Appendix A

SANITARY SEWER FLOW MONITORING AND INFLOW/INFILTRATION STUDY

City of Oroville

Sanitary Sewer Flow Monitoring and Inflow / Infiltration Study

August 2007

V&A

CITY OF OROVILLE

SANITARY SEWER FLOW MONITORING
and
INFLOW / INFILTRATION STUDY

Prepared for:

CAROLLO ENGINEERS
2700 Ygnacio Valley Rd., Suite 300
Walnut Creek, CA 94598

Prepared By:

V&A CONSULTING ENGINEERS
Lake Merritt Plaza
1999 Harrison Street, Suite 975
Oakland, CA 94612

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APPENDIX A – Flow Monitoring Sites, Graphs, and Information

EXECUTIVE SUMMARY

V&A Consulting Engineers (V&A) has completed sanitary sewer flow monitoring and inflow and infiltration (I/I) analysis within the City of Oroville. Flow monitoring was conducted over a three-month period from February 7, 2007 through May 9, 2006 at 12 flow monitoring sites, as chosen by Carollo Engineers. The 12 flow monitoring sites are shown in Figure 2 on Page 5 of this report.

Table 1 includes infiltration indicators (R-Values[1], I/I per IDM[2]) and inflow indicators (Peaking Factors [PF][3]) for each flow monitoring site as measured over the entirety of the flow monitoring period. Values that exceeded commonly used threshold values are shown in **red**.

Table 1. Collection System Site I/I Results

Threshold Values: R-Value > 5%, PF > 3.0

Site	Average Dry Weather Flow (MGD)	Infiltration Indicators			Inflow Indicators		
		Total I/I (Millions of Gallons)	R-Value (%)	I/I per IDM	Peak Flow (MGD)	Peaking Factor	Peak I/I (MGD)
Site 1	0.0022	2,000	0.0%	100	0.009	**4.27**	0.008
Site 2	2.54	22,720,000	4.1%	N/A	8.79	**3.47**	5.97
Site 3	1.34	10,388,000	4.4%	8,800	4.43	**3.30**	2.91
Site 4a	0.59	2,224,000	2.2%	4,100	1.60	2.71	0.94
Site 4b	0.36	2,306,000	3.2%	5,800	1.34	**3.70**	0.93
Site 5	0.26	2,046,000	3.6%	7,300	1.21	**4.61**	0.91
Site 6	0.17	2,094,000	**5.7%**	16,000	0.66	**3.97**	0.53
Site 7	0.63	6,345,000	**5.7%**	13,300	2.62	**4.14**	2.09
Site 8	0.10	520,000	1.1%	5,000	0.31	3.00	0.20
Site 9	0.33	4,104,000	**17.2%**	32,200	1.32	**4.05**	1.02
Site C1	0.06	98,000	1.9%	10,400	0.15	2.66	0.09
Site C2	0.013	192,000	**6.0%**	14,200	0.19	**14.47**	0.18

[1] R-Value is the percentage of rainfall that permeates into the sewer system. Sewer Basins with R-Values<5% are often considered to be performing well. Keefe, P.N. "Test Basins for I/I Reduction and SSO Elimination", 1998, WEF Wet Weather Specialty Conference.

[2] I/I per IDM uses the total pipe length upstream of the monitoring location to normalize the relative magnitude and severity of I/I.

[3] "Peaking Factor" is the peak wet weather flow divided by the average flow.

Figure 1 graphically demonstrates the infiltration and inflow indicators graphically.

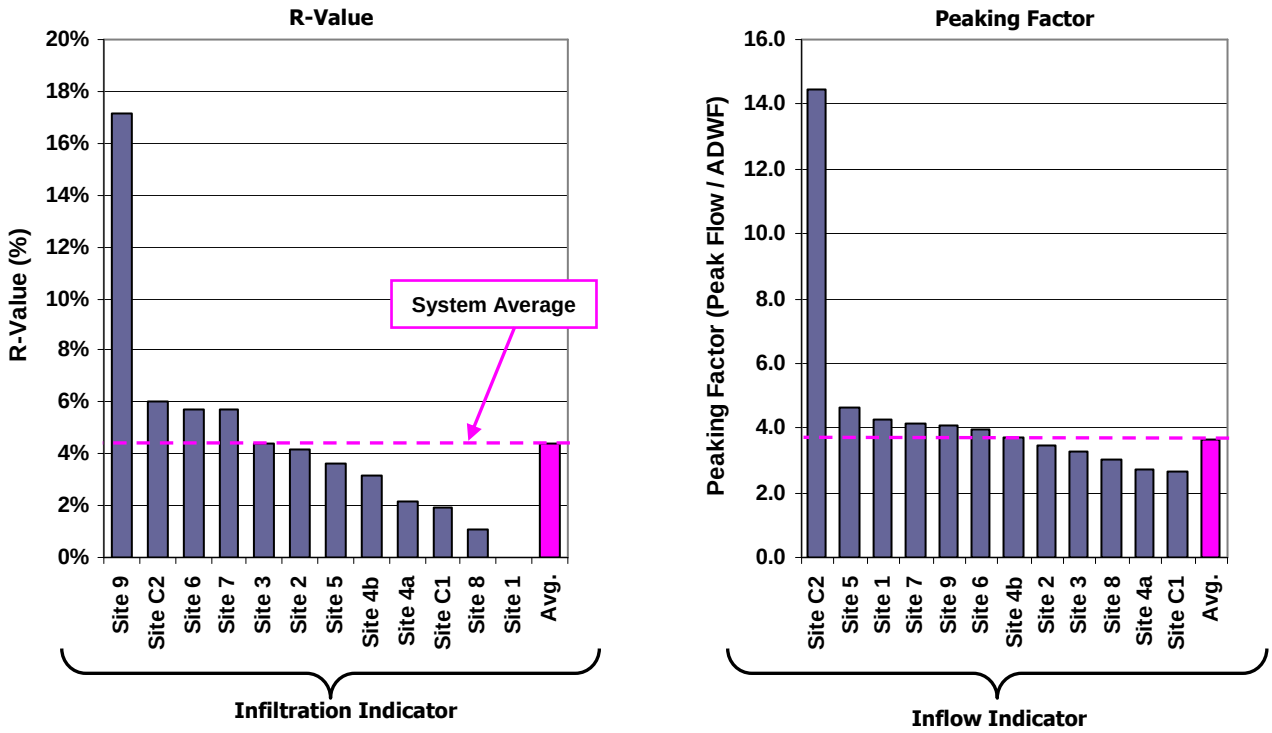

Figure 1. Infiltration and Inflow Indicators by Monitoring Site

The following I/I analysis results are noted:

- **Infiltration**
  - The system average R-Value was approximately 4.4%. This is less than the threshold value of 5%.
  - Site 9 had R-Values significantly higher than the other monitoring sites at approximately 17%. Sites C2, 6 and 7 exceeded R-Value threshold values of 5%.
- **Inflow**
  - The system average for Peaking Factor was approximately 3.6. This exceeds the threshold value of 3.0.
  - Site C2 had peaking factors significantly higher than the other monitoring sites. Sites 5, 1, 7, 9 and 6 had peaking factors that were greater than average within this collection system.

- **Groundwater Infiltration** Site 9 may have higher than normal groundwater infiltration during periods of dry weather flow.

- **Pipe Capacity:** Site 9 exceeded the 0.75 threshold and surcharged 2.8 inches above the crown. Sites 2 and 3 exceeded threshold limits; however, this may have been caused by a backflow hydraulic event purposely caused at the treatment facility.

V&A advises that future I/I reduction plans consider the following recommendations:

1. **Determine I/I Reduction Program:** The District should examine its I/I reduction needs to determine a future I/I reduction program.
    a. If peak flows, sanitary sewer overflows, and pipeline capacity issues are of greater concern, then the program may be weighted to investigate and reduce sources of inflow within the sites with the greatest inflow problems.
    b. If total infiltration and general pipeline deterioration is of greater concern, then the program may be weighted to investigate and reduce sources of infiltration within the sites with the greatest infiltration problems.
    c. Sites to be investigated as a part of the I/I reduction program can be prioritized per the results illustrated in Figure 1 and shown in Table 2.
2. **I/I Reduction Methods:** Potential I/I reduction methods include the following:
    a. smoke testing
    b. mini-basin flow monitoring
    c. night-time reconnaissance work to (1) investigate and determine direct point sources of inflow, and (2) determine the areas and/or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection. Future CCTV inspection as used for condition assessment of the collection system should be prioritized to inspect the pipes within the sites per the results illustrated in Figure 1.
3. **I/I Reduction Cost Effective Analysis:** The District should conduct a study to determine which is more cost-effective: (1) locating the sources of infiltration and inflow and systematically rehabilitating or replacing the faulty pipelines; or (2) continued treatment of the additional storm water I/I flow.

INTRODUCTION

V&A was retained by Carollo Engineers to conduct sanitary sewer flow monitoring within the West County Wastewater District (WCWD) collection system to assist with the study of infiltration and inflow (I/I) for a master planning effort. Flow monitoring was conducted over a 9-week period from January 13, 2006 through March 21, 2006 at nine flow monitoring sites. The scope of work includes the following tasks:

- Install flow monitoring equipment at nine monitoring sites for 2 months during the wet weather period. Flow data shall be recorded at 15-minute intervals.
- Conduct I/I analysis to differentiate base flows from I/I flows for the sites monitored.

Figure 2 shows a site map of the project area. Table 2 describes the physical characteristics of the flow monitoring sites and drainage basins. Figure 3 shows a map provided by Carollo indicating the basin boundaries. Detailed descriptions of the individual flow monitoring sites, including photographs, are included in *Appendix A*.

Table 2. Details of Sanitary Sewer Drainage Sites

Monitoring Site	Metering Sites Drainage Basins[4] (Acre)	Average Dry Weather Flow (MGD)
Site 1	436	10.3
Site 2	7,589	N/A
Site 3	3,335	450.27
Site 4a	1,425	207.7
Site 4b	1,009	151.35
Site 5	790	107.07
Site 6	514	49.92
Site 7	1,668	193.36
Site 8	856	48.86
Site 9	345	49.95
Site C1	72	3.63
Site C2	45	5.21

[4] Basin boundaries were determined by consulting system maps to determine upstream drainage areas. Acreages were determined by determining tracing basin boundaries, using an AutoCAD function to determine basin area, and scaling appropriately.

