m<sup>3</sup> (16.5 yd<sup>3</sup>). The forebay captured 2871 kg (6329 lbs) or 3.5 m<sup>3</sup> (4.6 yd<sup>3</sup>) of the sediment load. This resulted in an overall efficiency of the forebay of 32 % based on weight or 28 % based on volume of sediment inflow. The non-volatile sediment capture rate was 35 % as compared to 22 % for the volatile sediments (Table 3).

	Weight (kg)			Volume (m <sup>3</sup> )		
	Non-volatile	Volatile	Total	Non-volatile	Volatile	Total
Inflow	7019	2013	9032	5.8	6.7	12.6
Captured	2436	435	2871	2.0	1.5	3.5
Lost	4583	1578	6161	3.8	5.3	9.1
<b>Efficiency</b>	<b>35 %</b>	<b>22 %</b>	<b>32 %</b>	<b>35 %</b>	<b>22 %</b>	<b>28 %</b>

*Table 3. Forebay sediment capture rate and efficiency.*

Peak flow rates into the forebay ranged from a median of 0.40 m<sup>3</sup>/s (14.2 ft<sup>3</sup>/s) to high of 1.41 m<sup>3</sup>/s (49.7 ft<sup>3</sup>/s). At the median flow rate the residence time in the forebay was less than 6 minutes, which not only gave little time for settling of the sediments but might have re-suspended some of the finer grain sediments and organics.

There was a wide variation in seasonal sediment concentrations of the storm water runoff as shown in Figure 4. Spring had the highest mean concentration at 100 g/m<sup>3</sup> (0.006 lbs/ft<sup>3</sup>) of sediments while the autumn months had the least at 43 g/m<sup>3</sup> (0.003 lbs/ft<sup>3</sup>). Multi-year analysis would be needed to confirm this seasonal trend.

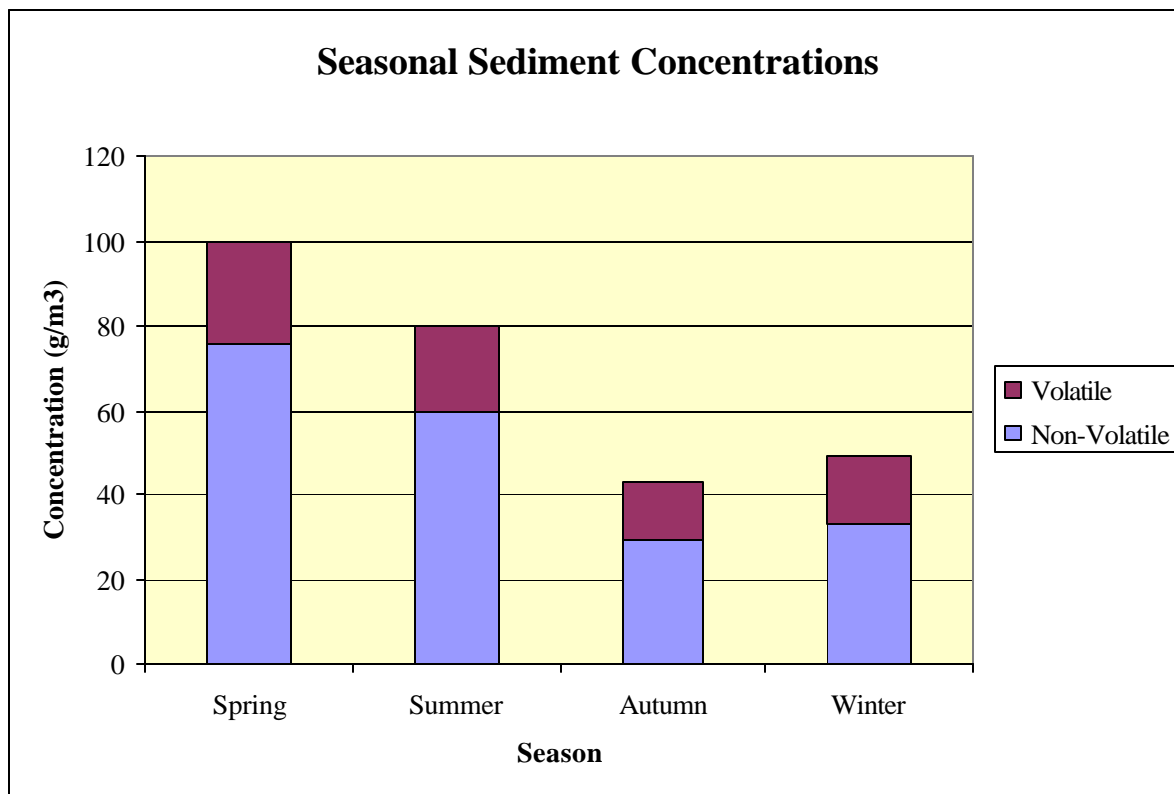


Figure 4. Seasonal sediment concentration of storm water inflow.

## Summary

The forebay captured a substantial amount of the storm water sediments that were destined for Anchorage Canal. Sediment capture efficiencies of forebays are typically from 50 to 90 % (USEPA, 1999), however these are based on designs for systems that have much longer residence times (24 hrs) and larger surface areas in relation to drainage area. Based on the small size of the forebay and minimal retention time the Anchorage Canal forebay performed as well as could be expected with an overall efficiency of 28 % based on volume.

The outflow design of the forebay needs modification as evidenced by the severe scour at the outfall. The outfall weir should either be widened to decrease outflow velocity and/or the canal bottom should be hardened to prevent erosion.

The evaluation year was completed without the occurrence of a major storm event. The largest storm monitored (7.59 cm, 3.0 in) was the equivalent of a 2-year return frequency 12-hour storm (Bonnin, et al., 2004). The ability of the forebay to trap the sediment in runoff from larger storm events can not accurately be estimated. Two factors will affect efficiency as storm water flow increases; at one point the overland flow will increase to a sufficient velocity to erode the sandy soil and transport it into the drainage system, substantially increasing the forebay loading rate. In addition, the higher velocity water flow through the forebay might re-suspend trapped sediments and flush them into the canal.



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