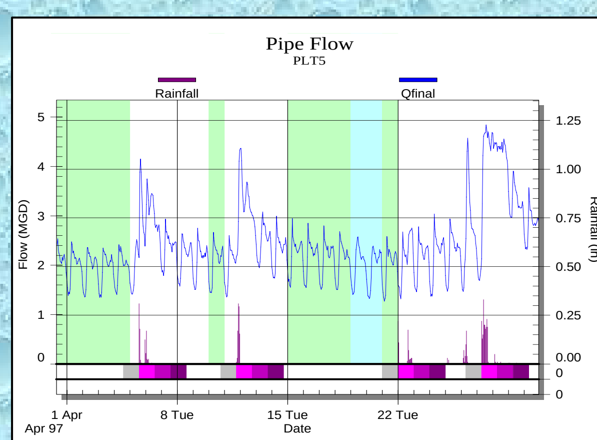
Regional Infiltration/Inflow (I/I) Control Program
King County, Washington

2000/2001
Wet Weather Flow Monitoring

KING COUNTY



May, 2001

King County Regional Infiltration/Inflow Control Program
Wet Weather Technical Memorandum
2000/2001 Monitoring Period

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ACKNOWLEDGEMENTS

The Wet Weather Technical Memorandum was prepared by the Earth Tech Team (ETT) under the direction of Program Manager Marcos Lopez and lead author Pat Stevens (ADS Environmental Services (ADS)), for the King County Regional I/I Control Program as part of King County Contract No. 93051E. King County I/I Program Manager is Gunars Sreibers. The Technical Memorandum presents the results from the 2000/2001 wet season flow metering program as part of the Regional effort to identify and quantify infiltration and inflow in Local Agency sewer systems.

Primary ETT authors of this document were Pat Stevens and Gillian Woodward of ADS. Marcos Lopez, Eric Bergstrom, Ed Pier and Frank Willmann of ETT provided QA/QC Review.

King County Regional Infiltration/Inflow Program
Wet Weather Technical Memorandum
2000/2001 Monitoring Period

A. Executive Summary

1. Background

The King County Wastewater Treatment Division operates the collection trunk sewers and two wastewater treatment plants in King County to collect and treat wastewater from 34 Local Agencies in King and Snohomish Counties. The total length of all Local Agency separated sewers in the King County service area is approximately 17.5 million feet. This total does not include the combined sewer system in Seattle. Historically, the system experiences significant infiltration and inflow (I/I) during the wet season from October to March. King County has initiated a multi-year effort to:

1) Determine the wet weather performance and geographic distribution of I/I throughout the Local Agencies tributary to the King County collection system;
2) Conduct several pilot rehabilitation projects to evaluate rehabilitation effectiveness within the Local Agency sewer system;
3) Develop and calibrate an accurate hydraulic model of the system and
4) Prepare an implementable King County Regional I/I Control Program (Program).

This Technical Memorandum addresses the wet weather performance of the Local Agency separated sewer system. Wet weather performance in this document means the establishment of a rainfall-to-I/I relationship for each Mini Basin component of a Local Agency system and benchmarking that Mini Basin against the I/I standard established in the King County Code of 1,100 Gallons per Acre per Day (GPD/Acre) for a 30 minute peak.

2. Methodology

To assure that wet weather performance of all Agencies are measured equitably, it was determined that the entire system would be subdivided into Mini Basins containing approximately 20,000 Linear Feet (LF) and that the Mini Basin monitoring in all Agencies would occur simultaneously. A total of 807 flow meters were in simultaneous operation from November 1, 2000 to January 15, 2001, a period of 76 days. In addition, 146 of the meters were used as model calibration points and 75 of the meters were permanently installed for long-term trend analysis. Rainfall data were developed using CALAMAR radar rainfall technology and a network of 72 calibrating rain gauges.

The initial flow metering objectives were:

- Track long term trends on large long term basins;
- Divide the entire system of local lines connecting to King County sewers into uniformly sized Mini Basins that average 20,000 linear feet in size;
- Isolate flows crossing agency boundaries provided the flow is from basins comprised of 10 manholes or more and
- Measure at least 95% of each Local Agency's sewers with a Mini Basin meter. Local sewers not metered with a temporary meter will be considered part of the King County sewer.

3. Results

a) Rainfall

The two-month period of November and December was the second driest on record since 1945. At the Sea-Tac airport there were only 5.77 inches for the two months compared to the normal 11.74 inches. An I/I analysis can be conducted when an observable system-wide response occurs in the sewer network. Four rain events resulted in observable, but minor sewer responses in the network. An I/I analysis was conducted for those four rain events. The range of rainfall over the entire service area for the four events is listed in Table A1.

Table A1
Range of Rainfall for Four Events over Service Area

Date of Rain Event	Rainfall (Inches)	Rainfall Event Frequency *
November 7, 2000	0.7 – 1.3	< 2 year
November 26, 2000	0.8 – 1.4	< 2 year
December 16, 2000	0.2 – 0.8	< 2 year
January 4, 2001	0.4 - 0.9	< 2 year

* Source Seattle Intensity-Duration-Frequency Curve 1903 - 1951

b) I/I Measurements

The magnitude of I/I measured was lower than experienced in normal years, because the widely spaced rains provided sufficient time for the system recover between rains and the low accumulation of rain did not provide the opportunity for the soil to become saturated. As a result of the low rainfall some Program objectives were fulfilled and others were not.

The Program was successful in completing a total of 95.7% of possible I/I measurements for all the Mini Basins and all the rain events. The flow meters experienced an overall uptime of 96%. The Program was successful in identifying a wide range of geographically-distributed Mini Basins that exhibited levels of I/I exceeding the King County design standard for “Excessive” I/I of 1,100 Gallons per Acre per Day for a 30-minute peak. Table A2 lists the total number of Mini Basins in each Local Agency and the number that exceeded the standard for at least one rain event. System-wide, 51% of the 730 Mini Basins in the Local Agencies exceeded this value. The Program objectives that could not be achieved were:

- Wet weather calibration of the hydraulic model, which requires several more intense rain events;
- Selection of pilot rehabilitation Mini Basins that depends on representative rainfall on saturated soils and high ground water and
- Establishment of a representative relationship between rainfall and RDII for each Mini Basin.

Table A2
Total Number of Mini Basins in Each Local Agency
and Number Exceeding 1,100 GPD/Acre for at Least One Rain Event

Local Agency	Total	Excessive	Local Agency	Total	Excessive	Local Agency	Total	Excessive
ALDERWOOD SD	38	10	HIGHLANDS SD	1	1	SAMMAMISH STATE PARK	1	1
ALGONA SA	3	3	ISSAQUAH SA	13	9	SAMMAMISH PLATEAU SD	22	7
AUBURN SA	30	10	KENT SA	41	33	SEATTLE SA	63	54
BELLEVUE SA	112	60	KIRKLAND SA	27	19	SHORELINE WMD (RONALD)	26	12
BLACK DIAMOND SA	4	0	LAKE FOREST PARK SA	2	2	SHOREWOOD APARTMENTS	1	1
BOTHELL SA	15	6	LAKEHAVEN UD	1	0	SILVER LAKE SD	4	0
BRIER SA	6	1	MERCER ISLAND SA	24	14	SOOS CREEK WSD	60	13
BRYN MAWR-LAKE RIDGE WSD	14	13	NE SAMMAMISH SWD	16	3	TUKWILA SA	6	4
CEDAR RIVER WSD	9	4	NORTHSHORE UD	49	17	VAL VUE SD	23	14
COAL CREEK UD	13	4	PACIFIC SA	5	2	WOODINVILLE WD	10	2
CROSS VALLEY WD	2	0	REDMOND SA	35	19	WOODWAY SA	1	0
EDMONDS SA	2	2	RENTON SA	51	29			

B. Overview of This Technical Memorandum

This Technical Memorandum is organized in two parts. The body provides background information to explain how the data were collected, how the analyses were conducted and how to interpret the results. The results and other information on each Mini Basin and metering site are contained in four appendices.

There were two separate analyses conducted on the flow metering data to achieve two different objectives. One analysis evaluated each Mini Basin in the context of King County code that establishes a design standard for local sewers. The standard specifies that any flow other than wastewater exceeding 1,100 Gallons per Acre per Day, for any 30-minute period, will be called "excess flow". Flow other than wastewater is called Total I/I in this memorandum. Total I/I is measured as a 30-minute peak flow rate and calculations are made on a 30-minute basis.

The second analysis evaluated each Mini Basin on the basis of its Rainfall Dependent I/I (RDII). The objective in using RDII is to establish a ratio of rainfall (i) to I/I (Q) that is unique to each Mini Basin. The ratio or relationship before rehabilitation is compared to the relationship after rehabilitation to quantify the improvement from rehabilitation. RDII is measured as a 24-hour volume of I/I corresponding to a discrete rainfall event and calculations are made on an hourly basis.

There are differences in the analysis procedures for these two evaluations and they produce differences in results. Those differences are described in Section 2.

Four Appendices are attached and their contents are described at the end of this document in Section H. Appendix A is a Total I/I analysis of Mini Basins in context of the King County local sewer design standard in terms of Gallons per Acre per Day for a 30-minute peak period. Appendix B is an analysis of Mini Basins in terms of RDII over a 24-hour period. These data are normalized by the length of sewer in feet and area in acres for each Mini Basin. Appendix C provides hydraulic information for each Metering Site. Appendix D contains maps and other supporting documents. Appendices A, B and C consist of Excel spreadsheets in both hard copy and digital format on CD.

C. Mini Basin and Metering Information

1. Mini Basin Nomenclature

A Mini Basin acquires its name from the meter measuring its flow. Mini Basins are formed by two types of meters with two naming conventions; one for Long Term Meters (LTM) and a second for Temporary Meters (TMP).

LTM - *LTM names are up to 8 characters in length with up to the first 5 characters representing the name of the King County trunk line in which the meter is installed. Some names are less than 5 characters in length. Up to 3 characters represent the number of the actual manhole containing the meter. For example:*

"BOECR002" = LTM installed on the Boeing Creek Trunk in manhole 002.

TMP - *TMP names are 6 characters in length with the first 3 characters representing the name of the Agency in which the meter is installed. The second 3 characters are sequential numbers representing the number of meters in the agency. Note that there are missing numbers in a few cases. For example:*

"AUB014" = Fourteenth TMP installed in Auburn

Table C1 lists the Agencies and the abbreviations used for naming TMP meters.

There were a total of 807 flow meters in operation and there were 806 Mini Basins. The difference is due to Mini Basin RNT030 in Renton, which has two outlets. Two flow meters RNT030A and RNT030B were combined to generate the Gross flow for Mini Basin RNT030.

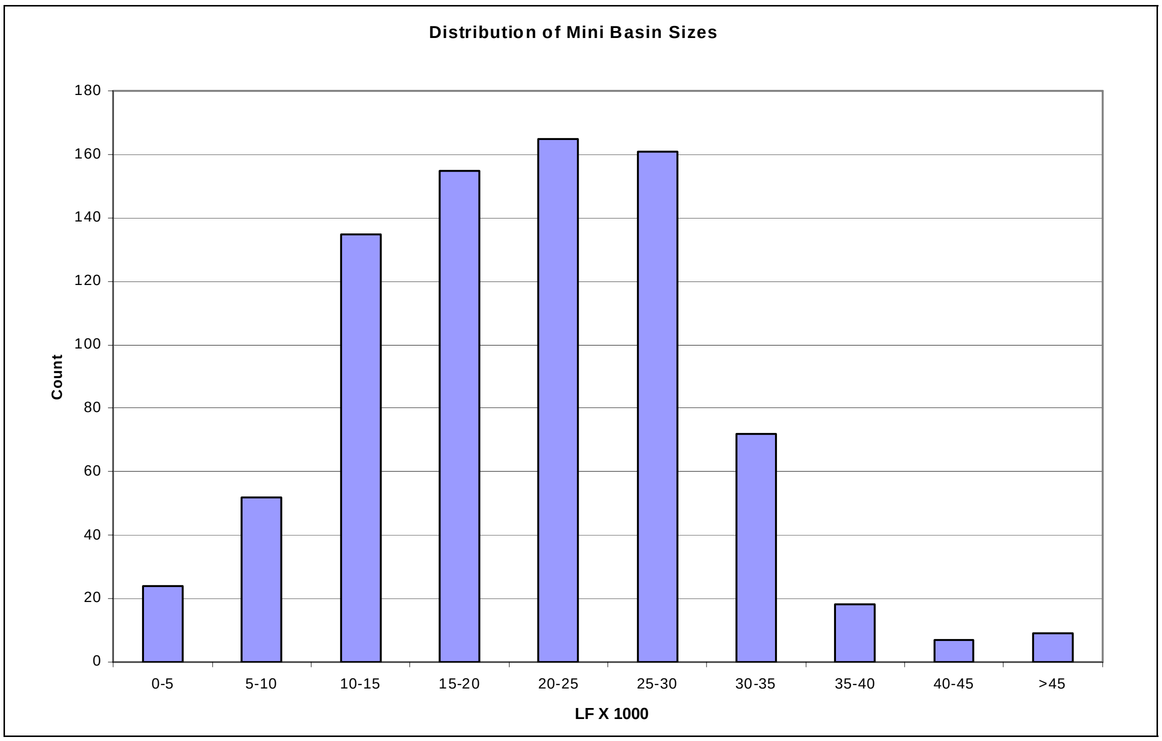
Table C1
Agency Abbreviated Names

ALDERWOOD SD	**ALD**	LAKEHAVEN UD	**LKH**
ALGONA SA	**ALG**	MERCER ISLAND SA	**MRC**
AUBURN SA	**ABN**	NE SAMMAMISH SWD	**NES**
BELLEVUE SA	**BEL**	NORTHSHORE UD	**NUD**
BLACK DIAMOND SA	**BLA**	PACIFIC SA	**PAC**
BOTHELL SA	**BOT**	REDMOND SA	**RDM**
BRIER SA	**BRR**	RENTON SA	**RNT**
BRYN MAWR-LAKE RIDGE WSD	**BLS**	SAMMAMISH STATE PARK	**SPK**
CEDAR RIVER WSD	**CDR**	SAMMAMISH PLATEAU SD	**SAM**
COAL CREEK UD	**CCR**	SEATTLE SA	**SEA**
CROSS VALLEY WD	**CRV**	SHORELINE WMD (RONALD)	**SHR**
EDMONDS SA	**EDM**	SHOREWOOD APARTMENTS	**SHD**
HIGHLANDS SD	**HLD**	SILVER LAKE SD	**SLV**
ISSAQUAH SA	**ISS**	SOOS CREEK WSD	**SOO**
KENT SA	**KNT**	TUKWILA SA	**TUK**
KIRKLAND SA	**KRK**	VAL VUE SD	**VAL**
LAKE FOREST PARK SA	**LFP**	WOODINVILLE WD	**WDN**
		WOODWAY SA	**WDY**

2. Mini Basin Size Distribution

It was determined that average Mini Basin size would need to be approximately 22,000 LF and that a maximum size should be approximately 32,000 LF. Smaller Mini Basins were created as meters were added to achieve 95% measurement of each Local Agency's system. Sewer networks seldom offer the opportunity for precisely breaking them into uniform basins. For example a 40,000 LF basin may be subdivided into only Mini Basins of 28,000 LF and 12,000 LF. Implementing this strategy resulted in the Mini Basin size distribution shown in Figure C1.

Figure C1
Distribution of Mini Basin Sizes (x 1,000 LF)



Larger Mini Basins are from two sources. One is a group of Mini Basins formed by long-term meters after the contributing local lines have been isolated with temporary Mini Basin meters. These Mini Basins consist of mostly King County Trunk Lines and, as discussed in Section F, I/I calculations have not been performed for these basins. The second source is from meters placed on lines entering the study area to isolate them for modeling purposes. For example a large area of Seattle's combined sewer enters the separated system through the Allentown Trunk. A meter was placed there to isolate combined sewer flows from separated sewer flows. Also two large basins in Edmonds are measured as they cross the County line into the Lake Ballinger Pump station as part of a wastewater swapping program with Edmonds.

3. Mini Basin Size in Linear Feet of Sewer and Acres

Mini Basin size information in Linear Feet (LF) and Acres was obtained through King County's Geographic Information System (GIS) and current sewer system data collected from the Local Agencies. Mini Basin boundaries were digitized around the basin defined by each meter and the resulting shape is a polygon. The GIS generated both the length of sewer within the polygon and the area of the polygon. Sewer length includes both the Local Agency lines and any King County lines within the Mini Basin. A few Mini Basins formed by LTMs consist almost exclusively of King County Trunk Lines and contribute little or no wastewater. Many of these non-contributing Mini Basins are large and contain more than the upper Mini Basin size limit of 35,000 LF of sewer. As discussed in Section F, these basins were not established for evaluation of Local Agency system I/I and are noted in Appendix A and Appendix B. (n/a* appears in the I/I results columns for these Mini Basins).

Local Agency lines labeled as force mains were excluded from the inventory of sewer lines in Mini Basins, but data from some Agencies do not distinguish between gravity lines and force mains. In those cases, the length of sewer in a basin includes both types of lines. In several cases the actual length of pipe in a basin was unknown and has been estimated. For example, a few Local Agencies had not provided digital information for all or a portion of the system in time for this work and lengths were estimated from hard copy maps. To make estimated numbers recognizable, they are given to only the nearest thousand feet, e.g. Mini Basin ALD021 was not completely digitized and the total length of sewer is listed at 30,000 LF.

Basin acreage is based on Mini Basin polygons and is calculated utilizing the County's GIS. Mini Basin boundaries were established on the GIS by using sewer line and street centerline mapping for guidance. Aerial photos were occasionally used to verify land use in unclear situations; but as a general rule any land within the interior of a logical sewer basin was included in the Mini Basin's acreage. For example the acreage of a Mini Basin with a school and soccer field in its interior will include the soccer field acreage. Conversely, if a school is located at the outer edge of a Mini Basin, the Mini Basin boundary may have excluded the soccer field. The same general rule applies to small parks or any type of undeveloped land within Mini Basins. The reader should be aware of this methodology in developing Mini Basin acreage when attempting to compare Mini Basins on a gallons per acre basis for either a 24-hour period or a 30-minute period.

4. Metering Sites

a) Types of Metering

Metering for the 806 Mini Basins was accomplished with three types of metering techniques listed in Table C2. Open channel area-velocity meters function by measuring the depth (cross sectional area) and the velocity of wastewater to calculate the rate of flow. Fill and draw measurements are performed at pump station wet wells through the timing of the fill and draw cycles. No sensors are placed in the flow with pump station metering technology. The Time-of-Travel meter is an existing meter operated by the Sammamish Plateau District at its connection to the Issaquah Trunk Line. Time-of-Travel technology functions by measuring the time required for an acoustic signal to travel across the flow at an angle. Velocity of the flow is calculated by comparing the upstream travel time to the downstream travel time. This is similar to timing a canoe crossing a river at an angle. It takes longer to paddle upstream than the return trip downstream.

Table C2
Types of Metering Technologies Used

Meter Types	
Open Channel Area-Velocity	
LTM	75
TMP	723
Fill & Draw	8
LTM Time-of-Travel	1
Total	**807**

b) Distribution of Pipe Diameters

Meters are installed on the incoming line to a manhole as shown in Figure C2.

Figure C2
Installation of Open Channel Area-Velocity Metering Equipment

Most of the metering occurred in small to medium-sized pipes within Local Agencies. Table C3 provides the distribution of pipe diameter at all the metering sites. The pump station meters are included in the category of 8-inch pipe. Over 69% of the meters were in pipes 15 inches and smaller. The 76 long-term meters (LTM) are measuring key nodes on large basins and consequently are located in larger pipes. Only 7 LTMs are in pipes 15 inches and smaller.

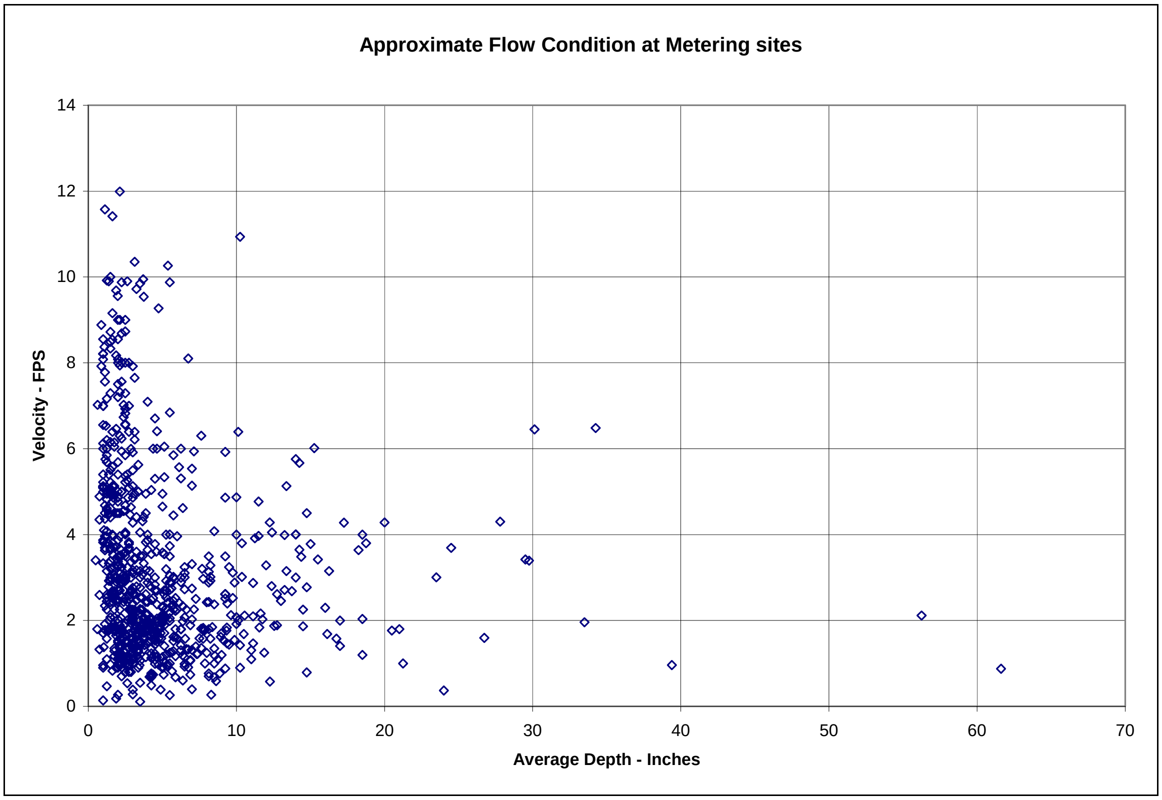
Table C3
Distribution of Metering Sites by Diameter

Diameter (In.)	Count	Percent	Cumulative %
8	200	24.8%	24.8%
10	120	14.9%	39.7%
12	142	17.6%	57.2%
14	5	0.6%	57.9%
15	93	11.5%	69.4%
18	88	10.9%	80.3%
21	33	4.1%	84.4%
24	45	5.6%	90.0%
27	11	1.4%	91.3%
30	15	1.9%	93.2%
36	19	2.4%	95.5%
42	10	1.2%	96.8%
44	1	0.1%	96.9%
48	6	0.7%	97.6%
50	1	0.1%	97.8%
52	1	0.1%	97.9%
54	1	0.1%	98.0%
60	3	0.4%	98.4%
72	8	1.0%	99.4%
84	2	0.2%	99.6%
90	1	0.1%	99.8%
108	2	0.2%	100.0%
Total	**807**	**100.0%**	

c) Depth and Velocity Range

The steep terrain over much of the service area resulted in many metering sites with flow that is both shallow and fast. Sixty-nine percent of the sites operated with less than 5 inches of flow and of these sites 43% operated with less than 3 inches of flow. Figure C3 illustrates the operating range of each of the 798 open channel metering sites based on estimates of average depth and average velocity. The very shallow and fast flow conditions sometimes result in non-laminar flow past the sensors that can cause intermittent data. Non-laminar flow is turbulent flow similar to white-water rapids in a river.

Figure C3
Approximate Flow Conditions at Metering Sites



d) Hydraulic Operating Conditions

The hydraulic operation conditions for each metering site were evaluated and sites with unusual conditions are noted in Appendix C. Table C4 is a sample of the full table. Conditions noted are:

1. Pipe diameter;
2. If the sewer operates in backwater;
3. If the sewer ever was completely full;
4. If there was a shift in conditions;
5. If the flow was influenced by pump station cycles;
6. If silt was present and
7. If a link exists to a scattergraph of the data.

Table C4
Sample Table of the Hydraulic Operating Conditions for Metering Sites – Appendix C

Site Name	Pipe Diameter	Site has operated in a backwater condition at least once during the monitoring period	Site has reached full pipe at least once during the monitoring period	Hydraulic Shift (s)	Apparent Pump Station Influence	Silt	Links to Selected Scattergraphs Illustrating Indicated Hydraulic Conditions	Additional comments
ABN001	12							
ABN002	10			X	X			
ABN003	12							
ABN004	10							
ABN005	12			X				
ABN006	10							
ABN007	18	X					**X**	
ABN008	15							
ABN009	18				X	X	**X**	
ABN010	10							

D. Infiltration/Inflow and RDII

1. Definitions - I/I and RDII

All I/I indicators are expressed as “Gallons” and there are two fundamental measurements for these “Gallons”: Infiltration/Inflow (I/I) and Rainfall Dependent Infiltration/Inflow (RDII). The two measurements are designed for different purposes and are discussed in this section. The King County Regional Infiltration/Inflow Program uses both measurements.

a) Infiltration and Inflow

The definition of I/I from **The Joint WEF Manual Of Practice FD2 – ASCE Manual and Report On Engineering Practice No. 62** is:

> *Infiltration is water that enters a sewer system from the ground through defective pipes, pipe joints, damaged lateral connections or manhole walls. Inflow is extraneous storm water that enters a sanitary sewer system through roof leaders, cleanouts, foundation drains sump pumps and cellar, yard and area drains.*

This traditional definition of separate infiltration and inflow components associates the source of I/I with the elapsed time when extraneous flow appears in a hydrograph. For example, it is normally assumed that any extraneous flow that remains 24 hours after the end of a rain is all infiltration from below ground defects and that a sewer responding quickly suffers from surface defects. This simplistic association of a defect with the elapsed time when extraneous flow appears in a hydrograph can be misleading. For example, because ground water and trench water elevations can respond rapidly, especially under wet, antecedent conditions, it is likely that a rapid response from traditional infiltration sources such as a cracked pipe may be incorrectly categorized as inflow.

b) Rainfall Dependent I/I

RDII is a measurement that quantifies I/I due exclusively to a previous discrete rain event. RDII purposefully excludes residual I/I from antecedent rainfall. RDII values from multiple discrete rain events are used to develop a rainfall to RDII relationship for each Mini Basin. The rainfall to RDII relationship is in turn used to quantify the relative performance of a Mini Basin and to quantify the I/I reduction after sewer rehabilitation. Quantifying the improvement in performance of a Mini Basin is complex and is affected by several variables. Variability includes differences in terrain, geology, ground water, method of construction, antecedent rain, season of year, age of sewers and pipe material. The techniques used to measure RDII reduce these variables by measuring the component of I/I due exclusively to a specific rain. Figure D1 shows RDII and other related components.

