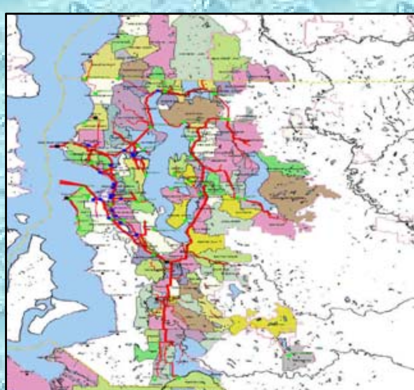
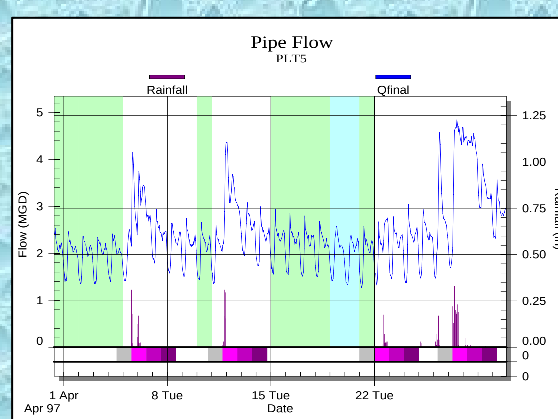
Regional Infiltration/Inflow (I/I) Control Program
King County, Washington

2001/2002 Wet Weather Flow Monitoring





King County
Department of Natural Resources and Parks
Wastewater Treatment Division

June, 2002

King County Regional Infiltration/Inflow Control Program
Wet Weather Technical Memorandum
2001/2002 Monitoring Period

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Primary ETT authors of this document were Patrick Stevens and Gillian Woodward of ADS. Marcos Lopez, Ed Pier and Mark Tobin of ET and Eric Bergstrom of HDR provided QA/QC review. Jeff Lykken of Tetra Tech/KCM and Tom MacBriar of Rosewater Engineering proofread the memo draft.

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King County Regional Infiltration/Inflow Control Program
Wet Weather Technical Memorandum
2001/2002 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 that collect and treat wastewater from 34 Local Agencies in King and Snohomish Counties. A third treatment plant is located on Vashon Island but was not included in this study. In the King County service area, the length of all Local Agency separated sewers is approximately 16 million feet (3,030 miles). Establishing the length of private property side sewers and/or laterals is presently in progress, but has been estimated to be 16 million feet (3,030 miles). The length of King County trunk sewers is approximately 0.9 million feet (170 miles) for a total in the service area of approximately 32.9 million feet (6,230 miles). This total does not include the combined sewer system in Seattle. Historically, the system experiences Infiltration/Inflow (I/I) during the wet season from October to March. As part of the Regional Wastewater Services Plan (RWSP) King County has initiated a multi-year effort to:

- Determine the wet weather performance and geographic distribution of I/I throughout the Local Agencies tributary to the King County collection system through flow monitoring;
- Conduct several pilot projects to evaluate the I/I reduction effectiveness of various rehabilitation approaches within the Local Agency sewer systems;
- Develop and calibrate accurate I/I and hydraulic models of the system and
- Prepare a King County Regional I/I Control Program for implementation.

A flow monitoring study was conducted during the winter of 2000/2001. This period is referred to as “last year” in this Memorandum, and due to limited rainfall on which to assess the wet weather performance of the system, the flow monitoring study was repeated in 2001/2002. This Technical Memorandum addresses the dry weather flow measured during the two flow studies as well as the wet weather performance of the Local Agency separated sewer system in 2001/2002.

2. Methodology

To assure that the wet weather performance of the Agencies was measured equitably, it was determined that the entire system would be subdivided into Mini Basins containing approximately 20,000 linear feet (LF) of sewer line and that the Mini Basin monitoring in all Agencies would occur simultaneously. Last year a total of 807 flow meters were used and for this study a total of 774 meters were used, 75 of which were permanently installed mostly within the King County collection system for long-term trend analysis. The reduction in the number of meters resulted from dropping several Mini Basins discharging to combined sewers and several Mini Basins that proved to be too small to accurately measure. Flow meters were in simultaneous operation from November 1, 2001 to January 15, 2002, a period of 76 days. Rainfall data for each Mini Basin were developed using CALAMAR radar rainfall technology and a network of 72 calibrating rain gauges listed in Table E1.

The initial flow metering objectives were to:

- Track long term flow trends within the King County collection system;
- Divide the entire system of Local Agency sewer lines into uniformly sized Mini Basins containing an average of 20,000 linear feet of sewer;
- Isolate flows crossing agency boundaries provided the flow is from a section of sewer with 10 manholes or more and
- Measure at least 95% of each Local Agency's sewers with a Mini Basin meter. Local Agency sewers not metered with a Mini Basin meter will be considered part of the King County sewer.

Wet weather performance in this document is defined as the rainfall-to-I/I relationship for each Mini Basin in each Local Agency.

3. Results

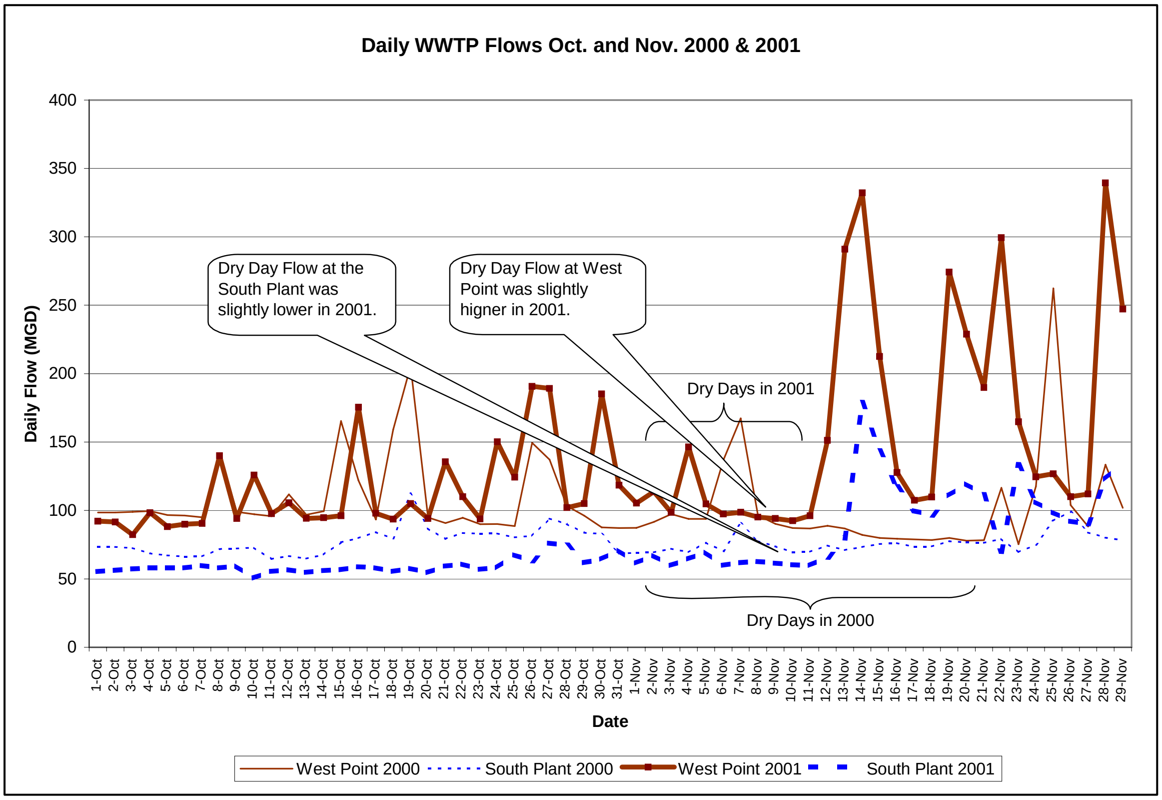
a) Dry Weather Flows

The average dry weather flow measured at all Mini Basin meters increased an average of 3% from last year. Of the 616 Mini Basin meters that were in the same location as last year, 206 Mini Basins (33.4%) were within 10% of last year's value. Another 206 Mini Basins (33.4%) increased by over 10% and 204 Mini Basins (33.1%) decreased by more than 10%. The decrease in dry weather flows could not be attributed to any one source including voluntary curtailment, water use, lower groundwater or reduced sales of water to commercial and industrial users.

A review of flow records at the two treatment plants was conducted to determine if significant differences in dry weather flow occurred. Compared to 2000, flow in early November 2001 during the dry day selection period was lower at the South Treatment Plant and higher at the West Point Treatment Plant. Figure A1 compares the daily flow at the South Plant and the West Point Plant for October and November 2000/2001 and 2001/2002. Although little rain fell during last year's study, the rainfall just prior to the study in September and October 2000 was slightly above average. The higher flows at West Point in 2000 reflect the higher rainfall totals since the plant treats most of the combined sewer portion of the system.

The periods during which dry days were selected for both years are shown on Figure A1. Dry days for 2001 were selected during a much shorter period in early November. Dry days for Mini Basins in 2000 were selected in November prior to November 22 while dry days for Mini Basins in 2001 were selected in November prior to November 12, 2001.

Figure A1
Daily Flow at Two Treatment Plants for 2000 and 2001



b) Rainfall

King County received an above-average amount of rainfall during the flow metering period. The average total rainfall at SeaTac airport for the months of November, December 2000 and January 2001 was 16.8 inches. Twenty-one point three (21.3) inches of rainfall was recorded there during the same three-month period in 2001/2002. During the flow metering period from November 1, 2001 through January 15, 2002, the King County service area received between 19 and 22 inches of rain, with the exception of the northern portion of the Alderwood area that received approximately 16 inches. Within King County, more rain fell in the south than in the north. The northern half of the service area received approximately 19 to 21 inches of rain, while the southern half received approximately 21 to 22 inches. On an event-by-event basis the rainfall varied dramatically over the service area. Rainfall maps for each rain event, as measured by CALAMAR, are included in Appendix B in the document Appendix B\Rainfall Maps\Rainfall Maps.doc.

An I/I analysis can be conducted when a measurable system-wide response occurs in the sewer network. There were approximately 18 discernable rain events during the period, but only 10 events resulted in measurable system-wide sewer responses and were suitable for I/I analysis. Table A1 lists both the range of rainfall and estimated return frequency for the 10 rain events. The range of rainfall is the least and greatest rainfall measured at any Mini Basin within the entire service area.

