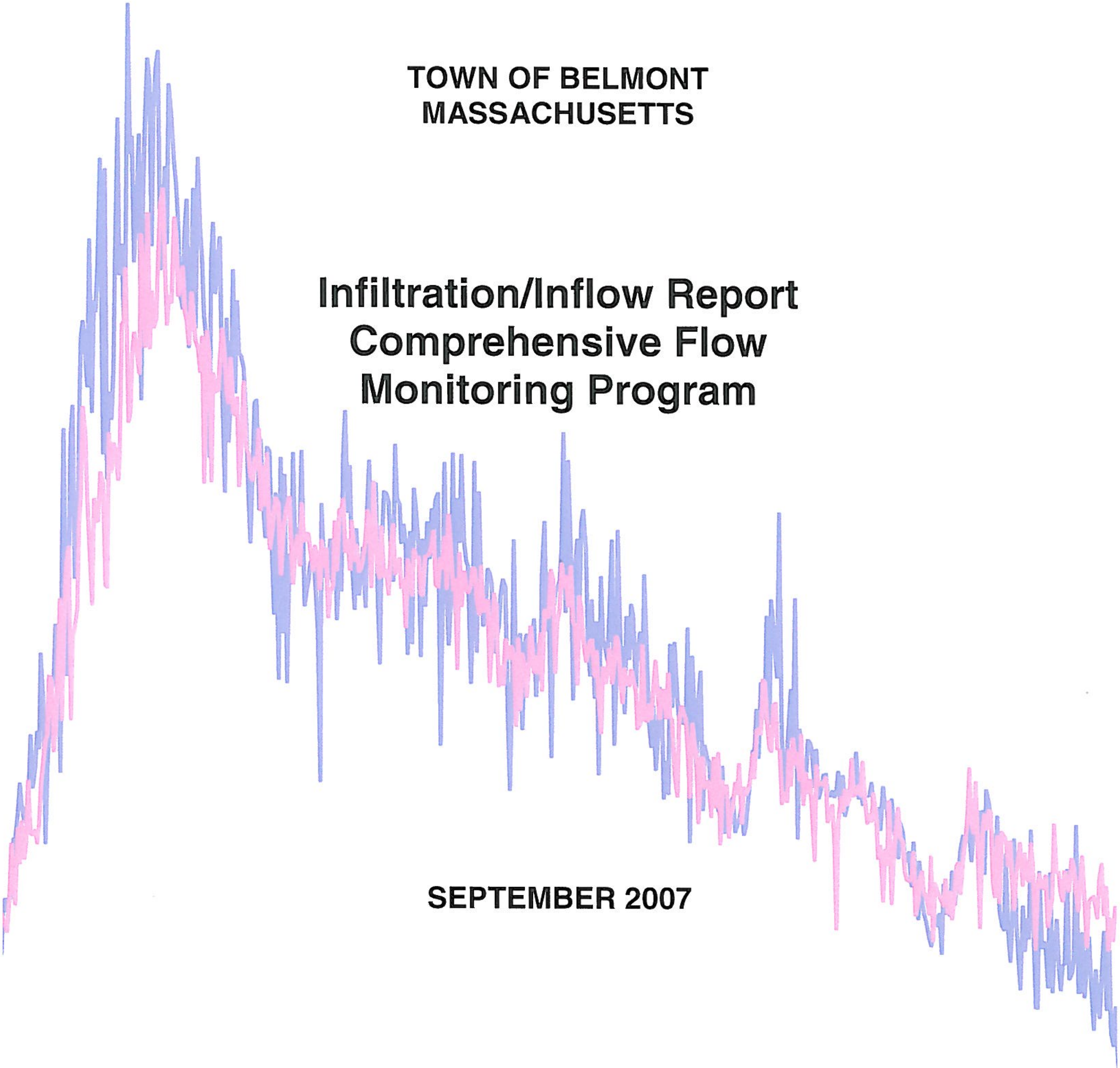
TOWN OF BELMONT
MASSACHUSETTS



Infiltration/Inflow Report Comprehensive Flow Monitoring Program

SEPTEMBER 2007

PREPARED BY:

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September 25, 2007

Office of Community Development
Homer Municipal Building
19 Moore Street
Belmont, Massachusetts 02478
Attn: Mr. Glenn Clancy, Director

Subject: Belmont, Massachusetts
Comprehensive Flow Monitoring Program
Infiltration/Inflow Report

Dear Mr. Clancy:

The Town of Belmont (Town) engaged Fay, Spofford & Thorndike, LLC, (FST) to conduct a comprehensive flow monitoring program of it's sanitary sewer system to identify areas contributing excessive infiltration and inflow (I/I). The purpose of this letter report is to summarize the results of the flow monitoring program conducted this past spring and present recommendations for more detailed sewer system evaluation survey (SSES) work. This report also summarizes the calibration of the Town's InfoWorks sanitary sewer model using the Spring 2007 flow monitoring data.

CONTINUOUS FLOW MONITORING

Methodology

Continuous flow monitoring was performed in accordance with DEP's "Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Survey", revised January 1993. The Guidelines recommend continuous flow monitors be installed at an interval of approximately one monitor for every 20,000 linear feet of sanitary sewer. Belmont has approximately 400,000 linear feet (76 miles) of sewer therefore twenty (20) flow monitors were utilized for this project.