The objective in using RDII is to establish a ratio of rainfall (i) to I/I (Q) that is unique to each Mini Basin. The ratio or relationship before rehabilitation is compared to the relationship after rehabilitation to quantify the improvement from rehabilitation. That relationship is known as a Q-to-i relationship and is described later in this Section. This relationship is also used by designers for sizing pipes and storage facilities.

RDII measurements are not intended to replace the Total I/I measurements used by modelers and designers. The RDII method removes the variation due to antecedent rainfall, ground water and minor changes in flow pattern. It is not appropriate to directly compare RDII measured from rain events during a dry season to rain events in a wet season since two distinct relationships will exist. When quantifying the improvement in sewer performance, it is important to conduct the measurements during the same hydrological season and similar rainfall pattern.

There are many different performance indicators that are used to measure and rank Mini Basins. The choice of indicator is a function of what data are available and what questions are being answered. Table D1 provides a partial list of 14 common indicators used throughout the U.S. along with the strength and weakness of each indicator.

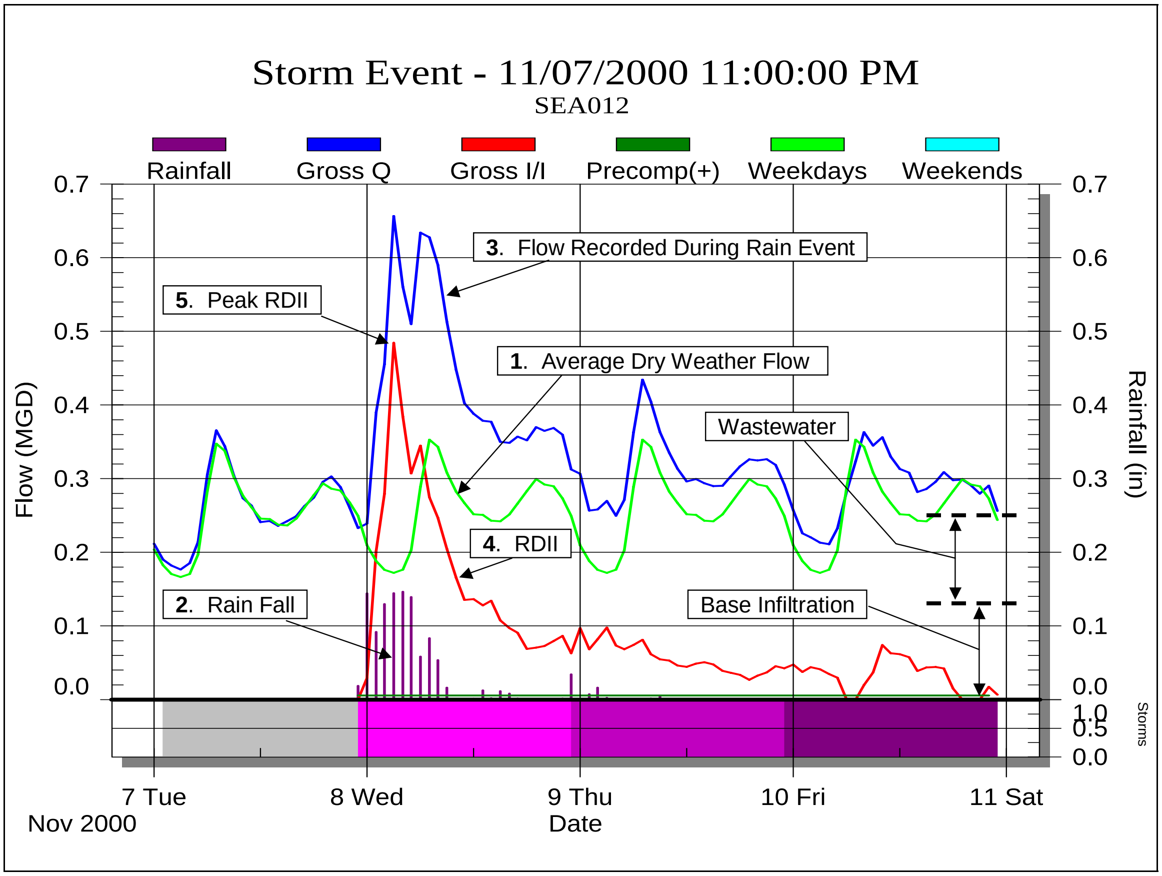
Table D1
RDII Performance Indicators

Wet Weather Performance Indicator	Normalized by Size	Normalized by Rainfall	Comments
Gallons (Volume)	No	No	Strength – Easy to determine Weakness - Not useful for I/I detection or sizing without other data, Ignores Rainfall
Gallon Per Day (1 Hour Peak Rate)	No	No	Strength – Easy to determine Weakness - Not useful for I/I detection or sizing without other data - Ignores Rainfall
GPD/Capita	Yes	No	Strength – Normalizes by population & can compare equal sized basins - Weakness – Ignores Rainfall
Peak Wet Weather to Average Dry Weather Ratio	No	No	Strength –Easy to determine – often "by eye" Weakness -Not useful without rain and basin size
GPD/Linear Feet of Sewer in Basin	Yes	No	Strength - Useful for ranking in equal basin sizes and rains Weakness – Ignores rainfall – Treats large and small diameter pipes equally
GPD/In. Diameter-Mile	Yes	No	Is infiltration/ foot print area. One GPD/in-mile = 440 GPD/ft^2. Originally used as criteria for Construction Grants. Term has similar limitation to above criteria. Strength – Normalizes by area of footprint Weakness – Ignores rainfall
GPD/Acre	**Yes**	**No**	**Strengths- Useful for ranking in equal terrain and equal rainfall** **Weakness – Ignores rainfall and varies with hilly and flat terrain.**
Gallons (vol.)/Inch Rain Usually for first 24 Hr. period	No	Yes	Strength - Useful for equal size basins Weakness - Ignores basin size
GPD (peak hourly rate)/In. per Hr (peak hourly rate)	No	Yes	Often used by modelers and for relief sewer sizing Strength – Accounts for rain Weakness - Ignores basin size.
GPD/Capita-Inch Rain	Yes	Yes	Strength – Accounts for rain and population in basin Weakness – Population and basin size may not correspond
GPD/LF-Inch Rain	**Yes**	**Yes**	**Strength – Accounts for rain and basin size** **Weakness – Treats large and small diameter pipes equally**
GPD/Acre/Inch Rain	Yes	Yes	Strength – Accounts for rain and basin size Weakness – Basins are difficult to define. May not be easy to translate result into design storm
Percent Rain as RDII or Runoff Coefficient - R_{RDII} or I/I coefficient	Yes	Yes	Similar to above, but over entire recovery period. Often used by modelers and for sizing storage facilities. There is no industry-standard name for this parameter
GPD/Acre/Inch of Indexed Rain	Yes	Yes	Uses rainfall from several historical periods – 1 day, 7 day, 30 day, and 180 days. Also called Antecedent Precipitation Index – Only parameter to take antecedent rainfall into account

For the King County Regional Infiltration/Inflow Control Program the performance indicators selected were RDII in GPD/LF/Inch of rain and Total I/I as GPD/Acre. Both are highlighted in yellow and bold font in Table D1. For each rain event, rainfall is measured by CALAMAR and RDII is measured as a 24-hour volume. The Q to I relationship produces the result GPD/LF/In of rain.

The indicator of GPD/Acre was also selected since King County Code establishes an I/I standard as a 30-minute peak of I/I in terms of gallons per day per acre. By calculating I/I on a 30-minute basis, the peak I/I can be determined. Figure D1 illustrates the various I/I components.

Figure D1
RDII and Other Related Components



2. Steps to Calculating I/I and RDII

At its simplest, the calculation of both I/I and RDII is the subtraction of normal dry weather flow from wet weather flow. Most of processes are the identical and are described in the following Sections a) through i). The difference between the two measurements is that RDII does not include either antecedent I/I or base infiltration. The differences are discussed in Section h).

a) Dry Day Selection

The normal dry day flow at each metering site is a fundamental value since it is subtracted from flow for each rain event. Candidate dry days are those days during which the flow is not under the influence of prior rains. For this study candidate dry days were those that met the antecedent (prior) rainfall conditions in Table D2.

Table D2
Test for Dry Days

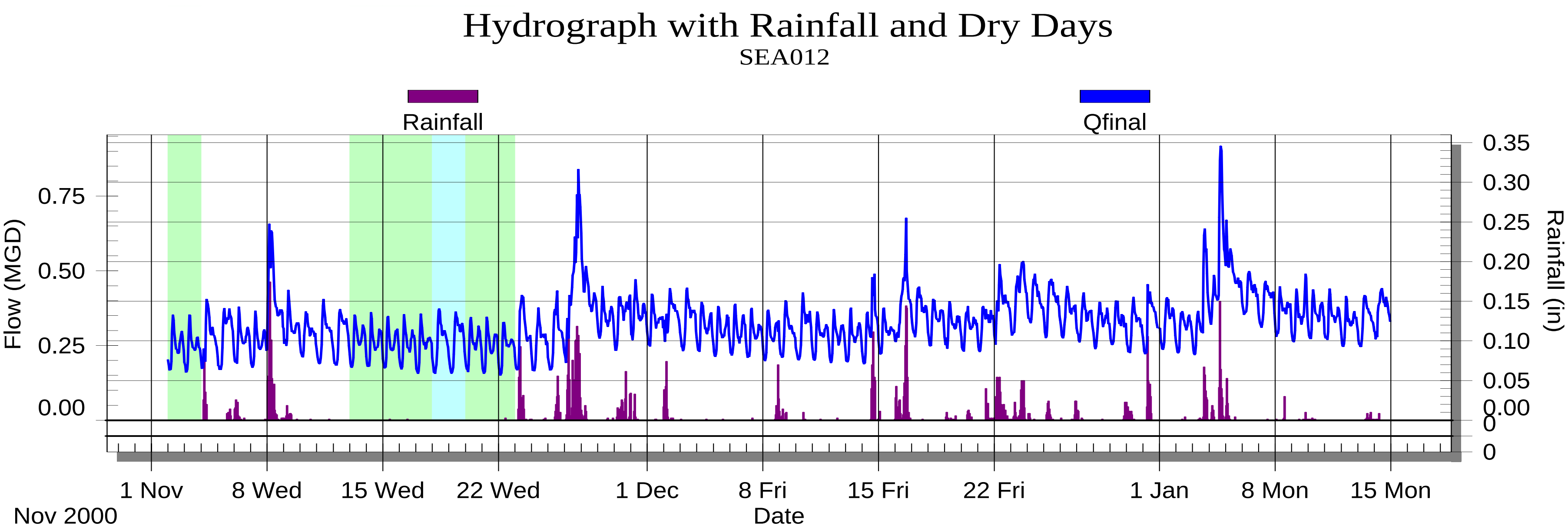
Number of Prior Days	Cumulative Antecedent Rain (Inches)
1	0.1
3	0.4
5	1.0

The group of candidate dry days undergoes further screening to exclude irregular days, and the remaining days are averaged to create the Average Dry Day Flow (ADDF) for each meter. During the flow metering period, the days meeting these criteria generally were in November. Dry Weather data are provided in Appendix B as Average Dry Day Flow (ADDF) in Million Gallons per Day (MGD).

ADDF quantities are given as both Gross and Net quantities. Gross ADDF is the average daily flow measured by a meter during the selected dry days. Net ADDF is the subtraction between the downstream meter and any upstream meters. For Mini Basins with no upstream meters the gross and net flows are the same. The net ADDF is considered a unique attribute of the Mini Basin and consists of all wastewater generated within the Mini Basin plus any base infiltration that exists. For the wet weather analysis, ADDF data has been separated into weekday and weekend quantities. The ADDF data reported in Appendix B are weekday flows.

As an example to show selected dry days, Figure D2 is a hydrograph from Mini Basin SEA012 for the entire 76-day metering period. The selected dry days are shown as colored bands in November. Weekdays are shown in green and the weekends are shown in blue. This Mini Basin is a residential neighborhood located in Seattle in the Thornton Creek area north of NE 95th Street. Mini Basin SEA012 was selected randomly as an example to show how RDII components are generated. The discussion of each RDII step that follows contains an example from Mini Basin SEA012. The discussion on land use includes example from other Mini Basins.

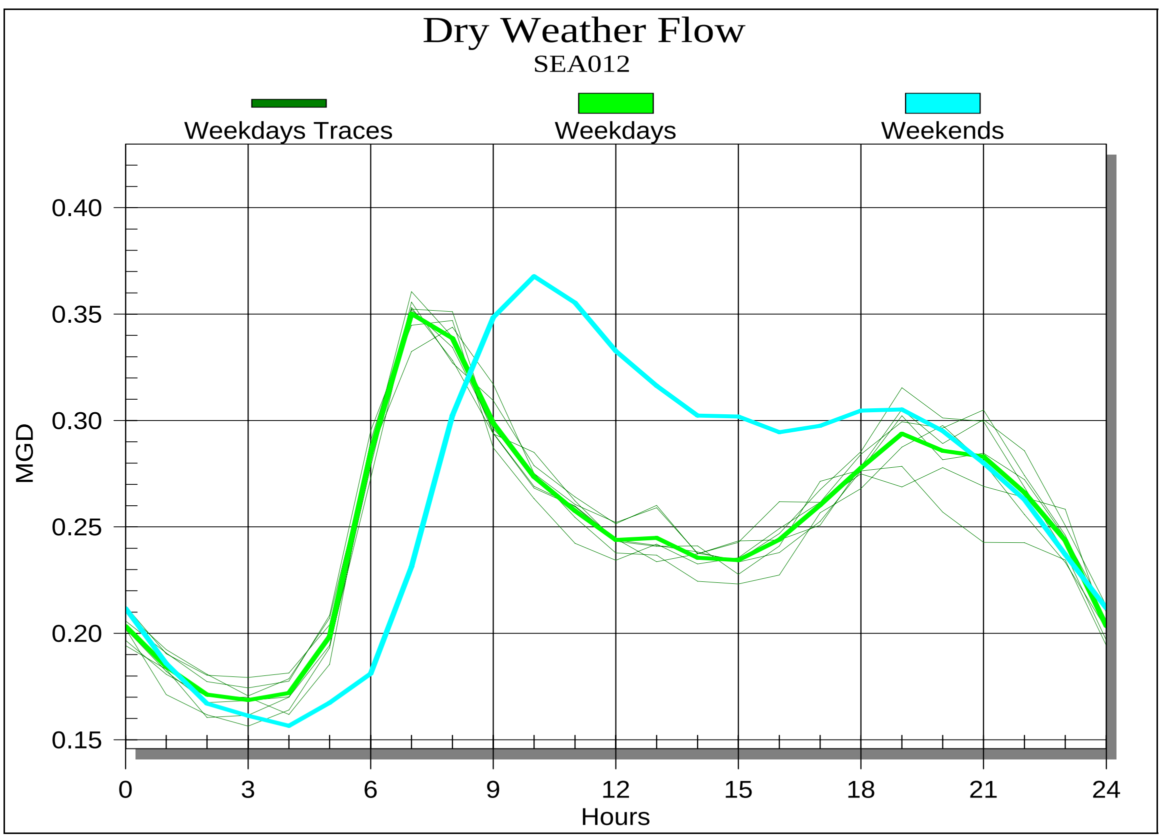
Figure D2
Hydrograph of Mini Basin SEA012 – Selected Dry Days are in Color



b) Dry Day Diurnal Hydrograph

There are two objectives for determining the representative dry day hydrograph for each Mini Basin. One is to establish the daily volume of wastewater generated within the Mini Basin. The second is to establish the shape or timing of the daily flow. This shape is called the diurnal (occurring daily) hydrograph. Selected dry days are grouped into weekday (green) days and weekend (blue) days and are averaged separately. The two diurnal hydrographs for Mini Basin SEA012 are shown in Figure D3. All of the weekday traces that were averaged to form the ADDF green diurnal hydrograph are shown as the group of dark green traces. ADDF volumes for the two day groups are nearly the same with weekdays being 0.254 MG and weekends 0.265 MG. Although the daily volumes for the two day groups are nearly the same there is a significant difference in the shape of the two daily diurnal hydrographs. The peak flow occurs at 7 am on weekdays and 10 am on weekends. The shapes these two diurnal day hydrographs are common to all residential Mini Basins and are the "signature" of residential land use.

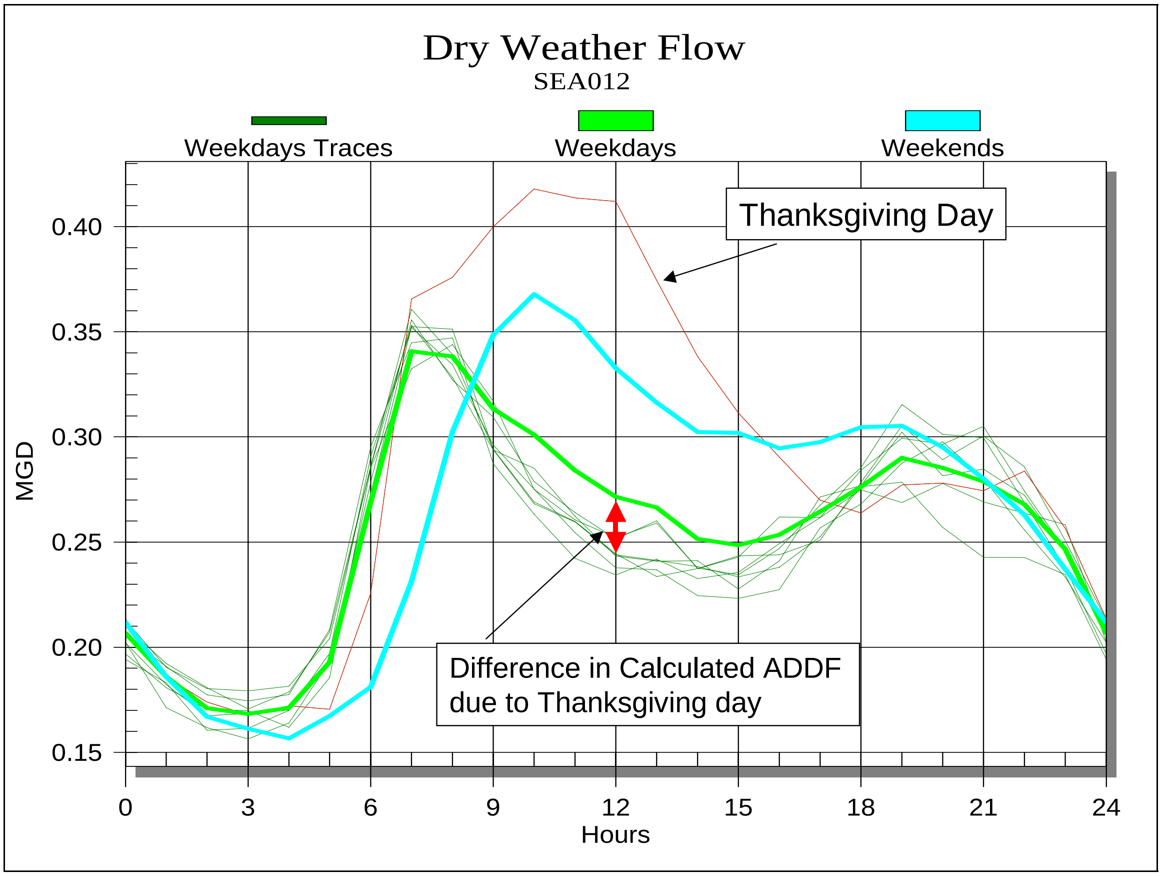
Figure D3
Dry Day Hydrographs for Mini Basin SEA012



c) Screening Candidate Dry Days

Only regular and repeatable dry days are selected for averaging. Displaying the traces from all the candidate dry days causes the unusual days to stand out. Candidate dry days that are unusual and can unduly affect the average flow are excluded from the averaging process. For example, Thanksgiving Day is a candidate dry day for the weekday group and is shown plotted in red in Figure D4. Thanksgiving day increases the ADDF at noon by the amount indicated by the red arrow. The difference is approximately 10% for the calculated noontime flow rate. Because the average can be affected, Thanksgiving and any other unusually shaped days are screened from the averaging process.

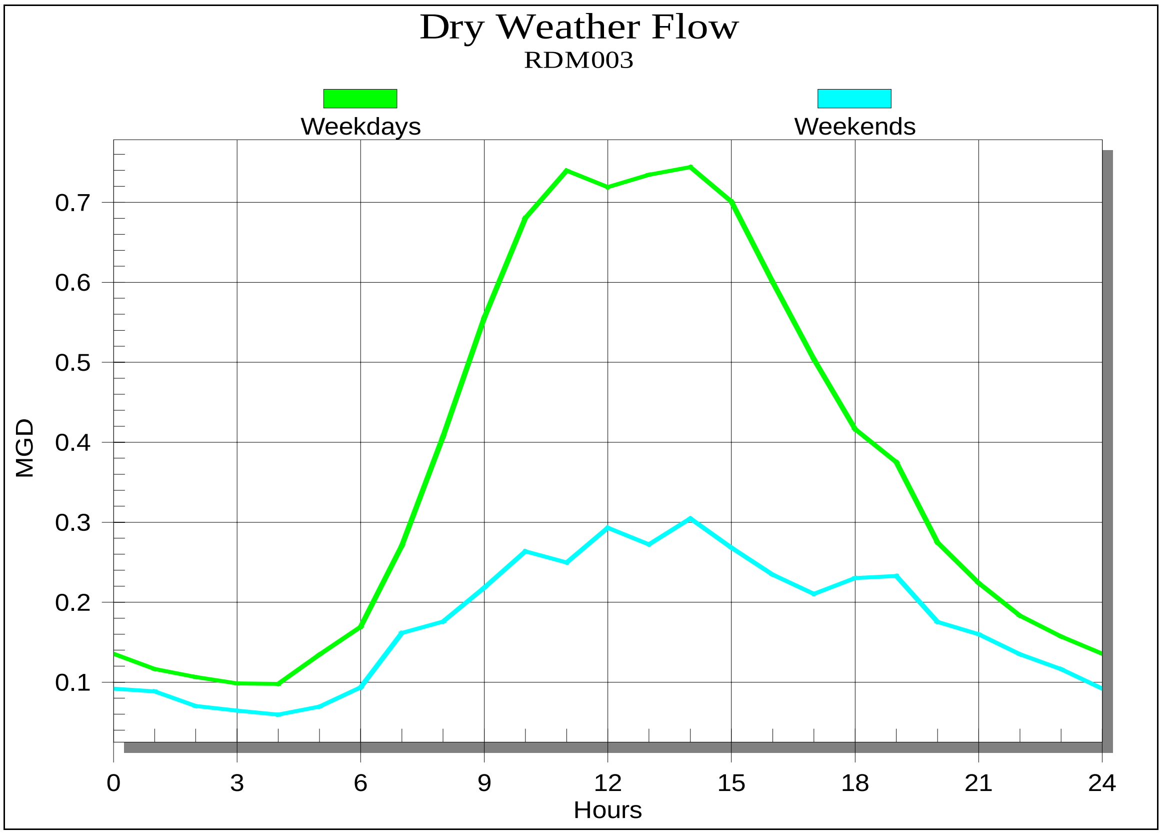
Figure D4
Impact of Unusual Dry Days on Dry Day Average



d) Hydrograph Shape and Land Use

Because there is a significant difference in the diurnal hydrograph based on land use, it is critical that representative diurnal hydrographs be established for every Mini Basin. Residential and commercial land uses are the most dramatic, but every land use has a "signature" hydrograph. Figure D5 is the dry day hydrograph from Mini Basin RDM003, which is located in Redmond and has much of the Microsoft campus within it. The shape is common to office/commercial land use with weekday flow much higher than weekend flow. Retail areas produce similar shapes, but with the weekdays and weekends swapped in magnitude.