Table A1
Range of Rainfall for 10 Events over Service Area

Date of Rain Event	Rainfall (Inches)
November 4, 2001	0.1 – 0.6
November 13, 2001	1.4 – 5.2
November 19, 2001	0.9 – 2.4
November 21, 2001	0.6 – 2.9
November 28, 2001	1.8 - 4
December 12, 2001	0.6 – 2.3
December 15, 2001	1.4 – 2.9
January 1, 2002	0.4 – 1
January 6, 2002	1 – 2.6
January 12, 2002	0.1 - 1

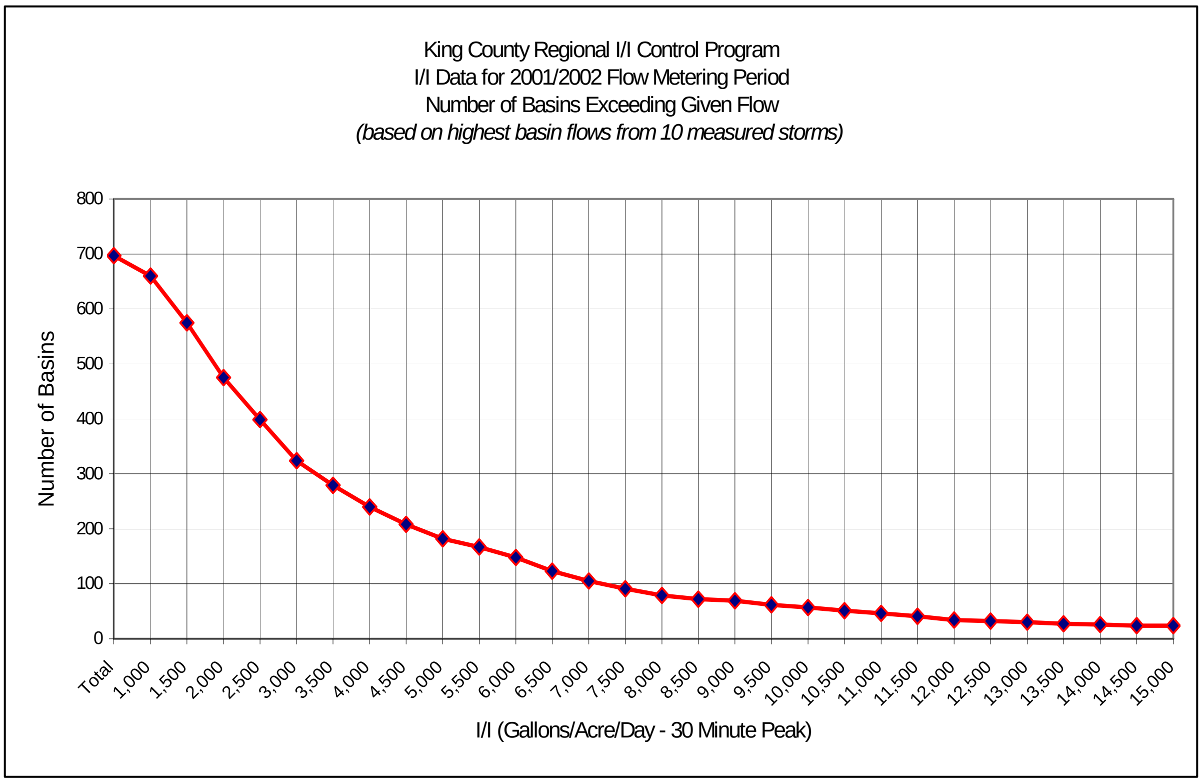
Please refer to Section E2 for detail on rainfall Intensity Duration Frequency (IDF) ranges for these storm events.

c) I/I Measurements

The Mini Basin temporary flow meters had an overall uptime of over 96.3%. This very high uptime resulted in the completion of a total of 96.4% of possible I/I measurements for all the Mini Basins and the 10 rain events. Meter uptime is defined as the percentage of data points that are recorded by a flow meter and considered valid. Conditions such as a build up of debris or surcharging can result in the sensors becoming fouled. Data collected during these conditions are considered not valid even though the meter continued to function. Meter uptimes are discussed in more detail in Section G and are listed in the attached spreadsheet UptimeFinal.xls.

Figure A2 shows the cumulative distribution of the maximum I/I measured for the Mini Basins for this year's metering period.

Figure A2
Total Number of Mini Basins Exceeding a Given Rate of I/I



B. Overview of This Technical Memorandum

This Technical Memorandum is contained on two compact discs (CD's). The first CD, "Wet Weather Technical Memorandum" or CD#1 contains this Technical Memorandum body plus two appendices. The second CD, "Graphics Documents" or CD#2 contains a collection of graphics for each Mini Basin. Some portions of last year's Technical Memorandum are repeated here if the material was considered an aid to a new reader in understanding this year's Technical Memorandum. The documents in this Technical Memorandum were created using Microsoft Office 2000 Word™, PowerPoint™ and Excel™. The user should ensure that the "Page Layout View" is used in Office 97 and the "Print Layout View" is used in Office 2000 for viewing Word documents. I/I results for each Mini Basin are contained in Appendices A and B and are on CD#1. Appendix B contains an overall map in a file called Minibasinmap.pdf plus 19 PDF detailed maps that are linked to file called Read This PDF Description.doc.

The I/I data collected in this study are presented in the following forms:

- Peak 30-minute I/I
  - Normalized by Acreage of each Mini Basin
  - Normalized by Linear Feet of sewer in each Mini Basin
- Volume of I/I over 72 hours
  - Normalized by Acreage of each Mini Basin
  - Normalized by Linear Feet of sewer in each Mini Basin
- Ratio of Peak Wet Flow to Dry Day Flow

In addition, a rainfall accumulation was calculated for each Mini Basin for each of the 10 rain events and those data are included in Appendix A.

Total I/I is measured as a 30-minute peak flow rate and calculations are made on a 30-minute basis. The peak 30-minute I/I was normalized (divided) by the acres in each Mini Basin. This method of normalization is consistent with the King County Title 28 code that establishes a design standard for local sewers.

A second normalization divides the peak 30-minute I/I by the linear footage of sewers in each Mini Basin. This method allows comparison of Mini Basin performance without the vagaries associated with calculating acreage within a Mini Basin as discussed in Section D.4. In general, normalizing by linear feet of sewer in Mini Basins provides a more dependable comparison between Mini Basins.

The 72-hour I/I volume is the entire volume of I/I measured within each Mini Basin for a 72-hour period after the start of the rain event. This analysis allows a distinction to be made between Mini Basins that experience direct sources of "Inflow" and "rapid Infiltration" versus those that may experience little or no direct sources of I/I, but sustained sources of Infiltration. These 72-hour volumes are also normalized by the acreage and linear footage of sewer in each Mini Basin.

Two Appendices are attached and included on CD#1 and their contents are described at the end of this document in Section H. Appendix A is a Microsoft Excel™ 2000 workbook containing rainfall information and all five I/I analyses for each Mini Basin for each rain event. Appendix B contains maps in PDF format and other Memorandum supporting documents. CD#2 contains a two-page Microsoft Word™ 2000 document for each Mini Basin. Select the "CLICK HERE!" document on the CD to review a description of the Mini Basin two-page document.

C. Mini Basin and Metering Information

1. Mini Basin Nomenclature

Mini Basins acquire their 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. 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 numbers identifying the meters in each agency. An example of the nomenclature is:*

"ABN014" = Fourteenth TMP installed in Auburn

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

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**	RONALD (SHORELINE/SHR)	**RON**
CEDAR RIVER WSD	**CDR**	SAMMAMISH STATE PARK	**SPK**
COAL CREEK UD	**CCR**	SAMMAMISH PLATEAU SD	**SAM**
CROSS VALLEY WD	**CRV**	SEATTLE SA	**SEA**
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**

2. Meters Renamed, Relocated or Dropped

Part of the re-metering plan for 2001/2002 was an evaluation of metering sites that were difficult to meter last year. Evaluated were sites with poor hydraulic conditions, sites on small basins with flow rates too small to measure and sites that flow out of the separated sewer area into a combined sewer system. A combination of map review with Local Agencies and field investigation resulted in 40 meters being relocated and 35 meters being dropped. Meters in lines flowing from Ronald to Edmonds were dropped as were non-modeling meters on lines from Val Vue and Bryn Mawr discharging to the Seattle Combined Sewer (CS) area. Two of the dropped meters were installed in new locations forming new Mini Basins.

Since last year's study, the Shoreline Wastewater Management District was renamed to Ronald Sewer District and a portion of the Seattle separated system was transferred to the Ronald Sewer District. As a result 39 meters now in the Ronald Sewer District were given a "RON" prefix. RON meters that were not relocated retained the same 3-digit number as the former SEA or SHR meter. Table C2 provides a listing of all meters and Mini Basins that experienced some type of change.

a) Renaming Strategy

Relocated meters were renamed to prevent a direct comparison of flows from the 2000 and 2001 metering periods. Table C2 correlates the names for the two metering periods and describes the Mini Basin change in linear feet in both the affected Mini Basin and the downstream Mini Basin.

Midway through the metering period it was discovered that the original Mini Basin boundary for NUD040 was incorrect due to incomplete original mapping. The correction resulted in NUD040 increasing from 7,315 LF to 22,281 LF and MCALE004 decreasing to 38,805 LF. Neither meter was relocated.

Two adjustments occurred to Mini Basin BOECR002 (in addition to the relocation of RON010 and the addition of RON042). Field investigation by King County staff determined that approximately 10,200 LF of sewer east and north of the Richmond Beach Pump Station is likely part of the Mini Basin. Secondly, meter RON008 was installed in the same manhole, but on the King County Trunk line, not the Ronald local line used last year by SHR008. The large Mini Basin BOECR002 was reduced by 22,496 LF to 28,706 LF.

b) Table of Meter Changes

Table C2
Inventory of Relocated, Renamed & Dropped Meters
Correlation Between 2000/2001 and 2001/2002

Site Name 2000/2001	STATUS	Site Name 2001/2002	Mini Basin Changes
SEA025	RENAME	RON028	None
SEA026	RENAME	RON029	None
SEA028	RENAME	RON030	None
SEA029	RENAME	RON031	None
SEA030	RENAME	RON032	None
SEA031	RENAME	RON033	None
SEA032	RENAME	RON034	None
SEA033	RENAME	RON035	None
SEA034	RENAME	RON036	None
SEA038	RENAME	RON038	None
SEA039	RENAME	RON039	None
SEA047	RENAME	RON040	None
SEA049	RENAME	RON041	None
SEA051	RENAME	RON043	None
SEA057	RENAME	RON044	None
SEA058	RENAME	RON045	None
SEA060	RENAME	RON046	None
SEA063	RENAME	RON047	None
SHR001	RENAME	RON001	None
SHR002	RENAME	RON002	None
SHR003	RENAME	RON003	None
SHR004	RENAME	RON004	None
SHR005	RENAME	RON005	None
SHR006	RENAME	RON006	None
SHR007	RENAME	RON007	None
SHR009	RENAME	RON009	None
SHR011	RENAME	RON011	None
SHR012	RENAME	RON012	None
SHR013	RENAME	RON013	None
SHR014	RENAME	RON014	None
SHR015	RENAME	RON015	None
SHR017	RENAME	RON017	None
SHR018	RENAME	RON018	None
SHR019	RENAME	RON019	None