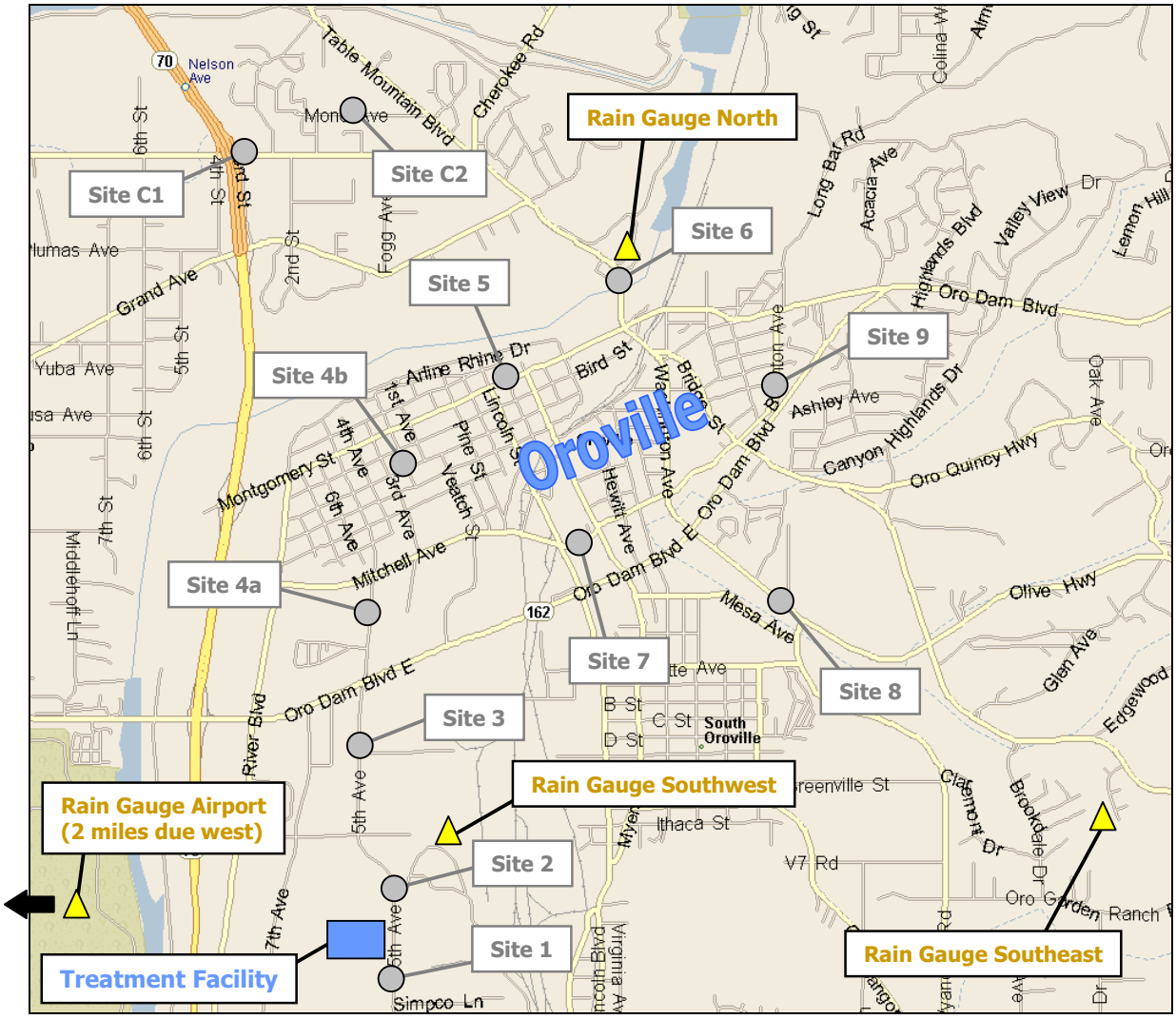

Figure 2. Site Map

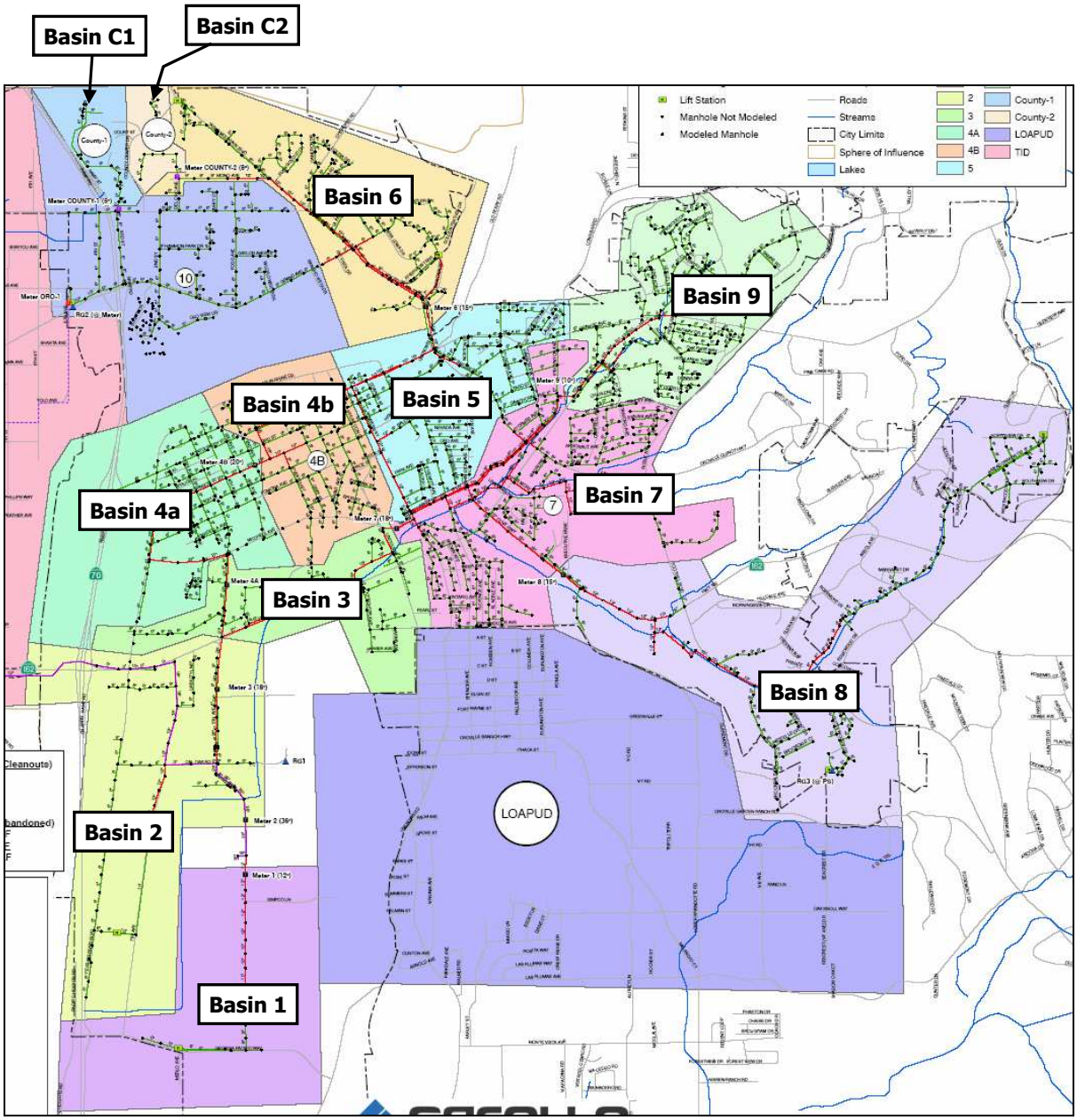

Figure 3. Basin Map

METHODS AND PROCEDURES

Meter Installation

Twelve Sigma 950 flow meters were installed by V&A in the sewer lines shown in Figure 2. Sigma meters use a pressure transducer to collect depth readings, and ultrasonic Doppler sensors on the probe to determine the average fluid velocity. Figure 4 shows a sketch of a typical flow meter installation.

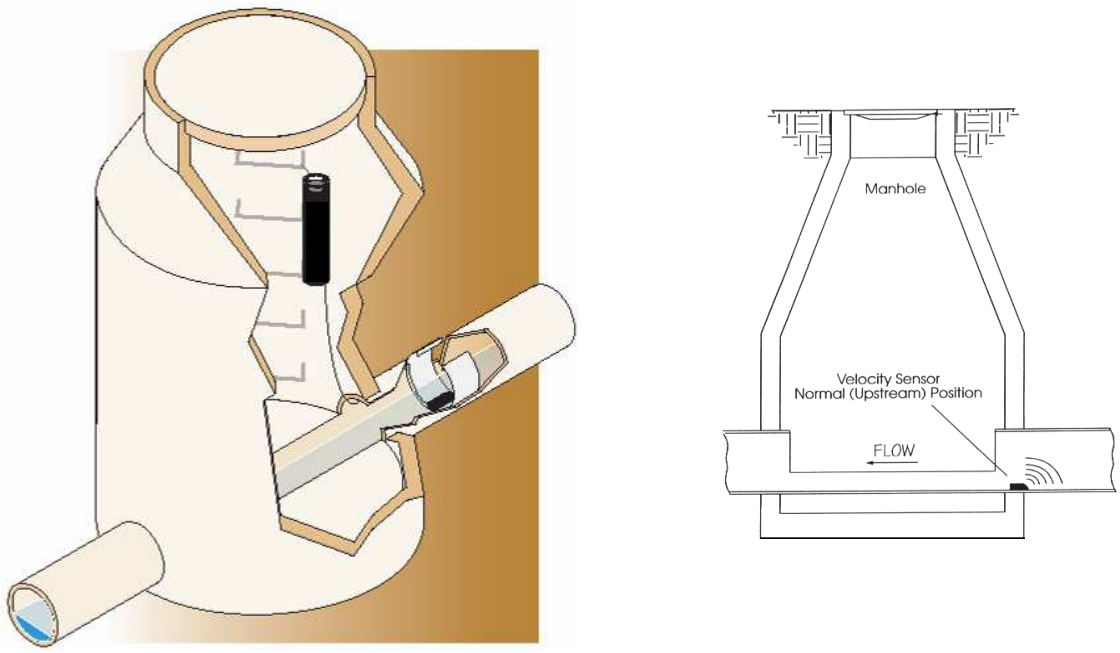

Figure 4. Flow Meter Installation

Continuous depth and velocity readings were recorded by the flow meters in 15-minute increments and downloaded into a computer spreadsheet program where the data could be analyzed and made report ready. Manual level and velocity readings were taken in the field during the flow meter installation and again when removed, and compared to the readings of the flow meters to ensure proper calibration and accuracy.