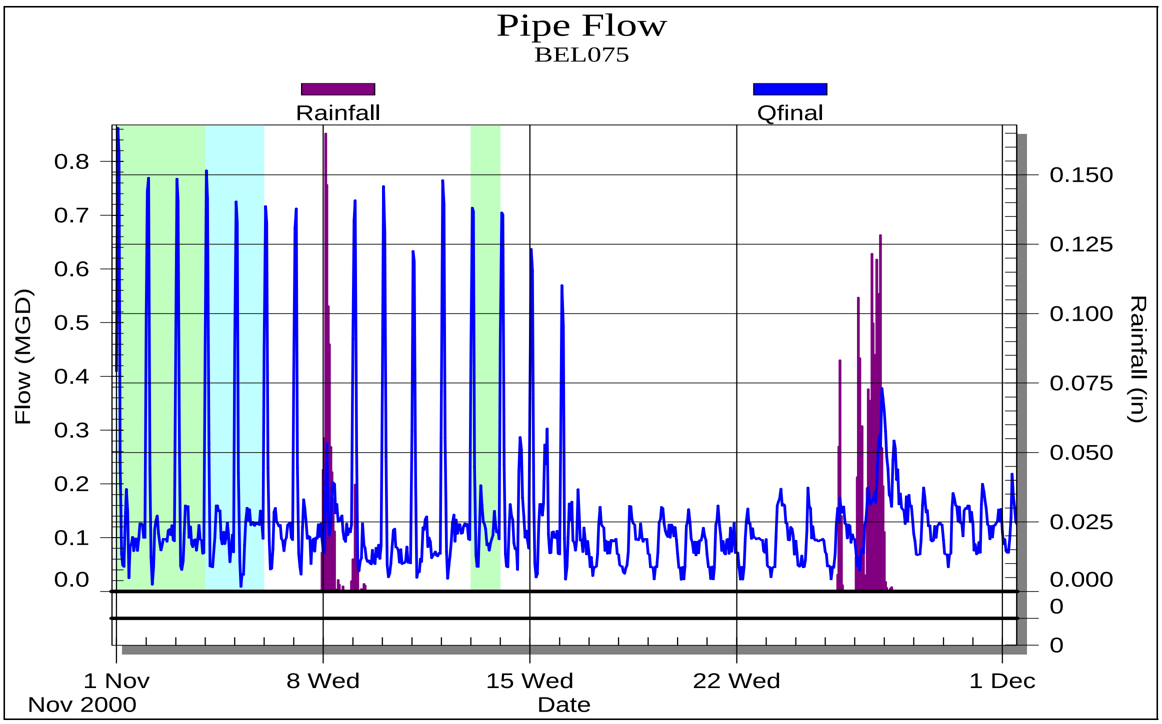
Figure D5
Mini Basin RDM003 Dry Day Hydrograph



e) Irregular Patterns

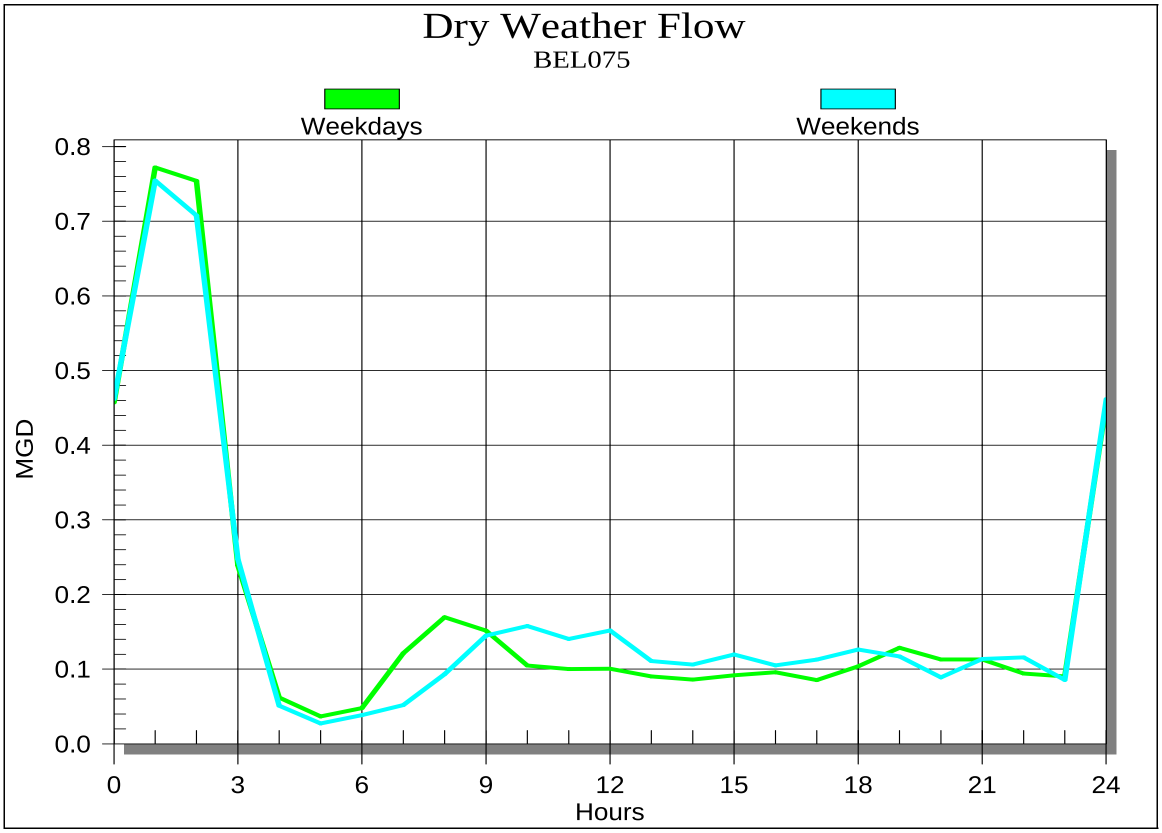
Most land use types produce both repeatable and regular flow patterns, but there are examples of flow patterns being neither repeatable nor regular. Seasonal flushing of lake lines, such as around Lake Washington and Lake Sammamish, is an example of a repeatable, but not a regular pattern. Lake line flushing is automatically controlled by a timer and results in a hydrograph similar to Figure D6 which is from Mini Basin BEL075 on the east shore of Cozy Cove near Yarrow Point. Lake line flushing occurring during the dry season was discontinued after November 16, 2000 and can be seen in this hydrograph of the month of November. The selected dry days are shown with the green and blue highlighting for weekdays and weekend, respectively. The average dry hydrograph for the two day groups are shown in Figure D7.

Figure D6
Lake Line Flushing in Mini Basin BEL075



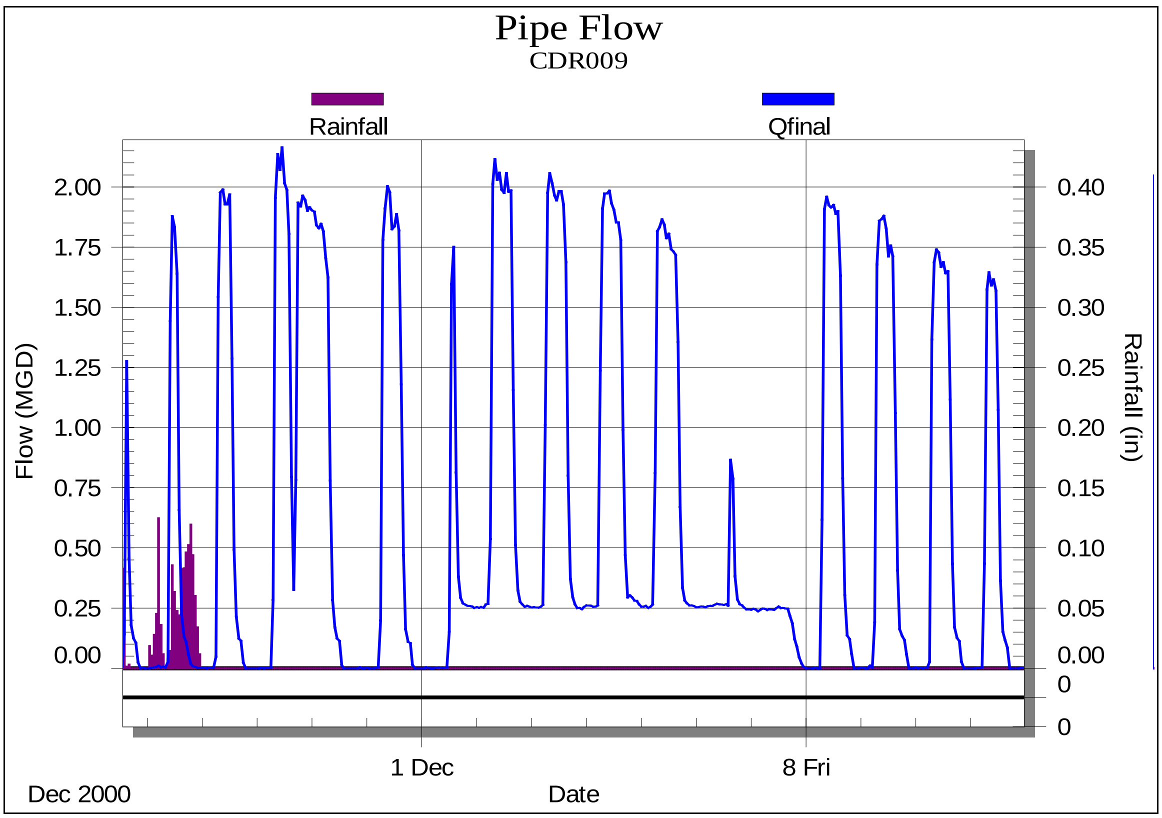
The selected dry days shown in Figure D6 produce the weekday and weekend diurnal hydrographs shown in green and blue, respectively, in Figure D7.

Figure D7
Mini Basin BEL075 Dry Day Averages



Some land uses produce neither repeatable nor regular patterns. An example of an irregular and not repeatable pattern is Mini Basin CDR009 (Figure D8), which is exclusively the flow from the Cedar Hill Landfill. Flow is not regular every day and varies widely from day to day. All flow is pumped and varies in both timing and flow rate. Areas that produce irregular patterns require an additional level of attention from a data analyst to accomplish the I/I subtraction. In this case a 24-hour volume of I/I can be calculated, but the calculated peak rate of I/I will be a function of the pump capacity.

Figure D
Irregular and Non Repeatable Flow Pattern 8



f) Base Infiltration

Base Infiltration (BI) is considered a component of I/I that is related to ground water and that could include leaking water lines, leaking plumbing fixtures and springs. It is considered a seasonal phenomenon affected by rainfall, but remains relatively steady over weeks and months. The most rigorous method for determining the quantity of base infiltration originating in a basin is to determine the quantity of water discharged to the sewers within the basin and subtract it from the measured sewer flow coming out of the basin. This is an expensive and sometimes difficult exercise and often is not done for a short-term flow metering study. Absent this information, other estimates can be used, such as assuming that BI equals a fixed percentage of the minimum nighttime flow.

For this analysis an empirical method for estimating base infiltration was used. The method is borrowed from the electrical power industry, which has estimated that the rate of residential power usage during the overnight hours is 12% of the daily average use. The assumption is made that overnight activity in a neighborhood will create water usage similar to electric power usage. This empirical method provides an estimate of wastewater production (WWP) in a Mini Basin based on the measured average (Avg.) and minimum flow (Min.) of the average dry day hydrograph.

Subtracting WWP from ADDF provides an estimate of base infiltration (BI). The equations to estimate (WWP) and (BI) are listed in Equations D1 and D2.

Equation D1

WWP = (Avg.- Min.)/ **X**

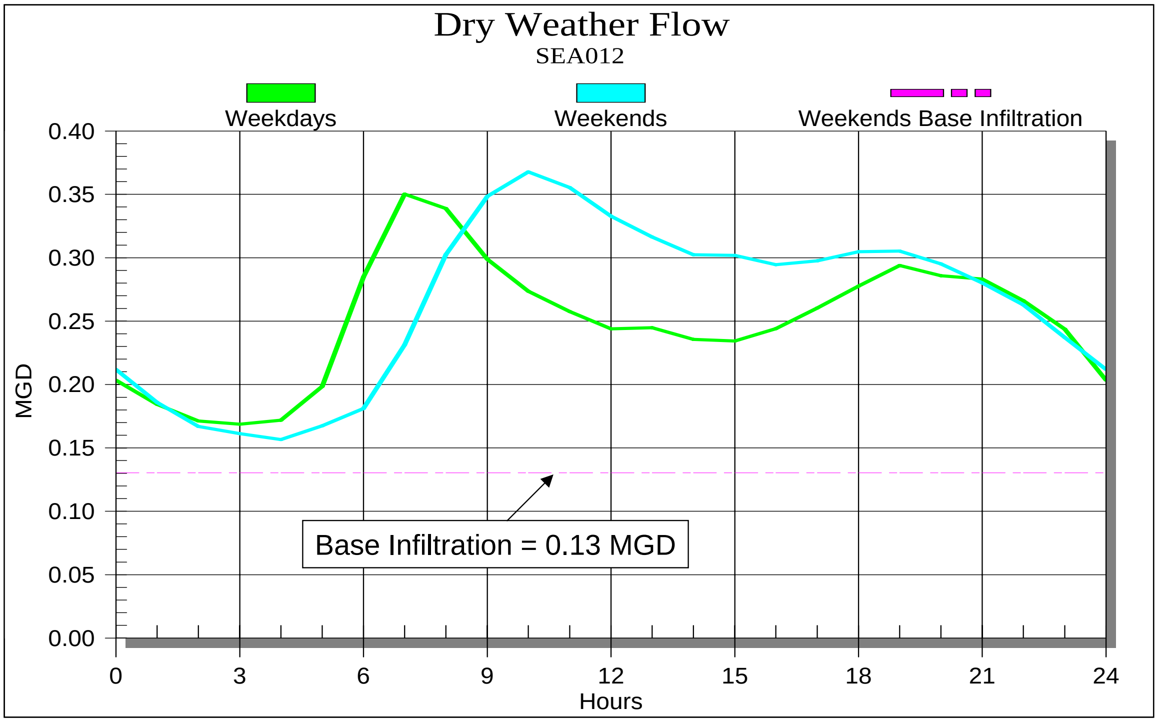
Equation D2

BI = ADDF – WWP

Where; **X** = .88 (from electric power industry)

In concept this approach estimates WWP based on the difference between average flow and minimum flow. As base infiltration varies over the year the difference between average and minimum flow (and WWP) is expected to remain constant. This method of estimating is reliable for residential neighbors in sewer basin sizes on the order of 20,000 LF. As basins become larger and travel time increases, the estimations decrease in reliability. Reliability also decreases in non-residential basins and in basins where the flow meter measures flow from cycling pump stations. Because this method is not consistently reliable it is recommended that users not use BI or WWP estimates for design purposes. When applied to Mini Basin SEA012 this method produces an estimated base infiltration of 0.13 MGD and is shown by the magenta line in Figure D9. ADDF is 0.254 MGD. This method depends upon a repeatable flow pattern each day.

Figure D9
Base Infiltration for Mini Basin SEA012

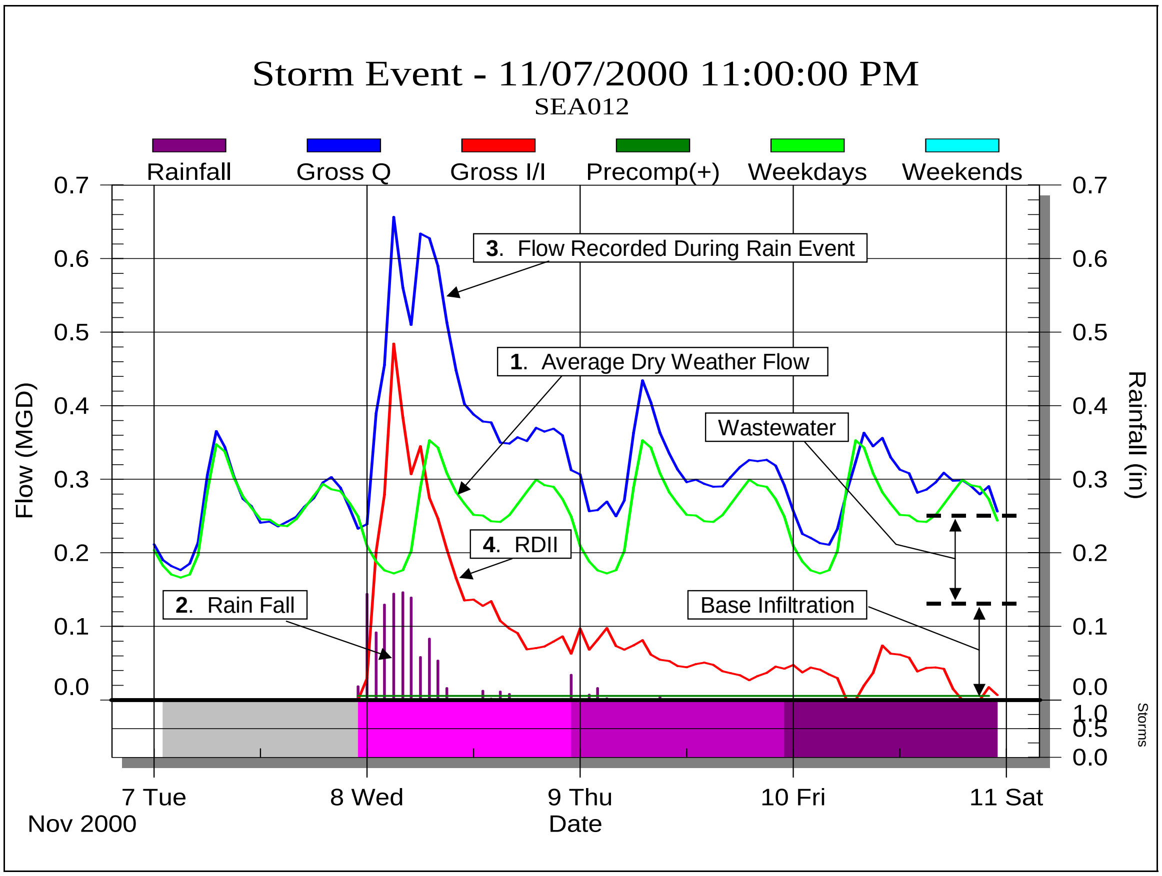


g) RDII Calculation

Figure D10 is called a Storm Hydrograph and consists of a collection of 3 hydrographs and a rainfall hyetograph showing the components of the RDII calculation for SEA012 for the November 7, 2000 rain event:

1. Average dry day hydrograph in green;
2. Rainfall hyetograph in magenta;
3. Flow recorded during the rain event in blue and
4. Calculated RDII in red.

Figure D10
Storm Event Components and 72-Hour Calculation Window



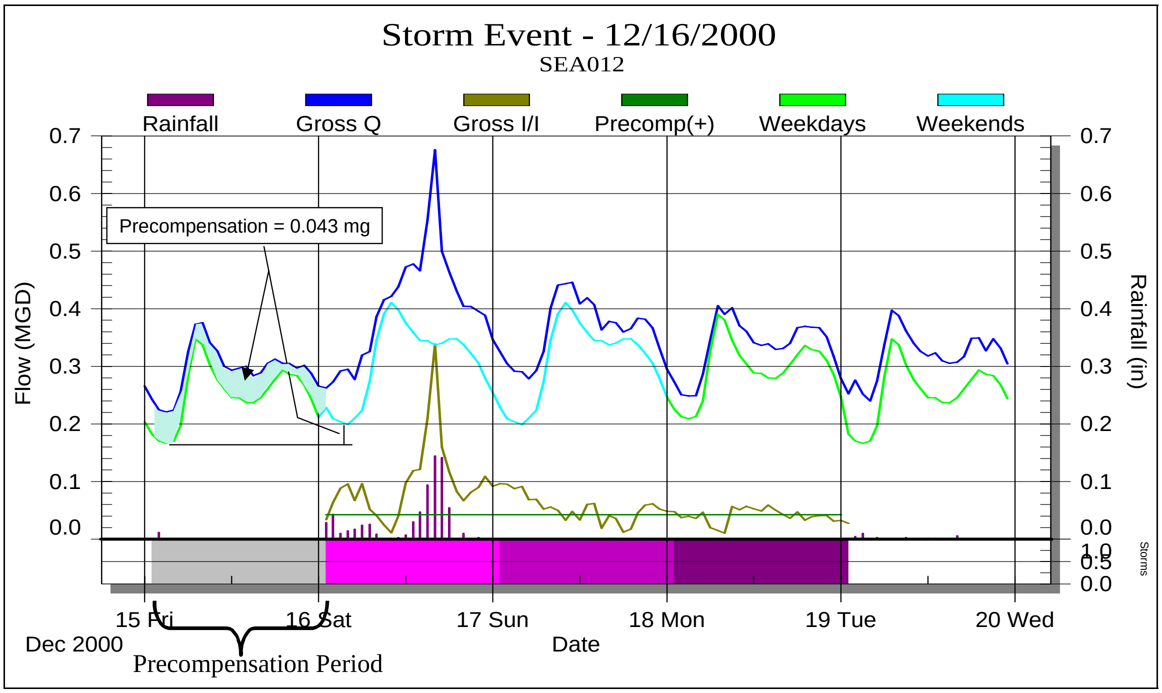
RDII is calculated during the "calculation window" by subtracting the average dry day flow from the recorded flow. For this study the calculation window extends 72 hours after the start of a rain event and consists of three 24-hour periods shown as three magenta bands. RDII volume is calculated for the first 24-hour period. In this example, the measured flow prior to the start of the rain is almost identical to the average dry day hydrograph in green. Average dry day flow is 0.25 MGD and that includes 0.13 MGD of base infiltration. Since the average dry day flow includes base infiltration the RDII calculation does not include base infiltration.

h) Precompensation – The Difference Between I/I and RDII

One of the goals for the King County Regional Infiltration/Inflow Control Program was to establish a relationship between rainfall and RDII for all Mini Basins. This relationship is usually referred to as a Q (RDII) to i (rainfall) relationship. The objective of a Q to i relationship is to establish the relationship between rainfall and the volume of RDII that is directly caused by a discrete rain event.

If the measured flow just prior to the rain is higher or lower than the ADDF, the dry day flow pattern is raised up or down to match the volume of the measured flow of the prior day. There are several reasons for the prior day to differ from the average dry day. Reasons include normal variation in daily flows and the lasting effect of previous rains. Figure D11 illustrates an example of this process for Mini Basin SEA012 during the December 16, 2000 rain event.

Figure D11
Precompensation for Mini Basin SEA012 for Calculation of RDII

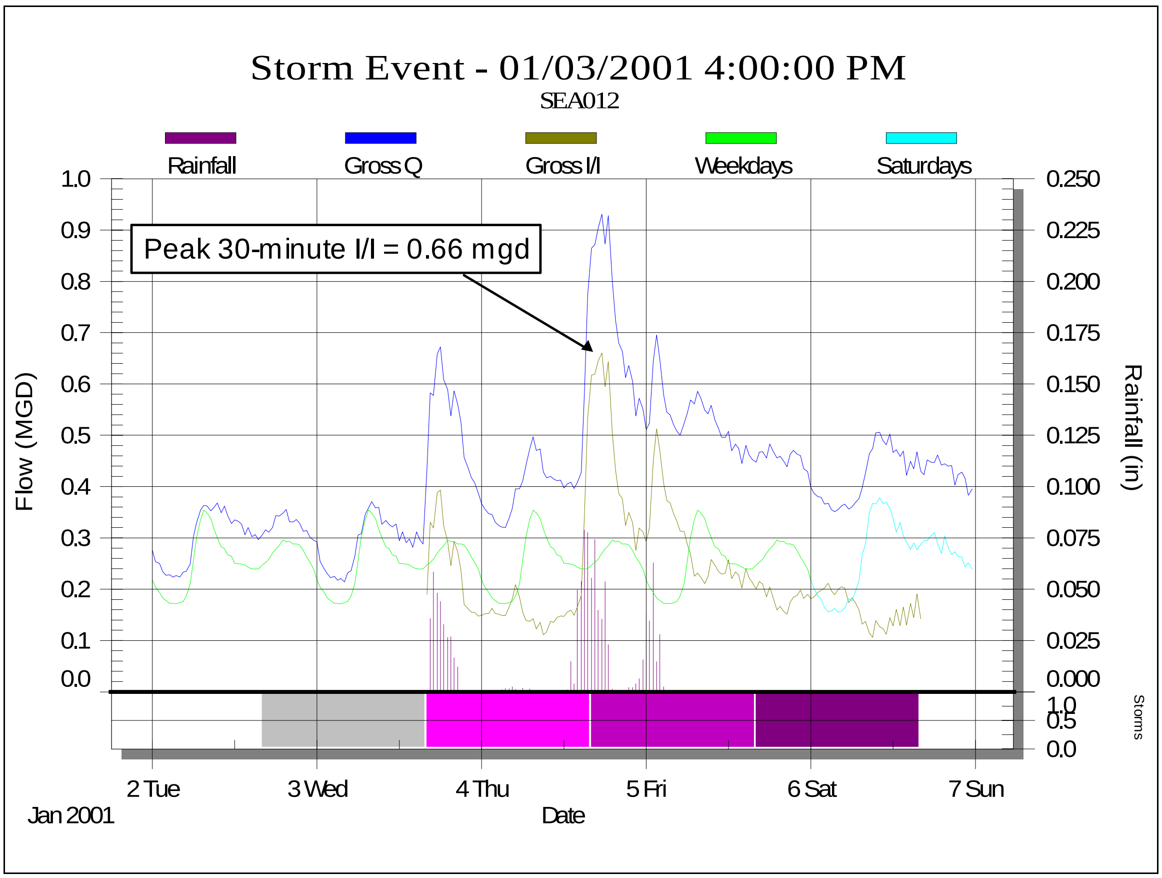


During the "Precompensation Period", the measured volume is compared to the ADDF. The Precompensation Period is the 24-hour period prior to the start of the rain shown as the gray bar spanning most of the day of December 15, 2000. In this example the volume comparison over the precompensation period was 0.043 MGD higher than the average dry day flow (shown in shaded green). The dry day hydrograph is moved up by 0.043 MGD on December 16, 2000 effectively removing 0.043 MGD of infiltration from the I/I calculation. The remaining I/I is due exclusively to the rain on December 16, 2000 and is defined as RDII. As discussed in this document calculated I/I and calculated RDII differ only by the amount of precompensation that may be applied. In Figure D11, the calculated I/I, whether a peak rate or daily volume, will be 0.043 MGD higher than the equivalent RDII calculation.

i) Peak 30-minute I/I and Peak Total I/I

The King County Code establishes "excess flow" as flow other than sewage and industrial wastewater exceeding 1,100 Gallons per Acre per Day in any 30-minute period. This describes a 30-minute peak rate of Total I/I divided by the acreage in the basin (Peak Total I/I in GPD/Acre). Peak Total I/I is obtained by adding Base Infiltration to Peak I/I. Peak I/I is measured in 30-minute time intervals and without the use of precompensation. As an example, the 30-minute Peak I/I for Mini Basin SEA012 is 0.66 MGD (rounded to two decimal places) as shown in Figure D12. The basin size for Mini Basin SEA012 is 202 Acres. In Appendix A, for Mini Basin SEA012, the Estimated Base Infiltration is 349 GPD/Acre and the Peak Measured I/I (30-minute) for the January 3, 2000 rain event is 3,283 GPD/Acre. The Estimated Peak Total I/I (30-minute) is the sum of these two numbers and is equal to 3,632 GPD/Acre. The value of Estimated Peak Total I/I is reported for each rain event in Appendix A.

Figure D12
30-Minute Peak I/I for Mini Basin SEA012



3. Wet Weather Performance (Q to i)

The scope of work for this study called for a series of four Q to i diagrams for each Mini Basin and they are provided in Appendix D. The four Q to i diagrams fall into two basic categories. One category is a volume-to-volume relationship comparing the volume of rain in inches to the volume of RDII in gallons. The second is a rate-to-rate relationship comparing the rate of rainfall in inches/hour and rate of RDII in Million Gallons per Day (MGD). The amount of rain is plotted on the x-axis and the response (RDII) is plotted on the y-axis. As a general rule, Mini Basins that leak the worst have well developed pathways for water to enter the sewer and have the best fitting Q to i diagrams. The “tightest” Mini Basins exhibit more of a “shotgun pattern” in Q to i diagrams.