Site Name 2000/2001	STATUS	Site Name 2001/2002	Mini Basin Changes
SHR020	RENAME	RON020	None
SHR022	RENAME	RON022	None
SHR024	RENAME	RON024	None
SHR025	RENAME	RON025	None
SHR026	RENAME	RON026	None
SHR008	RELOCATE	RON008	Gains 22,496 LF from BOECR002, Now 32,298 LF
ABN005	RELOCATE	ABN031	Loss of 1110 LF to ABN019. Now 17.892 LF
ABN007	RELOCATE	ABN032	Gain of 1885 LF from WINT003
ALD017	RELOCATE	ALD039	Loss 9,298 LF to ALD012. Now 10,792 LF
ALD029	RELOCATE	ALD040	Loss of 3635 LF to ALD041. Now 19,330 LF
ALD036	RELOCATE	ALD041	Gain of 4014 LF now 30,026 LF
BEL010	RELOCATE	BEL113	Loss of 8,546 LF to BEL038. Now 12,400 LF
BEL036	RELOCATE	BEL115	Loss of 2932 LF to BEL038. Now 5568 LF
BEL067	RELOCATE	BEL116	Gain of 1446 LF from BEL068. Now 25,196 LF
BEL090	RELOCATE	BEL117	Gain of 325 LF from BEL054. Now 26,304 LF
BOT007	RELOCATE	BOT017	Loss of 2541 LF to BOT002 Now 16,356 LF
BOT008	RELOCATE	BOT018	Gain to 32,323 LF - BOT009 drops to 17,873 LF
CCR004	RELOCATE	CCR014	Loss of 890 LF to CCR003. Now 25364 LF
CRV002	RELOCATE	CRV003	Gain of 1249 LF from LBEARA03. Now 28,009 LF
ISS011	RELOCATE	ISS014	Gain from 17,781 LF from dropped ISS010, loss of 3590 LF to ISS004, Now 28,904 LF
KNT018	RELOCATE	KNT044	D/S below siphon. Now 27,926 LF. Gained 4254 LF from KNT015 now 15,710 LF
KNT020	RELOCATE	KNT045	MB reduced by 507 LF to KNT012
KNT027	RELOCATE	KNT046	Reduced by 1139 LF to AUBRN002
KNT040	RELOCATE	KNT047	Reduced by 1149 LF
KRK016	RELOCATE	KRK031	Drop 4811 to ESI14058, Now 5,522 LF
MRC004	RELOCATE	MRC020	1298 LF to MRPS018. Now 14,992 LF
MRC014	RELOCATE	MRC021	Now 14,615 flowing east (not west) to MRC016, which grew by ~1700 LF to 26,317 LF
NUD023	RELOCATE	NUD050	Decreased to12, 067 LF and NUD025 increased to 32,864 LF
NUD033	RELOCATE	NUD052	Same pipe segment. Gained 94 LF
NUD037	RELOCATE	NUD053	Loss of 1394 LF to SWAMP004
RDM012	RELOCATE	RDM036	Drop to 15,787 to RDM031. Now 36,058 LF
RDM025	RELOCATE	RDM037	Now 12,712 LF
RDM028	RELOCATE	RDM040	Loss of 700 LF to RDM039
RDM029	RELOCATE	RDM039	Moved 1 MH d/s 298 feet. NLKS3057 reduced 298 LF
RNT031	RELOCATE	RNT052	Moved U/S 3 MH. 3200 LF to RNT054. Now 22,930 LF
RNT051	RELOCATE	RNT054	Loss of 5722 LF to ESI1003
SHR010	RELOCATE	RON010	New basin has 13,449 LF This relocated meter was not renamed
SHR023	RELOCATE	RON023	Increase of 526 LF from BOECR002
SHR021	RELOCATE	RON027	New basin of 27759 LF taken from MCALE025

Site Name 2000/2001	STATUS	Site Name 2001/2002	Mini Basin Changes
SEA035	RELOCATE	RON037	Basin increased 1 pipe segment, 330 LF
SAM006	RELOCATE	SAM023	With new lines not shown on map is now 40,842 LF
SEA010	RELOCATE	SEA064	Now 15,078 LF. SEA011 increased to 21,759 LF
SEA048	RELOCATE	SEA066	Down stream in a vault. Very small increase in LF
SEA062	RELOCATE	SEA067	Increases to 7078 LF, THORN001 drops to 28,340 LF
TUK001	RELOCATE	TUK007	1 MH d/s of siphon, now 15,059 LF
ALG001	DROP		Becomes part of PAC005 - now 17,606
ALG002	DROP		Becomes part of PAC005 - now 17,606
BEL002	DROP		Becomes Part of BEL003 - 13,280+13595=26875
BLS004	DROP	BLS013	Becomes Model Basin BLS013 then to Seattle CS area
BLS005	DROP	BLS013	Becomes Model Basin BLS013 then to Seattle CS area
BLS008	DROP	BLS013	Becomes Model Basin BLS013 then to Seattle CS area
BLS010	DROP		To Seattle CS area
BLS011	DROP	BLS013	Becomes Model Basin BLS013 then to Seattle CS area
BLS012	DROP	BLS013	Becomes Model Basin BLS013 then to Seattle CS area
BLS014	DROP		To Seattle CS area
BRR005	DROP		Combines with NUD036 - 20436+5929=26365 LF
CCR010	DROP		Combined with RNT042, Now 23,109 LF
ISS010	DROP		Combines 17,781 with ISS014. Now 28,904 LF
KNT037	DROP		Becomes KNT033, 23,400+4301=27,701 LF (see below)
KNT039	DROP		Becomes KNT033, 27,701+3832=31533 LF
KRK013	DROP		Joins ESI14058. Now 41,926 LF
KRK024	DROP		Joins ESI14058. Now 41,926 LF
KRK026	DROP		Joins ESI14058. Now 41,926 LF
KRK027	DROP		Joins BEL096 10,506+3,795= 14,301 LF
NES014	DROP		Combined with RDM030 – little development yet
SEA050	DROP		Joins KENMR000 40,123
SEA052	DROP		Joins KENMR000 40,123
SEA053	DROP		Joins KENMR000 40,123
SEA056	DROP		Joins KENMR000 40,123
SHR016	DROP		Small mini basin 4977 LF to Edmonds
VAL004	DROP		To Seattle CS area
VAL005	DROP		To Seattle CS area
VAL006	DROP		To Seattle CS area
VAL008	DROP		To Seattle CS area
VAL009	DROP		To Seattle CS area
VAL010	DROP		To Seattle CS area
VAL011	DROP		To Seattle CS area
VAL012	DROP		To Seattle CS area
VAL023	DROP		To Seattle CS area

Site Name 2000/2001	STATUS	Site Name 2001/2002	Mini Basin Changes
WDY001	DROP		Combines with RON011
	RE-USE	RON042	This new basin and relocated RON010 reduce BOECR002 (see below)
	RE-USE	RDM038	New basin divided former RDM027. Now 18,514 LF
NUD040	CORRECTION	NUD040	Basin boundary correction, increases to 22,281, MCALE004 to 38,805LF
BOECR002	CORRECTION	BOECR002	With all changes drops from 63,296 LF last year to 28,706 LF.

3. 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. Sizing the Mini Basins in this manner reduces the skewing effect of comparing I/I results from basins that widely range in size (basins that are larger appear to perform better) and ensures a manageable target area in which sewer system evaluation surveys (smoke testing, manhole inspection) and rehabilitation can occur. 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 breaking them precisely into uniform basins. For example the only choice for subdividing a 40,000 LF basin may be 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 of Sewer)

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 larger Mini Basins contain 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 portion of Seattle's combined sewer area 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. I/I calculations were conducted on the Edmonds basins.

4. 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 to the system. Many of these non-contributing Mini Basins are large and contain more than the upper Mini Basin size limit of 32,000 LF of sewer. As discussed in Section F, these basins were not included in the evaluation of Local Agency system I/I.

Both the acreage and sewer lengths in each Mini Basin have been updated since last year. Last year's basin acreage was based on Mini Basin polygons drawn by using sewer line and street centerline mapping for guidance and all land within the interior of a 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 included the soccer field acreage. The hydraulic modeling work completed over the last year resulted in a refinement of the actual sewered area within each Mini Basin and those refined areas are used in these data. Generally the Mini Basin areas are smaller this year due to non-sewered areas being removed.

Local Agency lines labeled as force mains were excluded from the inventory of sewer lines in Mini Basins, however 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. Side sewer or building sewer locations and lengths were not readily available from most Local Agencies. For estimating purposes a general rule is that the length of side sewers in a system is approximately equal to the length of public sewers in a system.

The sewer network has been updated from 2000/2001 to 2001/2002 where additional data were made available by the Local Agencies and the new sewer lengths are used in this analysis. 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.

5. Metering Sites

a) Types of Metering

Flow metering was accomplished with the four types of metering techniques listed in Table C3. Open channel area-velocity meters function by measuring flow depth (cross sectional area) and flow velocity in gravity sewers to calculate the rate of flow. Pump station meters function by recording fill and draw cycles and calculating flow with wet well measurements. No sensors are placed in the flow with pump station metering technology. Time-of-travel meters function by calculating flow based on the time required for an acoustical signal to travel across the flow stream. The Time-of-Travel meter is an existing meter operated by the Sammamish Plateau Sewer District at its connection to the Issaquah Trunk Line. SFE Global Inc (SFE) installed a customized compound flow weir at site RDM040 from November 7, 2001 to January 16, 2001. An ADS depth sensor measured the depth of flow over the weir and flow was calculated by SFE using the proprietary Depth vs. Flow relationship associated with the weir.

Table C3
Types of Metering Technologies Used

Meter Types	
Open Channel Area-Velocity	
LTM	75
TMP	689
Fill & Draw	8
LTM Time-of-Travel	1
Weir	1
Total	**774**

b) Distribution of Pipe Diameters

Open channel area-velocity 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 C4 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 68.5% of the meters were in pipes 15 inches and smaller. The 75 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.

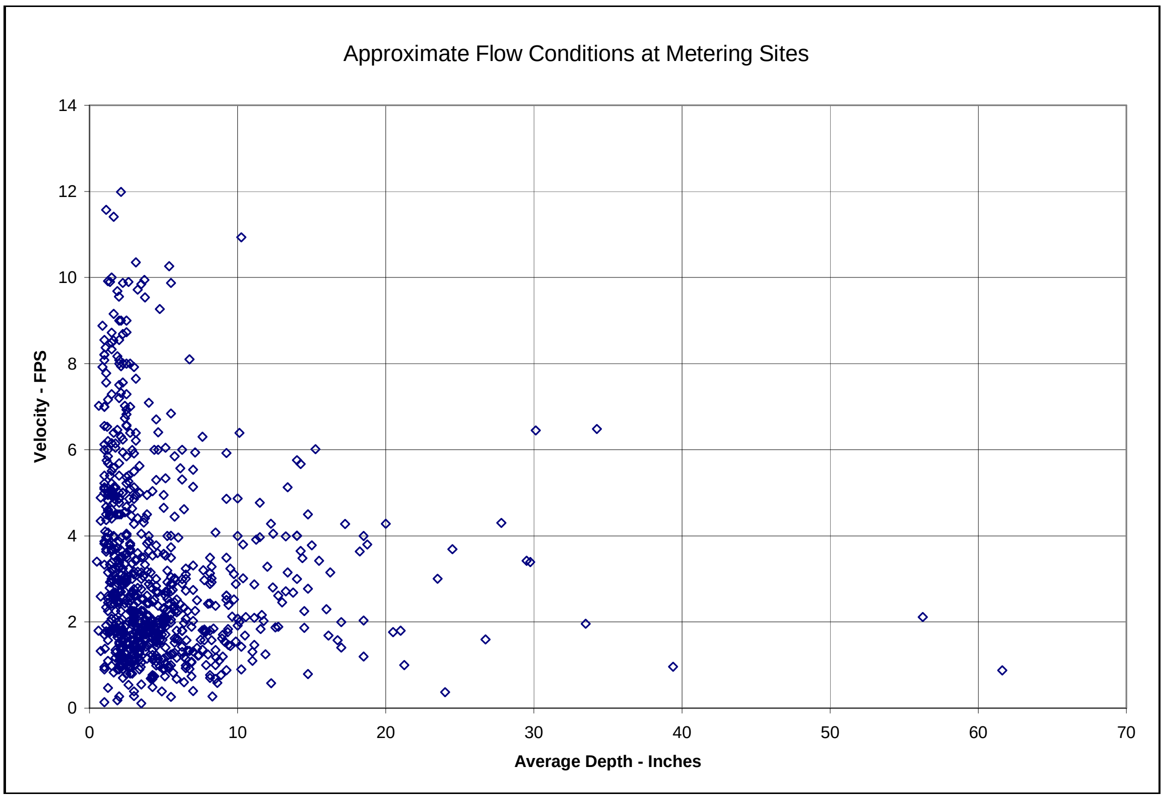
Table C4
Distribution of Metering Sites by Diameter

Diameter In.	Count	Percent	Cumulative %
8	176	22.7%	22.7%
10	115	14.9%	37.6%
12	139	18.0%	55.6%
14	6	0.8%	56.3%
15	94	12.1%	68.5%
18	87	11.2%	79.7%
21	32	4.1%	83.9%
24	45	5.8%	89.7%
27	10	1.3%	91.0%
30	14	1.8%	92.8%
36	19	2.5%	95.2%
42	10	1.3%	96.5%
44	1	0.1%	96.6%
48	7	0.9%	97.5%
50	1	0.1%	97.7%
52	1	0.1%	97.8%
54	1	0.1%	97.9%
60	3	0.4%	98.3%
72	8	1.0%	99.4%
84	2	0.3%	99.6%
90	1	0.1%	99.7%
108	2	0.3%	100.0%
Total	**774**	**100.0%**	

c) Depth and Velocity Range

The steep terrain over much of the service area resulted in many metering sites with flow that was both shallow and fast in both the 2000/2001 and 2001/2002 monitoring periods. Figure C3 illustrates the general operating range of the 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. The final data uptime for the 698 (this number includes the pump stations and weir) temporarily installed meters (95.3%), indicates the limited extent to which non-laminar flow conditions contributed to intermittent flow data during the flow monitoring period.