RAINFALL RESULTS

Four rain gauges were utilized to capture the rain events over the course of this study. Refer to Figure 2 for rain gauge locations.

The rain events over the course of this study were differentiated into four rainfall events to be used for I/I analysis, shown in Table 3. Figure 5 graphically displays the rainfall events recorded over the flow monitoring period (Rain Gauge Southwest shown).

Table 3. Summary of Storm Events

Storm Event No.	Total Rain (in)				Event Period	Event Description	Estimated Soil Condition prior to Event
	North	South West	South East	Airport			
Event 1	3.91	4.07	3.39	3.46	**Feb 7 – Feb 12**	Continuous and relatively intense rainfall.	Mostly Dry
Event 2	2.63	2.93	2.07	2.20	**Feb 22 – Feb 27**	Continuous and relatively intense rainfall in saturated soil conditions.	Saturated
Event 3	0.44	0.36	0.26	0.35	**Mar 26**	Decent late-season rainfall event.	Saturated
Event 4	0.97	1.03	1.02	0.96	**April 21**	Decent late-season rainfall event.	Saturated

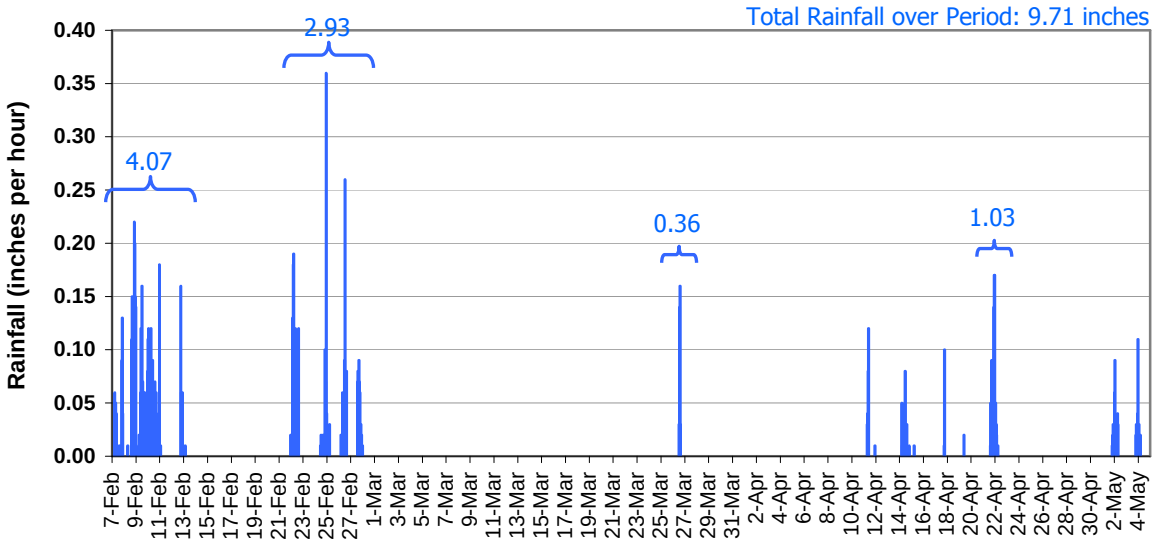

Figure 5. Oroville Rainfall Activity over Flow Monitoring Period

Figure 6 shows the rain accumulation plot of the rain gauge, as well as the historical average rainfall for the District during this project duration.

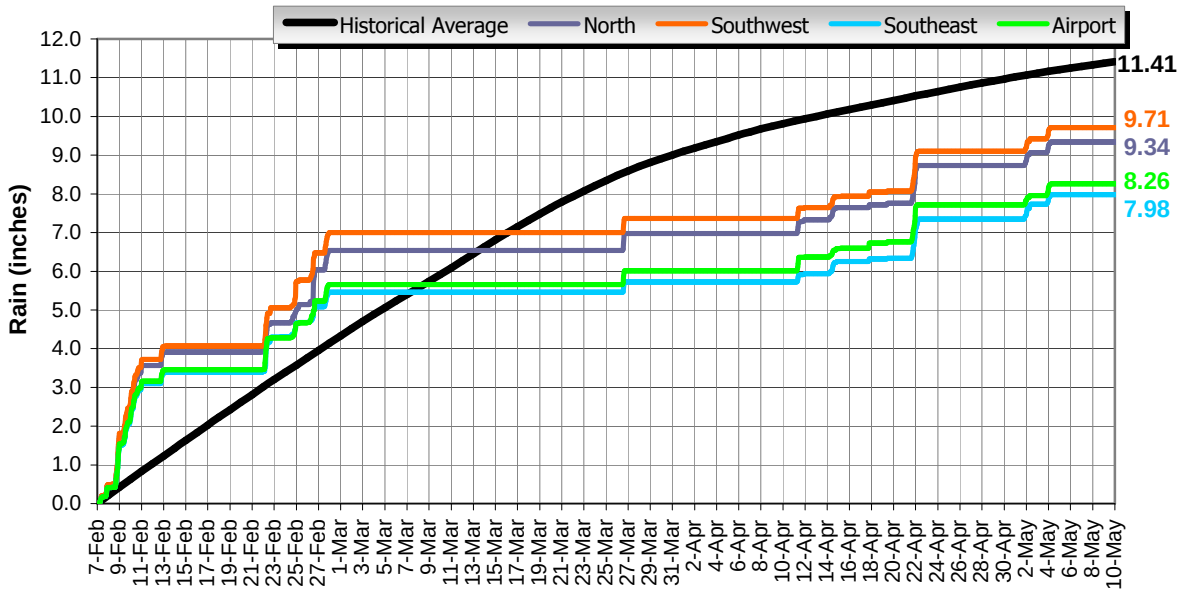

Figure 6. Rainfall Accumulation Plots

The historical average rainfall is shown for comparison to the rainfall that occurred over the course of the flow monitoring period (February 7, 2007 through May 9, 2007). The historical data was taken from the Western Regional Climate Center (WRCC) at Station 046521 at Oroville, California. Rainfall data from the years 1970 through 2000 were used to determine these averages. The historical average over the monitoring period is 11.41 inches. The rain gauge indicated rainfall totals from 7.98 inches to 9.71 inches, 70% to 85%, respectively, of normal levels for this period of time.

Rain Gauge Triangulation

The rainfall affecting the sanitary sewer collection system must be calculated based on the proximity to the rain gauge locations. The mean precipitation for the sanitary sewer collection system was calculated by taking data from seven local rain gauges and using the Inverse Distance Weighting (IDW) method. The IDW is an interpolation method that assumes the influence of each rain gauge location diminishes with distance. The center of a sanitary sewer collection system was identified and a weighted average was taken of the precipitation data from nearby rain gauge locations. The IDW function is as follows:

$$weight(d) = \frac{1/d^p}{\sum 1/d^p}, \quad \text{where:} \quad d = \text{distance} \quad p = \text{power } (p > 0)$$

The value of p is user defined. The most common choice for hydrological studies of watershed areas is $p = 2$. Figure 7 and Table 4 illustrate the IDW method (sample data). The rain gauge distribution as calculated for each flow monitoring site is shown in Table 5.

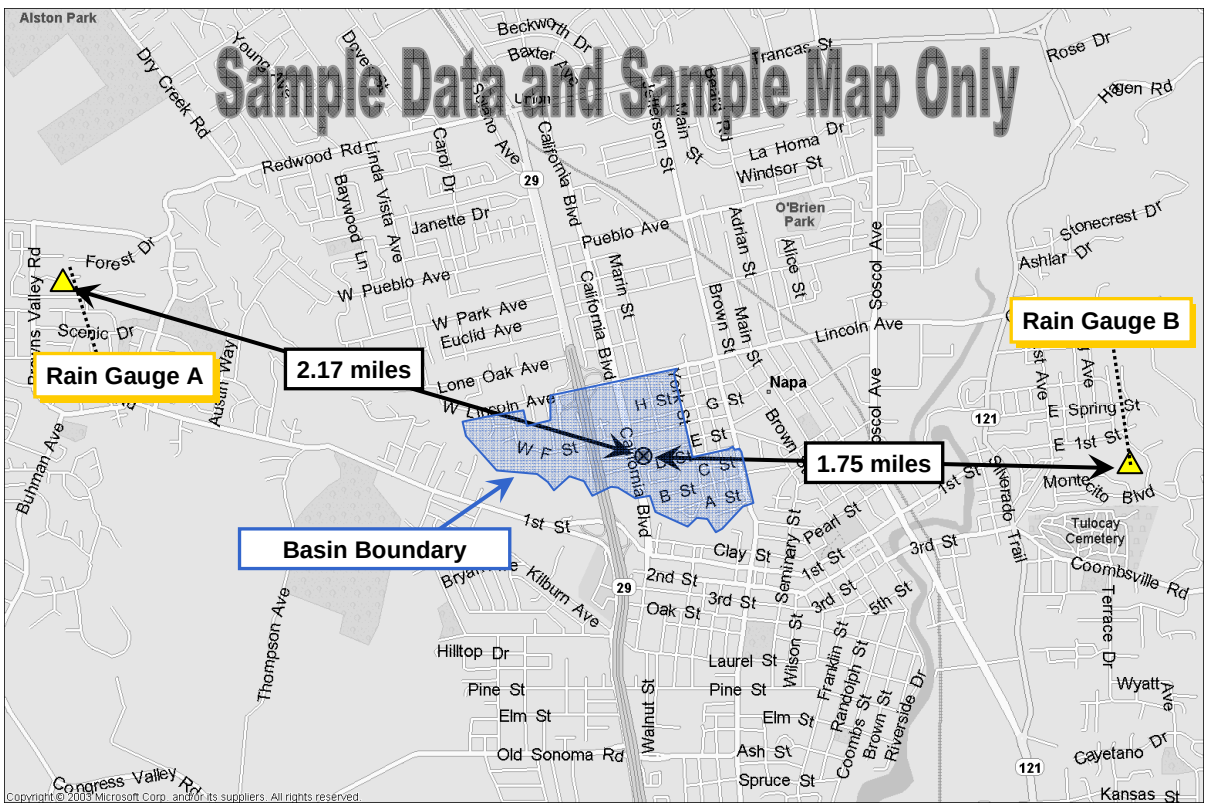

Figure 7. Rainfall Inverse Distance Weighting Method

Table 4. IDW Method (Sample)