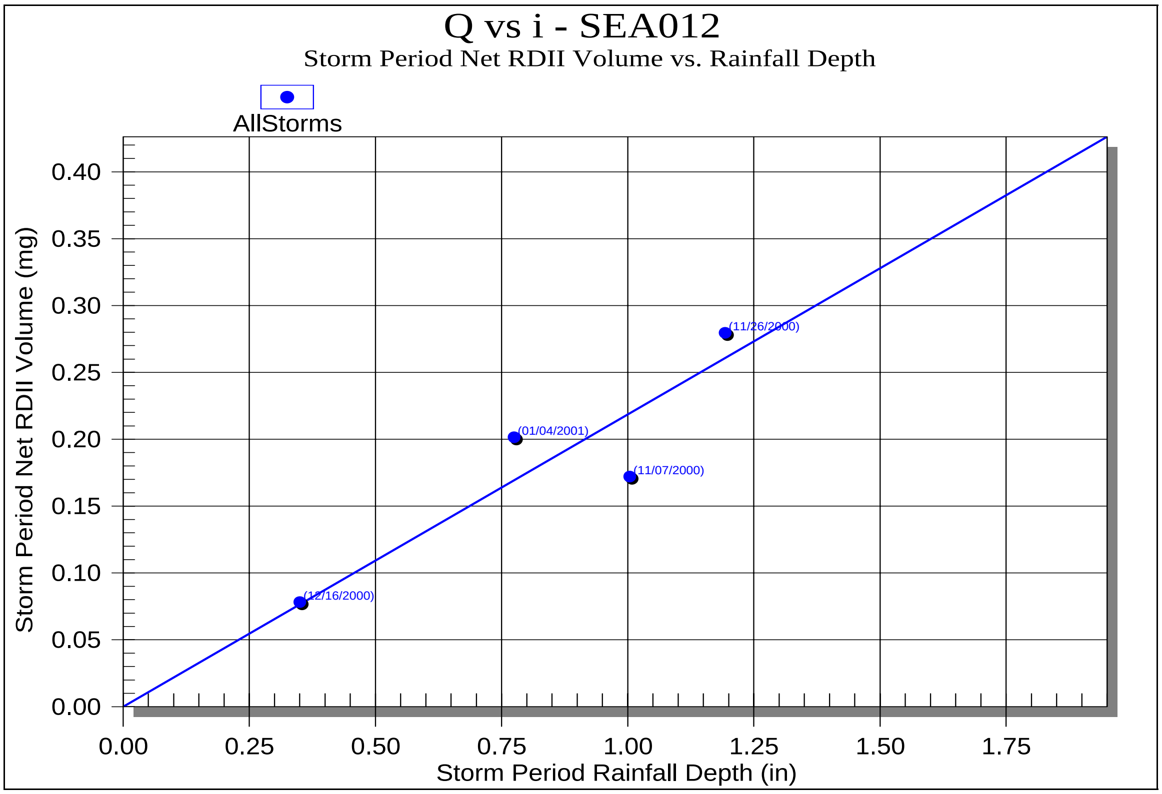
In practice, a best-fit line is drawn through several rain events to establish a relationship for each Mini Basin. Judgment must be exercised to assure that the rain events are sufficient in number and similarity to determine if a best-fit line is appropriate. The examples shown below have best-fit lines drawn through the data points to show how the relationship is developed. However since the rain events for this study period were few, all small, varied in character and occurred during an unusually dry period, it would be inappropriate to consider these responses suitable for the I/I program objective. Therefore the Q to i diagrams included in this memorandum do not have a best-fit line. The best-fit line is shown on these four examples to illustrate the concept.

These products are offered as data for subsequent engineering analysis and are not intended for direct use in design, sizing of facilities or predicting wet weather performance in periods of more intense rain. The four forms of Q to i diagrams below are all from Mini Basin SEA012.

a) Volume-to-Volume Storm Period

The Volume-to-Volume (Storm Period) form (Figure D13) plots the rainfall volume of the storm period (24 hrs.) to the RDII volume for the same period. Some users use this form for sizing off-line storage facilities. This form works well for distinct rain events with suitable time for the system to recover between events.

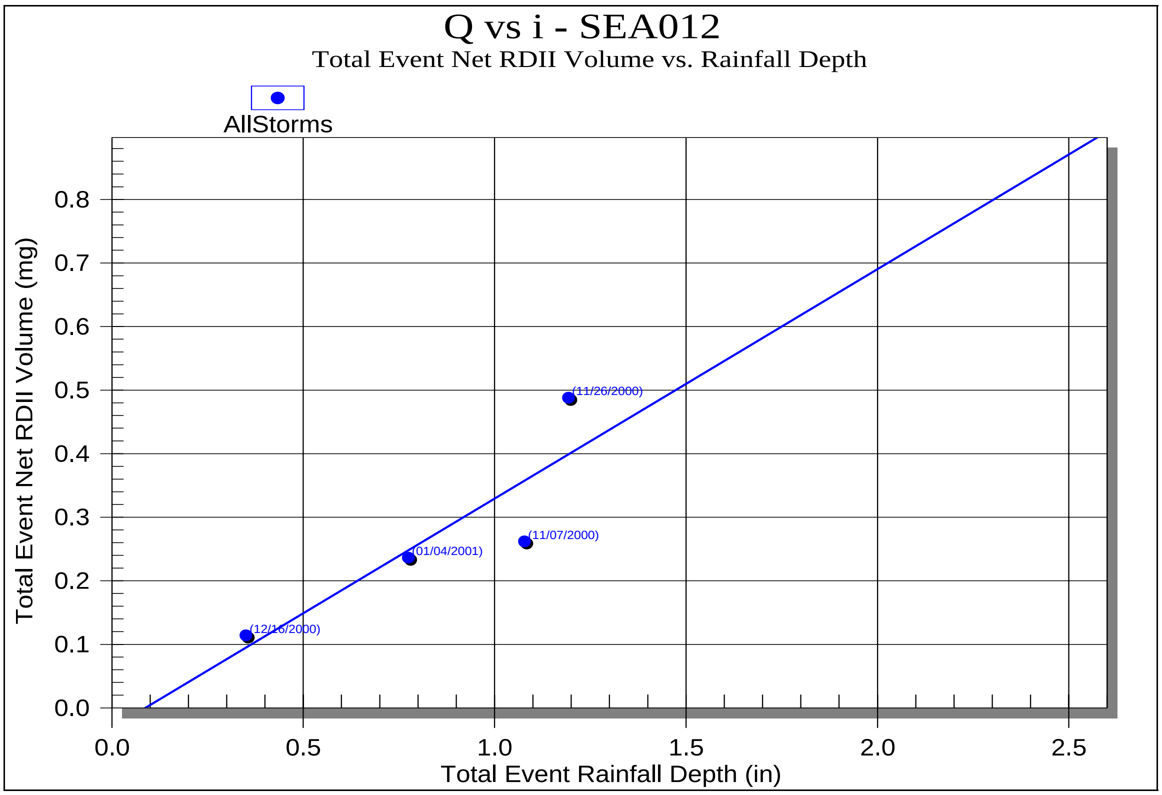
Figure D13
Volume-to-Volume Q to i



b) Volume-to-Volume Total Event

The Volume-to-Volume (Total Event) form**,** Figure D14, plots the rainfall volume of the total event against the volume of RDII of the entire event, which includes the storm day and two recovery days. The total event is 72 hours long and is the period within which most Mini Basins have recovered from a rain event. Some users like this form for sizing storage facilities, but subsequent rains that fall in the second or third 24 hr. period after the storm can skew these data.

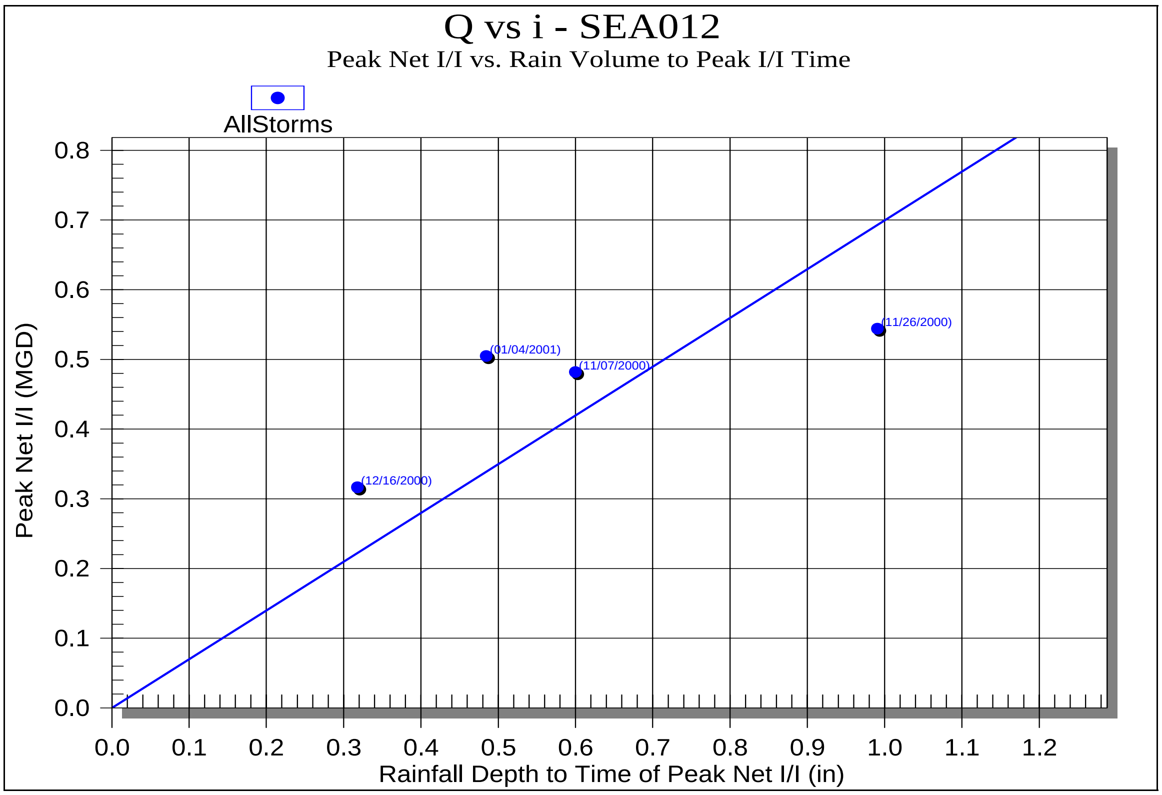
Figure D14
Volume-to-Volume (Total Event) Q to i



c) Volume-to-Rate

The Volume-to-Rate form (Figure D15) plots the rainfall volume falling up to the time of the peak rate of RDII to the rate of peak RDII. Some users prefer this form since it recognizes that rain falling after the RDII peak does not contribute to the peak.

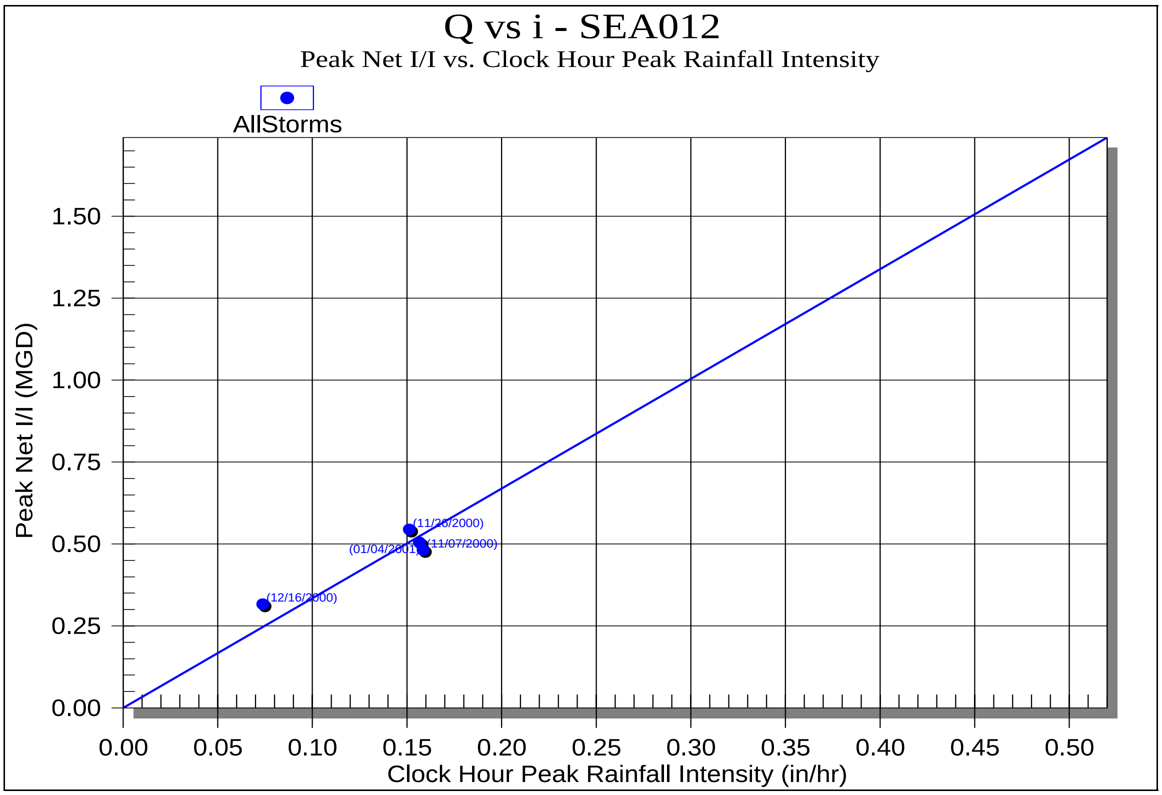
Figure D15
Volume-to-Rate Q to i



d) Rate-to-Rate

The Rate-to-Rate form (Figure D16) plots rainfall in inches/hour and RDII in MGD. Storm sewer and open channel designers use this form, because the rate of storm flow is usually the sole criteria for sizing pipe or channels.

Figure D16
Rate-to-Rate Q to i



E. CALAMAR Rainfall Measurement

The sewer system is contained in a rectangular area of approximately 1100 square miles (2800 Km^2) in western King County, Snohomish County and Pierce County, Washington. The area is hilly with nearly 1000 feet (300 meters) of relief in the sewered area. The cost of a conventional rain gauge network with sufficient density to assure accuracy of rainfall measurements prompted the County to consider CALAMAR, a well-developed French technology using radar images from the National Weather Service NEXRAD Radar. CALAMAR is provided by RHEA, SA of Nanterre, France.

1. Principles of Radar Technology

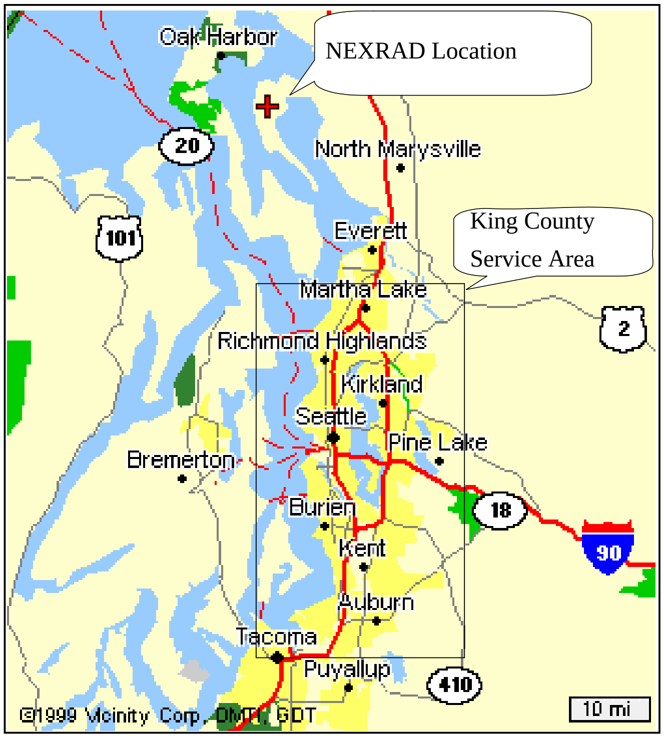
The advent of the National Weather Service's NEXRAD weather radar system provides a major advance in the ability to locate and track rainfall with geographic precision. While the geographic precision of NEXRAD is accurate, its ability to measure the intensity of rainfall is not accurate. With the addition of CALAMAR, it is possible to have reliable, geographically precise and accurate rainfall measurements over an entire service area.

CALAMAR (CAlcul de LAMes d'eau a l'Aide du Radar) translates to "Calculating Rain with the Aid of Radar". CALAMAR calibrates and processes the NEXRAD data in a unique and patented way that produces rainfall measurements with a typical accuracy of +/- 10%. This is a far higher degree of accuracy than is available from "raw" radar data, or from rain gauges alone. Accurate rainfall measurements take much of the uncertainty out of calculating relationships between rainfall and RDII whether it is by modeling or direct measurement. CALAMAR provides:

- *Geographic resolution of 1 Km^2 (0.4 square mile);*
- *Rainfall measurements between gauges with an accuracy of +/-10% and*
- *Measurements over various geographic areas in an 11,000 square mile region around the radar.*

Figure E1 shows the location of the NEXRAD radar in relation to the King County service area. The sewer service area is contained in a rectangular area approximately 25 miles (40 Km) wide and 45 miles (73 Km) long. The NEXRAD radar is located on Camano Island and is operated by the National Weather Service.

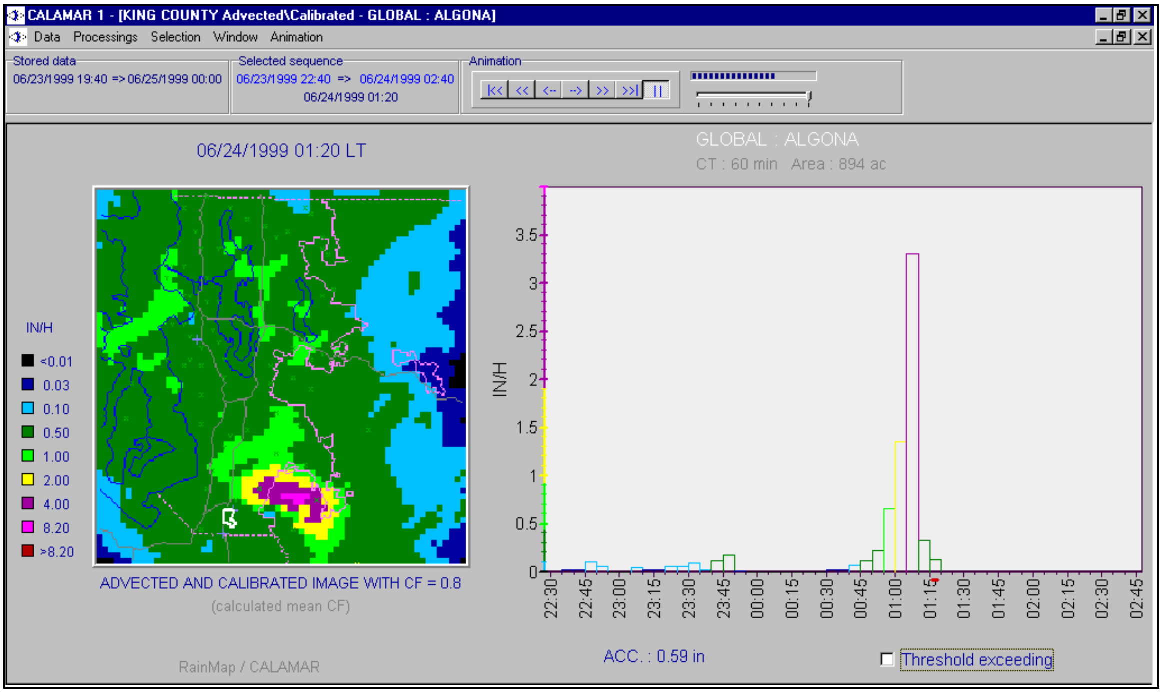
Figure E1
NEXRAD Location



CALAMAR operates by acquiring raw reflectivity images from the NEXRAD radar and processes the data with geographic resolution of 1 Km^2 pixels. Rain gauges provide "ground truth" such that, when calibrated, image pixels with rain gauges under them equal the rain gauge value. This process works well on a storm-by-storm basis since each type of storm produces a characteristically different radar image. However, such a large area provides the opportunity for multiple storms of different characteristics to occur simultaneously within the service area. To assure that only the rainfall in each region in the service area is used to calibrate the radar image for that region, the service area has been divided into eight (8) calibration zones of 200 to 500 Km^2 each.

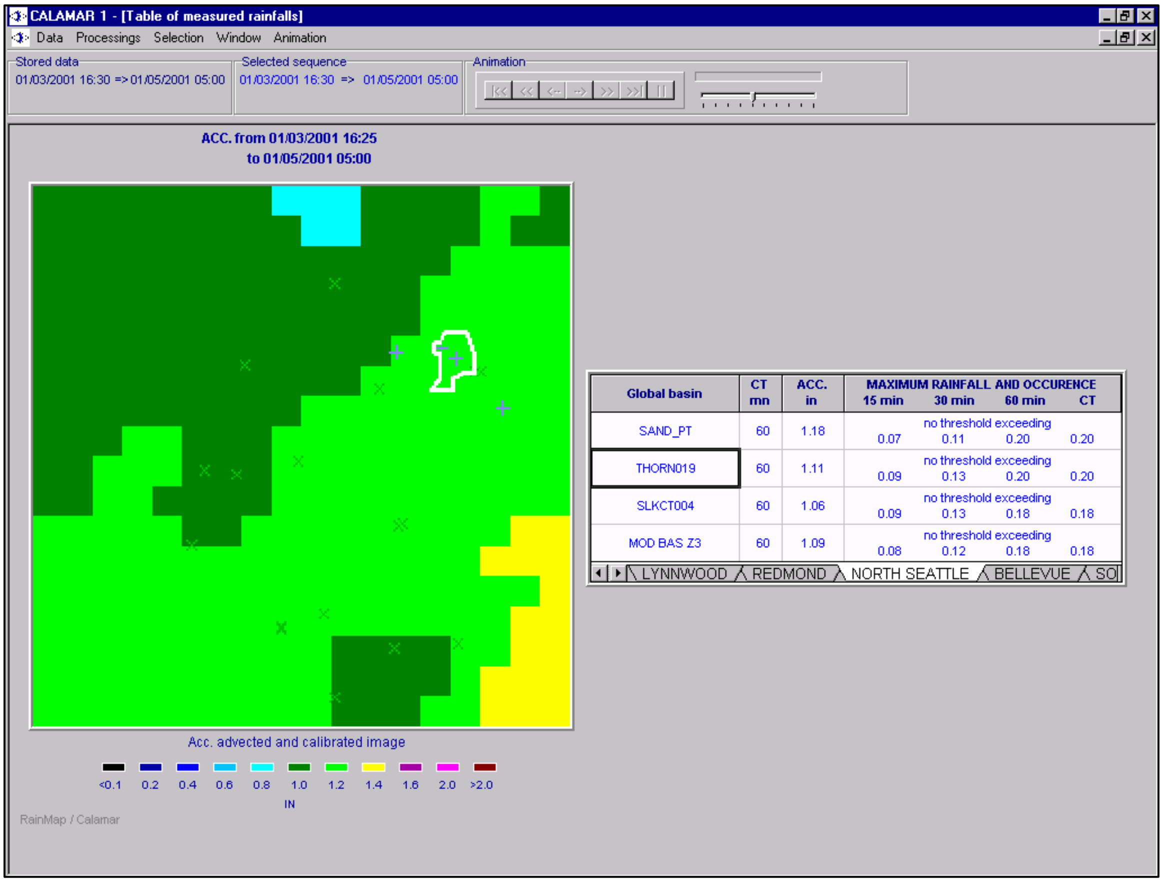
The output from CALAMAR is both graphical and tabular. Graphical views include simultaneous views of the radar image and a hyetograph. Figure E2 provides an example of the radar image on the left and the hyetograph on the right. The image shows a red and yellow rain cell just after it passed over the City of Algona and the hyetograph shows the rainfall intensity in 5-minute steps.

Figure E2
Simultaneous views of the Radar Image and a Hyetograph in CALAMAR



A second graphical output is an image of accumulated rainfall plus a table of accumulated rainfall. Figure E3 shows the accumulated rainfall image on the left for North Seattle calibration zone and a table of accumulated rainfall on the right. The outlined boundary on the image is the model basin above LTM Thorn019.

Figure E3
Accumulated Rainfall for Model Basin THORN019



2. Network of Calibrating Rain Gauges

The King County Wastewater Treatment Division (WTD) and Water and Land Resources Division (WLRD) each operate a network of rain gauges throughout King County. An additional 25 gauges were installed to create sufficient density for calibration by CALAMAR. The new gauges bring the total number of calibration gauges to 72. Table E1 is an inventory of all rain gauges.