Figure C3
Approximate Flow Conditions at Metering Sites



D. Infiltration/Inflow

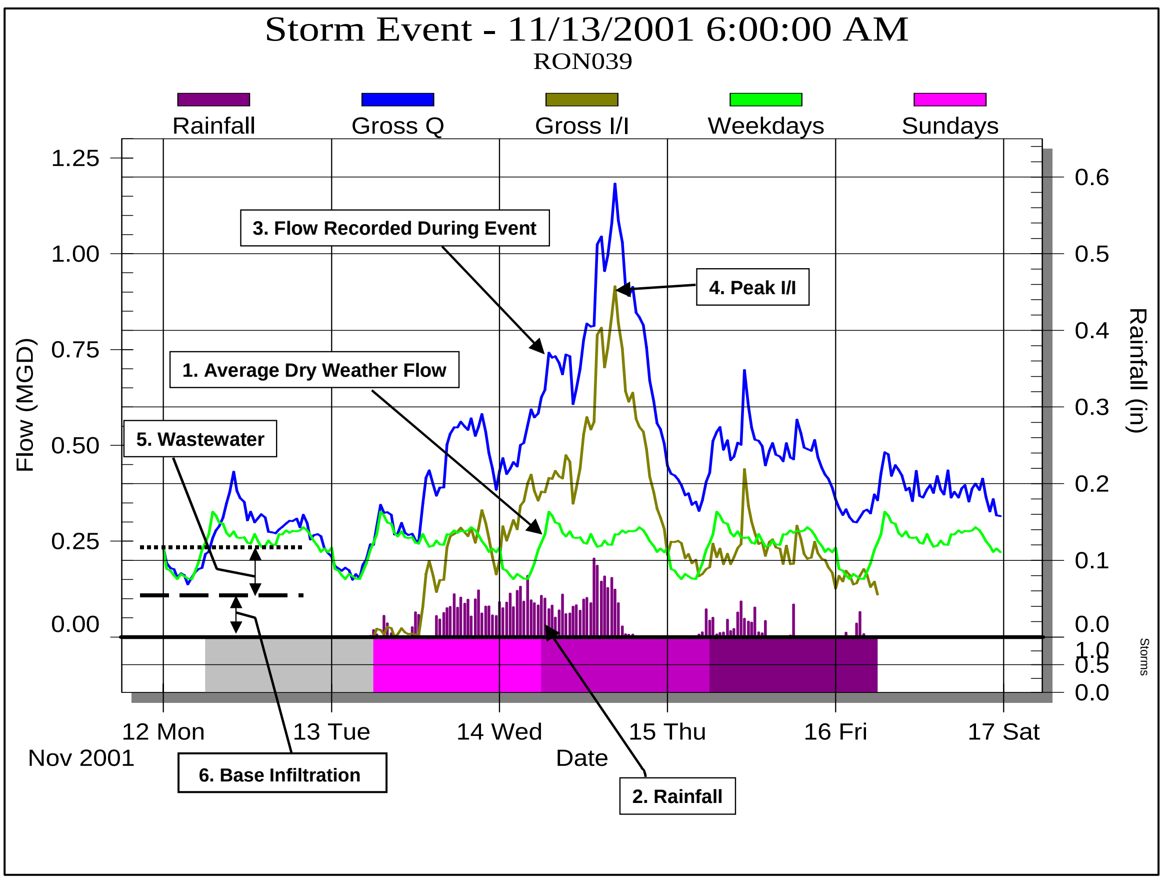
1. Definition of I/I

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.

Regardless of the source, I/I results in a measurable increase in flow during a rain event. Figure D1 shows the components of I/I discussed in this Memorandum. The I/I hydrograph (4) shown in Figure D1 is the difference between the recorded flow (3) and the average dry weather flow (1). This I/I hydrograph is the I/I due to rainfall and does not include base infiltration.

Figure D1
I/I Hydrograph and Other Related Components



2. Characterizing I/I as Inflow, Rapid Infiltration and Base Infiltration

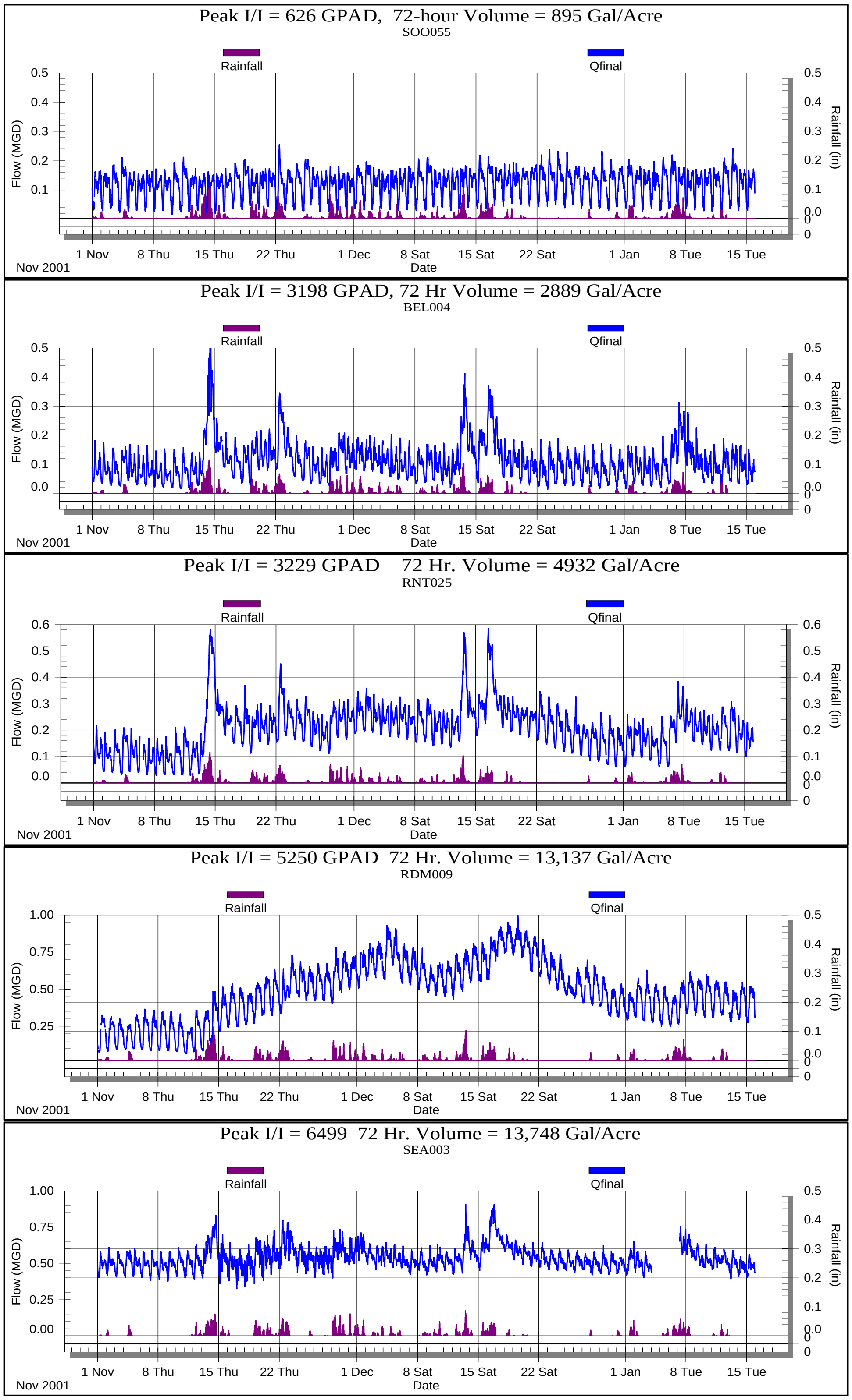
I/I traditionally is viewed as falling into three basic categories; direct inflow, rapid infiltration and slow infiltration (base infiltration). This traditional view of I/I components associates the source of I/I with the elapsed time after the start of the rain event when extraneous flow appears in a hydrograph. It is normally assumed that I/I remaining 24 hours after the end of a rain is mostly infiltration from underground defects, while 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 with heavy antecedent rains, it is likely that a rapid response from traditional infiltration sources such as a cracked pipe may be incorrectly categorized as inflow.

However, much can be learned about the type of defects in a Mini Basin by the general shape of its I/I response over a period of several rain events. Figure D2 shows hydrographs from five Mini Basins, each exhibiting different I/I characteristics. The title of each hydrograph shows the Peak 30-minute I/I flow rate in Gallons per Acre per Day and the I/I volume over a 72-hour period in Gallons per Acre. The value for these two measurements is the maximum reading recorded during the metering period. The calculation of these two parameters is discussed in Section 3. g) *Calculated I/I*.

These five hydrographs are shown in order of increasing I/I severity from top down. They all are independent basins and have no meters upstream. The top hydrograph has little base infiltration and little response to rain. The second and third both have high direct inflow/rapid infiltration but the third Mini Basin’s slow recovery indicates it experiences slow infiltration. The fourth Mini Basin experiences little inflow but high infiltration. The fifth Mini Basin experiences some inflow/rapid infiltration and high base infiltration.

Figure D2
Five Mini Basins with Different Types of I/I Sources



3. Steps to Calculating I/I

At its simplest, the calculation of I/I is the subtraction of normal dry weather flow from wet weather flow. The process requires several separate steps to ensure that the measurements are valid and as accurate as possible. The following steps are described in Sections a) through h).

a) Dry day selection
b) Dry day diurnal hydrograph
c) Substituting dry day during holiday rain events
d) Hydrograph shape and land use
e) Irregular patterns
f) Estimating base infiltration
g) I/I calculation
h) Total I/I is Calculated I/I Plus Base Infiltration

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 prior rains do not influence the flow. For this study candidate dry days were those that met the antecedent (prior) rainfall criteria in Table D1.