To collect adequate information during seasonal high groundwater wet weather periods, the continuous flow monitors were installed for approximately 10 weeks. Each monitor is equipped with an ultrasonic depth sensor and a Doppler velocity sensor and recorded both depth and velocity measurements every 15 minutes. A detailed description of the flow monitoring equipment is provided as Appendix A. A rain gage was installed at the Department of Public Works facility on C Street to measure precipitation during the flow monitoring period.

Delineation of Tributary Areas

Utilizing the Town's GIS mapping of the sanitary sewer network as a base, the sewer network was analyzed to delineate 20 tributary areas. A continuous flow monitoring device was installed at the outlet point from each area. The general locations for the continuous flow monitors were determined utilizing the GIS mapping. During meter installation, if the initial manhole or pipeline was not physically suitable to accommodate a flow monitor then the adjacent upstream/downstream manholes were investigated until a suitable location was identified. As shown on the Sewer Flow Monitoring Plan in Appendix B, sixteen areas discharge to MWRA's metered Outfall BM-CB-01 on Flanders Road and four areas discharge to the MWRA's metered Outfall BM-CB-02C on Thingvalla Avenue. Table 1 summarizes pipe sizes and lengths for each Area.

Due to the configuration of the sewer system, combined with the project constraint of 20 flow meters, approximately 4,585 feet of sewer on Trapelo Road (tributary to Thingvalla Avenue) was not included in the continuous flow monitoring. Additionally, a small section of sewer in the vicinity of Garrison/Oliver Roads flows east to the Town of Arlington and is not included in this study. However, these areas will be investigated in subsequent SSES phase work.

Continuous Flow Monitoring

Installation of all monitors, by FST's subconsultant Flow Assessment Services (FAS), was completed by April 4, 2007 and the monitors were removed on May 29, 2007. The Sewer Flow Monitoring Plan shows the locations of the flow monitors. A flow schematic for the 20 monitors is presented in Figure 1.

Data from the flow monitors can be visually analyzed in the form of hydrographs. Figure 2 is the hydrograph for flow monitor T and includes flow from the sixteen districts that discharge to the MWRA Outfall BM-CB-01 at Flanders Road. Both the average daily flow in million gallons per day (MGD) and rainfall depth in inches are plotted versus time. Installation sketches and hydrographs for each meter, as well as maximum, minimum, and average daily flow tabulations are included in Appendix C.

Flow monitor T was located one manhole downstream of the MWRA's meter at Outfall BM-CB-01 so that area tributary to both meters is virtually identical. Figure 3 plots flows from monitors T and BM-CB-01 together and illustrates good correlation between the two meters.

There were seven significant rain events, greater than 0.50 inch of accumulation and without a break in excess of 300 minutes, which occurred during the flow monitoring period. These events are as follows:

Storm Start Date	Rain Total	Peak Rain/Hour
April 4	1.38"	0.18"
April 12	1.02"	0.28"
April 15	3.49"	0.31"
April 16	0.51"	0.05"
April 27	1.07"	0.27"
May 16	3.22"	0.48"
May 19	0.58"	0.17"

It should be noted that during data analysis, an anomaly was discovered with flow monitor Q, whereas the combined flow from upstream flow monitors (F, H, J, P, O) was significantly greater than Q (upstream flow should be less than or equal to downstream flow). Subsequently, the flow monitor used at site Q was tested at FAS's facility and determined to be functioning properly. Upon further analysis, FAS believes the recorded velocities were low, most likely due to a localized abnormality in the flow stream at the monitor. As a result, readings from monitor Q were not utilized during FST's infiltration/inflow analysis. Rather, the netted area represented by flow monitor Q was incorporated into downstream monitor T (i.e. areas Q and T were combined).

INFILTRATION/INFLOW ANALYSIS

Infiltration

The DEP Guidelines define infiltration as the component of wastewater that enters a sewer system (including service connections and foundation drains) from the ground through means which include, but are not limited to, defective pipes, pipe joints, connections or manholes. In Figure 2, the magnitude of infiltration can be determined by inspection of the area under the lowest points of the hydrograph. These low points occur during early morning hours when sewer usage is at a minimum and it is generally assumed that 90% to 100% of flow measured by the monitors can be attributed to infiltration. Visual inspection of the hydrograph shows that at flow monitor T, infiltration entering the sewer system remained in excess of 3.0 MGD through April. The hydrograph also clearly shows the prolonged impact of rain-induced infiltration created by the large storm events.

Infiltration was analyzed during dry weather conditions from May 8 - 10. Analysis during dry weather conditions presumes inflow contributions are at a minimum and, therefore, it can be assumed that all extraneous flow is attributed to infiltration resulting from seasonal high groundwater levels. Table 2 shows that the average total infiltration from May 8 - 10 was approximately 2.4 MGD. The measured infiltration for each flow monitoring area was calculated by taking 90% of the averaged minimum daily flows. The net infiltration for each area was calculated in accordance with the flow schematic (Figure 1).

The inch-diameter-miles (IDM) of sewer were calculated for each Area. Table 2 calculates and ranks the Areas by gallons per day (GPD) of infiltration per IDM. The DEP guidelines recommend conducting SSES investigations in all areas shown to have a GPDIDM above 4,000.