Table E1
Rain Gauge Inventory

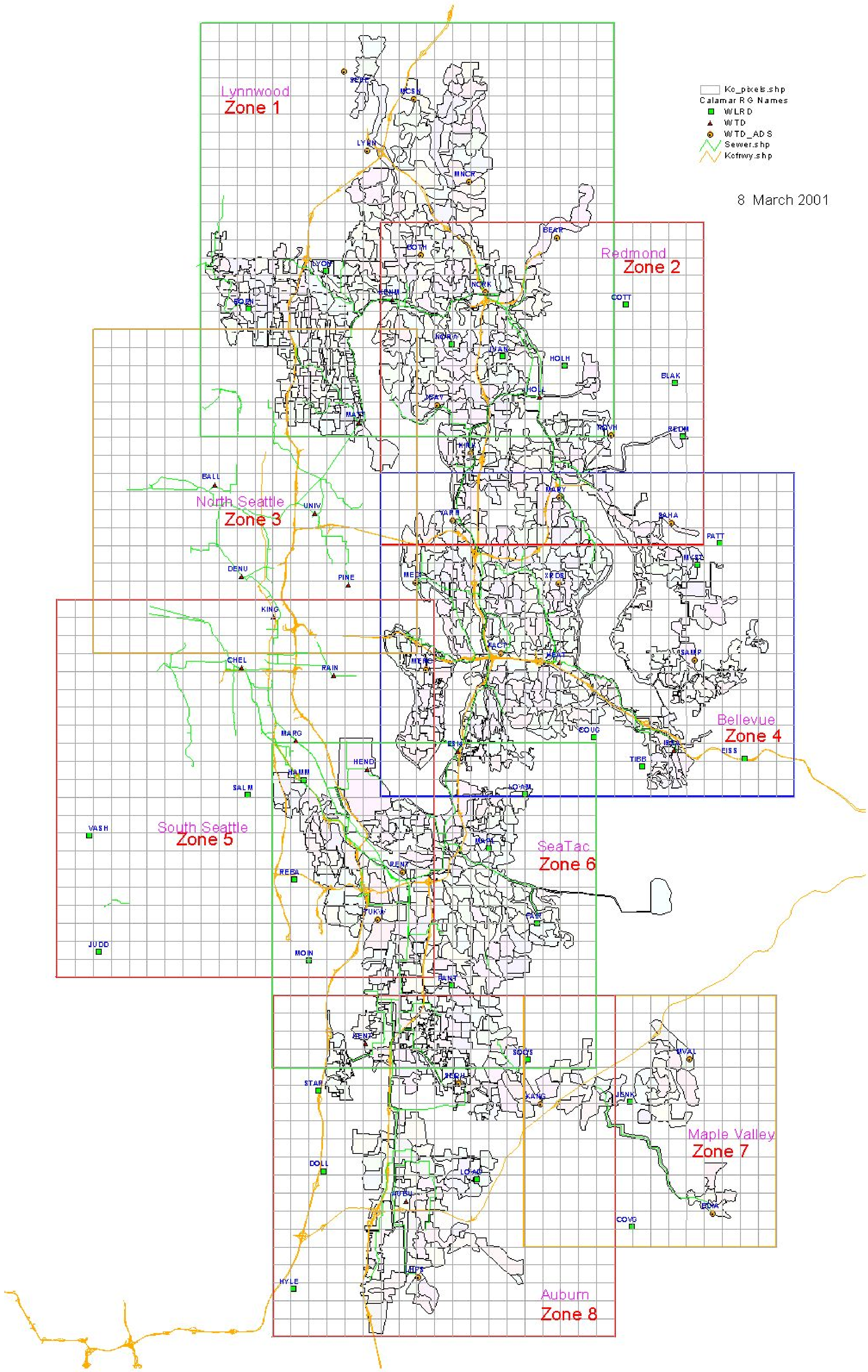
WLRD GAUGE_#	GAUGE_NAME	CALAMAR NAME	DESCRIPTION
02V	Blakely Ridge	BLAK	Blakely Ridge Precipitation, near Redmond.
04U	Boeing Creek	BOEN	Shoreline Community College near Seattle.
02W	Cottage Lake	COTT	At King County Fire Station near Cottage Lake
63Y	Cougar Mountain	COUG	Cougar Mountain Park
09U	Covington Creek	COVG	Near Horseshoe Lake, near Black Diamond.
11U	Des Moines Creek	MOIN	In Tyee Golf Course, in SeaTac.
14U	East Fork Issaquah	EISS	East Fork Issaquah Precipitation, west of High Point.
31Y	Fairwood	FAIR	None
HCU	Hamm Creek	HAMM	None
51W	Hollywood Hill	HOLH	In Hollywood, north of Redmond.
26U	Jenkins Creek	JENK	Near Shadow Lake.
27U	Juanita Creek	JUAN	K.C. Fire Station in Kingsgate.
28U	Judd Creek	JUDD	Vashon Cemetery
41V	Lake Dolloff	DOLL	South of Lake Dollof, near Federal Way.
42U	Lake Reba	REBA	Near Lake Reba detention facility.
32U	Lower Green River	LOWG	At K.C. Fire Station, near Auburn.
37U	Lower May Creek	LOWM	Near Renton.
35U	Lyons Creek	LYON	At Brugers Bog KCPW Shop in Lake Forest Park.
31U	Maplewood	MAPL	Near Renton.
MLU	Mystic Lake	MYST	At Fire station
24V	East Fork Hylebos	HYLE	None
43U	North Vashon	VASH	Heights Water District
51U	Norway	NORW	South Bothell.
03Y	Panther Creek	PANT	Panther Regional Detention Pond, near Kent.
48U	Patterson Creek	PATT	SR 202 near Redmond.
18V	Redmond UPD	REDM	In Northridge UPD
50U	Salmon Creek	SALM	15th Ave SW north of SW 106th ST.
54V	Soos Creek	SOOS	In Soos Creek Park.
41U	Star Lake	STAR	South of Star Lake, near Federal Way.
67U	Tibbetts Creek	TIBB	On SR 900, near Issaquah.
Note: VASH gauge did not operate during the study			
WTD GAGE_#	**GAUGE_NAME**	**CALAMAR NAME**	**DESCRIPTION**
XXXXXX0770	25 West Main St., Auburn	AUBU	25 West Main St., Auburn
XXXXXX4992	5000-6000 block James, Kent	KENT	5000-6000 block James, Kent
XXXXXX3145	525 1st Ave., Issaquah	ISSA	525 1st Ave., Issaquah
LQF815078VL	Ballard RS	BALL	Ballard RS
LQF806078VL	Chelan RS	CHEL	Chelan RS
LQF813178VL	Denny Way RS	DENU	Denny Way RS
LQF773078VL	East Marginal Way PS	MARG	East Marginal Way PS
LQF783078VL	East Pine PS	PINE	East Pine PS
LQF335214VL	ESI Sect. 4, Manhole R02-25, Renton	ESI4	ESI Sect. 4, Manhole R02-25, Renton
	Heathfield PS	HEAT	Heathfield PS
LQF774078VL	Henderson PS	HEND	Henderson PS
LQF308078VL	Hollywood PS	HOLL	Hollywood PS

LQF788078VL	Kenmore PS	KENM	Kenmore PS
LQF801078VL	King Street RS	KING	King Street RS
LQF786078VL	Matthews Park PS	MATT	Matthews Park PS
LQF770078VL	Rainier Ave PS	RAIN	Rainier Ave PS
LQF819078VL	University RS	UNIV	University RS
New WTD Gauges	**New RG_NUMBER**	**CALAMAR NAME**	**DESCRIPTION**
N/A	1	SEQU	Sequoia Jr. HS
N/A	2	LHPS	Lakeland Hills PS
N/A	3	KANG	Fire Station, 15635 Kent Kangley
N/A	4	MVAL	Maple Valley Retention Pond D92151
N/A	5	BDIA	Black Diamond PS, Jones Lake rd.
N/A	6	MERC	School Admin. Mercer Island
N/A	7	FACT	Factoria Transfer Station
N/A	8	MEDI	Medina PS
N/A	10	XRDS	Fire Station 3, 16100 NE 8th St
N/A	11	SAMP	Retention Pond, 235th Pl. N & 32nd St
N/A	12	SAHA	Retention Pond, 22124 Redmond Fall City Rd
N/A	13	NOVH	Retention Pond, 18808 103rd St. D90930
N/A	14	MARY	Marymoor Park
N/A	15	KIRK	Kirkland Maint. Center, 915 8th St
N/A	16	YARR	Yarrow Bay PS
N/A	17	NCRK	North Creek PS
N/A	18	BEAR	Retention Pond, 229th St SE & 75 Av SE
N/A	19	MNCR	Retention Pond, 19812 26th Dr. SE
N/A	20	BOTH	Intermountain Glass, 23905 Meridian Av. S
N/A	21	LYNN	Lynnwood HS
N/A	22	MCSN	Alderwood PS 17, Mill Creek
N/A	23	SERE	Fire Station 3, 4323 Serene Way
N/A	24	TUKW	Tukwila PS
N/A	25	RENT	Renton WWTP
N/A	26	JBAY	KC Service Center, Juanita Dr and 93rd Av.
Note: New WTD Gauge Number 9 not placed for the study			

3. Calibration Zones

The service area has been divided into eight (8) calibration zones of 200 to 500 Km^2 each to assure that only those rains within the zone calibrate each zone. The 8 calibration zones, the 72 rain gauges and the 2222 pixels of 1 Km^2 are shown in Figure E4. Figure E4 is also included as a JPEG file in the in Appendix D as file calamar_rgs_pixels_zones_6may01.jpg

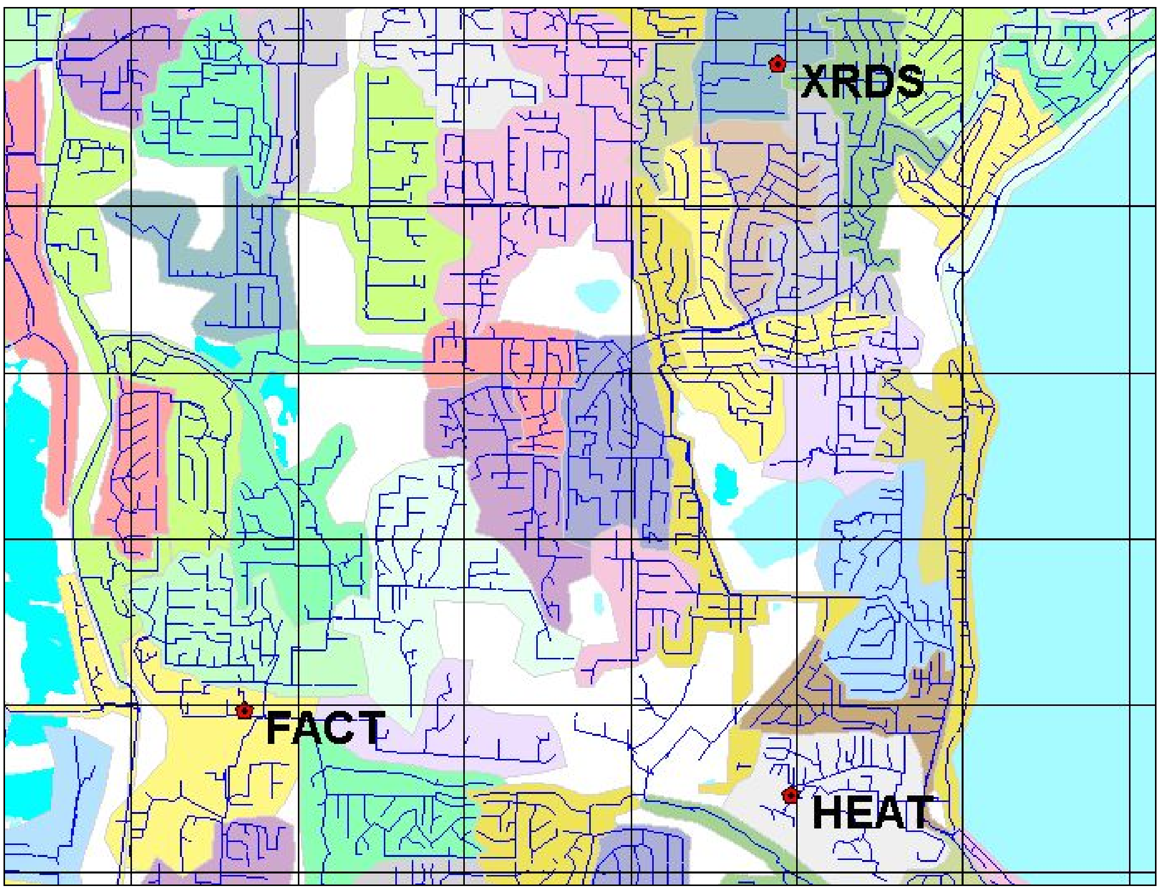
Figure E4
CALAMAR Calibration Zones



4. Pixel Rain Data

In its most elemental form, the output from CALAMAR is a series of rainfall measurements for every 1 Km^2 pixel in the service area. To provide perspective of 1 Km^2pixels and 20,000 LF Mini Basins, Figure E5 shows a collection of Mini Basins in the city of Bellevue with 1 Km^2 pixels superimposed. Also shown are three of several rain gauges that will calibrate Zone 4. Sanitary sewer lines are shown in each colored Mini Basin. CALAMAR produces a digital hyetograph for each pixel. Pixel rain data are converted to rain data for each Mini Basin as described in the next section.

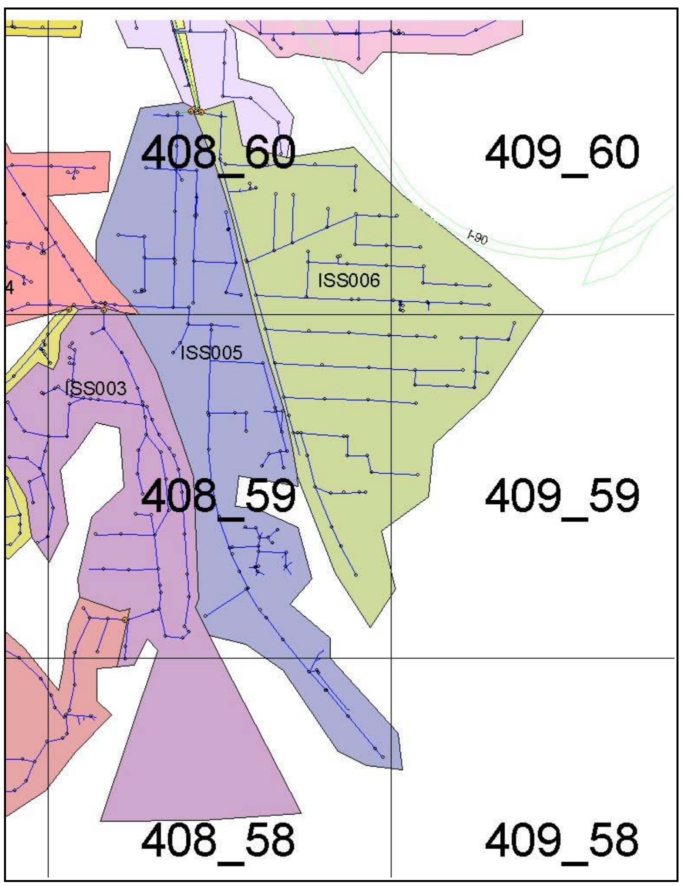
Figure E5
Bellevue Mini Basins, Three Rain Gauges and 1 Km^2 Pixels



5. Conversion from Pixel Data to Mini Basin Rain Data

A rainfall data file was created for each Mini Basin for each of the four storms that were analyzed. Most Mini Basins fall into more than a single pixel and a method was created to determine the average rainfall on each Mini Basin. Figure E6 shows several Mini Basins located in Issaquah and the CALAMAR pixels overlaid on the Mini Basins. The pixel numbers are derived from the approximate location in kilometers of the northwest corner of each pixel. The numbering system is similar to the Washington State Plane Coordinate System, but the starting coordinates are not the same. For example the pixel 408_59 is located 408 Km east and 59 Km north of the coordinate starting point.

Figure E6
Mini Basins located in Issaquah and the CALAMAR Pixels Overlaid on the Mini Basins



Many of the Mini Basins are positioned in multiple pixels. A method was developed using the GIS to determine the percent of rainfall on a Mini Basin coming from each pixel. Table E2 illustrates this method for Mini Basin ISS005. The yellow highlighting is on the 4 pixels that contribute to rainfall on Mini Basin ISS005 and the column "Percent" lists the percentage of each pixel. For example, nearly 54% of the rain on Mini Basin ISS005 comes from pixel 408_59. This process produces both time series and accumulated rainfall data for each Mini Basin. The accumulated rainfall for each Mini Basin and each rain event is listed in Appendix B.

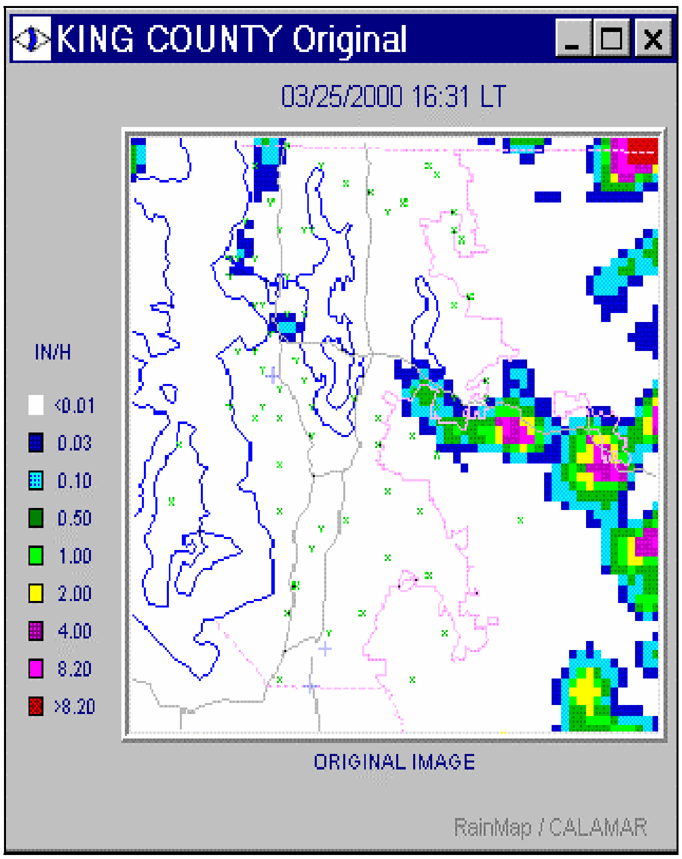
Table E2
Determination of Percent of Rainfall on a Mini Basin

BASIN	PERCENT	EAST	NORTH	PIXEL
ISS004	0.0002	406	60	406_60
ISS004	0.0311	407	59	407_59
ISS004	0.1228	407	59	407_59
ISS004	0.0000	408	59	408_59
ISS004	0.0000	408	59	408_59
ISS004	0.7432	407	60	407_60
ISS004	0.0357	408	60	408_60
ISS004	0.0670	408	60	408_60
ISS005	0.0052	409	58	409_58
ISS005	0.1000	408	58	408_58
ISS005	0.5397	408	59	408_59
ISS005	0.3549	408	60	408_60
ISS005	0.0001	408	60	408_60
ISS006	0.2003	409	59	409_59
ISS006	0.0006	409	59	409_59
ISS006	0.1273	409	60	409_60
ISS006	0.3393	408	59	408_59
ISS006	0.3326	408	60	408_60
ISS007	0.1790	409	60	409_60
ISS007	0.3648	409	61	409_61
ISS007	0.0389	408	61	408_61
ISS007	0.2614	408	60	408_60
ISS007	0.1560	410	61	410_61

6. Radar Measurement in Ground Clutter Areas

The National Weather Service's NEXRAD radar employs a ground clutter suppression routine. Ground clutter is a common form of anomalous data appearing on the radar image as the result of reflections off of non-precipitation objects, which could include pollution, insects, buildings, trees, mountains, etc. During the initial CALAMAR setup work, RHEA asked the National Weather Service to turn off the ground clutter routine to determine where clutter occurs in the service area. Figure E7 is an image collected with the suppression routine turned off. The colors represent ground clutter from the downtown Seattle buildings, the higher elevations of Bellevue on western Lake Sammamish, the Cougar Mountain area and the higher elevations of the Shoreline/Alderwood area. The NEXRAD ground clutter suppression algorithm is not advanced enough to remove clutter without also removing some precipitation in the same area.

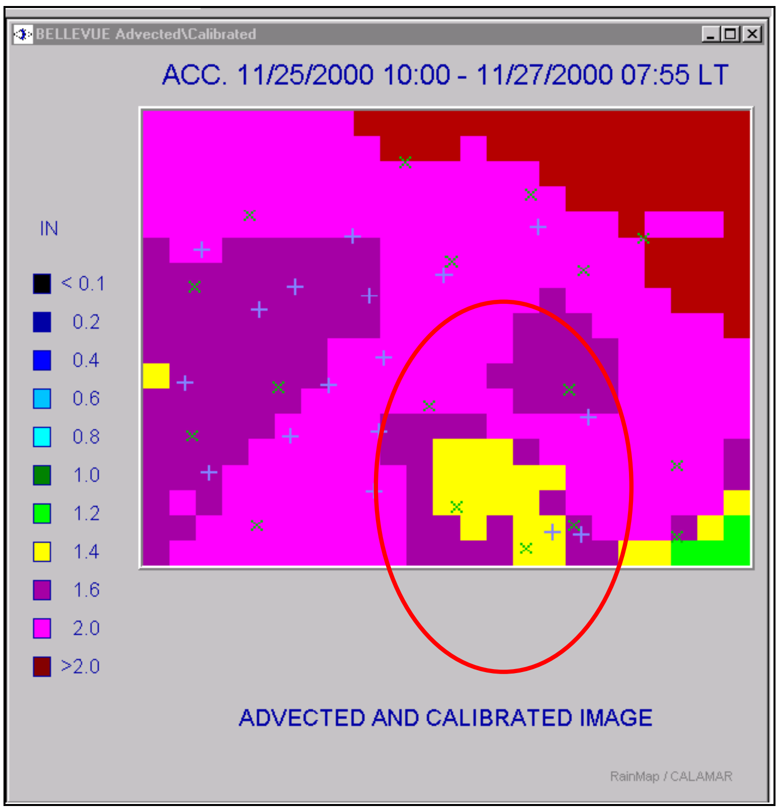
Figure E7
CALAMAR Image of King County indicating Areas Inducing Ground Clutter



CALAMAR has a patented routine for measuring rainfall in the ground clutter area by determining the direction and speed of the rain cells and projecting when the cells will be over the clutter areas. CALAMAR uses the projected rain intensity over the clutter area instead of the NEXRAD intensity. The CALAMAR routine depends on several past images to function correctly, but unfortunately the NEXRAD experienced significant numbers of lost images during the analyzed rain events. The lost images have little impact over the area with no ground clutter.

The combination of the lost NEXRAD images and CALAMAR's ground clutter routine resulted in rainfall "depression" in the Issaquah and Shoreline areas. Rainfall is under measured in the area where NEXRAD employs its ground clutter routine. Figure E8 shows the Bellevue calibration zone with the depressed pixels in Issaquah. The oval is drawn around the yellow pixels, which are under measuring rainfall.

Figure E8
Bellevue Calibration Zone with Depressed Pixels in Issaquah



This depression was remedied by employing a conventional rain gauge distribution for the affected Mini Basins. A total of 66 Mini Basins had conventional rain gauge substitutions for all or some of the rain events. Table E3 illustrates how the conventional rain gauge substitution was accomplished for the Issaquah Mini Basins. There are three rain gauges surrounding Issaquah and the table lists the percentage of each rain gauge applied to each Mini Basin. For example Mini Basin ISS008 rainfall consisted of 90% of rain gauge ISSA and 10% of rain gauge TIBB.

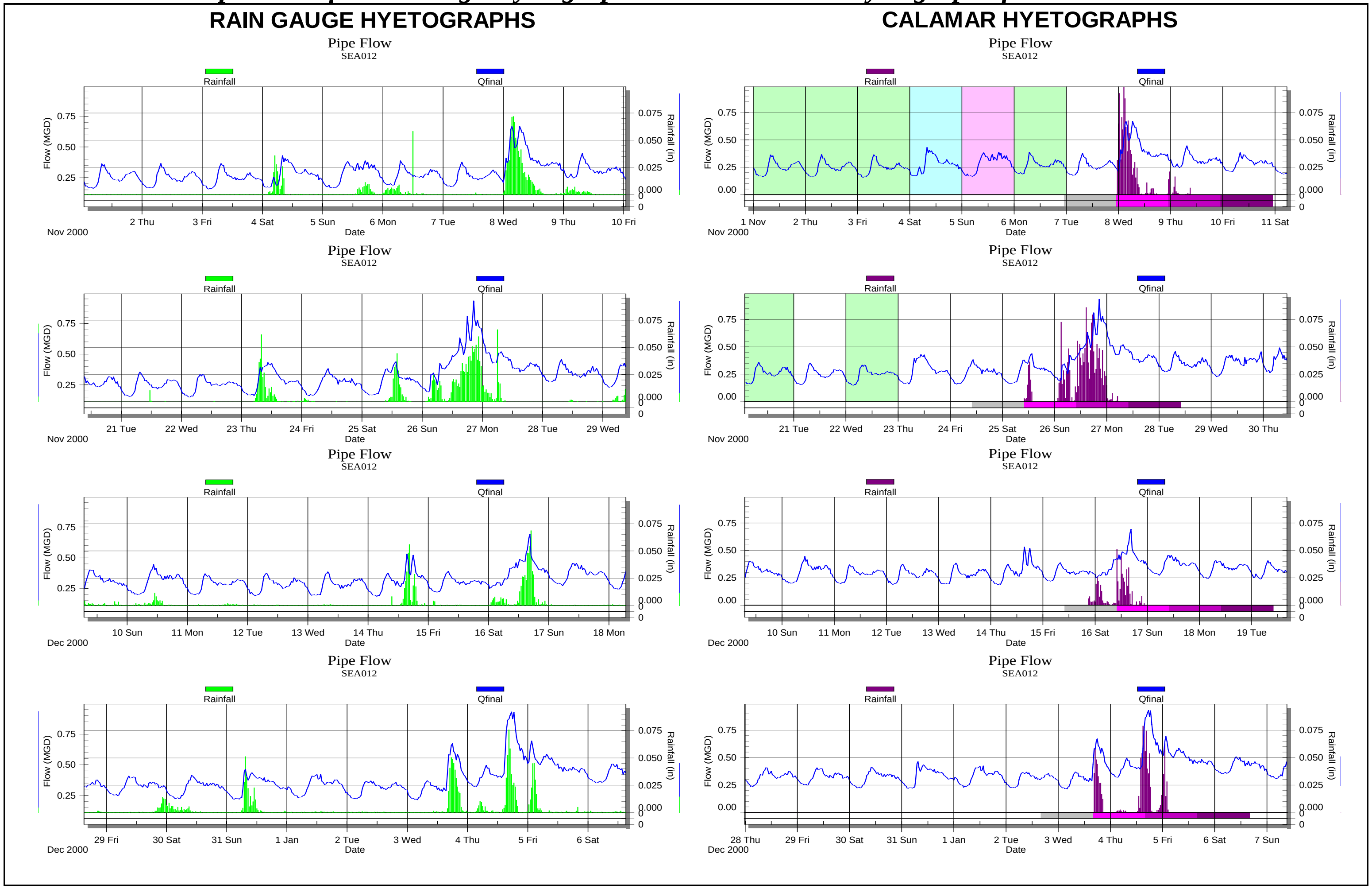
Table E3
Rain Gauge Distribution Percentage
for the Issaquah Mini Basins

Mini Basin	COUG	ISSA	TIBB
ISS001	80	10	10
ISS002	0	50	50
ISS003	0	50	50
ISS004	0	90	10
ISS005	0	95	5
ISS006	0	95	5
ISS007	0	95	5
ISS008	0	90	10
ISS009	33	33	33
ISS010	0	50	50
ISS011	0	50	50
ISS012	0	50	50
ISS013	0	50	50

7. Comparison of Rain Gauge and CALAMAR Hyetographs

To provide a background for understanding the rainfall patterns for the study period, Figure E9 shows rainfall for the 4 rain events and flow from Mini Basin SEA012. The column of 4 panels on the left shows the average rainfall from all rain gauges for a few days leading up to each of the 4 rain events. The column of 4 panels on the right shows the CALAMAR rainfall from Mini Basin SEA012 for similar periods of time. CALAMAR was used to process only the rain during the rain event so the small events not analyzed do not appear on the CALAMAR hyetographs.