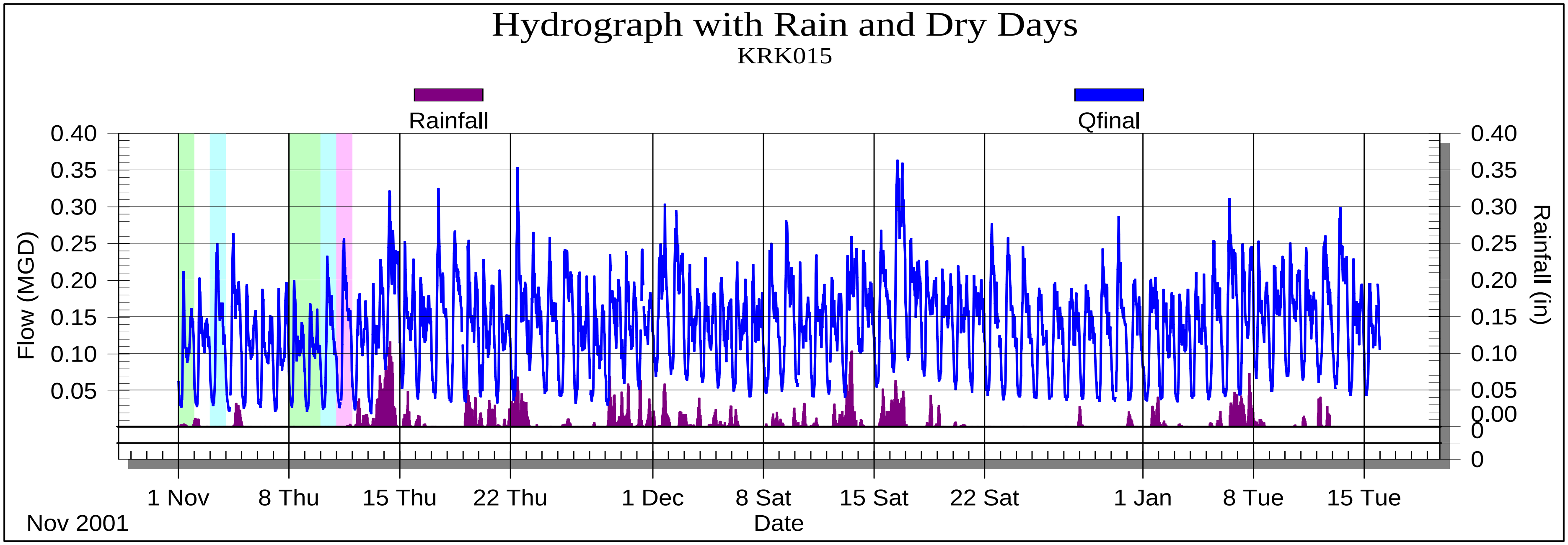
Table D1
Criteria for Dry Days

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 ensure that the days selected have similar daily shapes and are averaged together to create the Average Dry Day Flow (ADDF) for each meter. The days meeting these criteria generally were prior to November 12, 2001. Dry Weather data are provided in Appendix A as Gross Dry (Gross ADDF) and Net Day Flow (Net ADDF) in Million Gallons per Day (MGD). Gross ADDF is the average daily flow measured by a meter during the selected dry days. Net ADDF is the subtraction between the 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, Saturdays and Sundays. The ADDF data reported in Appendix A are weekday flows.

Figure D3 is a hydrograph showing an example of selected dry days from Mini Basin KRK015 for the entire 76-day metering period. The selected dry days are shown as colored bands in November. Weekdays are shown in green, Saturday is in blue and Sunday is in pink. This Mini Basin is a residential neighborhood located in Kirkland between I-405 and 132nd Avenue and north of 85th Street.

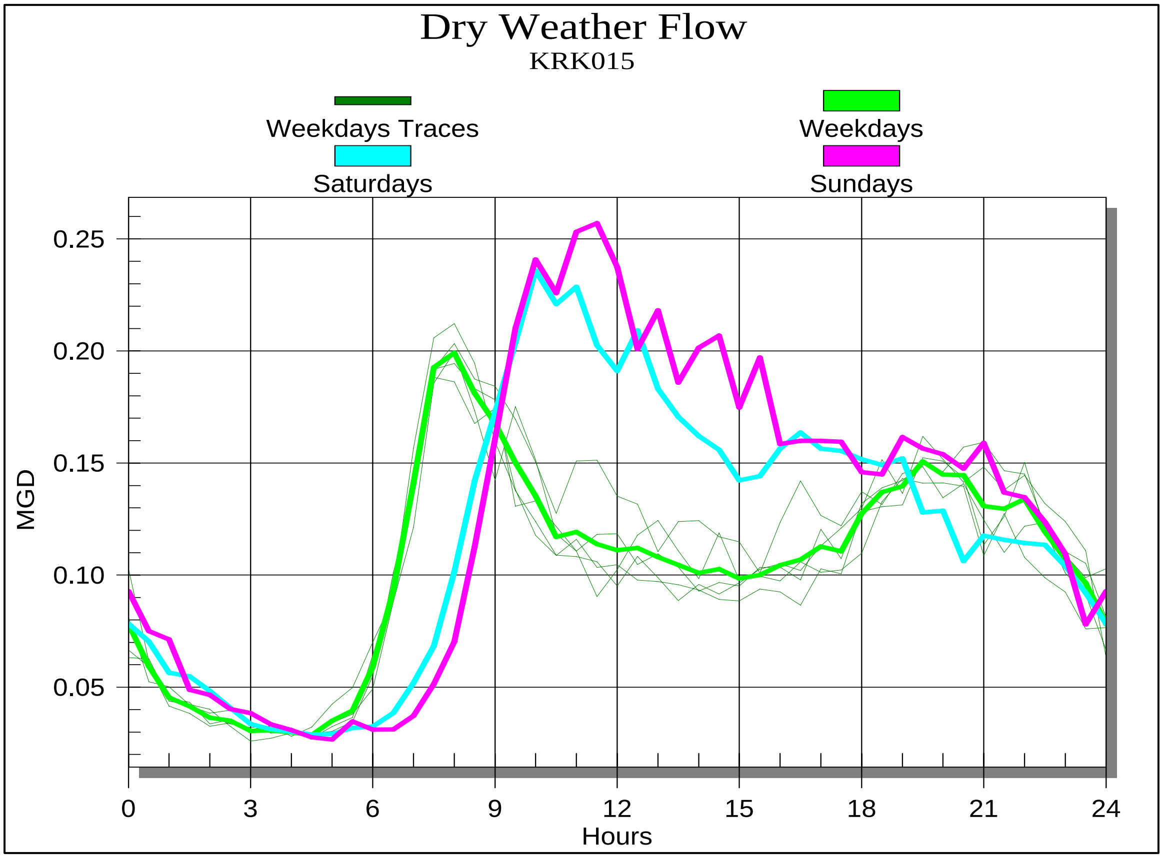
Figure D3
Hydrograph of Mini Basin KRK015 – Selected Dry Days Highlighted by Colored Bands



b) Dry Day Diurnal Hydrograph

There are two objectives for determining the representative dry day hydrograph for each Mini Basin. The first 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, Saturday (blue) days and Sunday (pink) days. The three day groups are averaged separately. The three diurnal hydrographs for Mini Basin KRK015 are shown in Figure D4. 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 three are similar with weekdays being 0.104 MG, Saturdays being 0.119 MG and Sundays being 0.126 MG. Although the daily volumes for the day groups are nearly the same there is a significant difference in the shape of the weekday and the two weekend shapes. The peak flow occurs between 7:30 a.m. and 8:00 a.m. on weekdays and 10 a.m. to 11 a.m. on weekend days. This shift in diurnal shapes between weekday and weekends is common to most residential Mini Basins and is the "signature" of residential land use.

Figure D4
Dry Day Hydrographs for Mini Basin KRK015



c) Substituting Dry Days During Holiday Rain Events

Measuring I/I during holidays can be difficult if no dry day pattern for that particular day exists. For this metering period, rain events occurred on Thanksgiving and New Years Day. Although it is difficult to know how the population in each Mini Basin responds during the holidays, experience indicates that holiday behavior by most people is similar to weekend behavior as far as water and sewer use goes. For this metering period the Sunday dry day was used to calculate I/I on Thanksgiving and Saturday was used for both the Friday after Thanksgiving (November 23, 2001) and for New Years Day.

Figures D5 and D6 show the impact of the Thanksgiving substitution. Figure D5 shows the I/I hydrograph when a weekday dry day shape is used. For demonstration purposes the hydrograph of Wednesday November 21, 2001 was used as the dry day shape for all subtractions. Notice that the increase in flow in the morning or "morning rise" occurs approximately 2 hours later than a normal weekday. Peak I/I is calculated to be 0.2 MGD.

Figure D5
Impact of Unusual Dry Days on Dry Day Average

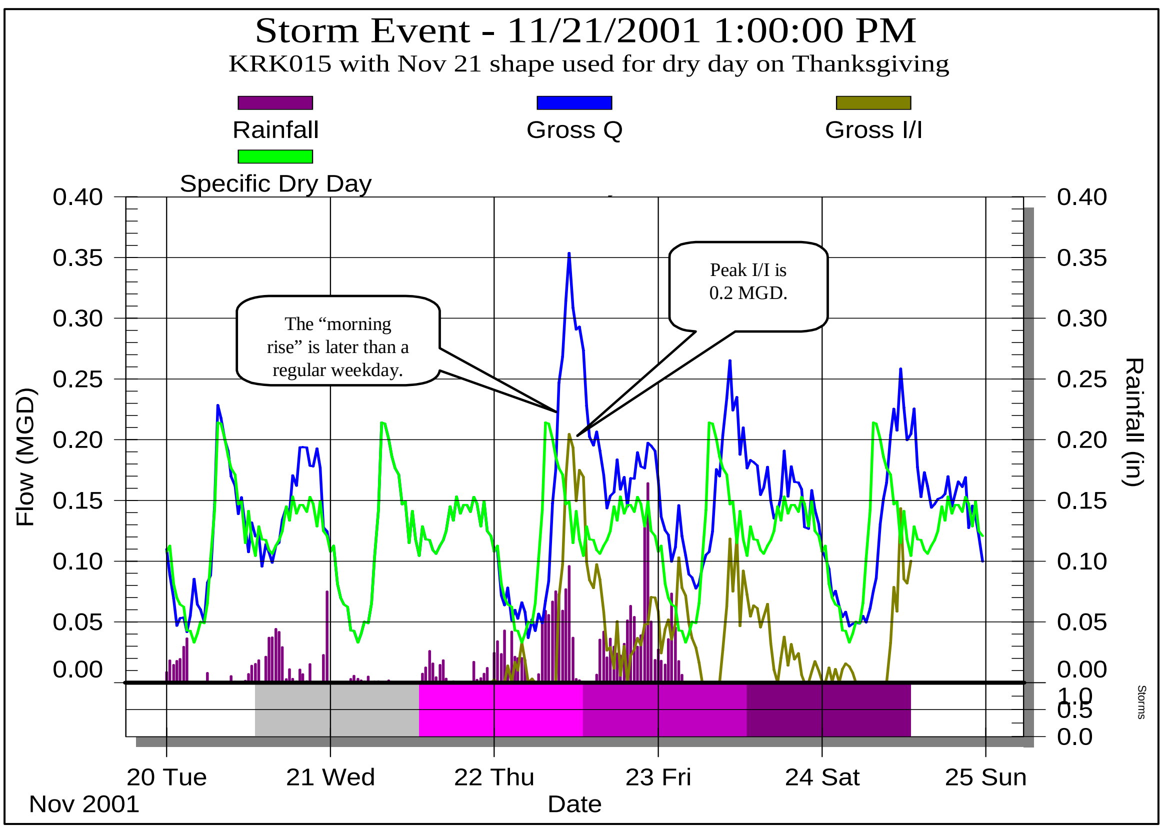
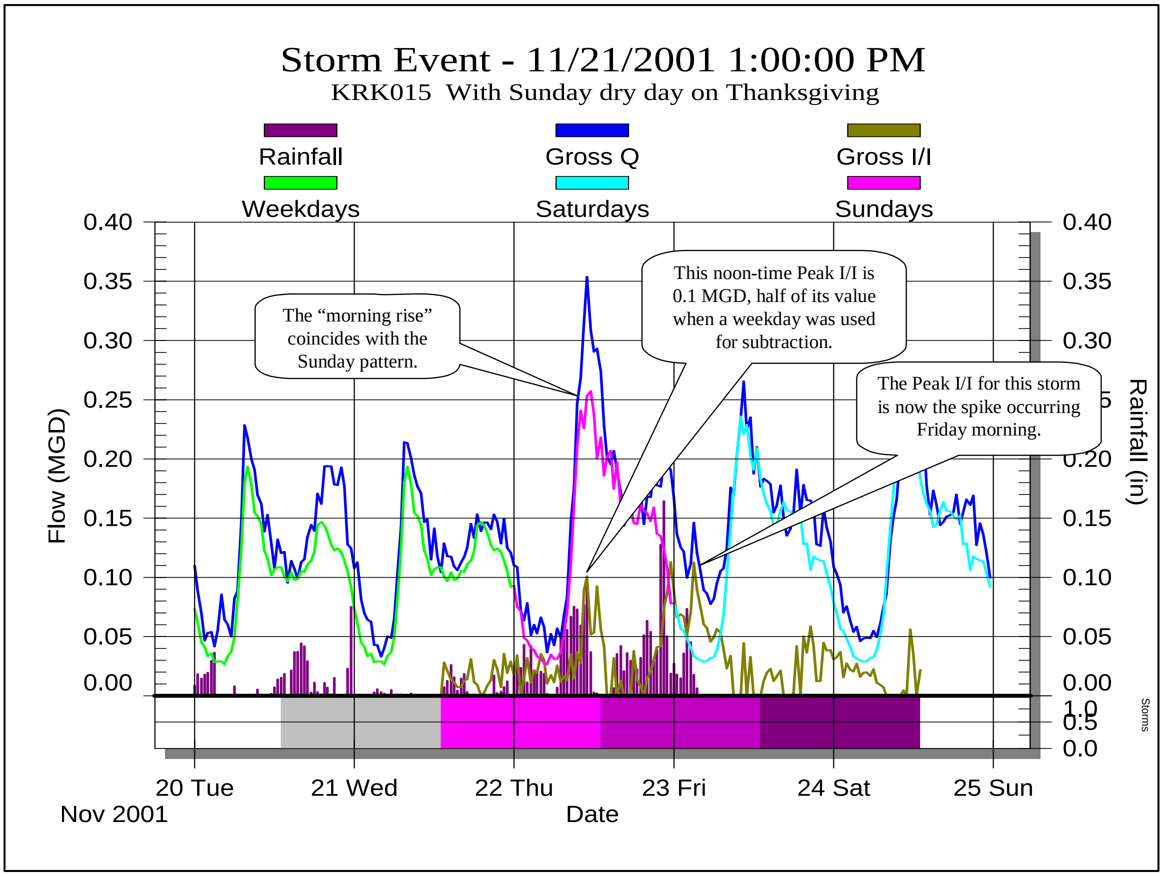