As shown on Table 2, there are eight areas with GPDIDM's greater than 4,000, accounting for 74% of the total infiltration through 42% of the total IDM (43% of the total linear footage). Considering inclusion of area D (3,903 GDPIDM), then 80% of the Town's total infiltration occurs in 48% of the total IDM (50% of the total linear footage). Consequently, SSES phase infiltration investigations are recommended in areas P, J, K, C, G, M, E, H and D (a total of 193,000 lf).

Inflow

The DEP Guidelines define inflow as the component of wastewater that enters a sewer system (including service connections) from sources which include, but are not limited to, sump pumps, roof leaders, cellar drains, yard drains, area drains, drains from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, catch basins, cooling towers, storm waters, surface runoff, street wash waters or drainage. In Figure 2, inflow is represented by the large spikes coinciding with the storm dates listed above. The sharp vertical rise is indicative of water entering directly into the sewer system without having to percolate through the soil and enter via pipeline defects. Visual inspection of the hydrograph shows that at flow monitor T, during the April 15 storm event, flows exceeded 13 MGD due primarily to inflow.

For the purpose of this analysis, inflow was assumed to begin at the onset of the significant rainfall event, continue through the storm, and last 48 hours after the conclusion of the rainfall event. This period is divided into the three segments as follows:

- Storm Period - Begins with the onset of a significant rainfall event and continues to the conclusion of the rainfall event. The storm period is an indication of direct inflow sources.

- Recovery Period No. 1 (R1) – 24 hours beginning at the conclusion of the storm period and is an indicator of residual inflow as well as delayed inflow sources such as sump pumps and footing drains.

- Recovery Period No. 2 (R2) - 24 hours beginning at the conclusion of R1 and is an indicator of rain-induced infiltration.

Inflow analysis was performed using FAS's "FAST" software. FAST creates a database, which includes the continuous flow monitoring information for each site, meter balancing relationships and rainfall information. The total inflow volume for a particular storm event is the area between the storm event hydrograph and comparable dry weather hydrograph.

The April 15 storm event (3.49") was chosen for inflow analysis. The days immediately prior to the April 4 storm event were used as a comparative dry weather period (i.e. equivalent base flow including sewage and infiltration). Figure 4 illustrates the storm event and dry weather hydrographs superimposed for flow monitor T. From Figure 4, it is clearly seen that with the onset of rain, the storm event hydrograph separates from the dry weather hydrograph as a result of inflow.

As shown in the Table 3, Belmont's total inflow (including storm period, R1 and R2) for the April 15 storm event was approximately 22 million gallons (MG). The net inflow for each area was calculated in accordance with the flow schematic (Figure 1) and the areas prioritized by total inflow gallons per linear foot of sewer. The DEP guidelines recommend conducting SSES investigations in areas accounting for 80% of the total inflow. Inspection of the cumulative totals presented in Table 3 indicates that 80% of Belmont's total inflow volume occurs in just over half (52%) of the Town's total sewer system linear footage. Consequently, SSES phase inflow investigations are recommended in areas E, B, G, K, F, O, D, H, M, R and P (a total of 201,000 lf).

Comparison to 1981 Study

A Sewer System Infiltration/Inflow Analysis of Belmont was conducted by FST from 1980 to 1981 and its results were submitted in June of 1981. This study divided the Town into twenty-three sewer subdistricts to measure flow rates. Instantaneous nighttime flow measurements (manual weir) at the outlet of each subdistrict were used to calculate infiltration. Continuous depth monitoring (Manning dippers) at eight (8) locations was used to calculate inflow. The 1981 continuous depth meters and nighttime flow locations are shown on the Sewer Flow Monitoring Plan.

The scope of this report does not include conducting a detailed comparison of results between the 1981 and 2007 I/I studies. However, a general overview reveals that the distribution of I/I throughout Belmont has remained relatively constant. The Flanders Road Outfall (T) was responsible for 85% of the Town's total infiltration in 2007 versus 84% in 1981. With regards to inflow, the Flanders Road Outfall was responsible for 83% in 2007 versus 76% in 1981. The Thingvalla Avenue Outfall accounts for remaining I/I.

MODEL CALIBRATION

The continuous flow monitoring data was imported into the Town's InfoWorks sanitary sewer model to individually calibrate model predicted flow from each major drainage area under multiple flow conditions. The calibration graphic for each meter for the period of April 9 – 24, 2007 is provided in Appendix D. Additionally, a recent upgrade from InfoWorks version 7.5 to 8.0 allowed for more detailed analysis and troubleshooting of model errors. As a result, the 2006 model predicted flooding volumes and locations described in FST's Preliminary Hydraulic Report (PHR), February 2007, were greatly reduced.

The PHR used the May 13-16, 2006 storm data for model predictions. Under surcharged conditions (i.e. sewage above the crown of the pipe), the 2006 model predicted flooding at 85 locations with 70 MG overflowing. With free discharge from MWRA interceptors, the model predicted flooding was reduced slightly to 83 locations and 66 MG. These preliminary results indicated I/I generated from within Belmont to be the major contributor to sanitary sewer backups in the sewer system.

However, running the same May 2006 storm data with the updated and calibrated 2007 model, model predicted flooding under surcharged conditions occurred at only 17 locations with 4.0 MG of overflow. With free discharge from MWRA interceptors, the 2007 model predicted flooding occurred at 5 locations with 2.4 MG of overflow. These results indicate that extraneous flow from within Belmont and the backwater effect from the MWRA system to be relatively equal contributors to sanitary sewer backups in Belmont's sewer system.