Rain Gauge	Distance (miles)	$1/d^2$	Weight (%)
Rain Gauge A	2.17	0.2124	39.4%
Rain Gauge B	1.75	0.3265	60.6%
Totals		**0.5389**	**100%**

Table 5. Rain Gauge Distribution, Oroville

Site	Distance (miles)				Weight (%)			
	North	South West	South East	Airport	North	South West	South East	Airport
Site 1	2.81	0.873	2.44	3.08	7.4%	76.6%	9.8%	6.2%
Site 2	0.84	1.16	2.28	3.54	58.1%	30.7%	7.9%	3.3%
Site 3	0.58	1.49	1.86	4.19	79.2%	11.8%	7.6%	1.5%
Site 4a	0.57	1.45	2.34	3.75	81.0%	12.4%	4.8%	1.9%
Site 4b	0.22	1.73	2.33	4.05	97.2%	1.6%	0.9%	0.3%
Site 5	0.09	1.88	2.38	4.19	99.6%	0.2%	0.1%	0.0%
Site 6	0.55	2.27	2.91	4.19	90.1%	5.2%	3.2%	1.5%
Site 7	1.13	1.80	1.24	4.80	43.9%	17.3%	36.4%	2.4%
Site 8	2.01	2.01	0.37	5.19	3.2%	3.2%	93.2%	0.5%
Site 9	0.96	2.39	1.86	5.13	68.5%	11.0%	18.2%	2.4%
Site C1	1.40	2.50	3.68	3.56	62.0%	19.4%	9.0%	9.6%
Site C2	1.23	2.47	3.52	3.72	67.6%	16.8%	8.3%	7.4%

Storm Event Classification

It is important to classify the relative size of the major storm events that occur over the course of a flow monitoring period[5]. Storm events are classified by intensity and duration. Based on historical data, frequency contour maps for given intensity and duration storm events have been developed by the National Oceanic and Atmospheric Administration (NOAA) for all areas within the continental United States. For example, the NOAA Rainfall Frequency Atlas[6] classifies a 10-year, 24-hour storm event in Oroville as 4.00 inches (Figure 8). This means that in any given year, there is a 10% chance (1/10) 3.51 inches of rain will fall in any 24-hour period.

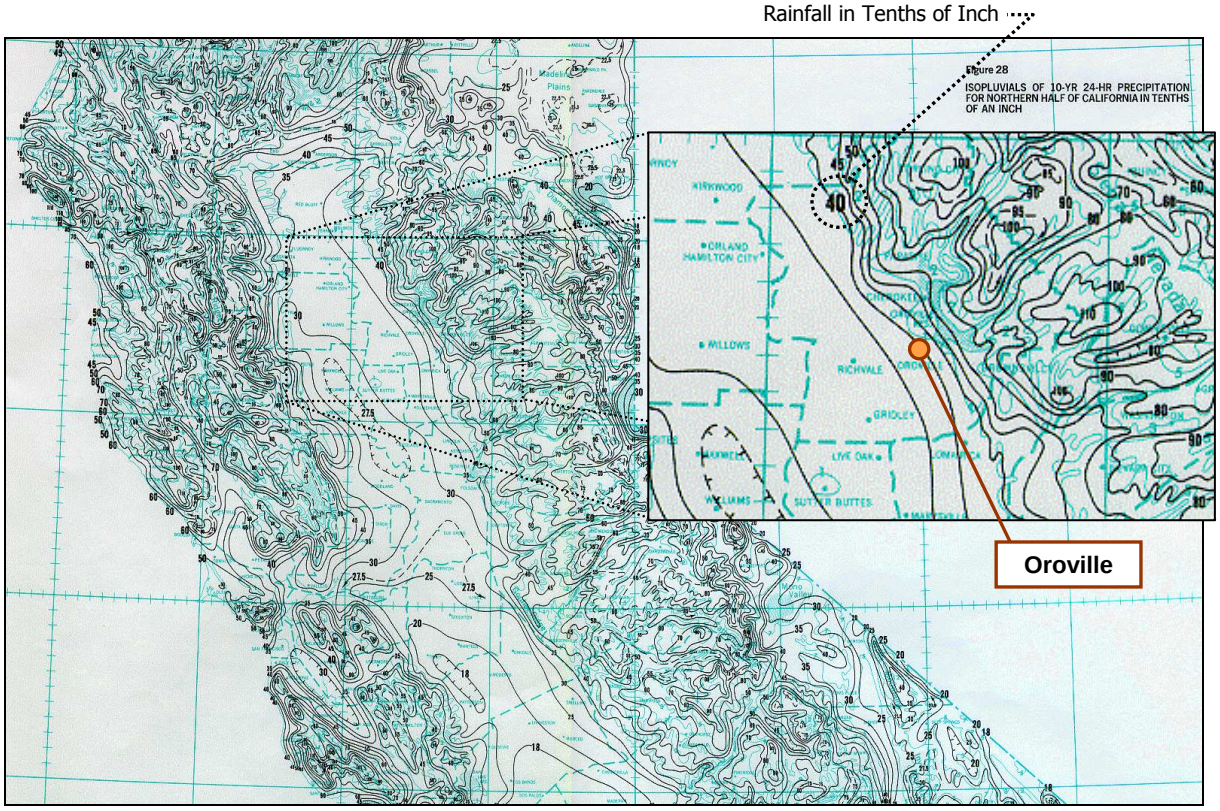

Figure 8. NOAA Southern California Rainfall Frequency Map

From the NOAA frequency maps, the rainfall totals for Oroville for 1-hour, 6-hour and 24-hour period durations, and 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year period intensities, were plotted to develop a rain event frequency map specific to the City of Oroville, shown in Figure 9.

[5] Sanitary sewers are often designed to withstand I/I contribution to sanitary flows for specific sized "design" storm events.

[6] NOAA Western U.S. Precipitation Frequency Maps Atlas 2, 1973 <http://www.wrcc.dri.edu/pcpnfreq.html>.

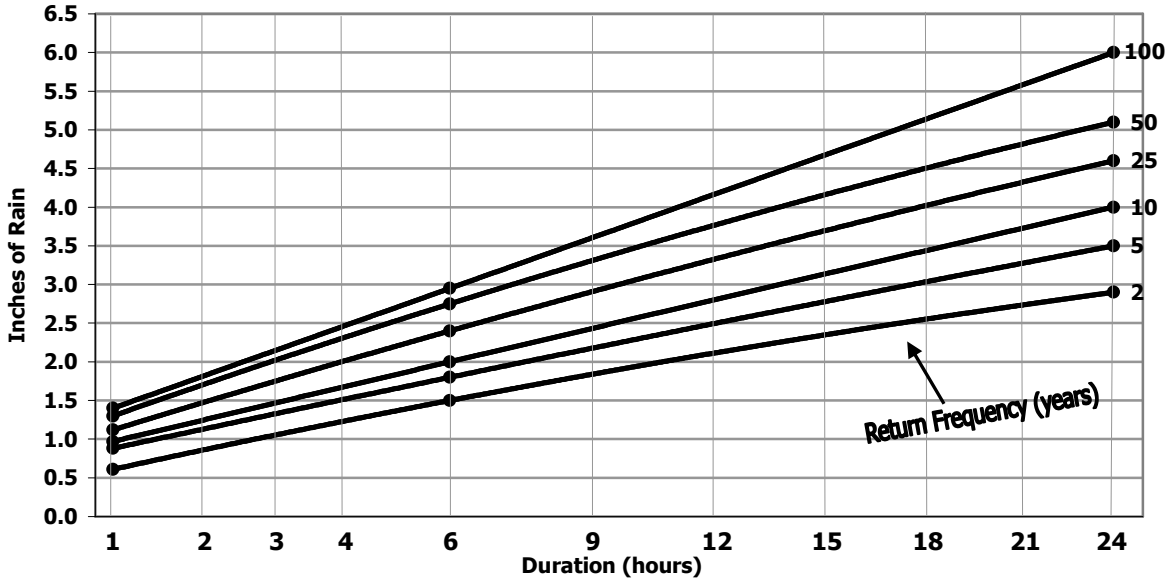

Figure 9. Oroville Rainfall Frequency Map

The highest rainfall in any 1-hour period was 0.36 inches and occurred during Event 2. The highest rainfall for any consecutive 6-hour period was 0.94 inches, and highest rainfall for any consecutive 12-hour period was 1.31 inches, both occurring during Event 1. Peak measured densities by hourly periods were calculated for the largest rainfall event, as summarized in Table 6.

Table 6. Peak Measured Rainfall Densities per Hourly Period

Rainfall Duration	Total Rainfall (inches)	Storm Event
1 hr	0.36	Event 2
3 hr	0.57	Event 1
6 hr	0.94	Event 1
12 hr	1.31	Event 1
18 hr	1.34	Event 1
24 hr	1.80	Event 1

Superimposing the peak measured densities by storm event on the Oroville Rainfall Frequency Map will determine the classification of the storm event, shown in Figure 10.