Figure D6 shows how the dry day subtraction was actually conducted with the Sunday dry day substituted for Thanksgiving and the Saturday dry day used for the Friday after Thanksgiving. Two changes result from these substitutions. The noontime peak I/I of 0.2 MGD in the previous Figure D5 was reduced by one-half to 0.1 MGD when Sunday's shape was substituted for the Weekday shape. The second change is that the Peak I/I for this event occurs early Friday morning instead of Thanksgiving noon.

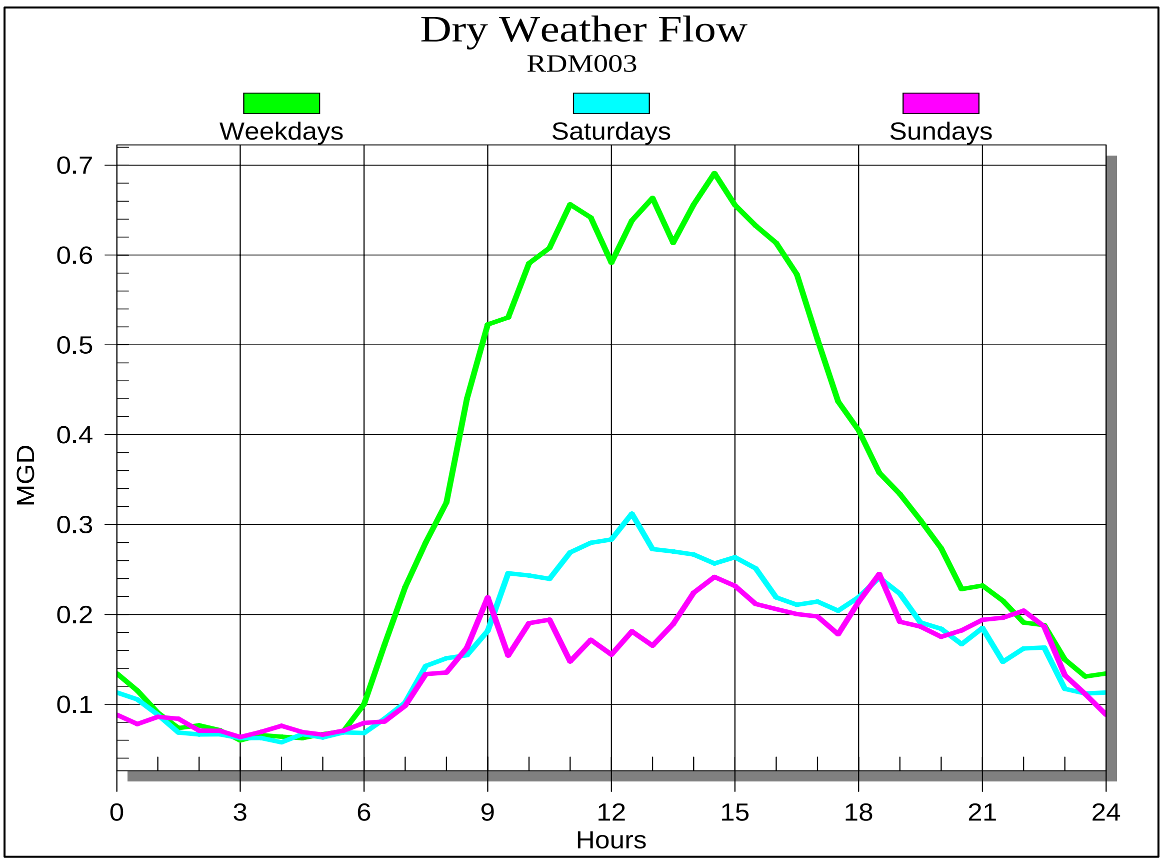
Figure D6
Impact of Unusual Dry Days on Dry Day Average



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. Every land use has a "signature" hydrograph, but residential and commercial land uses exhibit the most pronounced hydrograph shapes as shown in Figures D4 and D7 respectively. Figure D7 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.

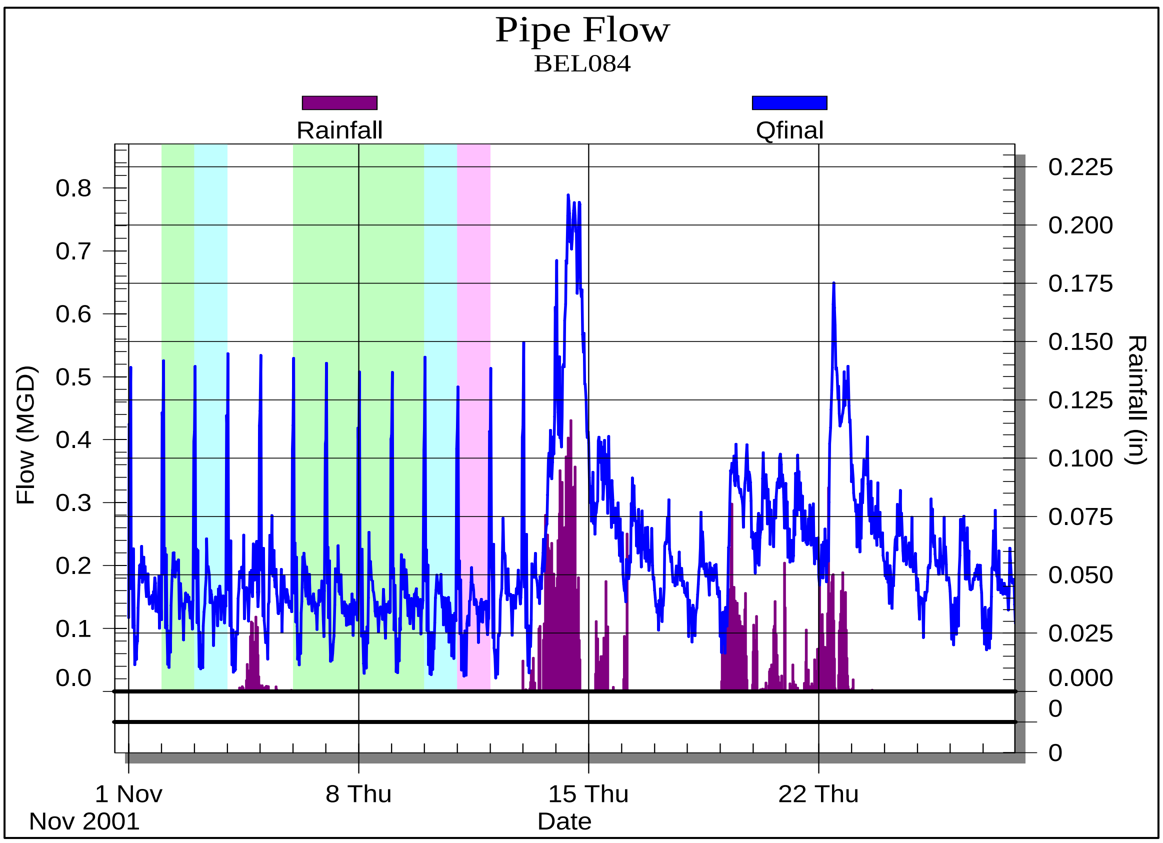
Figure D7
Mini Basin RDM003 Dry Day Hydrograph



e) Irregular Patterns

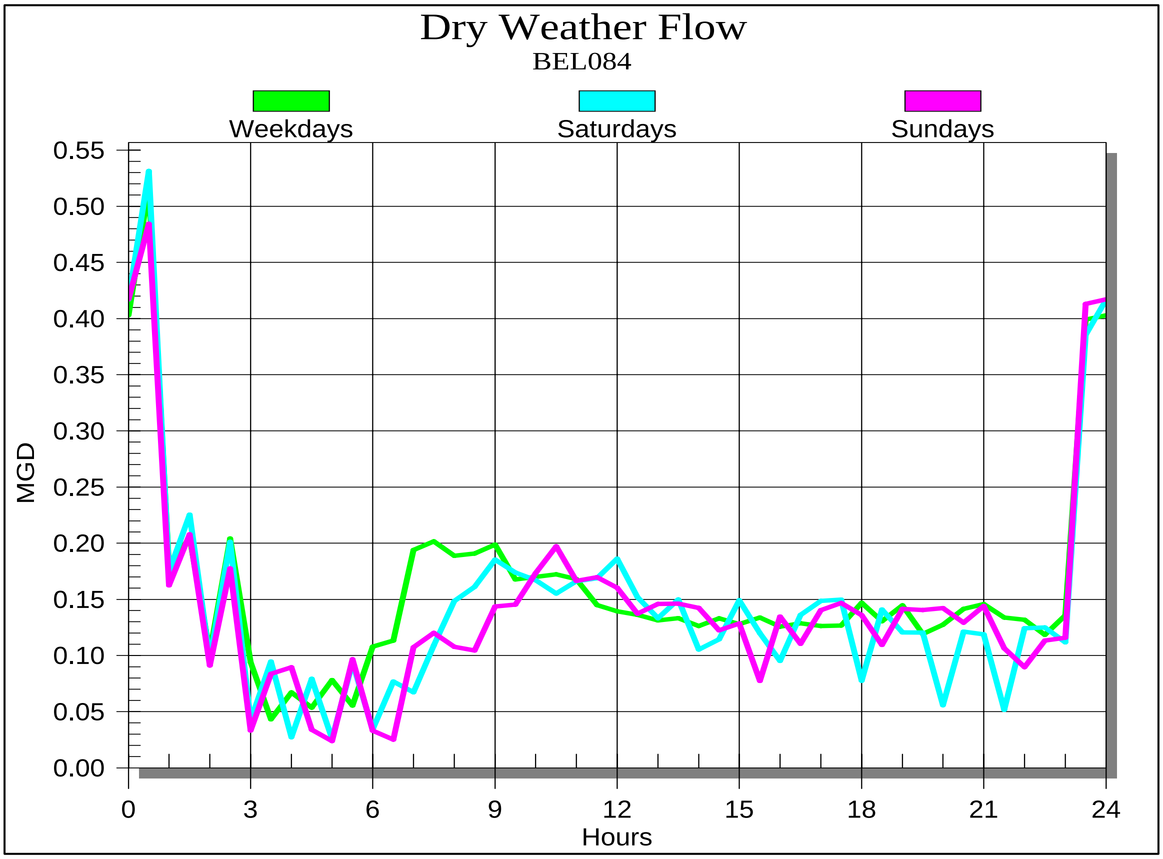
Most land use types produce both repeatable and regular flow patterns, but there are examples of flow patterns that are neither repeatable nor regular. Seasonal flushing of lake lines, such as around Lake Washington and Lake Sammamish, result in a repeatable (it happens the same way each time), but not regular (it occurs randomly) hydrograph pattern. A timer automatically controls flushing of lake lines in Mini Basin BEL084 and the result is the hydrograph shown in Figure D8. Mini Basin BEL084 is the area west of the Medina Pump Station. The selected dry days are shown with the green, blue and pink highlighting for weekdays and Saturday and Sunday, respectively. The average dry hydrograph for the three day groups from this site are shown in Figure D9.