SSES RECOMMENDATIONS

SSES Scope of Work

SSES phase investigations are recommended in areas B, C, D, E, F, G, H, J, K, M, O, P and R to identify specific I/I sources and to determine the appropriate rehabilitation method. The recommended scope of work for each SSES task is based on the DEP Guidelines as follows:

Infiltration:
- 193,000 lf nighttime flow isolations
- 1,500 manhole inspections (from surface)
- CCTV inspection (quantity to be determined)

Inflow:
- 1000 house inspections
- 200,000 lf smoke testing of pipelines
- 20 dyed-water flooding
- dyed-water tracing (as required)

Schedule

Smoke testing is widely used to identify direct and indirect sources of storm water and groundwater entry into the sanitary sewer system. Smoke testing must be conducted during periods of low groundwater and is recommended for this Fall (2007). Dyed-water flooding to confirm smoke testing results would be performed concurrently. House inspections to identify sump pumps or other illicit connections to the sanitary sewer are also recommended for Fall 2007.

Nighttime flow isolations and manhole inspections are the primary method used to identify sources of infiltration. To be most effective, FST recommends this work be conducted in early Spring 2008 (March & April) during the seasonal high groundwater period. CCTV inspection, as determined by the results of the nighttime flow isolations, will be conducted in late Spring 2008 (May & June).

GIS Database

FST recommends SSES phase tasks include adding supplemental information to the Town's exiting GIS database. Computerized database forms will be developed to support SSES data collection.

A Manhole Inspection Form will record the physical condition of the manhole at the time of inspection. Data from these forms will be electronically linked to the GIS attributes for each manhole to facilitate evaluation of the sewer system and so that Town personnel will be able to readily obtain pertinent information for each structure.

A Property Inspection Form will record I/I sources discovered during resident/business building inspections (i.e. sump pumps, roof drains, open cleanouts, etc.). Data from these forms will be electronically linked to the GIS attributes for each address. The database will then be used to generate electronic maps graphically depicting information such as houses with sump pumps.

SSES Cost

The estimated costs to perform the recommended scope of SSES work is:

Nighttime Flow Isolation	$ 58,000
Manhole Inspections	$ 75,000
CCTV Inspection Allowance	$ 150,000 *
House Inspections	$ 70,000
Smoke Testing	$ 77,000
Dyed-Water Flooding	$ 10,000 *
Dyed-Water Tracing	$ 11,000 *
GIS Database	$ 21,000
SSES Report	$ 16,000
Estimated Total Price:	**$ 488,000**

* Actual scope/cost to be determined

We are available to meet with you to discuss the findings of this report at any time upon your request.

Very truly yours,
FAY, SPOFFORD & THORNDIKE, LLC.
By

Justin D. Gould, P.E.
Principal Engineer

cc: Mr. Peter J. Castanino, Town of Belmont
Mr. Kevin Brander, MADEP
Mr. Ralph Jones, The Cadmus Group, Inc.

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TABLE 1
SEWER SYSTEM SUMMARY