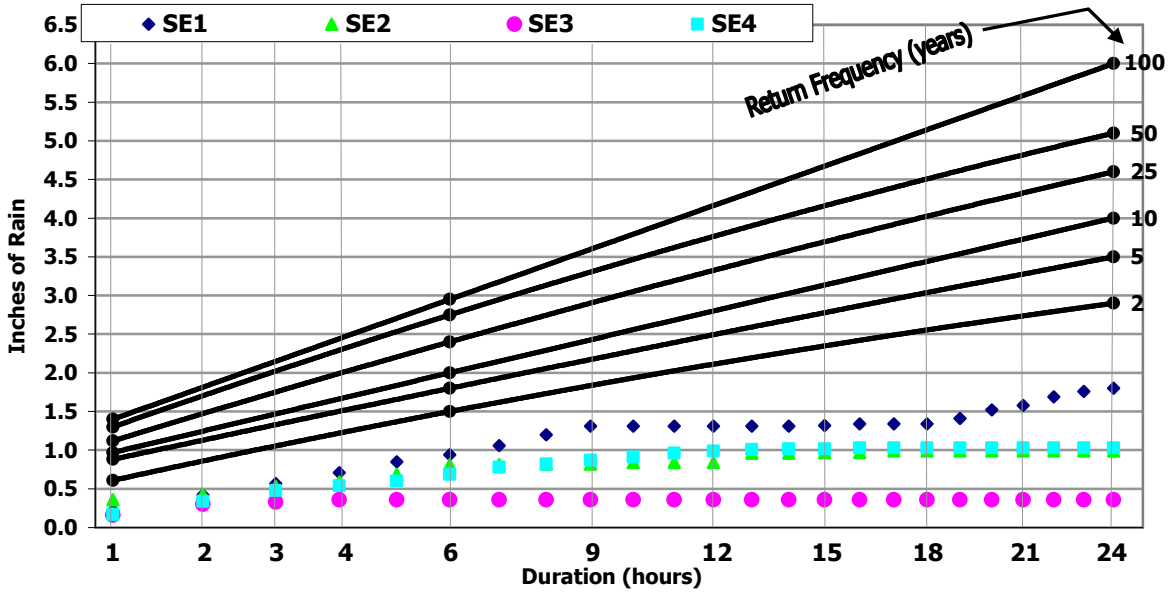

Figure 10. Storm Event Classification

At no time could any of the storm events be classified as a 2-year storm event. All storm events are classified as **less than** a 2-year events.

RESULTS

Dry Weather Flow Results

Weekday and weekend flow patterns vary and must be separated when determining average dry weather flows. For this project, the following days were least affected by rainfall and were used to determine weekend and weekday average flows:

- Weekdays: February 6 – 10, 13 – 15, 21 - 24
- Weekends: February 5, 11, 12, 19, 25

Figure 11 shows a sample of the average dry weather flow graph that was generated for each flow monitoring site. Graphs for each site are located in *Appendix A*.

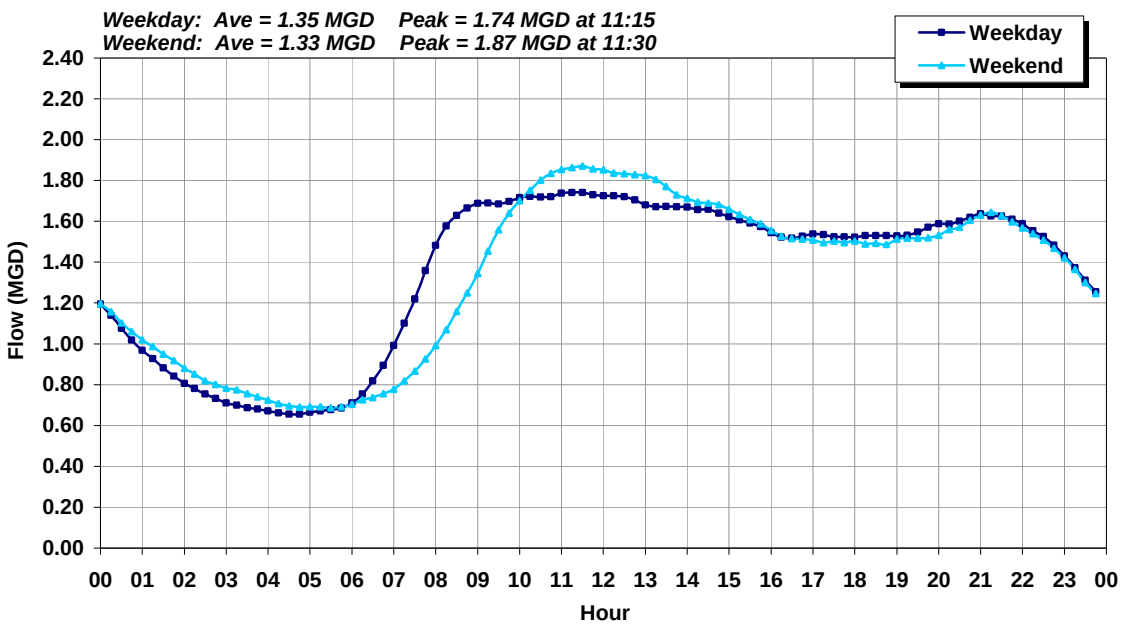

Figure 11. Site 3: Average Dry Weather Flow

Table 7 lists the average dry weather flow (ADWF) and average peak dry weather flows (PDWF) recorded during this study for the sites that were directly monitored.

Table 7. Dry Weather Flows

Location	Average Dry Weather Flow (MGD)		Weekend/ Weekday Ratio	Average Peak Dry Weather Flow (MGD)		PDWF/ADWF Ratio	
	Weekday	Weekend		Weekday	Weekend	Weekday	Weekend
Site 1	0.0022	0.0020	0.93	0.00	0.00	1.61	1.27
Site 2	2.53	2.57	1.02	3.42	3.86	1.35	1.50
Site 3	1.35	1.33	0.99	1.74	1.87	1.29	1.41
Site 4a	0.59	0.58	0.98	0.77	0.84	1.29	1.44
Site 4b	0.37	0.35	0.97	0.49	0.53	1.34	1.50
Site 5	0.26	0.26	0.97	0.36	0.38	1.38	1.47
Site 6	0.17	0.17	1.01	0.27	0.27	1.65	1.63
Site 7	0.64	0.62	0.97	0.82	0.86	1.29	1.39
Site 8	0.10	0.10	1.01	0.15	0.16	1.50	1.60
Site 9	0.33	0.33	1.00	0.45	0.46	1.39	1.40
Site C1	0.057	0.055	0.96	0.09	0.08	1.62	1.47
Site C2	0.013	0.011	0.85	0.05	0.04	3.39	3.33

Dry Weather Ground Water Infiltration Analysis

Dry weather (baseline) flow can be expected to have a predictable diurnal flow pattern. While each site is unique, experience has shown that, given a reasonable volume of flow and typical loading conditions, the daily peaks and lows fall into a predictable range when compared to the daily average flow. If a site has a large percentage of ground water infiltration occurring during the periods of dry weather flow measurement, the amplitudes of the peak and low flows will be dampened[7]. Figure 12 shows a sample of two flow monitoring sites, both with nearly the same average daily flow, but with considerably different peak and low flows. In this *sample* case, Site B1 may have a considerable volume of ground water infiltration.

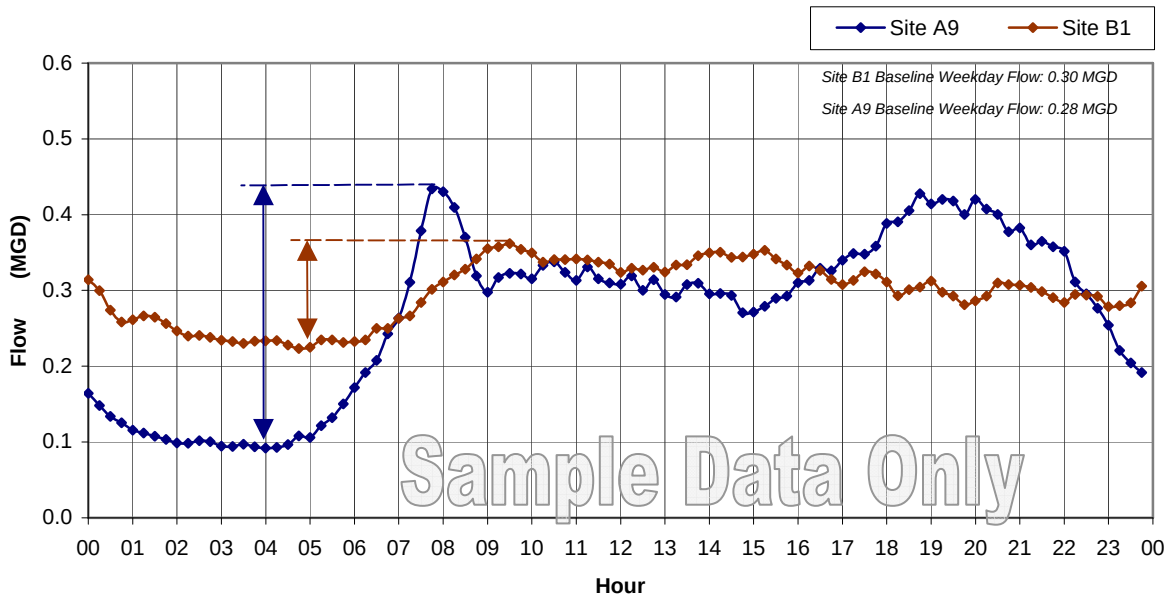

Figure 12. Ground Water Infiltration Sample Figure

It can be useful to compare the peak-to-baseline and low-to-baseline flow ratios for all flow metering sites. A site with abnormal ratios, and with no other reasons to suspect abnormal flow patterns (such as proximity to pump station, treatment facilities, etc.), has a distinct possibility of higher levels of ground water infiltration in comparison to the rest of the collection system. Figure 13 plots the peak-to-baseline and min-to-baseline flow ratios against the baseline flows for all sites monitored during this study. The dotted line shows "typical" min-to-baseline flow

[7] Theoretically imagining an extreme case, if there were 0.2 MGD of baseline flow and 2.0 MGD of groundwater infiltration, the peaks and lows would be barely recognizable; the baseline flow would be nearly a straight line.

ratios per the Water Pollution Control Federation[8]. There are no established peak-to-baseline ratios, but a system trendline has been drawn to better distinguish sites that fall outside the system trends. The min-to-baseline ratio should be taken with more weight as low flows during early morning hours are generally more predictable than peak flows.