Figure E9
Comparison of Rain Gauge Hyetographs and CALAMAR Hyetographs for 4 Rain Events

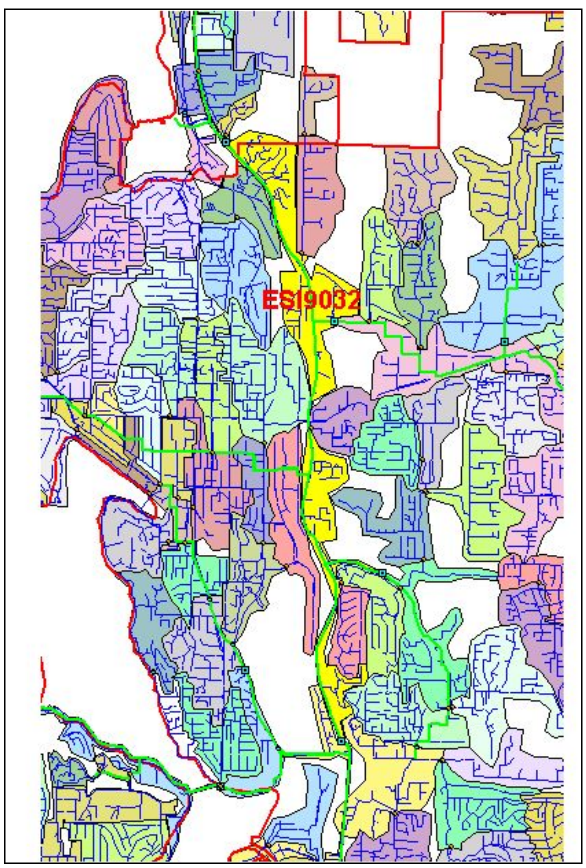


F. Evaluation of Calculated Flow Results

1. Relative Magnitude of Gross and Net Flows

The long-term meters (LTM) for the King County Regional Infiltration/Inflow Control Program were installed at key points on the King County trunk sewers to be operated prior to and after the temporary metering. This positioning allows for long-term trend analysis and hydraulic model calibration. The strategy for temporary meter (TMP) placement was to measure at least 95% of Local Agency sewers in Mini Basins and this resulted in nearly all local sewers being isolated from the King County trunk sewers. This strategy results in "remnant" Mini Basins formed by a LTM. "Remnant" Mini Basins exist at several locations on the King County trunk sewers. An example is Mini Basin ESI9032 located in Bellevue and shown as the yellow basin in Figure F1. The objectives of the Program include evaluation of I/I in the Local Agency Sewer systems and calibration of a hydraulic model; these remnant Mini Basins result from the combination of these two objectives, but were not intended, nor are they appropriate for, I/I analysis calculation.

Figure F1
Mini Basin ESI9032 – Example "Remnant" Mini Basin



2. Number of Upstream Subtractions

Uncertainty in flow measurement increases with the number of subtractions required to quantify net flow produced within a Mini Basin. Meter placement was designed to minimize the number of subtractions. The ideal situation is having a meter at the outlet of a basin with no metered flow entering from upstream. Having one subtraction is next best and so forth. Table F1 categorizes Mini Basins by the number of subtractions required to quantify net flow and lists the number of Mini Basins in each category. The planning was successful in maximizing the number of meters not requiring a subtraction. Fifty-five percent (442) of the Mini Basins required no subtraction. As a general rule, five (5) or more subtractions produce calculations that may add uncertainty to the subtraction. As those basins with over five subtractions were usually the "remnant" Mini Basins discussed above, the impact on evaluation of Local Agency System I/I is minimal. The number of upstream subtractions required to calculate net flow for each Mini Basin is included in Appendix A and the list of upstream meters is included under Appendix D in Upstream_Meter_Relationship.xls.

Table F1
Number of Upstream Subtractions Required to Calculate Net Flow
And Number of Mini Basins in each Category

Number of Subtractions	0	1	2	3	4	5	6	7	8	9	10	12	17	Total
Mini Basins in category	442	181	101	40	15	8	4	3	5	2	5	1	1	808

3. Base Infiltration

Section D 2. f) discusses the empirical method used to estimate base infiltration (BI). The method uses the diurnal ADDF hydrograph as shown in Figure D9. The presence of pump station cycling distorts the average-to-minimum flow relationship found in normal gravity flow sewers and can significantly distort the BI estimate. Figure F3 shows the hydrograph from BEL013, which is heavily influenced by a pump station with lake line flushing.

Figure F3
Hydrograph from BEL013 Showing Pump Station Influence

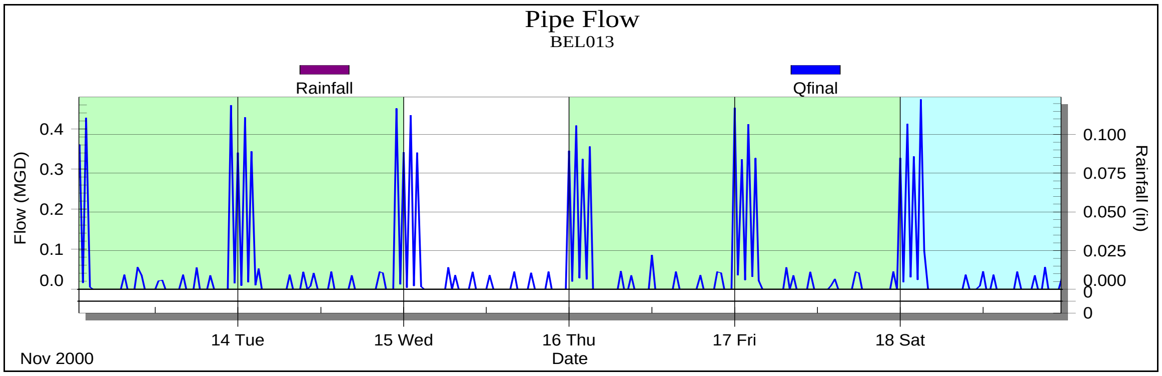
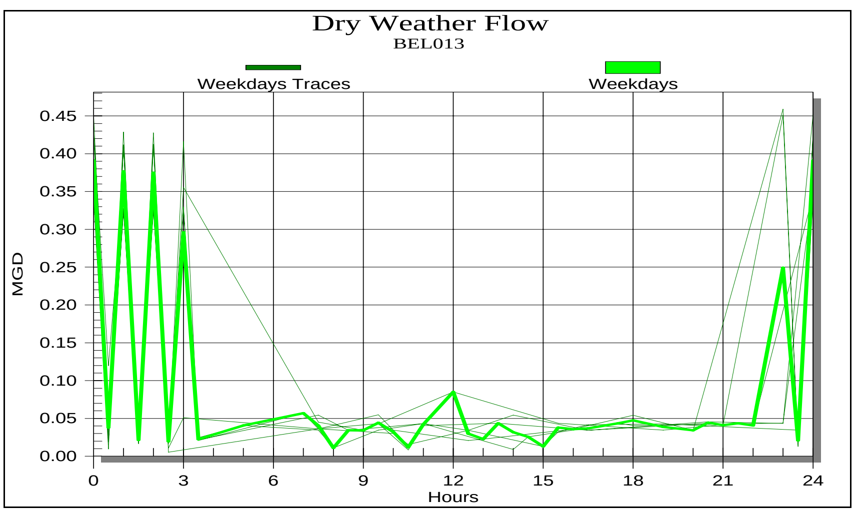


Figure F4 shows the diurnal ADDF hydrograph from BEL013 along with all the traces from the selected weekday dry days. The pattern is controlled by pump cycles and is not the smooth shape anticipated by the BI estimation method. The BI estimation method calculates BI at – 0.008 MGD. Negative BI values can be calculated from pump station flow as well as from Mini Basins that have multiple upstream meter subtractions. Negative BI values are reported as zero (0) in Appendix A. No method for estimating BI is immune to this phenomenon.

Figure F4
ADDF Hydrograph for Selected Dry Days for BEL013 – BI = -0.008 MGD



4. Peak I/I in 30-minute Intervals

"I/I" is calculated by subtracting the ADDF from measured flow on 30-minute intervals. The calculated Peak I/I can be an event not related directly to the rain response. Minor changes in the timing of flow are a common cause. Two examples are the presence of a holiday and a change in work hours. Figure F5 is the storm hydrograph from BRR005 in Brier for the rain event of November 7, 2000. Flow on Veterans Day, Friday November 10, 2000 was similar to the weekend flow pattern as residents likely delayed their morning activities. The delay resulted in a calculated Peak I/I of 0.027 MGD, which is twice the Peak I/I of 0.012 MGD due to the rain event. Also the calculated peaks are "jumpy" due to upstream pump station cycling. If pump station flow is a major contributor to the Mini Basin flow, the calculated Peak I/I will approximate the pump capacity. The peaks from Veterans Day affected many Mini Basins so the analysis for this rain event excluded Peak I/I measurements within the last 24-hour period in the calculation window (72 hours from start of rain.)

Figure F5
Significant Increase in Peak I/I in Mini Basin BRR005 Due to Veterans Day

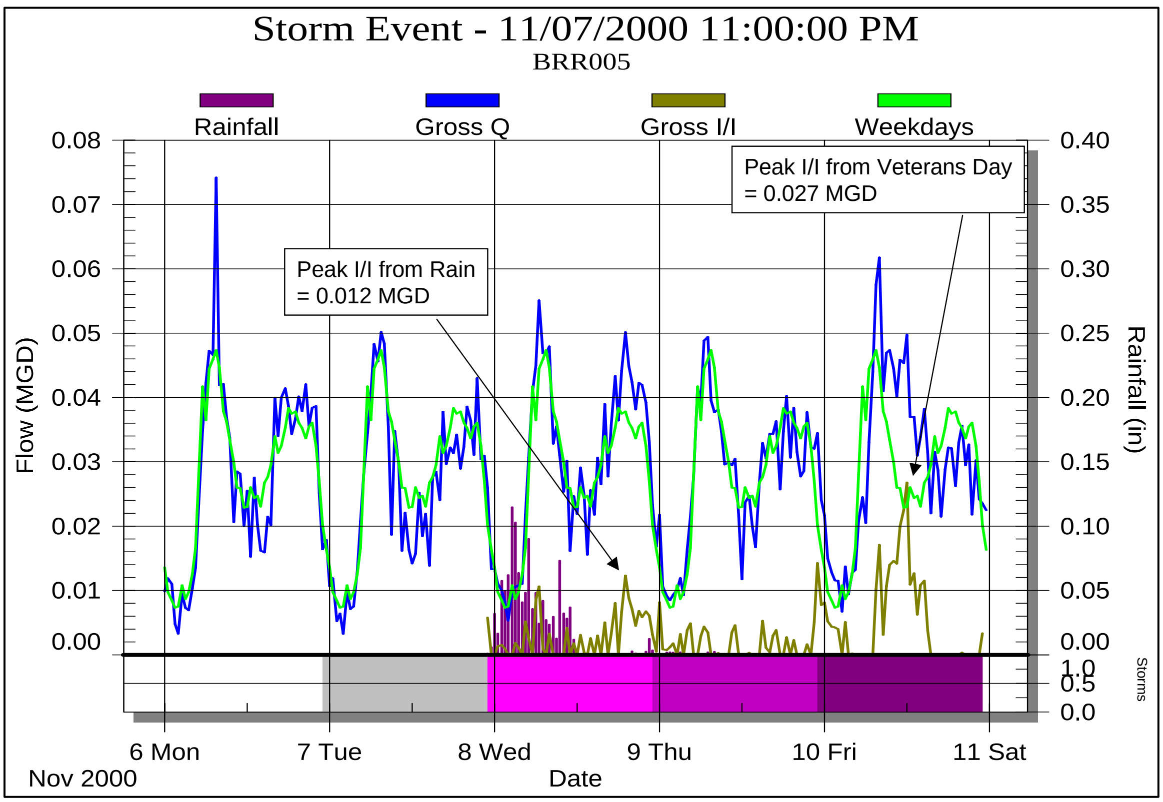
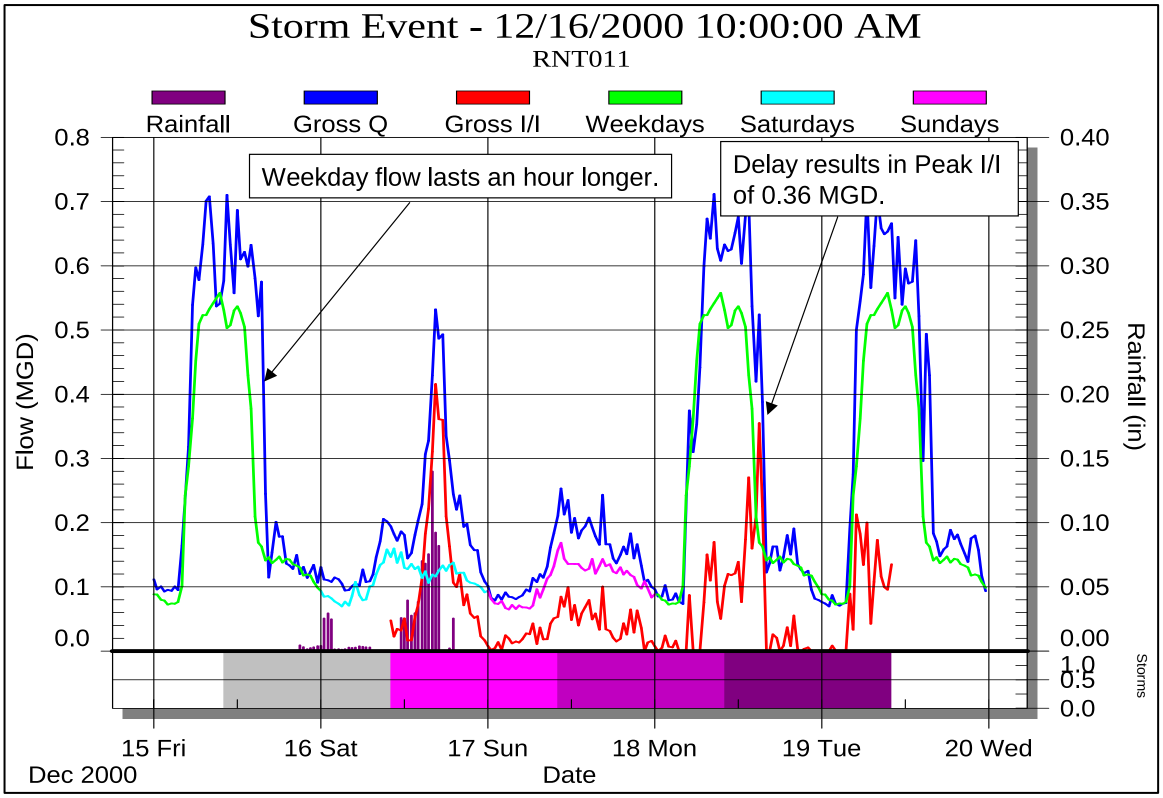


Figure F6 is the storm hydrograph from the December 16, 2000 rain event from Mini Basin RNT011 in Renton. This Mini Basin contains downtown office/commercial use plus the Boeing Engineering Center. There is a dramatic difference in dry day shapes between weekdays and weekends, which is common for this land use. The measured weekday flows remain high for an hour or so longer than average dry day, due apparently to extended work hours from early in November. The calculated Peak I/I is 0.41 MGD from the rain and 0.36 MGD from the extended work hours. The analysis for this rain event excluded Peak I/I measurements within the last 24-hour period in the calculation window, so this phantom Peak I/I was disregarded.

Figure F6
Extended Work Hours Cause Increase in Calculated Peak I/I in Mini Basin RNT011

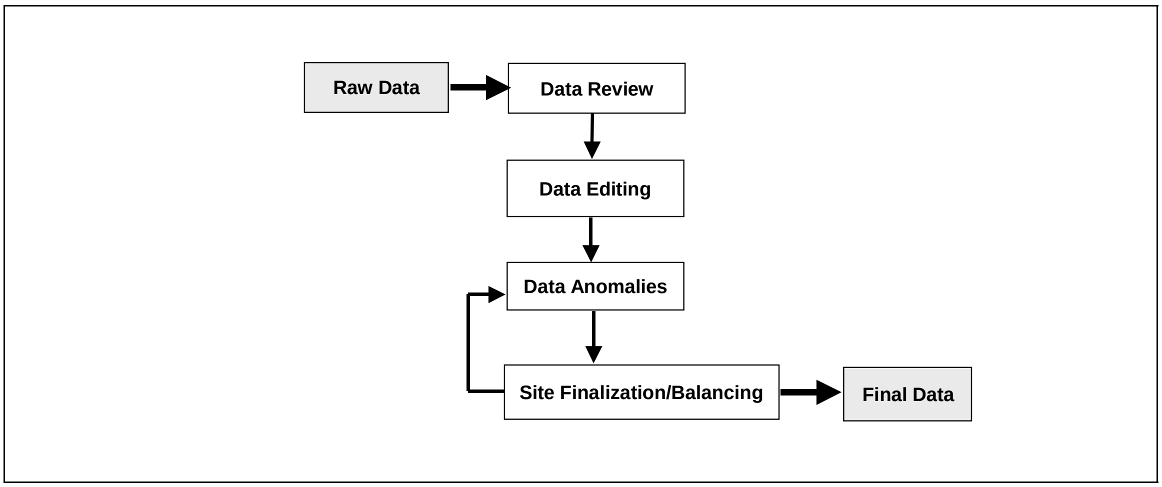


G. The Process for Analyzing Flow Data

Raw data collected by flow meters undergo several processes to achieve the status of final data. Final data are used to calculate dry weather flow and I/I. This series of steps brings a high level of reliability to I/I calculations.

There are several key steps in processing raw data to final data as illustrated in Figure G1 and these steps are discussed in Sections G1 – G4.

Figure G1
Steps to Process Raw Data to Final Data



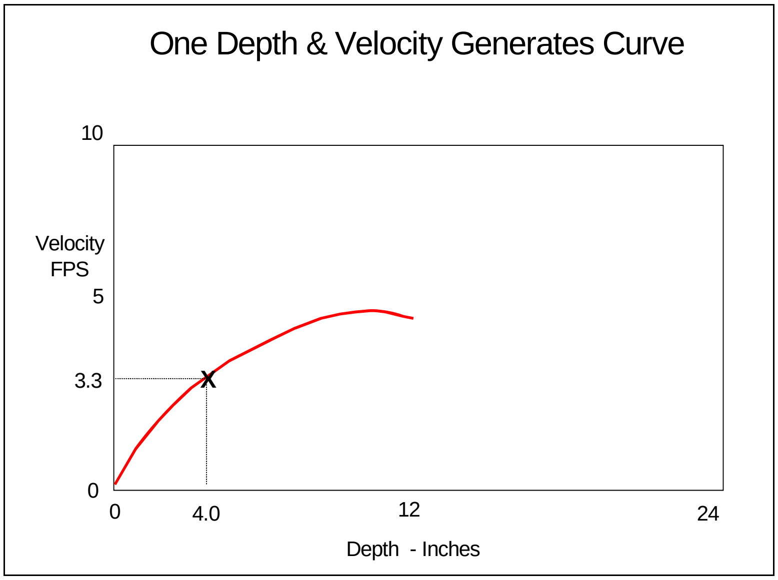
1. Scattergraphs for Understanding and Editing Flow Data

A new technique and has been developed within the last 7 years for using a scattergraph to analyze flow data. It has become an integral part of the ADS data analysis process and it is important for the reader to understand the scattergraph principles and editing methods. In addition the scattergraph technique offers insight to understanding sewer hydraulics. Many of the hydraulic observations in Appendix C are derived from scattergraphs. This section is intended to provide an introductory background in scattergraph principles and provide examples of some of the hydraulic observations that can be made. The scattergraph technique can also be applied to data editing as a method of “reconstituting” velocity data. Data reconstituting is discussed later in this section.

a) Scattergraph Principles

The scattergraph technique is based on the theoretical Manning pipe curve, which describes the relationship between the depth and velocity in open channel gravity flow sewers. For a given depth of flow, there is a unique and predictable velocity. A theoretical pipe curve is generated for any sewer by adjusting the Manning equation to pass through a pair of contemporaneous depth and velocity readings (Figure G2).

Figure G2
The Pipe Curve Originates At Zero
and Passes through a Field Measurement

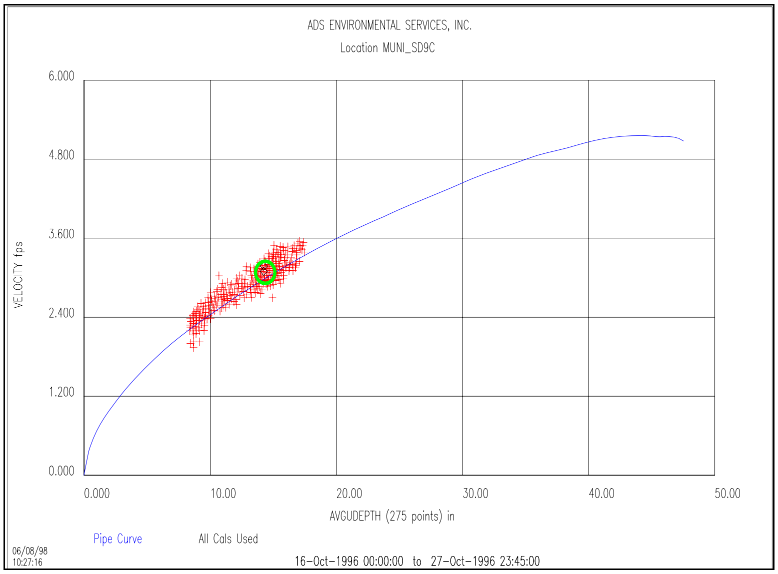


The theoretical Manning equation often does not represent the actual hydraulics many pipes, however, it is sufficient as an approximate standard against which actual data points can be compared. The plot of paired depth and velocity readings from an open channel flow meter over several days should form a pattern similar to the pipe curve.

Figure G3 is an almost ideal scattergraph displaying three sets of data

1. A Manning pipe curve;
2. Depth and velocity data points collected by a flow meter for 10 weeks and
3. Several pair of manual depth and velocity field measurements to verify proper operation encircled in green.

Figure G3
Three data Sets Combined to Verify Accuracy



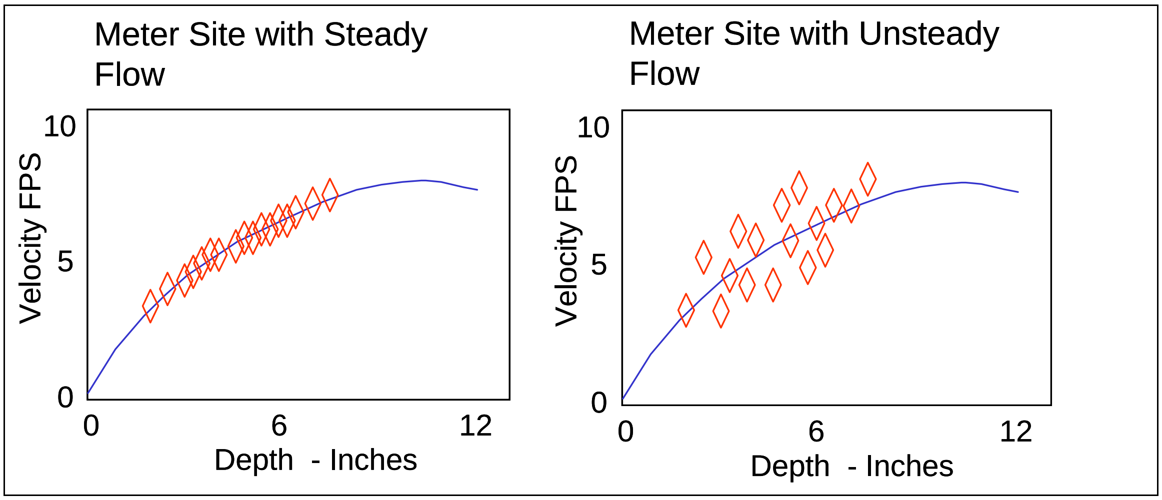
The highly linear grouping of the data indicates that the meter is collecting repeatable data. The fact that all three data sets coincide so well indicates the meter is also accurate.

Note that scattergraphs in this document adhere to mathematical convention and display the independent variable (depth) on the X-axis. This differs from most textbooks that historically have plotted depth on the vertical Y-axis.

b) Steady and Unsteady Flow

A review of a scattergraph can provide information on the steadiness of flow. Steadiness of flow is a function of how rapidly the depth and velocity changes. The left scattergraph in Figure G4 is from steady flow, which occurs in sewers without pump stations or other rapidly, changing flow. The scattergraph on the right would be expected from rapidly changing flow such as with a cycling pump station upstream.

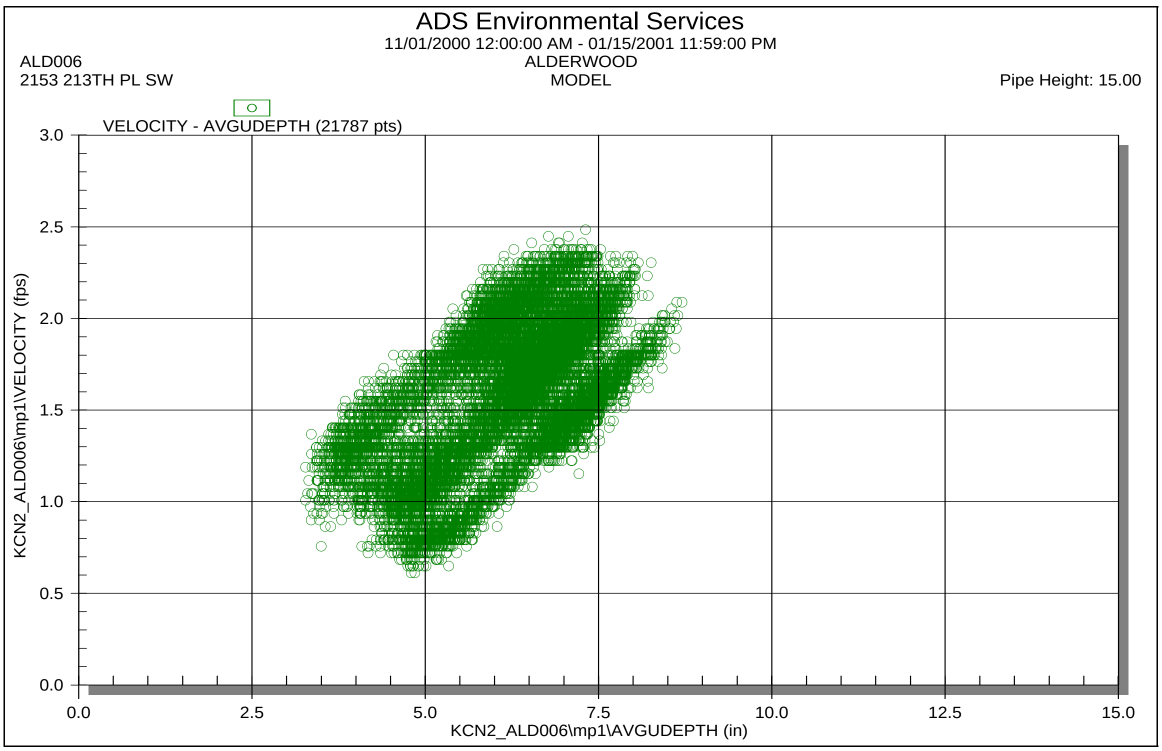
Figure G4
Steady Versus Unsteady Flow Effects on Data Presented in Scattergraph Format



c) Shifting Debris

Debris and silt in sewers can cause considerable hydraulic change over time and such changes downstream of the meter are recognized by shifts in the pattern traced by depth and velocity data. Figure G5 illustrates this event in Mini Basin ALD006 located in the Alderwood Sewer District. The characteristic feature of shifting debris is the gradual shift of the flow pattern to a deeper and slower condition, which is lower and to the right on the scattergraph. Often such conditions are due to debris collecting during dry weather and being washed away during wet weather. The cause of the debris is downstream of the meter and was not identified by the field crew. A major shift occurred on November 17, 2000 when the pattern shifted from the lower right to the upper left. This change corresponds to the debris being removed or washed away.