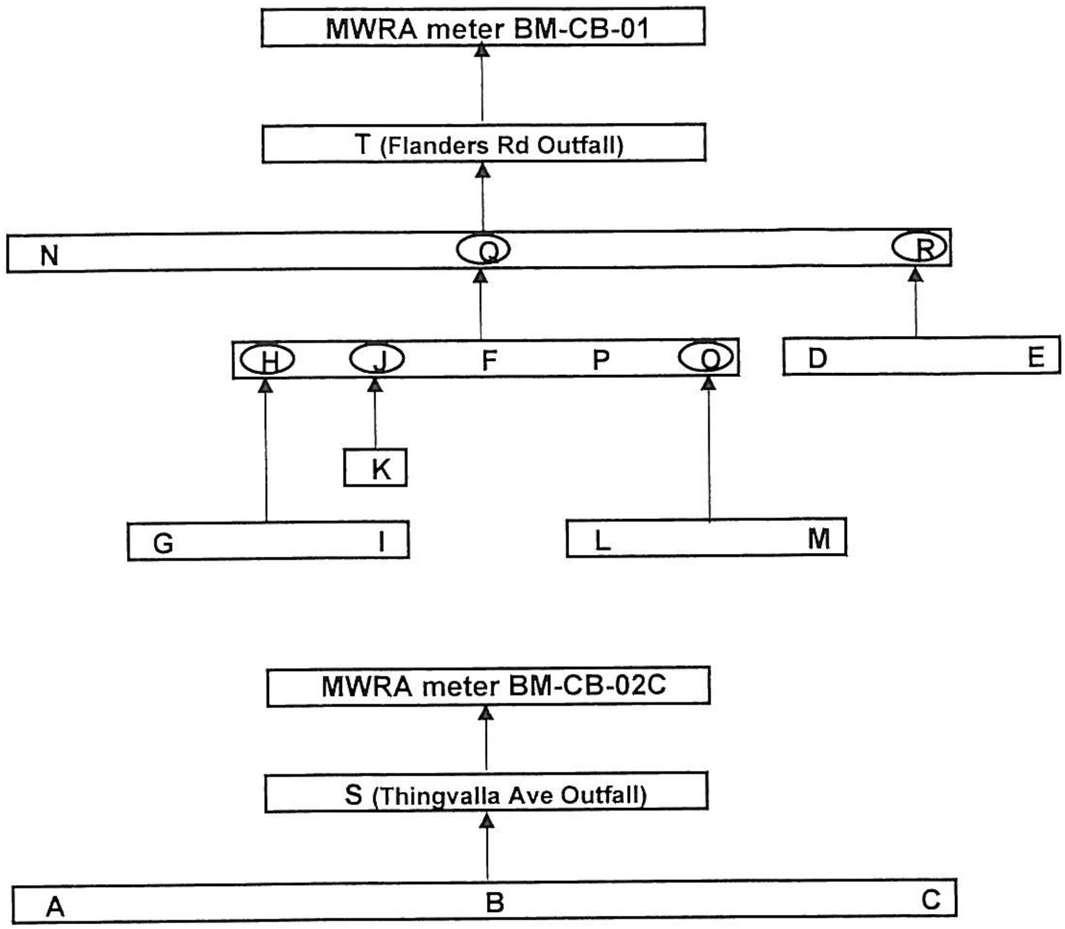
Tributary Area	4-in	5-in	6-in	8-in	10-in	12-in	15-in	16-in	18-in	20-in	24-in	30-in	36-in	Total (ft)	Total (mi)
A			18,348		516	2,656								21,520	4.08
B			134	9,466	1,547									11,147	2.11
C			7,129	20,637										27,766	5.26
D			12,528	9,388	2,754	570	1,399							26,638	5.05
E			887	7,727										8,614	1.63
F		268	11,483	10,889	909	822								24,371	4.62
G			6,403	2,943	189									9,535	1.81
H			8,677	16,816	2,410	1,128	2,079		163		1,164			32,437	6.14
I			3,695	14,271	2,282	1,530								21,778	4.12
J		119	1,671	9,162	128	2,127	364		9,801					23,373	4.43
K			749	27,033	1,041	2,196		1,250	890					33,160	6.28
L				17,744	1,265	1,582								20,591	3.90
M				19,804	1,613	1,247								22,665	4.29
N				21,727	1,064	1,084	2,217							26,092	4.94
O				9,632		169	404		1,102					11,307	2.14
P	102		2,248	6,317	61									8,728	1.65
Q				2,410	16	551			188		2,589	4,133		9,887	1.87
R			1,644	8,693	307		268			103	1,276			12,291	2.33
S			3,011	8,624	332	1,691	658		587					14,902	2.82
T			1,160	10,948	4,463		206				1,468	1,486	657	20,388	3.86
Total (ft)	**102**	**386**	**79,767**	**234,230**	**20,900**	**17,352**	**7,595**	**1,250**	**12,732**	**103**	**6,497**	**5,619**	**657**	**387,191**	73.33
Total (mi)	**0.02**	**0.07**	**15.11**	**44.36**	**3.96**	**3.29**	**1.44**	**0.24**	**2.41**	**0.02**	**1.23**	**1.06**	**0.12**	73.33	

TABLE 2
INFILTRATION ANALYSIS
May 8-10, 2007 Dry Period

Tributary Area	Sewer Length (ft)	IDM	Measured Infiltration (MGD)			Net Infiltration (MGD)	Cumulative Infiltration		Cumulative Length		Gallons/Day per IDM
			Meter	Percentage	Actual*		(MGD)	(%)	(ft)	(%)	
P	8,728	12	0.144	90%	0.129	0.129	0.129	5%	8,728	2%	10,490
J	23,373	55	0.926	90%	0.833	0.458	0.587	24%	32,101	8%	8,262
K	33,160	56	0.417	90%	0.376	0.376	0.963	40%	65,261	17%	6,755
C	27,766	39	0.275	90%	0.247	0.247	1.210	50%	93,027	24%	6,286
G	9,535	12	0.076	90%	0.068	0.068	1.279	53%	102,562	26%	5,655
M	22,665	36	0.217	90%	0.196	0.196	1.474	61%	125,227	32%	5,450
E	8,614	13	0.067	90%	0.060	0.060	1.535	64%	133,841	35%	4,750
H	32,437	54	0.379	90%	0.341	0.248	1.783	74%	166,278	43%	4,581
D	26,638	39	0.169	90%	0.152	0.152	1.935	80%	192,916	50%	3,909
B	11,147	17	0.071	90%	0.064	0.064	1.999	83%	204,064	53%	3,684
R	12,291	23	0.319	90%	0.287	0.075	2.074	86%	216,355	56%	3,305
F	24,371	33	0.119	90%	0.107	0.107	2.181	91%	240,726	62%	3,206
L	20,591	33	0.105	90%	0.095	0.095	2.276	95%	261,316	67%	2,881
N	26,092	44	0.082	90%	0.073	0.073	2.349	98%	287,408	74%	1,682
A	21,520	35	0.046	90%	0.041	0.041	2.391	99%	308,928	80%	1,190
I	21,778	34	0.027	90%	0.024	0.024	2.415	100%	330,706	85%	710
O	11,307	20	0.337	90%	0.303	0.012	2.427	101%	342,014	88%	629
S	14,902	25	0.404	90%	0.364	0.011	2.438	101%	356,916	92%	438
T (+Q)	30,275	87	2.269	90%	2.042	-0.032	2.406	100%	387,191	100%	-364
Total	387,191	667	6.449	N/A	5.804	2.406	N/A	N/A			