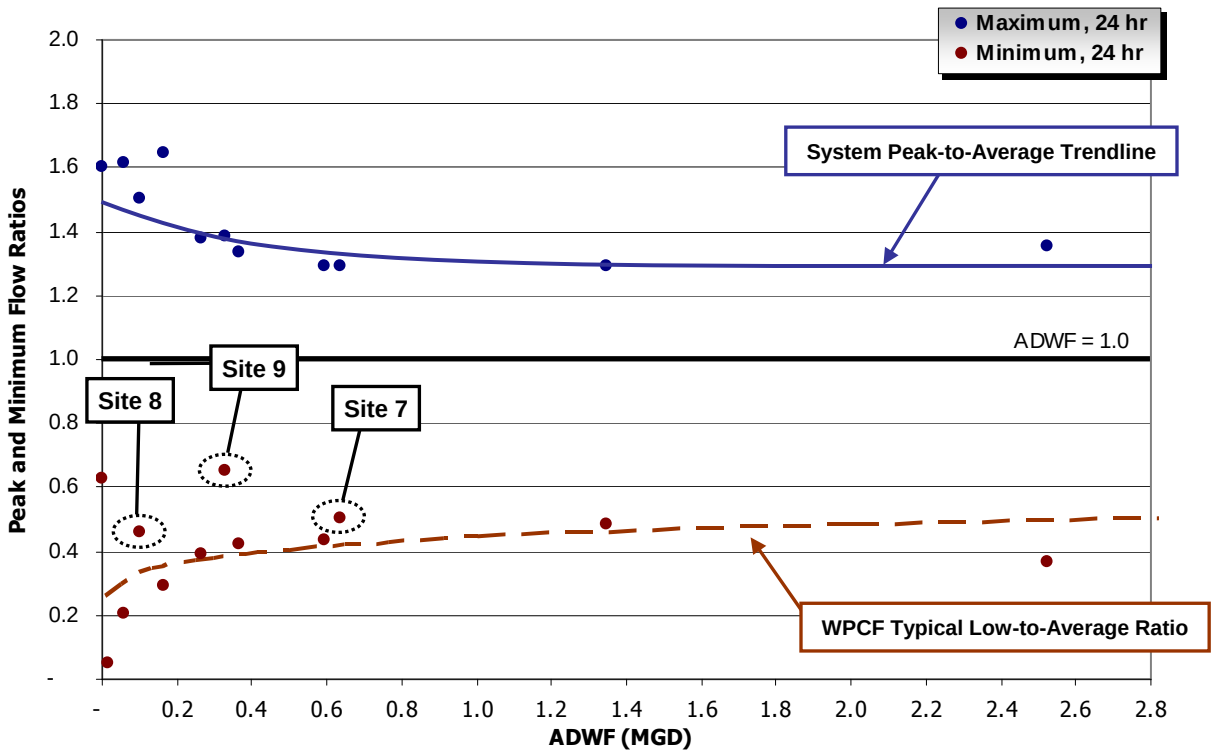

Figure 13. WCWD Peak and Minimum Flow Ratios vs. ADWF[9]

The following groundwater analysis results are noted:

- Site 9 had Min-to-Baseline Ratios that fell considerably outside of the typical min-to-baseline ratios as defined by WPCF. Site 8 and Site 7 had Min-to-Baseline Ratios that fell moderately outside of the typical min-to-baseline ratios. This may indicate higher than normal groundwater infiltration during periods of dry weather flow.

[8] WPCF Manual of Practice No. 9 "Design and Construction of Sanitary and Storm Sewers"

[9] Due to attenuation, it should be expected that sites with larger flow volumes should not have quite the peak-to-average and low-to-average flow ratios as sites with lesser flow volumes, which is why the typical and system trendlines slope closer to 1.0 as the ADWF increases, as shown in the figure.

Inflow/Infiltration Methods

I/I Definitions

Infiltration/inflow (I/I) consists of storm water and groundwater which enters the sewer system through pipe defects and improper storm drainage connections, defined as follows:

Inflow

Definition: Storm water inflow (SWI) is defined as water discharged into the sewer system, including private sewer laterals, from direction connections such as downspouts, yard and area drains, holes in manhole covers, cross connections from storm drains, or catch basins.

Impact: This component of I/I creates a **peak** flow problem in the sewer system and, together with RDI (explained below) dictates the required capacity of downstream pipes and transport facilities to carry these peak instantaneous flows. Because the response and magnitude of inflow is tied closely to the intensity of the storm event, the short-term peak instantaneous flows may result in surcharging and overflows within a collection system. Severe inflow may result in sewage dilution, resulting in upsetting the biological treatment (secondary treatment) at the treatment facility.

Cost of Source Identification and Removal: Compared to infiltration sources, SWI locations are usually less difficult to find and usually less expensive to correct. These sources include direct and indirect cross connections with storm drainage systems, roof downspouts, and various types of surface drains. Generally, the costs to identify and remove sources of SWI are low compared to potential benefits to public health and safety, or the costs of new facilities to transport the resulting peak flows.

Graphical Identification: Inflow is usually recognized graphically by large magnitude, short duration spikes immediately following a rain event.

Infiltration

Definition: Infiltration is defined as water entering the sanitary sewer system through defective pipes, pipe joints, and manhole walls, and may include cracks, offset joints, root intrusion points, and broken pipes.

Impact: Infiltration typically creates long-term annual **volumetric** problems, the major impact being the cost of pumping and treating the additional volume of water, of paying for treatment (for municipalities that are billed strictly on flow volume).

Cost of Source Detection and Removal: Infiltration sources are usually harder to find and more expensive to correct than inflow sources. Infiltration sources include defect in deteriorated sewer pipes and/or manholes, and may include cracks, offset joints, root intrusion points, and broken pipes. The sources may be wide-spread throughout a sanitary sewer system.

Graphical Identification: Infiltration is often recognized graphically by a gradual increase in flow after a wet weather event. The increased flow typically sustains for a period after rainfall has stopped and then gradually drops off as soils become less saturated, and as groundwater levels recede to normal levels. (Exception: RRI will graphically look more like SWI than infiltration.)

Infiltration can be further subdivided into components as follows:

- **Groundwater Infiltration** – Groundwater infiltration (GWI) depends on the depth of the groundwater table above the pipelines as well as the percentage of the system submerged. The variation on groundwater levels and subsequent GWI are seasonal in nature. On a day-to-day basis, GWI rates are steady and will not fluctuate greatly.
- **Rainfall Dependant Infiltration (RDI)** – This component occurs as a result of storm water and enters the sewer system through pipe defects similar to GWI, but due to rapid response, affects the system by contributing to **peak** flows as well as to the **total I/I volume**. This component may be further categorized as being rainfall-responsive or rainfall-related.
  - **Rainfall responsive infiltration (RRI)** is storm water which enters the collection system indirectly through pipe defects, but normally in sewers constructed close to the ground surface such as private laterals. RRI is independent of the groundwater table, and reaches defective sewers via the pipe trench in which the sewer is constructed, particularly if the pipe is placed in impermeable soil and bedded and backfilled with a granular material. In this case, the pipe trench serves as a conduit similar to a French drain, conveying storm drainage to defective joints and other openings in the system. Note: this type of infiltration can have a very quick response and graphically can look very similar to SWI.
  - **Rainfall related infiltration** is storm water that first percolates directly into the soil and then migrates to an infiltration point. Typically, the time of concentration for rainfall related infiltration may be 24 hours or longer, but depends on the soil permeability and saturation level.

Figure 14 illustrates the possible locations and components of I/I.

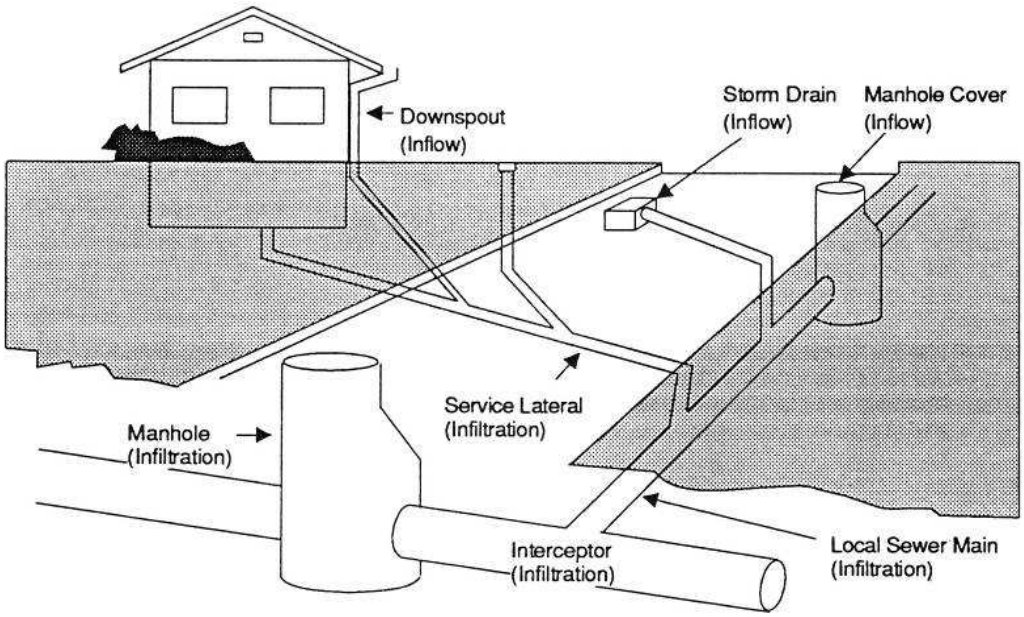

Figure 14. Infiltration / Inflow Locations and Components

Graphical Identification of I/I Components

Figure 15 shows sample graphs indicating the typical graphical response patterns for inflow and infiltration.