Figure D8
Lake Line Flushing in Mini Basin BEL084



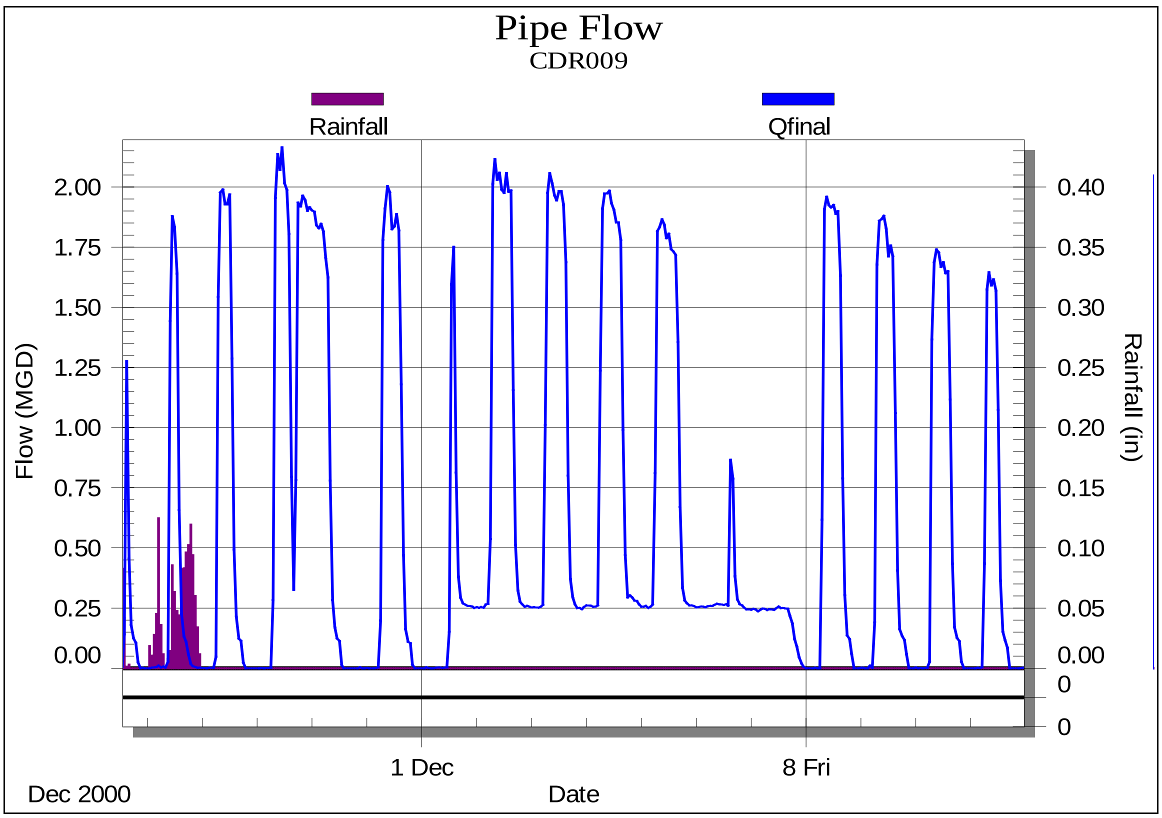
The selected dry days shown in Figure D8 produce the weekday, Saturday and Sunday diurnal hydrographs shown in green, blue and pink, respectively, in Figure D9.

Figure D9
Mini Basin BEL084 Dry Day Averages



Some land uses produce neither repeatable nor regular patterns. An example of an irregular and non-repeatable pattern is Mini Basin CDR009 (Figure D10), which is exclusively the flow from the Cedar Hill Landfill from metering in 2000. The flow pattern 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 D10
Irregular and Non Repeatable Flow Pattern from 2000 metering



f) Estimating 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 may be a seasonal phenomenon as rainfall affects ground water levels, but generally 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 from each building 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. Without 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 the average wastewater production (WWP) in a Mini Basin based on the average flow (ADDF) and minimum flow (MDF) 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

$$WWP = (ADDF - MDF) / \underline{X}$$

Where; $\underline{X}$ = .88 (from electric power industry)

Equation D2

$$BI = ADDF - WWP$$

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 neighborhoods with sewer basin sizes on the order of 20,000 LF. As basins become larger and travel time increases, this method decreases in reliability.

A refinement to this empirical method, the Stevens/Schutzbach equation, uses a curve fitting technique to increase the reliability of the BI estimation at meters with higher flows. Equation D3 is the Stevens/Schutzbach equation that was used to estimate base infiltration in all Mini Basins. ADDF is the average flow and MDF is the minimum flow of the dry day hydrograph.

Equation D3
Stevens/Schutzbach Equation

$$BI = \frac{0.4 * MDF}{1- 0.6 (MDF/ADDF) \wedge ADDF^{0.7}}$$

Equation D3 is also dependent on average and minimum flows that occur in traditional residential flow patterns. Reliability decreases in non-residential basins and in basins where the flow meter measures flow from cycling pump stations. Although there are limitations, this method is considered the best for estimating BI using only flow data. 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 KRK015 Equation D3 produces an estimated base infiltration of 0.02 MGD indicated by the red line in Figure D11. The ADDF is 0.101 MGD.

Figure D11
Base Infiltration for Mini Basin KRK015

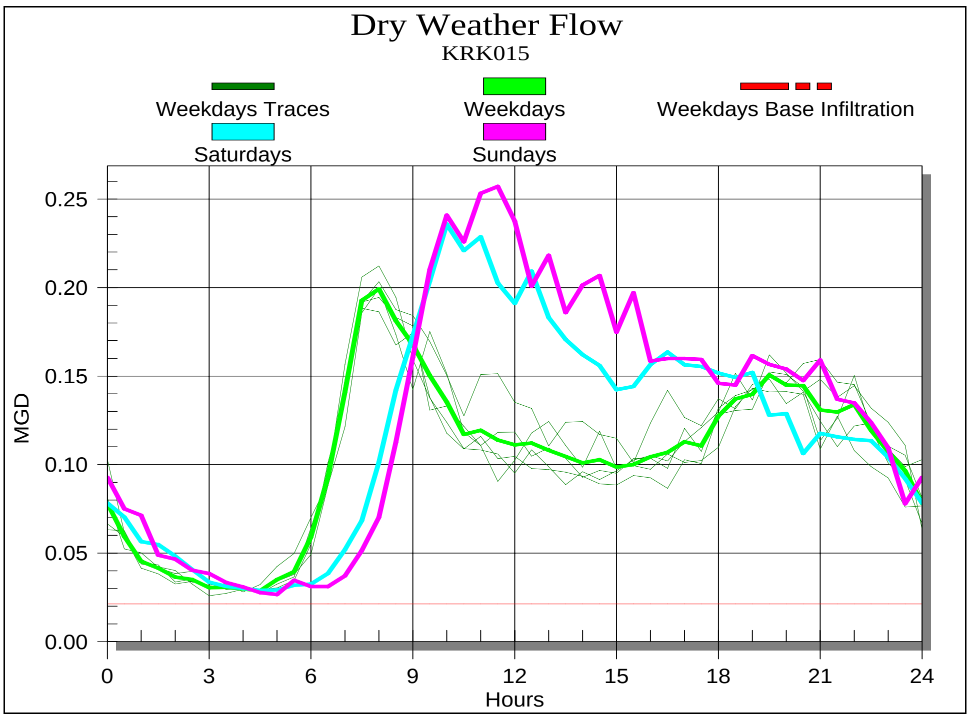
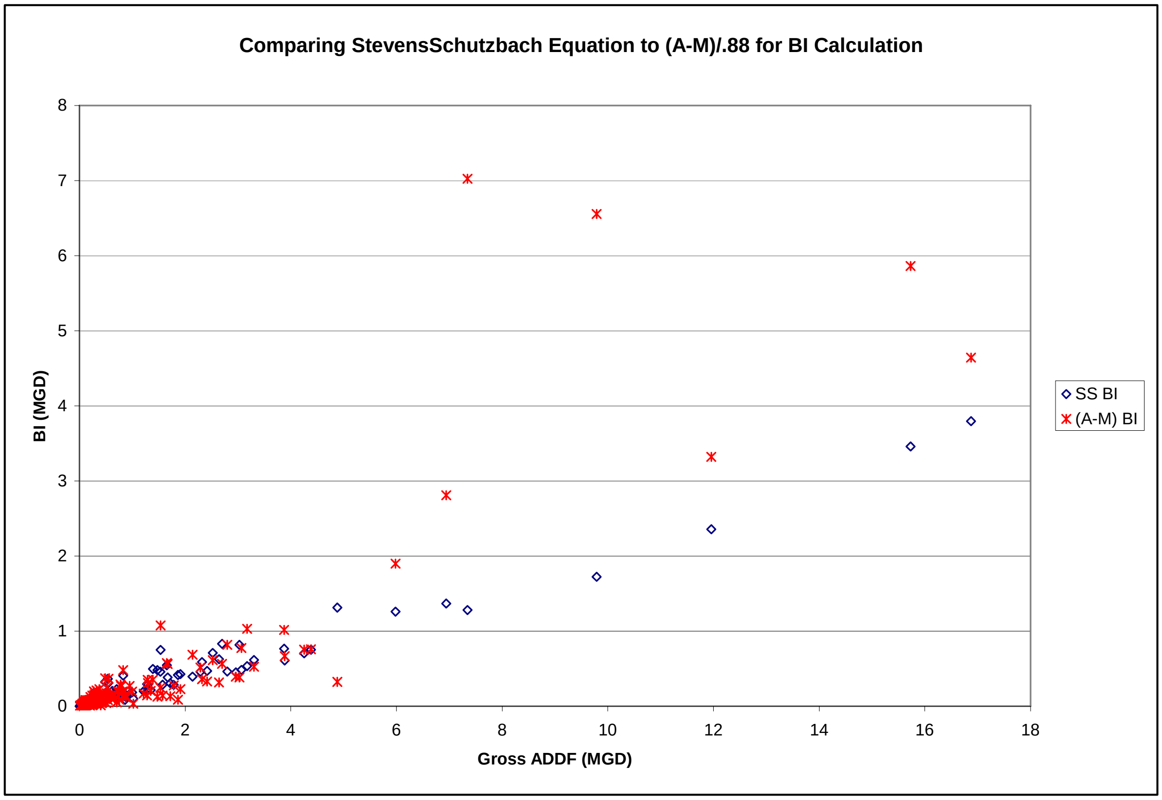


Figure D12 compares the BI estimated by the Stevens/Schutzbach method and the method defined by Equation D1. Compared are BI estimates for 270 meters from the northern third of the King County service area. The methods produce similar results for flows under 1 MGD and there are significant differences at higher flows. In general the Stevens/Schutzbach method generates a lower BI estimate.