TABLE 3
INFLOW ANALYSIS
April 15, 2007 Storm Event

Tributary Area	Sewer Length (ft)	IDM	Total Inflow Volume	Net Inflow Volume	Net Inflow Severity (gal/lf)	Cummulative Net Inflow (MGD)	Cummulative Footage (ft)	Cummulative Net Inflow (%)	Cummulative Footage (%)	Net Storm Volume (MG)	Net R1 Volume (MG)	Net. R2 Volume (MG)
E	8,614	13	1.06	1.06	123.6	1.06	8,614	5%	2%	0.40	0.37	0.29
B	11,147	17	1.33	1.33	118.9	2.39	19,762	11%	5%	0.23	0.58	0.51
G	9,535	12	1.09	1.09	113.9	3.48	29,297	16%	8%	0.39	0.40	0.29
K	33,160	56	3.50	3.50	105.6	6.98	62,457	32%	16%	0.92	1.40	1.18
F	24,371	33	2.28	2.28	93.6	9.26	86,827	43%	22%	0.79	0.89	0.60
O	11,307	20	3.34	1.05	92.7	10.31	98,135	48%	25%	0.28	0.33	0.44
D	26,638	39	2.27	2.27	85.2	12.58	124,773	58%	32%	0.92	0.85	0.50
H	32,437	54	3.44	2.21	68.0	14.78	157,210	68%	41%	0.45	0.95	0.81
M	22,665	36	1.33	1.33	58.9	16.12	179,874	75%	46%	0.31	0.55	0.47
R	12,291	23	4.01	0.68	55.0	16.79	192,166	78%	50%	0.23	0.30	0.15
P	8,728	12	0.43	0.43	49.0	17.22	200,894	80%	52%	0.09	0.17	0.16
N	26,092	44	1.27	1.27	48.7	18.49	226,986	86%	59%	0.47	0.50	0.30
L	20,591	33	0.95	0.95	46.3	19.45	247,577	90%	64%	0.17	0.37	0.42
S	14,902	25	3.70	0.69	46.2	20.13	262,479	93%	68%	0.17	0.30	0.21
A	21,520	35	0.82	0.82	38.3	20.96	283,998	97%	73%	0.31	0.30	0.21
C	27,766	39	0.86	0.86	30.9	21.82	311,765	101%	81%	0.15	0.37	0.34
J	23,373	55	3.79	0.29	12.2	22.10	335,138	102%	87%	(0.07)	0.25	0.10
I	21,778	34	0.15	0.15	7.0	22.26	356,916	103%	92%	0.02	0.07	0.06
T (+Q)	30,275	87	17.91	(0.65)	(21.5)	21.61	387,191	100%	100%	(0.53)	(0.17)	0.05
Total	387,191	667		21.61	55.8	N/A	N/A	N/A	N/A	5.72	8.80	7.09



FST Area & Corresponding FAS Meter Designations

Area	Meter	Area	Meter
A	11	K	20
B	12	L	16
C	4	M	15
D	7	N	17
E	8	O	14
F	19	P	18
G	3	Q	13
H	2	R	6
I	9	S	10
J	1	T	5

FIGURE 1. SCHEMATIC OF TEMPORARY FLOW METERS

Prepared by Flow Assessment Services, LLC

For: in Belmont, MA

Site: 5 / Flanders Rd.