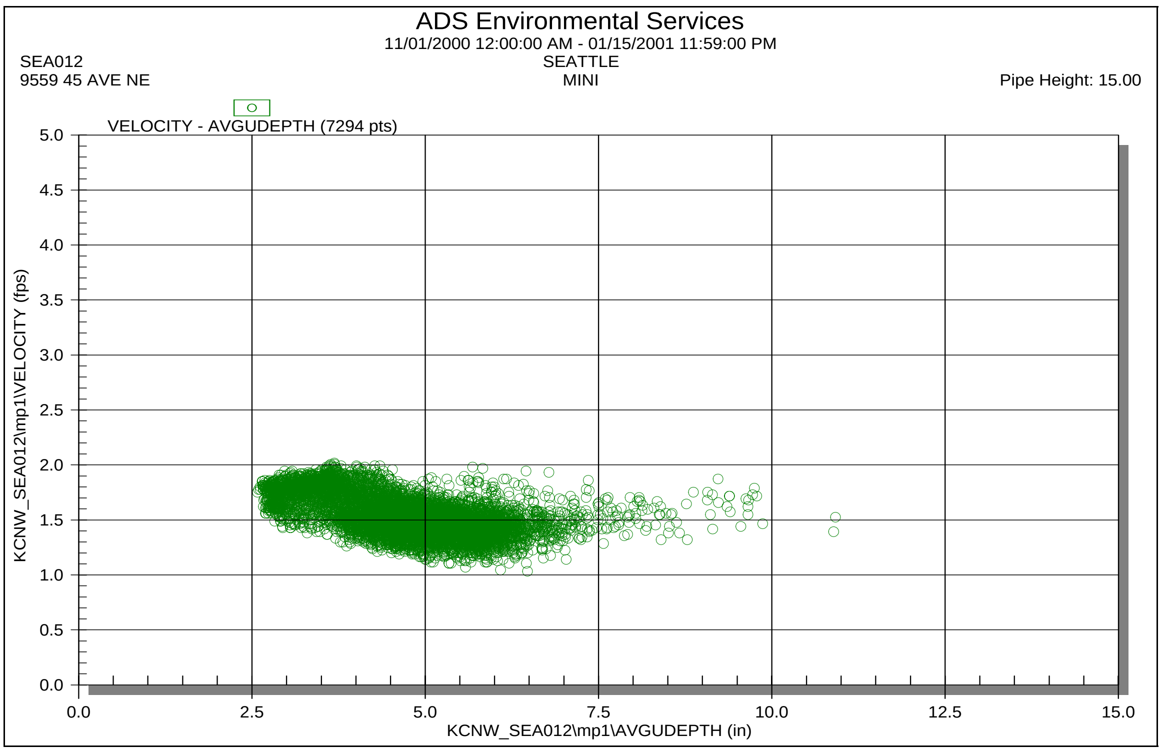
Figure G5
Effect of Shifting Debris and Silt on Data Presented in Scattergraph Format



d) Downstream Hydraulic Bottleneck

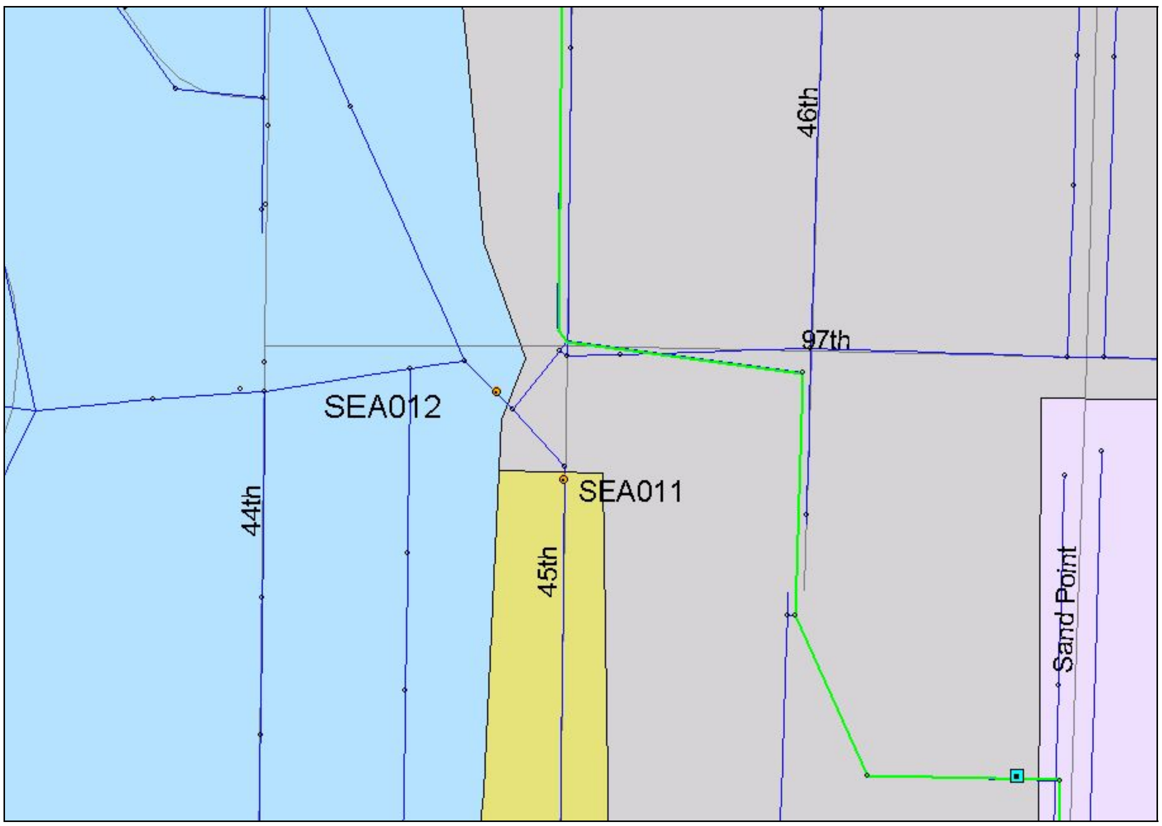
There are several metering sites at junctions with two or more incoming lines into the same manhole. These junctions often form hydraulic bottlenecks, which prevent either line from carrying full capacity. The characteristic pattern is a decrease in velocity with increasing depth. Figure G6 illustrates this effect at Mini Basin SEA012.

Figure G6
Scattergraph of SEA012 Meter Data Indicating Presence of Downstream Bottleneck



A map of Mini Basin SEA012 and sewer lines are shown in Figure G7. The metering site for Mini Basin SEA012 is on one of two incoming lines to a turning manhole. The sewer line from Mini Basin SEA011 enters the manhole from the opposite direction. In this condition the depth of flow is controlled by the combination of flow from both flows plus the head loss due to exit conditions of the outgoing line.

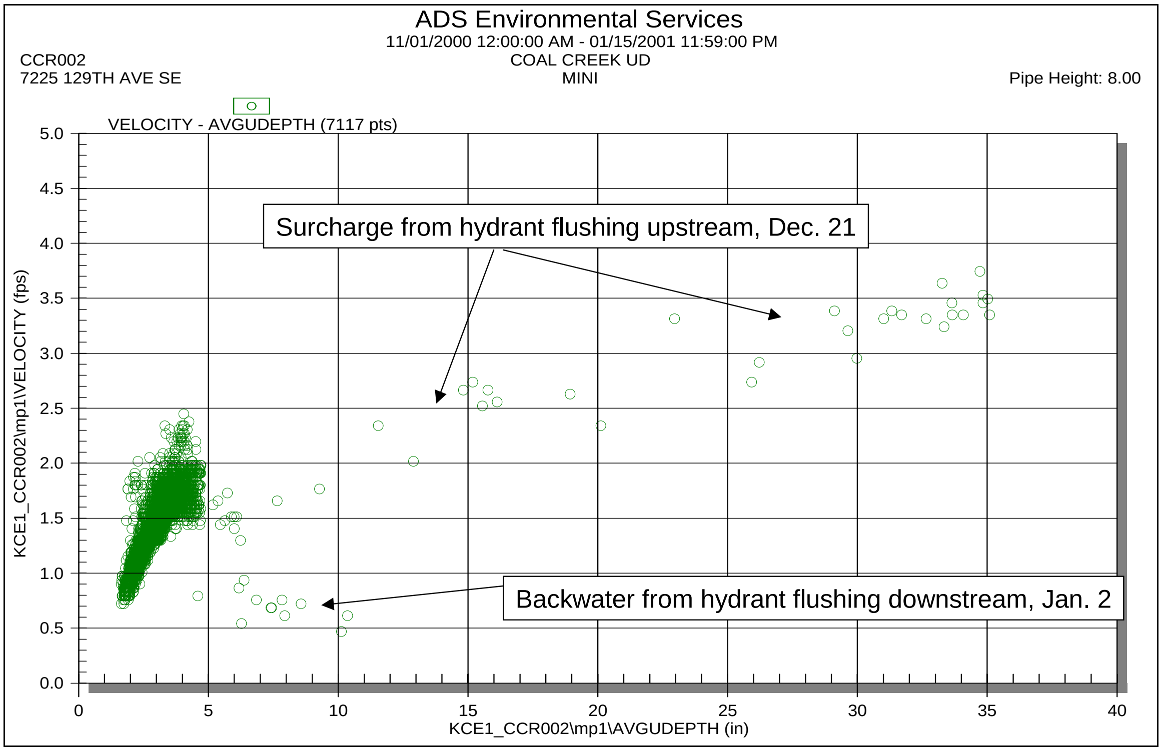
Figure G7
Location of Mini Basin SEA012



e) Unusual Hydraulics

The meter in Mini Basin CCR002 in Cedar River Water and Sewer District captured two distinctly different flow patterns during a flushing operation on a new potable water line. Flushing occurred upstream on December 21, 2000 and surcharged the metering site. Flushing occurred downstream on January 2, 2001 and caused the metering site to operate in a backwater condition. Both conditions are shown in Figure G8.

Figure G8
Scattergraph of both Surcharge and Backwater for CCR002



2. Editing Procedures

a) Data Review

Data Review is the process of evaluating the depth and velocity readings recorded by the flow meter at a set time interval (15 minutes for example). Data review is conducted by both the field crews during weekly data collections and by the analyst as processing continues. Field crews review the data to ensure that sensors are operating correctly and to look for invalid data resulting from sensors that may be affected by debris. Invalid depth or velocity readings may be taken by the meter if the Ultrasonic depth or Doppler velocity sensors require cleaning or if a sensor has failed and requires replacement. Debris such as rags, paper and grease can build up on sensors during normal operation and if the sewer experiences frequent surcharging. Invalid depth and velocity readings remain in the data set even after the data are edited. Invalid velocity data can often be “reconstituted”. Velocity reconstitution is discussed in Section G. 2. e).

b) Data Editing

Data Editing is the process of identifying and “flagging” data in the flow metering database. “Flagging,” means that the data record (date, time and entity value) is retained in the database but is accompanied by a “flag” indicating the validity status of the record. If an identifiable invalid reading was left in the database, final flow quantities calculated from that data record would be incorrect. Data analysis procedures ensure that all identifiable invalid data are either flagged or reconstituted. Profile™ software displays the flagged status of a data point by its color. Valid data may appear in any color except red, whereas invalid data is colored only in red. Valid data on a scattergraph defaults to green. Downtime for a meter is based the duration of invalid and missing data.

The following sections illustrate how invalid depth and velocity data are identified, flagged and reconstituted. Only data that are clearly invalid are flagged. If the possibility exists for questionable data to be the result of unusual hydraulics rather than invalid data, the data are not flagged or reconstituted.

I. Invalid Depth Data

Invalid depth and velocity data are identified through scattergraph analysis and/or hydrograph analysis. Figures G9 – G11 show how invalid depth data are identified and flagged.
Figure G9 is an example of invalid depth data identified through scattergraph analysis when debris built up on the ultrasonic sensor at the metering location.

Figure G9
Scattergraph of Invalid Depth Data due to Debris on Ultrasonic Depth Sensor

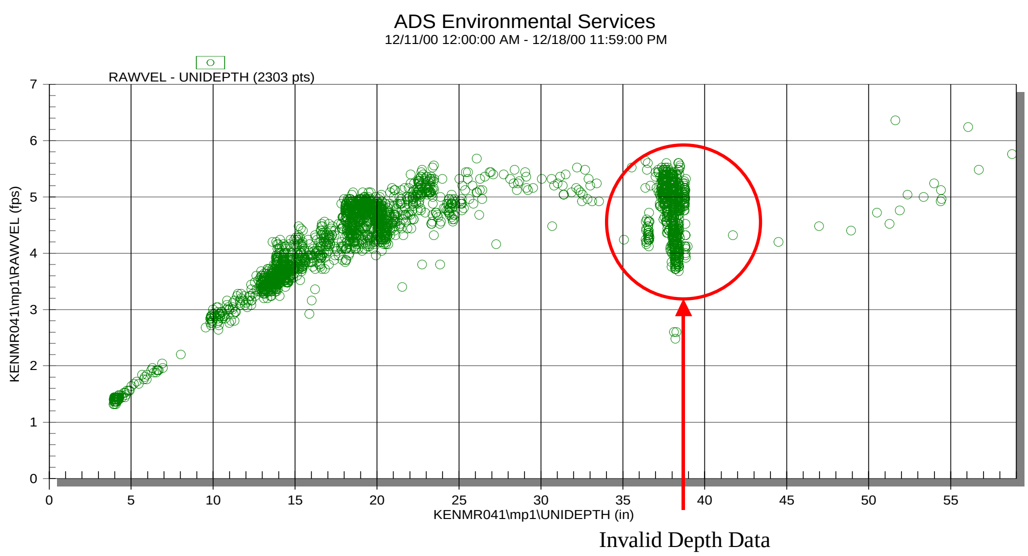
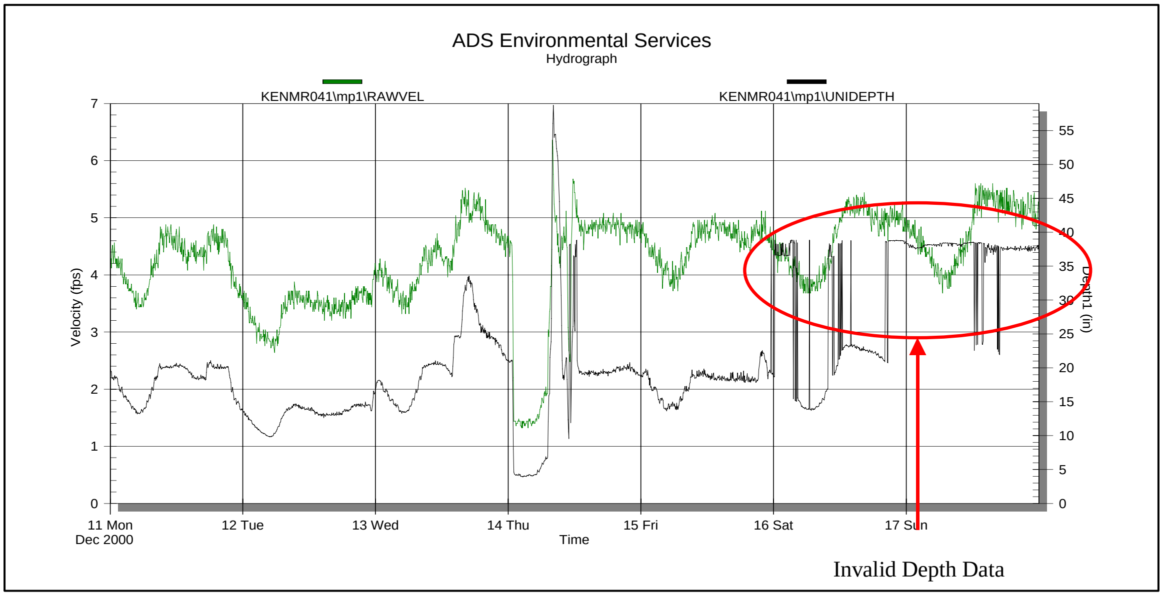


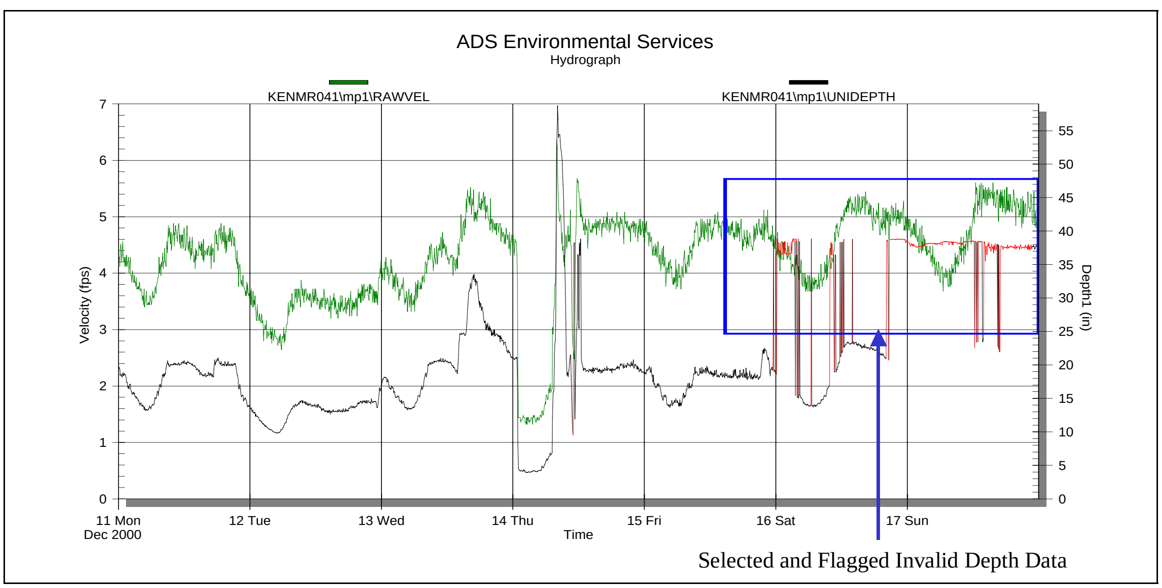
Figure G10 displays the same data as Figure G9, but in hydrograph format.

Figure G10
Hydrograph of Invalid Depth Data due to Debris on Ultrasonic Depth Sensor



The data analyst assigns an invalid data flag to the data graphically by "selecting" the invalid data within a blue box and, as illustrated in Figure G11, changes the data point or line color to red. The alternative to flagging the depth data is to reconstitute the depth data. The process of data reconstitution is explained in Section G. 2. e).

Figure G11
Selection and Flagging of Identified Invalid Depth Data on a Hydrograph



II. Invalid Velocity Data

Figures G12 – G14 illustrate how invalid velocity data are spotted and flagged. The invalid velocity data are the result of a sensor that became fouled.

Figure G12
Scattergraph of Invalid Velocity Data due to Debris on Velocity Doppler Sensor

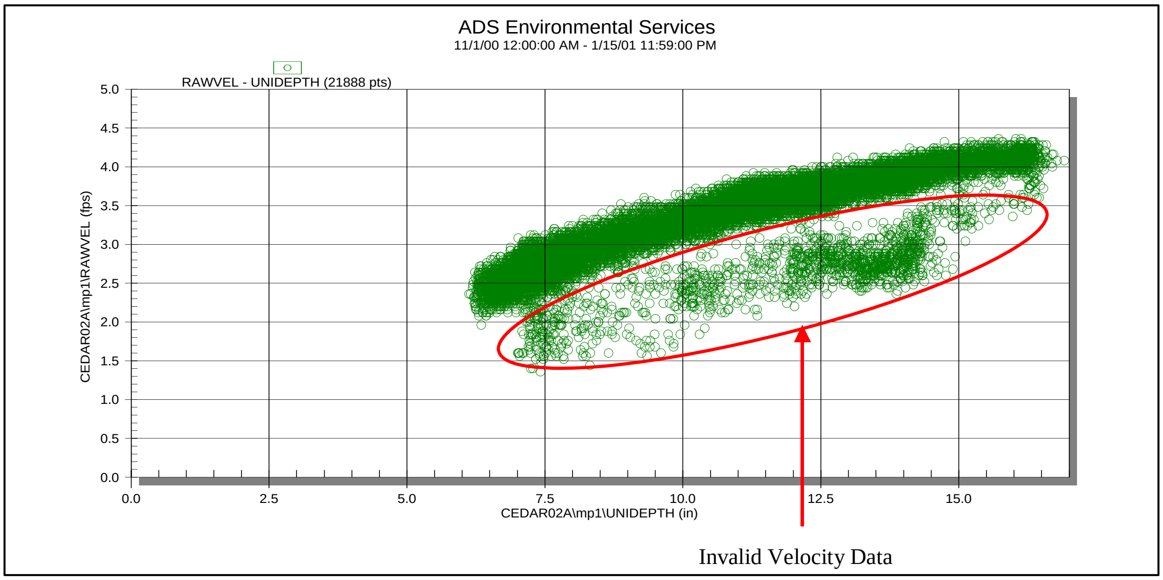
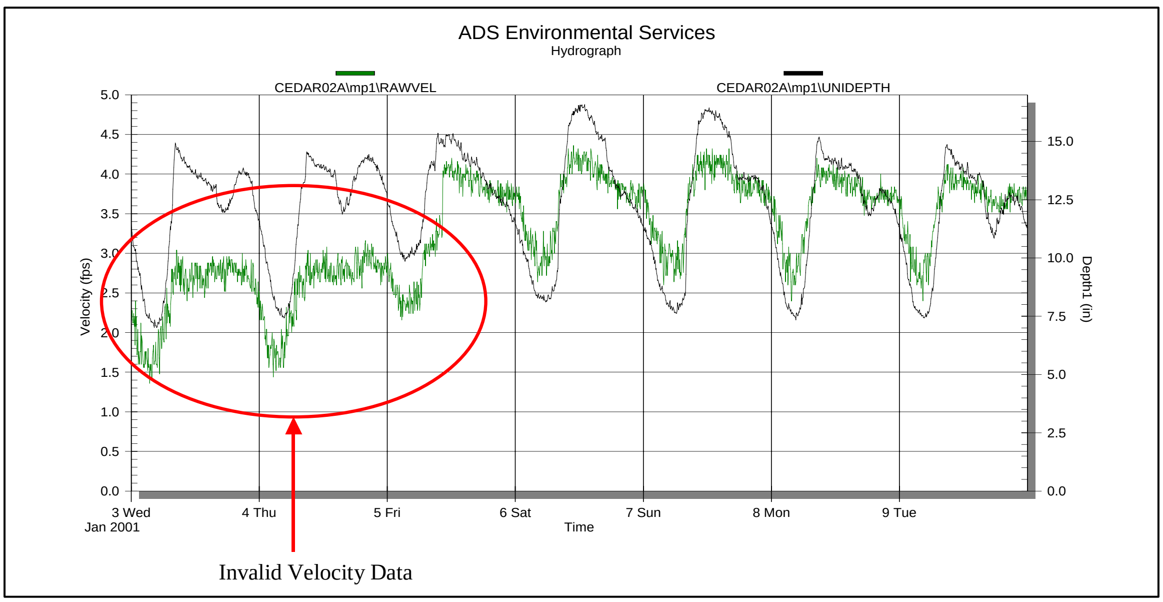


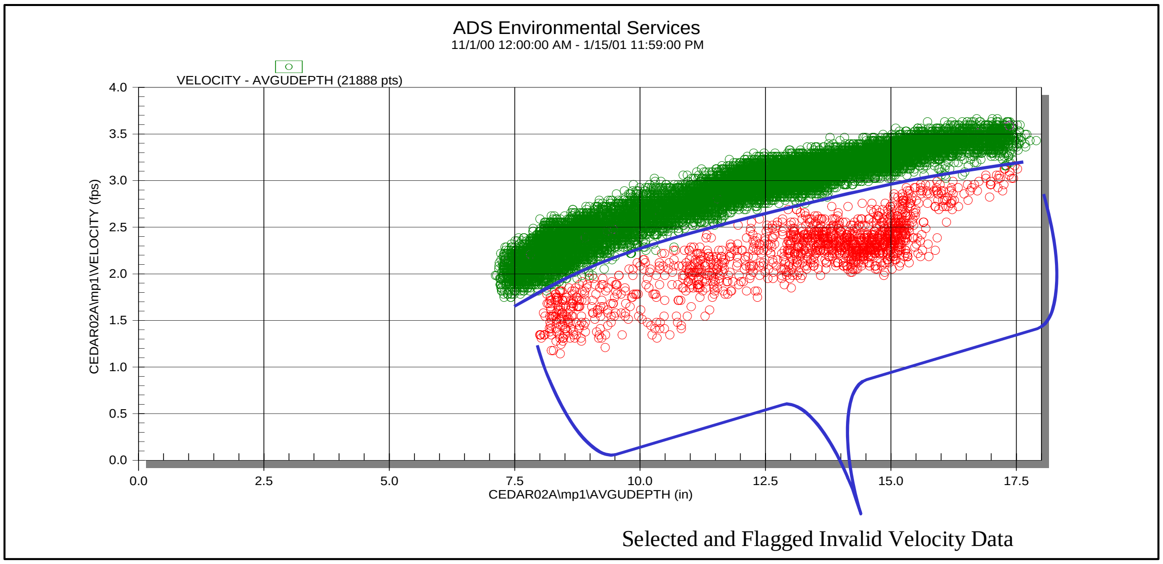
Figure G13 displays the same data, but in hydrograph format.

Figure G13
Hydrograph of Invalid Velocity Data due to Debris on Velocity Doppler Sensor



The data analyst assigns an invalid data flag to the data by selecting the invalid data. The color of the flagged data points automatically change color from green to red as illustrated on the scattergraph in Figure G14. The alternative to flagging the velocity data is to reconstitute the velocity data. The process of data reconstitution is explained in Section G. 2. e).

Figure G14
Selection and Flagging of Identified Invalid Velocity Data on a Scattergraph



c) Data Reconstitution

Reconstitution of data is a scattergraph-based process for restoring invalid data to an established pipe curve for the metering site. The process requires that the hydraulics at the metering site be regular and repeatable. A best-fit curve is fit to the scattergraph of valid data that represents the depth-velocity relationship for the metering site. Only depth or velocity data individually may be reconstituted for a given period of time. Figure G15 shows a blue best-fit curve drawn on a scattergraph. The red oval identifies invalid velocity data to be reconstituted.