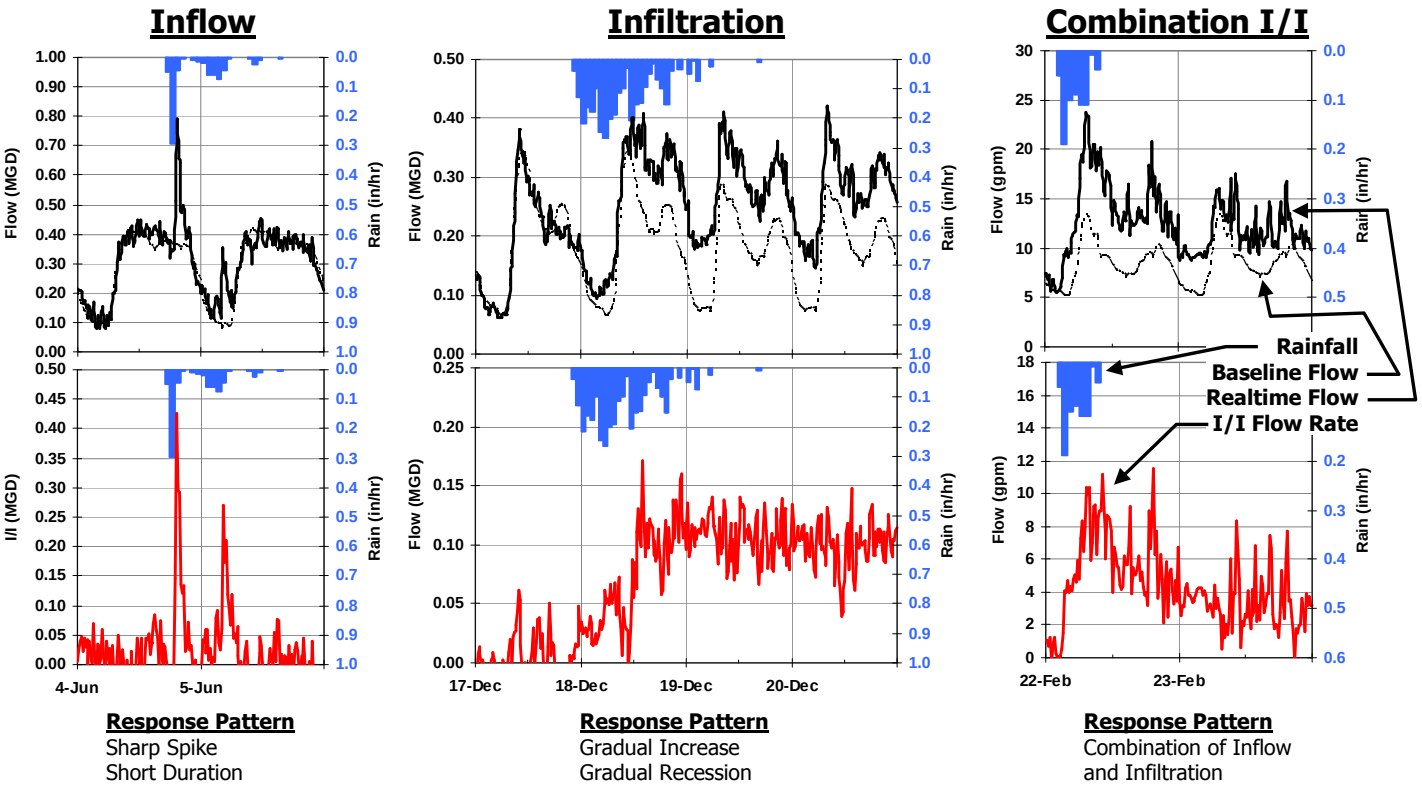

Figure 15. Infiltration/Inflow Graphical Response Patterns

I/I Analysis Techniques

After differentiating I/I flows from baseline flows, various calculations can be made to determine which I/I component is more prevalent at a particular site, and to compare the relative magnitude of the I/I components between drainage basins and between storm events, summarized as follows:

Infiltration Indicators

R-Value: Knowing the acreages of each basin and total I/I attributable to a storm event, the percentage of rainfall that permeates into each basin can be calculated and is called the R-Value. The R-Value method provides a means to compare the relative magnitude and severity of total I/I volume between different basins and different storm events. Systems with R-Values less than 5%[10] are often considered to be performing well and this criterion will be used for this study. Because the infiltration component is usually more predominant than the inflow component on a **totalized I/I volume** flow basis, R-Value is listed as an indicator of infiltration.

I/I per IDM Method: The Inch-Diameter-Mile (IDM) method uses length of pipe within the basins to normalize relative magnitude and severity of I/I. The IDM within each basin is calculated by multiplying the length of pipe in miles by the diameter of the pipe in inches. There is no threshold value for this method[11]; it should be used as a comparative tool to other sites, and as a complement to the R-Value. Similar to R-Value, because it is based on total I/I volume, it is predominantly an indicator of infiltration.

Inflow Indicators

Peaking Factor: Peaking Factor is defined as the Peak Wet Weather Flow divided by the Average Dry Weather Flow. Peaking factors can be used to determine the magnitude of the inflow component of I/I within a particular basin. It is more of an instantaneous measurement, therefore it should be noted and considered when a peaking factor is calculated from an addition or subtraction of flows, and is not directly monitored at a flow monitoring site. A peaking factor threshold value of 3.0 is commonly used for sanitary sewer design.

Figure 16 below shows a sample I/I graph that illustrates and summarizes the I/I response and I/I calculations made per site per storm event. Similar graphs for each site and storm event and are

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[10] Keefe, P.N. "Test Basins for I/I Reduction and SSO Elimination", 1998, WEF Wet Weather Specialty Conference, Cleveland

[11] From the WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", a typical specification allowance for groundwater infiltration into new pipe is between 250 and 500 gallons per day per inch-diameter mile (gpd/IDM). However, this is for groundwater infiltration only, and not for rain dependent inflow and infiltration.

located in *Appendix A*.

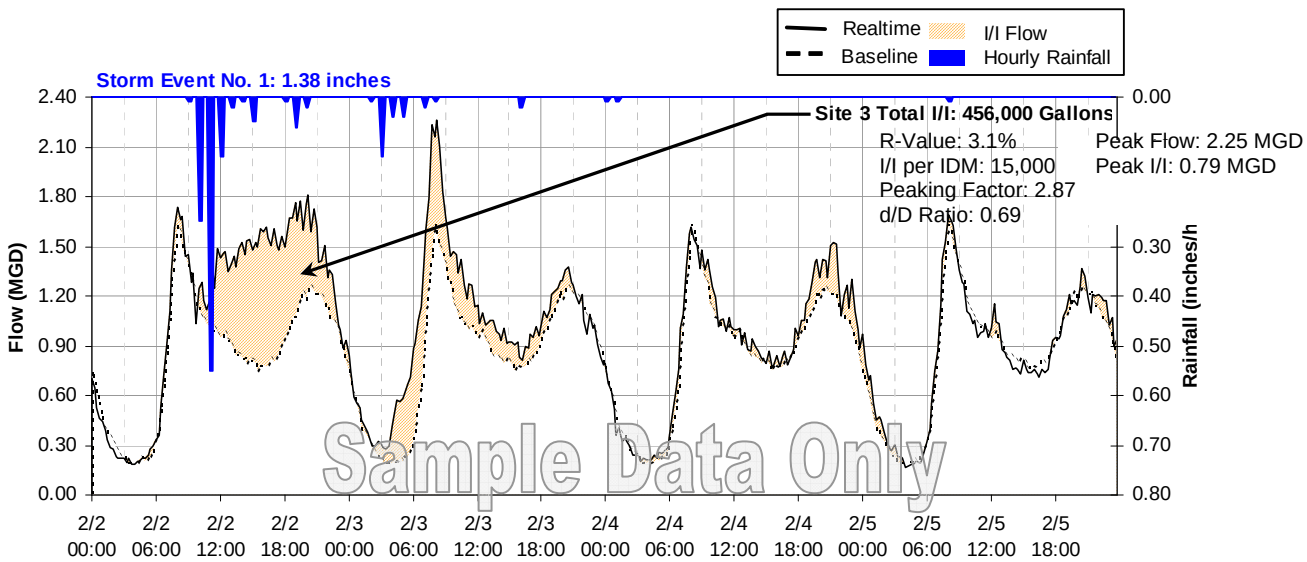

Figure 16. Sample I/I Flow Graph

Table 8 summarizes the I/I data collected for the study period on a site-by-site, storm-by-storm basis. Individual storm events may not capture lingering infiltration that may continue significantly beyond the completion of a storm event, whereas the "Period" values will capture all lingering infiltration until the final day of the study and should be more representative of actual values.