FLOW ANALYSIS

Period Covered: 03/23/2007 - 05/29/2007

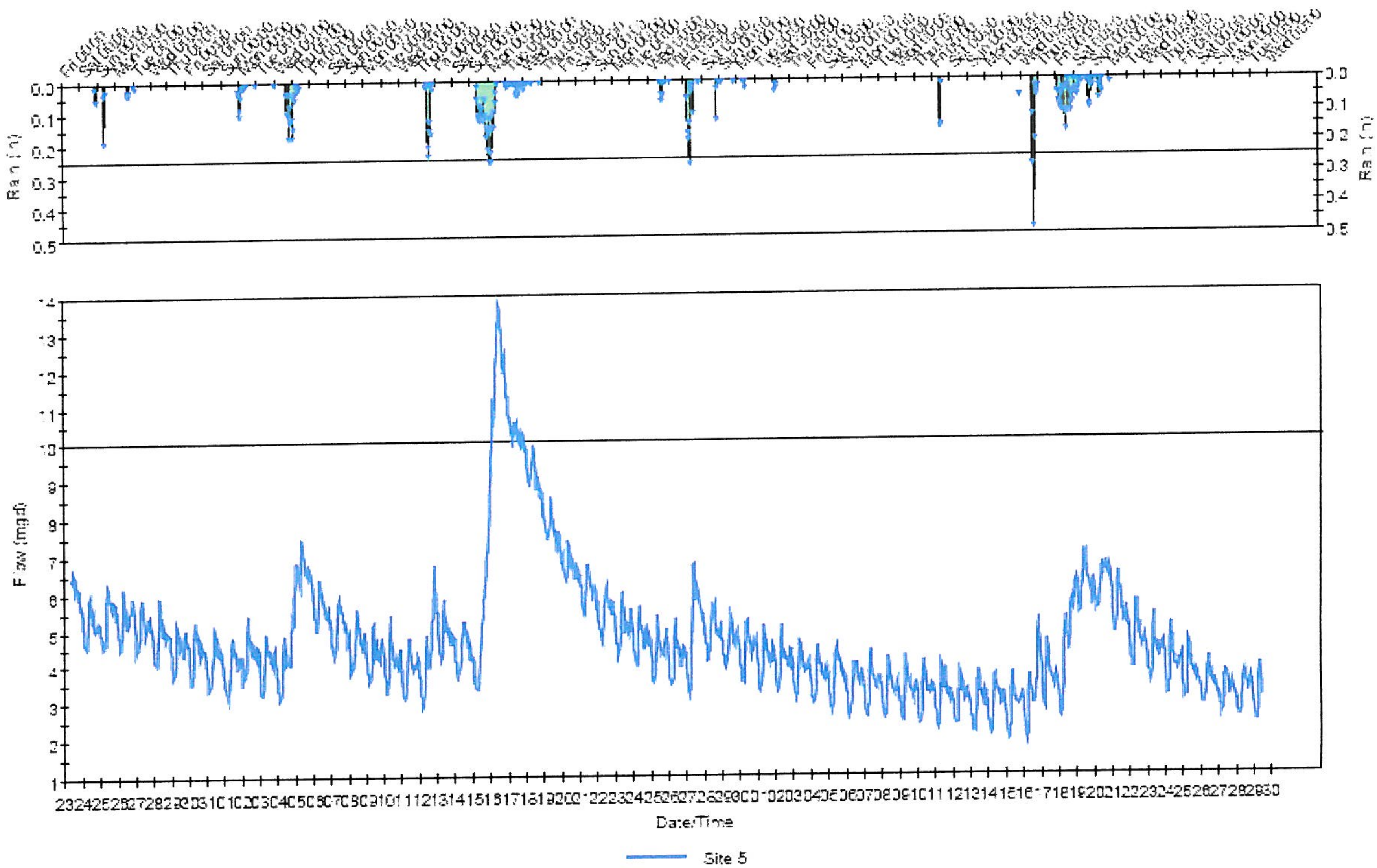


FIGURE 2. HYDROGRAPH: FLOW MONITOR T (SITE 5)

Prepared by Flow Assessment Services, LLC
For: in Belmont, MA
Site: BM-CB-1 / MWRA Site BM-CB-1