Figure G15
Best Fit Curve for Data Displayed on a Scattergraph

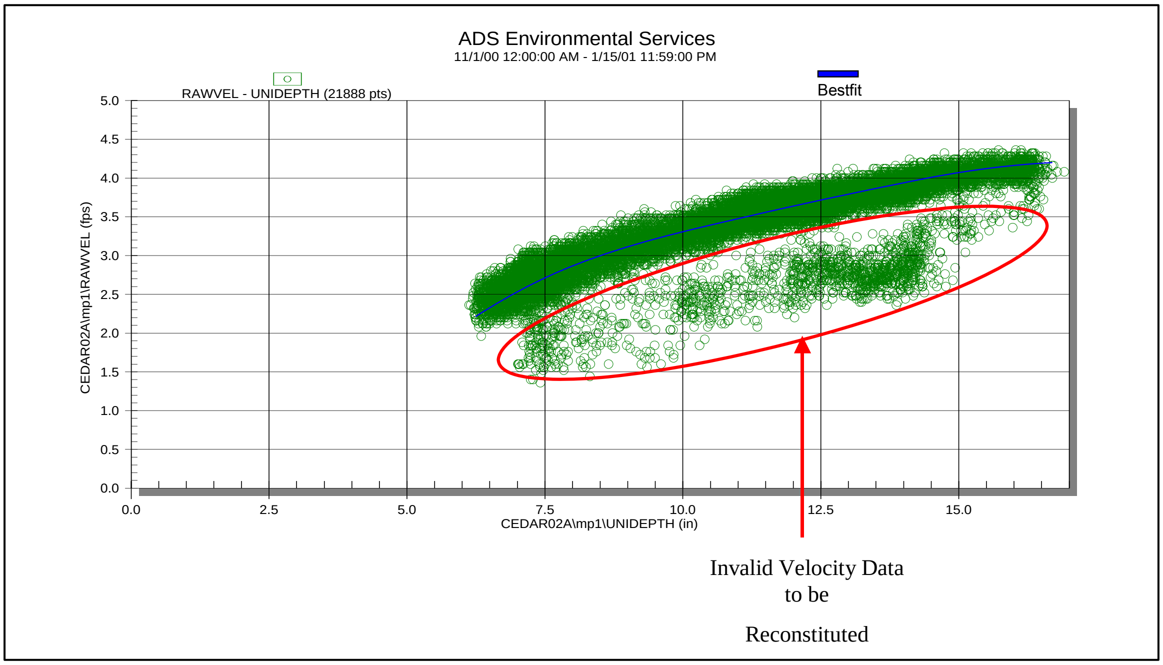


Figure G16 is an example of invalid velocity data being reconstituted. The magenta points on the blue best-fit line are the reconstituted velocity data points previously identified in Figure G15.

Figure G16
Reconstituted Velocity Data on a Scattergraph

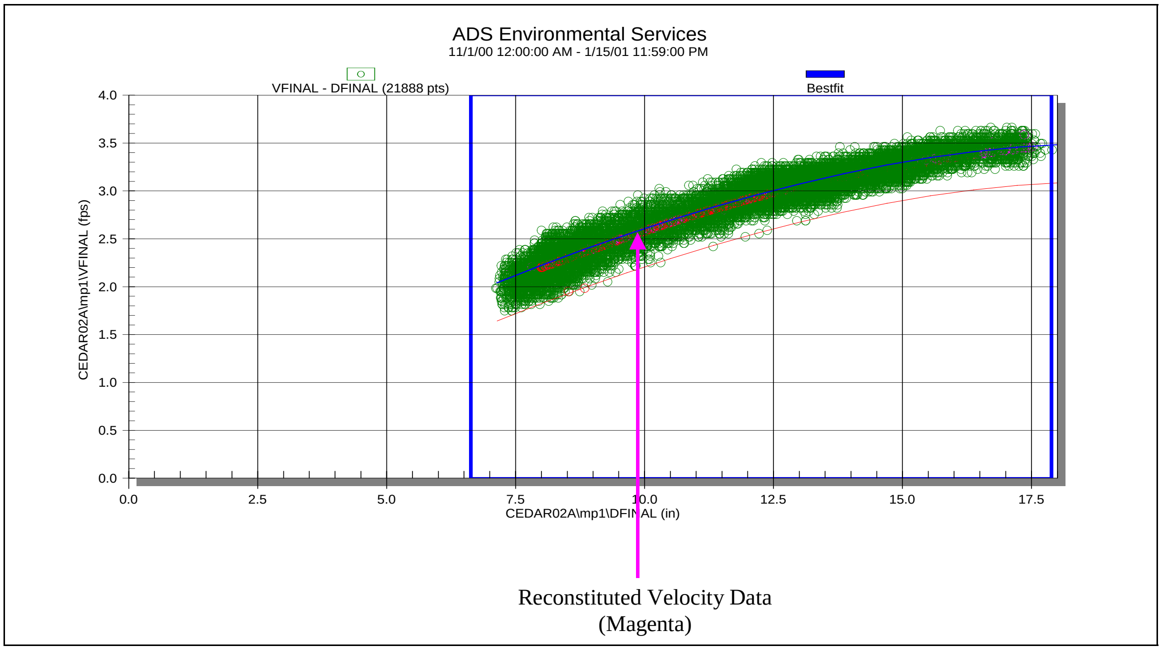
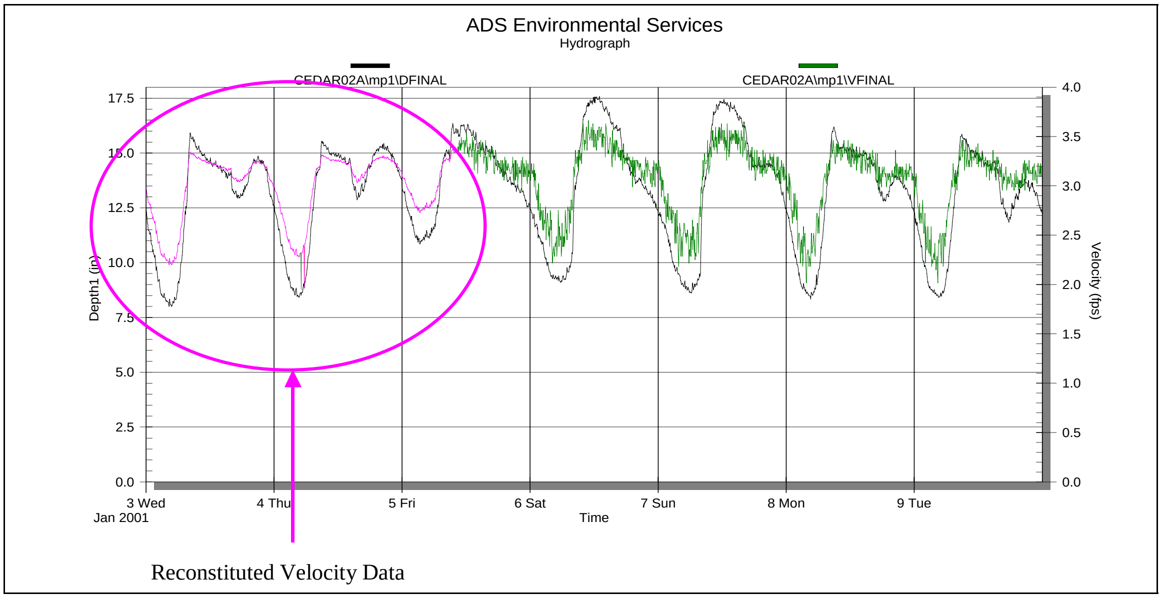


Figure G17 is the hydrograph of the reconstituted velocity data. The magenta velocity data are the reconstituted velocity data (existing data is green). The black data are the depth data that are valid throughout the time period.

Figure G17
Reconstituted Velocity Data on a Hydrograph



d) Data Anomalies

Data anomalies are those data sets that generate scattergraph patterns that do not conform to one of several expected hydraulic conditions. Additional field effort is spent confirming and investigating the hydraulic conditions at these sites. The data remain valid unless it is determined from a field visit that data do not represent actual field conditions. Figure G18 is a scattergraph that was initially considered a data anomaly. It was confirmed that this site exhibited a backwater condition at depths greater than 5 inches as a result of the grease and debris restricting the flow through the outgoing sewer from the meter location. Figure G19 is a photograph of the outgoing line conditions.

Figure G18
Data Anomaly Backwater Condition at ABN007

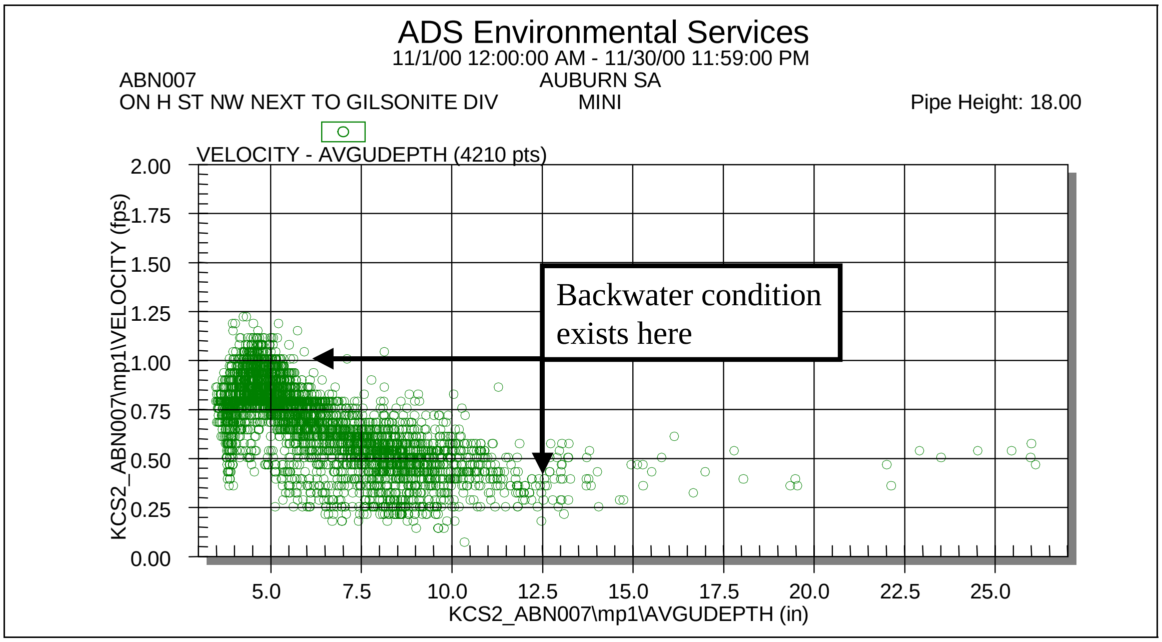


Figure G19
Photo of Outgoing Line at ABN007

3. Finalizing Meters with Confirmations

Data finalization is the process of comparing manual field confirmation data with meter data. This comparison is made to ensure correct meter installation and to ensure identification of any unusual hydraulic conditions (such as silt or poor flow channel conditions) that would not otherwise be detected without a field visit and that may have an impact on the final measured flow quantity. Confirmations are completed and evaluated by field crews at the meter location and data analysts in the office evaluate the information collected again.

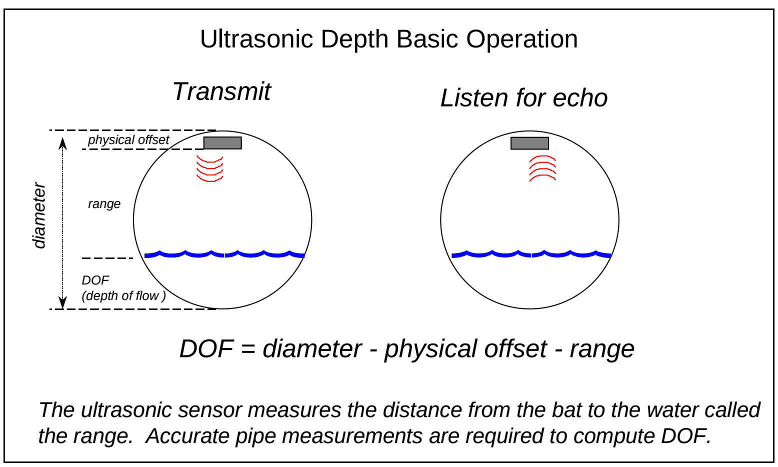
a) Field Crew Confirmations

Manual field measurements of the depth of sewer flow are taken using a ruler and the flow velocity is measured using a hand held propeller or magnetic, velocity meter. Field Crews descend the manhole to take manual measurements. After the Field Crew has recorded both depth and velocity manual measurements, the ultrasonic depth and Doppler velocity sensors attached to the monitor are activated to take a reading. This occurs *as soon as possible* after the time that the manual measurements were taken. The measurements taken by the Field Crew and recorded by the monitor are then compared to assure consistency.

b) Confirmation of Depth of Flow

The ultrasonic sensor is positioned at the top of the pipe measuring the distance to the water surface. Depth of Flow (DOF) is calculated as shown in Figure G20.

Figure G20
Calculating Depth of Flow using an Ultrasonic Depth Sensor



The DOF calculated by the meter and the DOF measured manually by ruler are compared to one another. If the difference between the meter calculated depth of flow and the manually measured depth of flow is greater than ±0.25 inches, it most likely signifies that one of the components of Figure G20 have been measured incorrectly. These components are remeasured and the confirmation performed again. Limited work space in the meter location manhole, limited bench room on which to stand or kneel in the manhole or poor flow conditions at the meter location (wavy or flow greater than 7 ft/s) are a few examples of conditions that may make it challenging to measure the components of Figure G20.

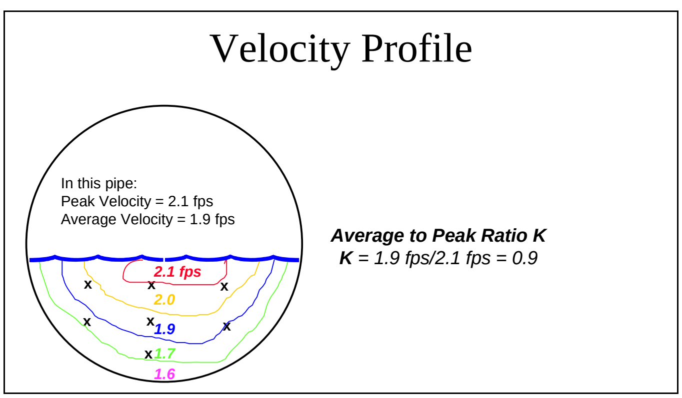
c) Confirmation of Velocity

The velocity measured by the meter is compared to the velocity measured by the manual hand-held velocity meter. If the measurements differ by greater than 0.25±ft/s, it most likely signifies that peak velocity has been measured incorrectly either by the field crew or by the meter. The confirmation is performed again until the source of error is located and fixed (velocity sensor replacement would be required if it was determined that the velocity sensor was failing to measure peak velocity). Peak velocity measurements are subject to the same challenges of limited workspace and flow velocities greater than 7 ft/s, as field depth measurements are.

In addition to the challenge associated with taking manual field confirmations detailed above, flow that is influenced by an upstream pump station increases the difficulty of taking a manual confirmation. The depth and velocity change rapidly at a meter location where the flow at a meter location is influenced by an upstream pump cycle. The change can happen so rapidly that the depth and velocity at the point in time when the field crew took a manual measurement and the depth and velocity recorded at the point in time that the meter sensors were activated manually by the field crew may be significantly different (greater than ±0.25 inches and/or greater than 0.25±ft/s). To confirm that the ultrasonic sensor at these sites is reading correctly, a flat surface is placed a known distance from the ultrasonic sensor and the ultrasonic sensor is activated to take and record a depth value. The recorded depth value is then compared to the known distance.

The Doppler velocity technology measures peak velocity, which is converted to an average velocity by an average to peak ratio (A/P). The A/P is site specific but in the vast majority of sites is 0.9. Sites with an average DOF consistently greater than 5 inches had velocity profiles performed to determine the A/P. Five (5) inches of flow is necessary to ensure a valid profile. The A/P is obtained by averaging point velocities taken throughout the flow as indicated in Figure G21. The profile conforms to ISO 748. Sites with an average DOF between 0 and 5 inches that could not be profiled use an A/P ratio of 0.90.

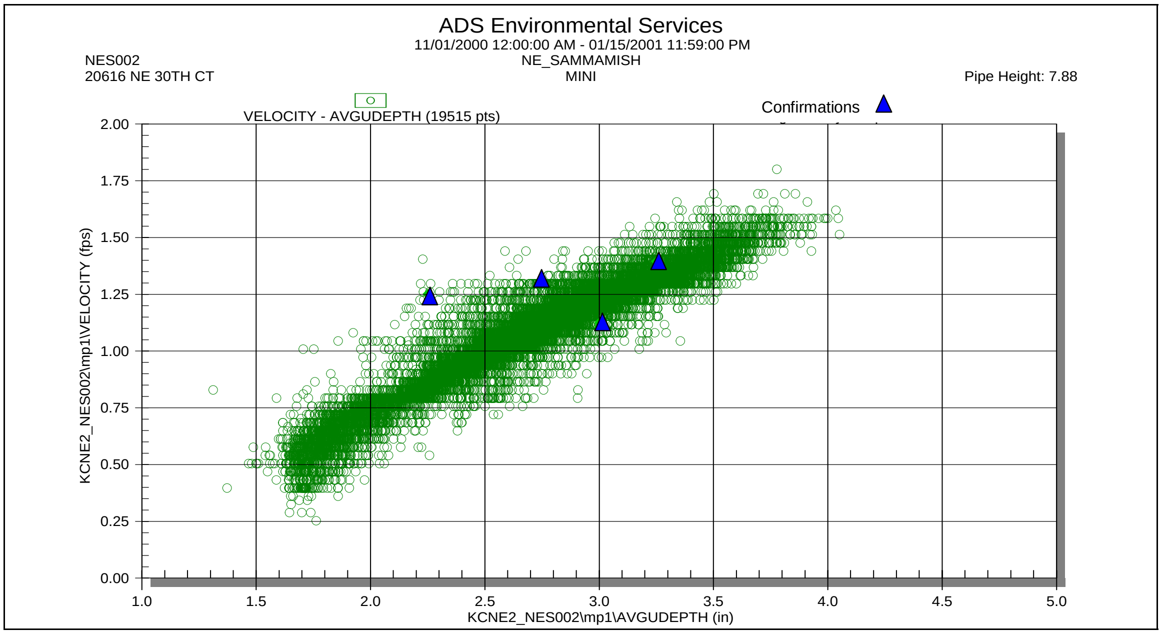
Figure G21
Example Velocity Profile in Sewer



d) Data Analyst Data Finalization Procedure

A data analyst evaluates field confirmations by plotting them in conjunction with a scattergraph of the data as illustrated in Figure G22. The confirmations that lie within the scattergraph confirm that the sensors and field confirmations are consistent and no further velocity or depth adjustments are required. If confirmations lie outside of the scattergraph, they may be used to adjust the depth and/or velocity data. Adjustments are not made until the flow balance procedure indicates that adjustments to the data are necessary to facilitate a flow balance.

Figure G22
Depth and Velocity Confirmations (Blue Triangles) Plotted on a Scattergraph



e) Calculating Q with the Continuity Equation

The meters used in the program are of the area-velocity type, which measure the depth and the velocity of wastewater flow. With finalized data, the rate of flow is calculated using the Continuity Equation shown in Equation G1.

Equation G1
Flow Continuity Equation

$$Q = \text{Cross Sectional Area} \times \text{Average Velocity}$$

Where:

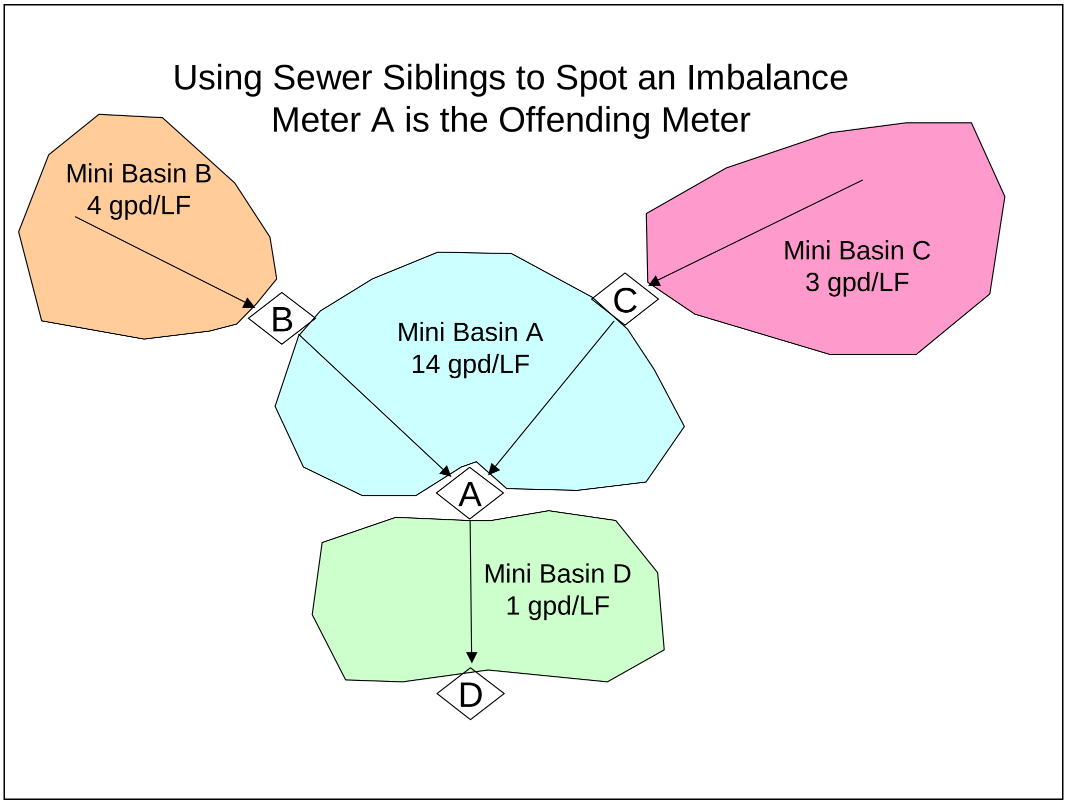
- Q is calculated in Million Gallons per Day;
- Cross Sectional Area of flow is in Square Feet and
- Average Velocity is in Feet per Second.

4. Flow Balancing Between Meters

Balancing is the last "fine tuning" procedure applied to the flow calculation by taking a network view of flow recorded from all upstream and downstream meters. Balancing is accomplished by comparing the calculated wastewater from a Mini Basin to the expected flow from the Mini Basin. One by one, each meter and its Mini Basin is evaluated along with the immediate upstream and downstream "sewer sibling" meters to arrive at wastewater production for a Mini Basin. "Sewer sibling" meters are those meters that are related by placement, immediately upstream and downstream of each other in the sewer system.

As a rule of thumb, a residential Mini Basin should produce wastewater at a rate of between 2 and 5 GPD/LF. Figure G23 is an example how Meter A is compared with its siblings on this basis. Mini Basins B and C are within the expected range. Mini Basin A is high and Mini Basin D is low. An offending meter is identified by a combination of high and low wastewater production in the Mini Basins upstream and downstream of it. This combination exists for Meter A and indicates that an additional level of attention by field crews or the analyst is required. The balancing step leads to adjustments that are smaller or finer than can be accomplished with manual field confirmations.

Figure G23
Using Sewer Siblings to Spot an Imbalance



H. Appendices

Appendices A and B share information on Gross and Net flows, acreage and CALAMAR measured rainfall. The calculation window was adjusted and widened during the Peak I/I analysis to include rainfall that preceded and followed the main rain event. As the result, the rainfall quantities in Appendix A are greater than those in Appendix B. Rainfall in Appendix B is the rainfall during the first 24-hour analysis period. In addition, the start times for the November 26, 2000 and January 4, 2001 rain events are earlier in Appendix A.

1. Appendix A – Measured 30-minute Peak I/I and Estimated Total Peak I/I

Appendix A is an Excel spreadsheet with data sorted by Mini Basin. The estimated Base Infiltration, expressed in GPD/Acre, is added to the measured Peak I/I for each rain event to develop the Estimated Total Peak I/I. Measured Peak I/I is in 30-minute intervals. Total I/I is any flow in the sewer other than wastewater and is discussed in Section D. Base infiltration, as discussed in Sections D 2 and F 4 is considered an estimate, not a measurement. The sum of the estimated base infiltration and the measured Peak I/I is also treated as an estimate in this Appendix. The following information is included:

a) Gross and Net flows in MGD;
b) Number of upstream meters subtracted to calculate net flows;
c) Mini Basin area in acres;
d) Estimated Base Infiltration in MGD and GPD/Acre;
e) CALAMAR measured rainfall for each Mini Basin and rain event;
f) Measured Peak I/I for each rain event and
g) Estimated Peak Total I/I for each rain event.

2. Appendix B – RDI/I and Rainfall Information

Appendix B contains Average Dry Day Flow and RDII volumes for each rain event. Wet weather data are organized by rain event. Event start time for each rain was the same for the entire service area and is listed in the header for each event. The items listed below are included in Appendix B. Definitions and explanations for each item are provided in Sections D and E.

a) Basin size information for sewer length and area of the Mini Basin.

b) Gross and Net Average Dry Day Flow (ADDF) in MGD.

c) Rainfall in inches for each event is provided for each Mini Basin. These rainfall data were established by the CALAMAR system and NEXRAD radar images calibrated by a network of rain gauges operated by the King County's Wastewater Treatment Division (WTD) and Water and Land Resources Division (WLRD).

d) Rainfall Dependent Infiltration and Inflow (RDII) for each Local Agency Mini Basin. RDII is measured as a volume in millions of gallons (MG) measured during a 24-hour period after the start of the event. RDII is the I/I due exclusively to the rain event and does not include infiltration existing prior to the rain.

e) "Normalized" RDII is given as a 24-hour volume in both Gallons per Linear Foot (G/LF) and G/Acre. Dividing the calculated RDII by the basin's LF or Acres produces these values. Normalized RDII measurements compensate for the size of each Mini Basin. No attempt has been made to assign a ranking to these values because of the low rainfall intensities and volume that occurred during the monitoring period. To put these values in perspective, a range of 2 to 5 G/LF is a common threshold that separates 'tight' Mini Basins from "leaking" Mini Basins. This range is regularly seen in systems that have experienced system-stressing rains common for the area.

3. Appendix C – Metering Site Information

Appendix C contains information about each metering site including:

a) Diameter of pipe at metering site;

b) Hydraulic observations of the sewer at the metering site and

c) Links to scattergraphs for selected sites.

4. Appendix D – Maps and Attachments

Appendix D is a folder containing supporting data in Word documents, Excel spreadsheets and maps in PDF format. Included are:

a) Map of the entire service area showing Mini Basins exceeding the Peak I/I rate of 1,100 Gal/Acre/Day;
b) Four Q to i diagrams for each Mini Basin found in a Word document named after the Mini Basin and
c) Spreadsheet of Upstream Meter Relationships that established the meters that must be subtracted to measure RDII for each Mini Basin.