Table 8. Site I/I Summary

Threshold Values: R-Value > 5%, PF > 3.0

Site	Storm Event No.	ADWF (MGD)	Infiltration Indicators			Inflow Indicators		
			Total I/I (Millions of Gallons)	R-Value (%)	I/I per IDM	Peak Flow (MGD)	Peaking Factor	Peak I/I (MGD)
1	Event 1	0.0022	1,000	0.0%	0	0.014	6.41	0.011
	Event 2		2,000	0.0%	100	0.009	4.27	0.008
	Event 3		0	0.0%	0	0.003	1.25	0.000
	Event 4		1,000	0.0%	100	0.006	2.74	0.004
2	Event 1	2.54	20,551,000	2.6%	N/A	12.36	4.87	8.73
	Event 2		22,720,000	4.1%	N/A	8.79	3.47	5.97
	Event 3		231,000	0.3%	N/A	4.76	1.87	1.82
	Event 4		1,701,000	0.8%	N/A	5.03	1.98	2.84
3	Event 1	1.34	9,218,000	2.6%	5,300	5.23	3.89	3.50
	Event 2		10,388,000	4.4%	8,800	4.43	3.30	2.91
	Event 3		212,000	0.6%	1,100	2.37	1.76	0.83
	Event 4		655,000	0.7%	1,500	2.49	1.85	1.38

Site	Storm Event No.	ADWF (MGD)	Infiltration Indicators			Inflow Indicators		
			Total I/I (Millions of Gallons)	R-Value (%)	I/I per IDM	Peak Flow (MGD)	Peaking Factor	Peak I/I (MGD)
4a	Event 1	0.59	2,452,000	1.6%	3,000	1.89	3.19	1.11
	Event 2		2,224,000	2.2%	4,100	1.60	2.71	0.94
	Event 3		36,000	0.2%	400	0.99	1.68	0.33
	Event 4		297,000	0.8%	1,500	1.03	1.75	0.46
4b	Event 1	0.36	2,466,000	2.3%	4,200	1.51	4.17	1.16
	Event 2		2,306,000	3.2%	5,800	1.34	3.70	0.93
	Event 3		61,000	0.5%	900	0.74	2.03	0.31
	Event 4		205,000	0.8%	1,400	0.70	1.93	0.39
5	Event 1	0.26	2,609,000	3.1%	6,200	1.55	5.91	1.18
	Event 2		2,046,000	3.6%	7,300	1.21	4.61	0.91
	Event 3		33,000	0.3%	700	0.50	1.91	0.20
	Event 4		147,000	0.7%	1,400	0.56	2.14	0.36
6	Event 1	0.17	2,244,000	4.1%	11,500	1.01	6.09	0.86
	Event 2		2,094,000	5.7%	16,000	0.66	3.97	0.53
	Event 3		30,000	0.5%	1,400	0.40	2.40	0.22
	Event 4		149,000	1.1%	3,100	0.58	3.45	0.39
7	Event 1	0.63	7,756,000	4.6%	10,800	3.46	5.47	2.84
	Event 2		6,345,000	5.7%	13,300	2.62	4.14	2.09
	Event 3		102,000	0.6%	1,500	1.19	1.88	0.45
	Event 4		330,000	0.7%	1,700	1.11	1.76	0.67
8	Event 1	0.10	678,000	0.9%	4,100	0.72	7.07	0.66
	Event 2		520,000	1.1%	5,000	0.31	3.00	0.20
	Event 3		14,000	0.2%	1,000	0.27	2.67	0.17
	Event 4		62,000	0.3%	1,200	0.31	3.08	0.20
9	Event 1	0.33	3,384,000	9.5%	17,800	1.48	4.54	1.19
	Event 2		4,104,000	17.2%	32,200	1.32	4.05	1.02
	Event 3		34,000	0.9%	1,700	0.66	2.01	0.33
	Event 4		377,000	4.1%	7,700	0.79	2.43	0.54
C1	Event 1	0.06	133,000	1.8%	9,500	0.13	2.32	0.06
	Event 2		98,000	1.9%	10,400	0.15	2.66	0.09
	Event 3		2,000	0.2%	1,200	0.12	2.05	0.04
	Event 4		12,000	0.6%	3,300	0.13	2.25	0.08
C2	Event 1	0.013	285,000	6.0%	14,200	0.27	20.99	0.26
	Event 2		192,000	6.0%	14,200	0.19	14.47	0.18
	Event 3		7,000	1.3%	3,100	0.09	6.64	0.07
	Event 4		37,000	3.1%	7,300	0.17	13.16	0.16

Figure 17 summarizes the infiltration and inflow indicators graphically. These graphs were generated using Storm Event 2 values.

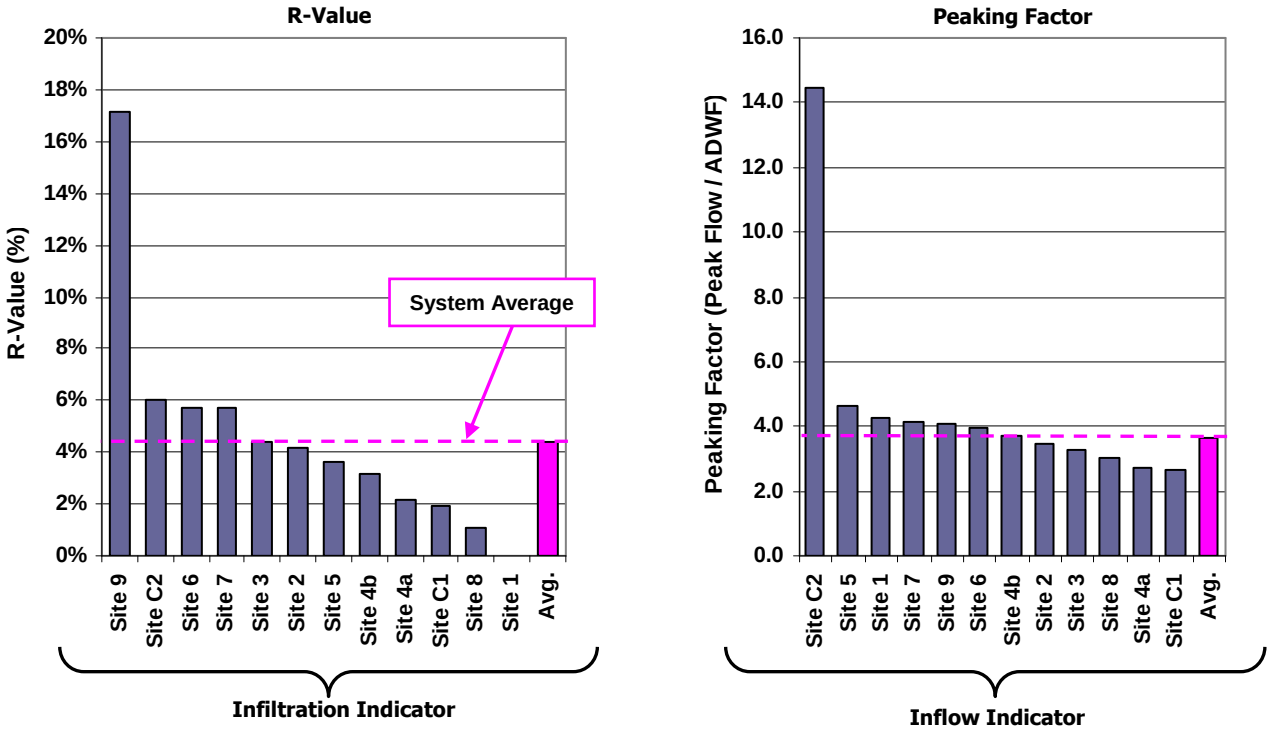

Figure 17. Bar Graphs of I/I Indicators by Site

The following I/I analysis results are noted:

- **Infiltration**
  - The system average R-Value was approximately 4.4%. This is less than the threshold value of 5%.
  - Site 9 had R-Values significantly higher than the other monitoring sites at approximately 17%. Sites C2, 6 and 7 exceeded R-Value threshold values of 5%.
- **Inflow**
  - The system average for Peaking Factor was approximately 3.6. This exceeds the threshold value of 3.0.
  - Site C2 had peaking factors significantly higher than the other monitoring sites. Sites 5, 1, 7, 9 and 6 had peaking factors that were greater than average within this collection system.

Pipeline Capacity Analysis

The d/D ratio is the peak measured depth of flow divided by the pipe diameter. A d/D ratio less than 0.75 is a common threshold value used for pipe design. Table 9 summarizes the peak recorded d/D ratios per site over the flow monitoring period.

Table 9. d/D Ratio per Site

Monitoring Site	d/D Ratio	Comments
Site 1	0.11	Capacity did not exceed threshold limits.
Site 2	**1.23**	Exceeded 0.75 threshold. Surcharged 8.4 inches above crown. Close to treatment facility -- possibly caused by treatment plant operations.
Site 3	**0.80**	Exceeded 0.75 threshold but did not surcharge.
Site 4a	0.41	Capacity did not exceed threshold limits.
Site 4b	0.46	Capacity did not exceed threshold limits.
Site 5	0.51	Capacity did not exceed threshold limits.
Site 6	0.35	Capacity did not exceed threshold limits.
Site 7	0.46	Capacity did not exceed threshold limits.
Site 8	0.44	Capacity did not exceed threshold limits.
Site 9	**1.28**	Exceeded 0.75 threshold. Surcharged 2.8 inches above crown.
Site C1	0.62	Capacity did not exceed threshold limits.
Site C2	0.29	Capacity did not exceed threshold limits.

The following pipe capacity analysis results are noted:

- **Pipe Capacity:** Site 9 exceeded the 0.75 threshold and surcharged 2.8 inches above the crown. Sites 2 and 3 exceeded threshold limits; this may have been caused by a backflow hydraulic event purposely caused at the treatment facility.

RECOMMENDATIONS

V&A advises that future I/I reduction plans consider the following recommendations:

1. **Determine I/I Reduction Program:** The District should examine its I/I reduction needs to determine a future I/I reduction program.
    a. If peak flows, sanitary sewer overflows, and pipeline capacity issues are of greater concern, then the program may be weighted to investigate and reduce sources of inflow within the sites with the greatest inflow problems.
    b. If total infiltration and general pipeline deterioration is of greater concern, then the program may be weighted to investigate and reduce sources of infiltration within the sites with the greatest infiltration problems.
    c. Sites to be investigated as a part of the I/I reduction program can be prioritized per the results illustrated in Figure 16.
2. **I/I Reduction Methods:** Potential I/I reduction methods include the following:
    a. smoke testing
    b. mini-basin flow monitoring
    c. night-time reconnaissance work to (1) investigate and determine direct point sources of inflow, and (2) determine the areas and/or pipe reaches responsible for high levels of infiltration contribution.
    d. CCTV inspection. Future CCTV inspection as used for condition assessment of the collection system should be prioritized to inspect the pipes within the sites per the results illustrated in Figures 16.
3. **I/I Reduction Cost Effective Analysis:** The District should conduct a study to determine which is more cost-effective: (1) locating the sources of infiltration and inflow and systematically rehabilitating or replacing the faulty pipelines; or (2) continued treatment of the additional storm water I/I flow.