COMPARISON TO SINGLE SITE
Period Covered: 03/21/2007 - 05/30/2007

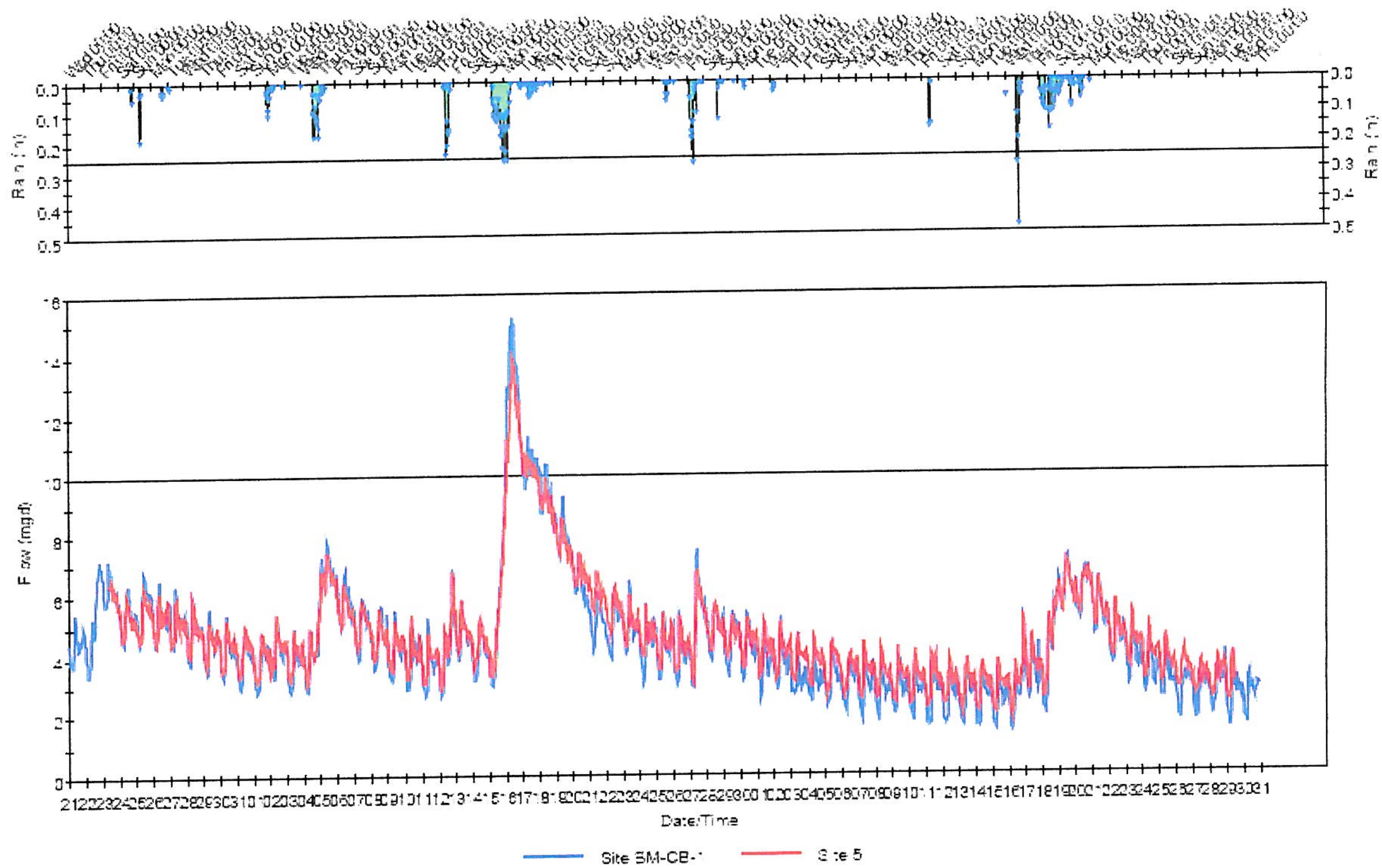
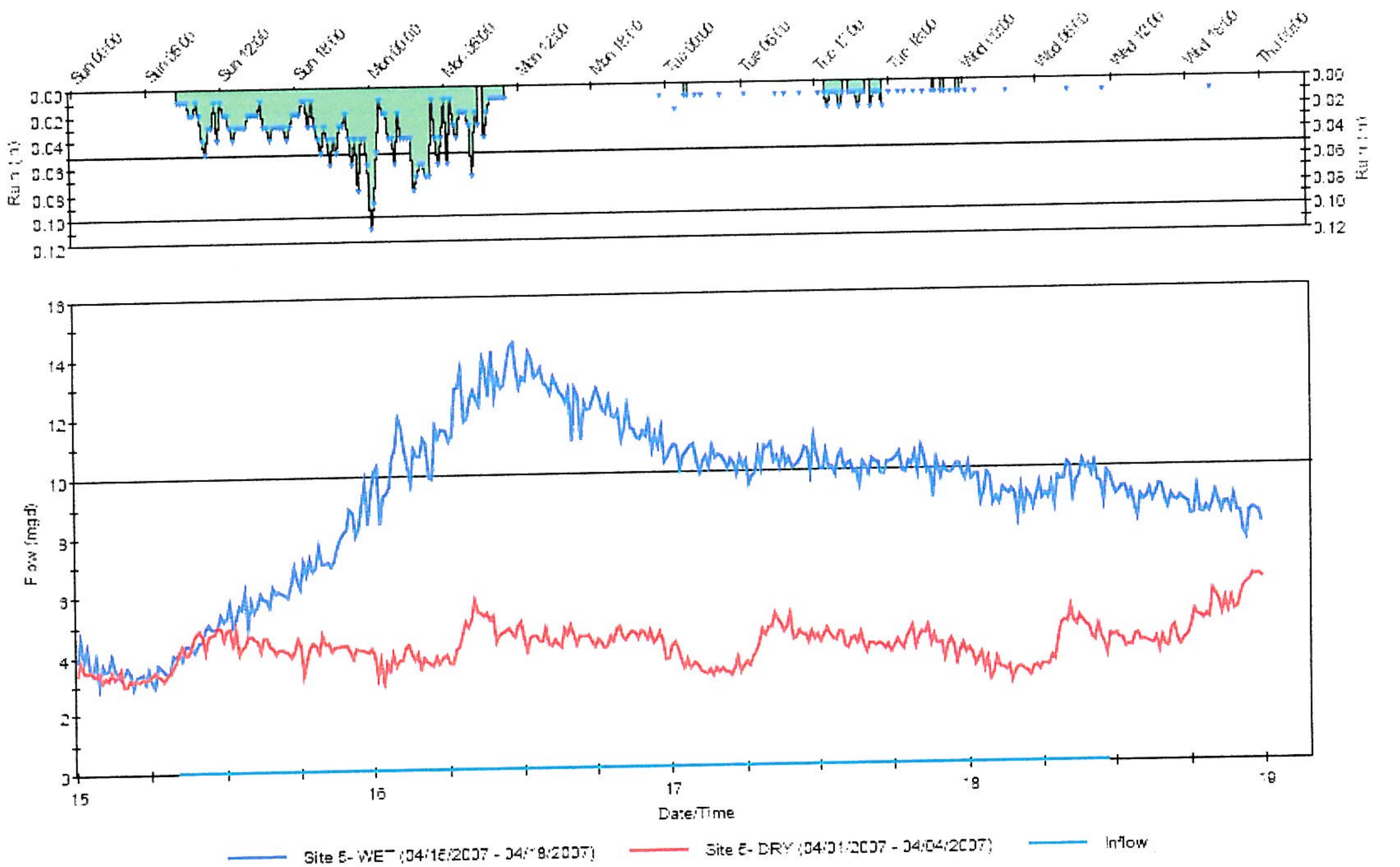


FIGURE 3. HYDROGRAPH: FLOW MONITOR T (SITE 5) & MWRA Outfall BM-CB-01

Prepared by Flow Assessment Services, LLC
For: in Belmont, MA
Site: 5 / Flanders Rd.

WET - DRY COMPARISON
Period Covered: 04/15/2007 - 04/18/2007 *(Wet)*
04/01/2007 - 04/04/2007 *(Dry)*



Total Inflow: 17.7483 MG

FIGURE 4. HYDROGRAPH: FLOW MONITOR T (SITE 5) INFLOW ANALYSIS