Figure D12
Comparison of Stevens/Schutzbach BI Estimation Method to Original Method

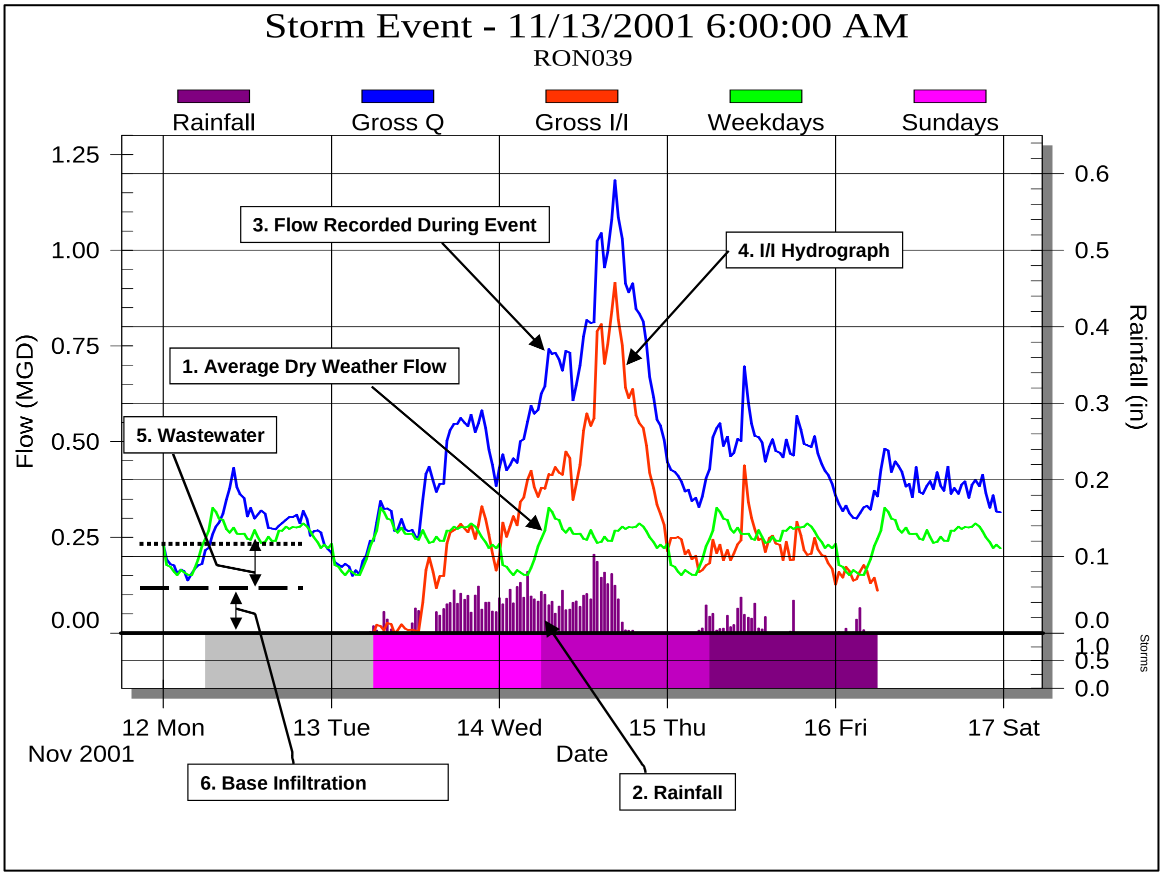


g) Calculated I/I

Figure D13 is a Storm Hydrograph and consists of a collection of 3 hydrographs and a rainfall hyetograph showing the components of the I/I calculation for RON039 for the November 13, 2001 rain event:

1. Average dry day hydrograph in green (1);
2. Rainfall hyetograph in magenta (2);
3. Flow recorded during the rain event in blue (3) and
4. Calculated I/I (excluding Base Infiltration) in red (4).

Figure D13
Storm Event Components and 72-Hour Calculation Window



I/I is calculated during the 72-hour "calculation window" by subtracting the average dry day hydrograph (1) from the recorded flow (3). By definition base infiltration is not included in this I/I calculation since it is part of the dry day quantity. 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. I/I volume is calculated for the entire 72-hour period. Although the I/I calculation in this example is not affected, the measured flow prior to the start of the rain is the day Veterans Day was observed (November 12, 2001). The morning rise was later and higher than normal and accounts for the discrepancy between the green diurnal curve and blue curve for measured flow during the dry day of November 12, 2001. Average dry day flow is 0.24 MGD and that includes 0.122 MGD of base infiltration.

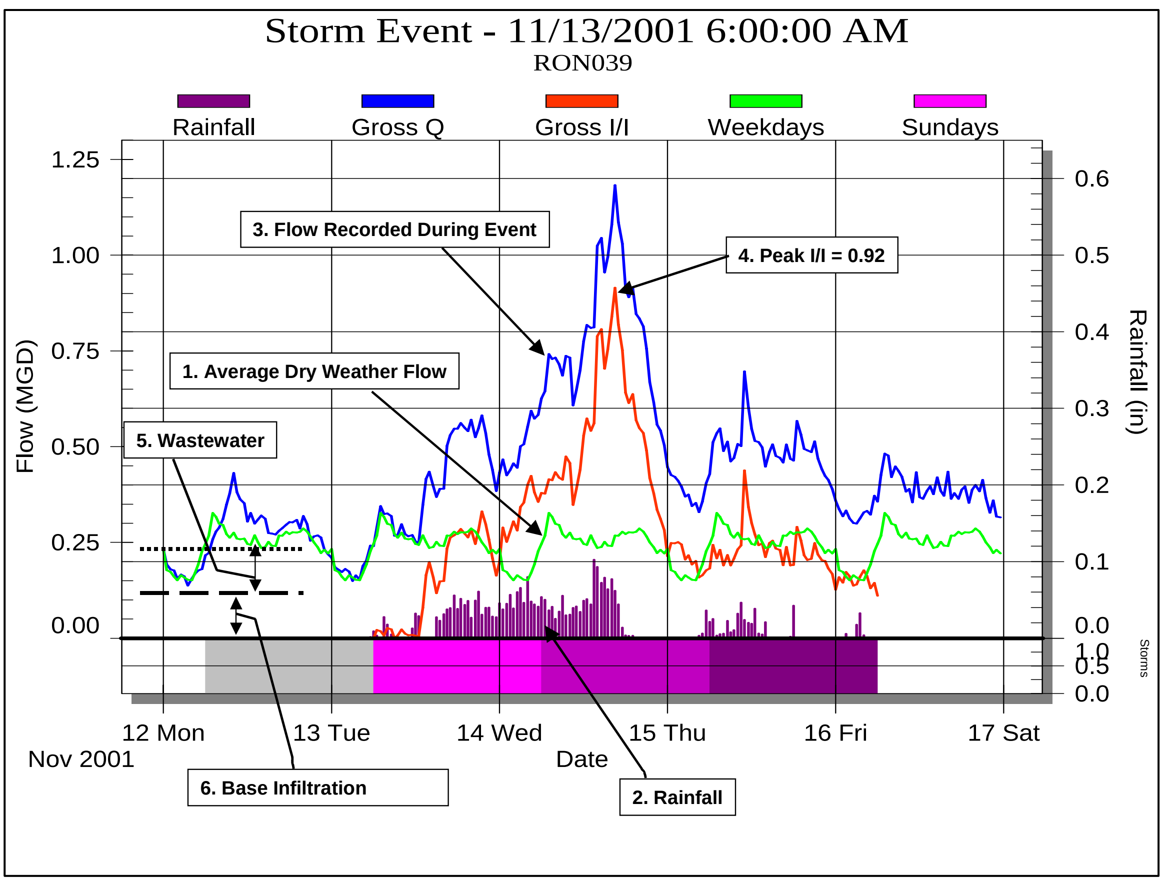
h) Total I/I is Calculated I/I Plus Base Infiltration

I/I used in this Memorandum and the values listed in Appendix A are Total I/I values. Total I/I is obtained by adding the estimated Base Infiltration (BI) to calculated I/I values. The units of Gallons per Day Acre (GPD/Acre) describe a 30-minute peak rate of Total I/I divided by the sewered acreage in the basin (Peak Total I/I in GPD/Acre). I/I is calculated in 30-minute time intervals and the Peak will be a 30-minute peak.

As an example in Figure D14, the 30-minute Peak I/I for Mini Basin RON039 is 0.92 MGD (rounded to two decimal places). BI is estimated to be 0.12 MGD so Peak Total I/I is the sum of the two (0.92 + 0.12) or 1.04 MGD. The basin size for Mini Basin RON039 is 183 Acres so the Peak Total I/I expressed in Gallons per Acre per Day is 1.04 MGD/183 Acres or 5,667 Gal/Acre/Day. This is the value reported in Appendix A for the November 13, 2001 rain event.

The values in Appendix A for 72-hour Total I/I volumes are obtained in a similar manner with three days of BI added to the calculated 72-hour I/I volume.

Figure D14
30-Minute Peak I/I for Mini Basin RON039



4. Wet Weather Performance (Q to i)

A graphical technique for evaluating and comparing the performance of Mini Basins in rain events with widely varying rain intensity is the Q to i diagram. "Q" is the calculated I/I, discussed in Section D. 3. g) and "i" is the corresponding rainfall. For each Mini Basin the diagram displays the relationship between each rain event and the resulting I/I. Two types of Q to i diagrams are included in a Word™ document for each Mini Basin presented in CD2. Figures D16 and D17 show the basic layout of Q to i diagrams and both figures are discussed in the following paragraphs.

One type is a 72-hour volume-to-volume relationship comparing the volume (depth) of rain in inches to the volume of I/I in millions of gallons. The second is a rate-to-volume relationship comparing Peak I/I to the rain falling prior to the time of the Peak I/I. The amount of rain is plotted on the x-axis and the response (I/I) is plotted on the y-axis. As a general rule, Mini Basins that leak the most 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 selected for a best-fit line are sufficient in number and in a similar season. By design, the data collected in this study were from two hydrologic seasons. Dry days were taken from the fall season, characterized by less frequent and less intense rains with "unsaturated" soil. Wet weather performance was measured in the winter season, characterized by more frequent and more intense rains and "saturated" soil. It appears that the hydrologic season changed after the very intense November 13, 2001 rain event and can be seen in Figure D15 by the increase in base flow. In many of the Mini Basins, particularly in the southern half of the service area, the November 13, 2001 event produced the most rain, but produced I/I that ranked in the middle range of the observed events.

Because of the two distinct hydrologic seasons, it would not be appropriate to attempt to fit a single best-fit line to all 10 rain events. The November 4, 2001, rain event is in the fall hydrologic season and the response in most Mini Basins is much less than the subsequent rains in the winter hydrologic season. These diagrams 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.

Last year four forms of Q to i diagrams were produced, but the rainfall patterns this year make two of them listed below inappropriate. The four types are:

- Total Event or 72-hour volume of I/I to 72-hour volume of rainfall (included in Appendix B) – This display is very useful because it captures the entire rain in events exceeding 24 hours and also because it captures most of the I/I from Mini Basins as they recover from an event.
- Rate of I/I to volume of rainfall (included in Appendix B) – This form compares the peak rate of I/I to the rainfall volume that fell only prior to the peak. It ignores the rainfall occurring after the peak I/I. This form is well suited to the Pacific Northwest rain events that often lack distinct beginnings, peaks and ends.
- Rate of I/I to rate of rainfall (not used this year) - The rates displayed are the peak rates of I/I and peak rate of rainfall. This method is used for a traditional convective

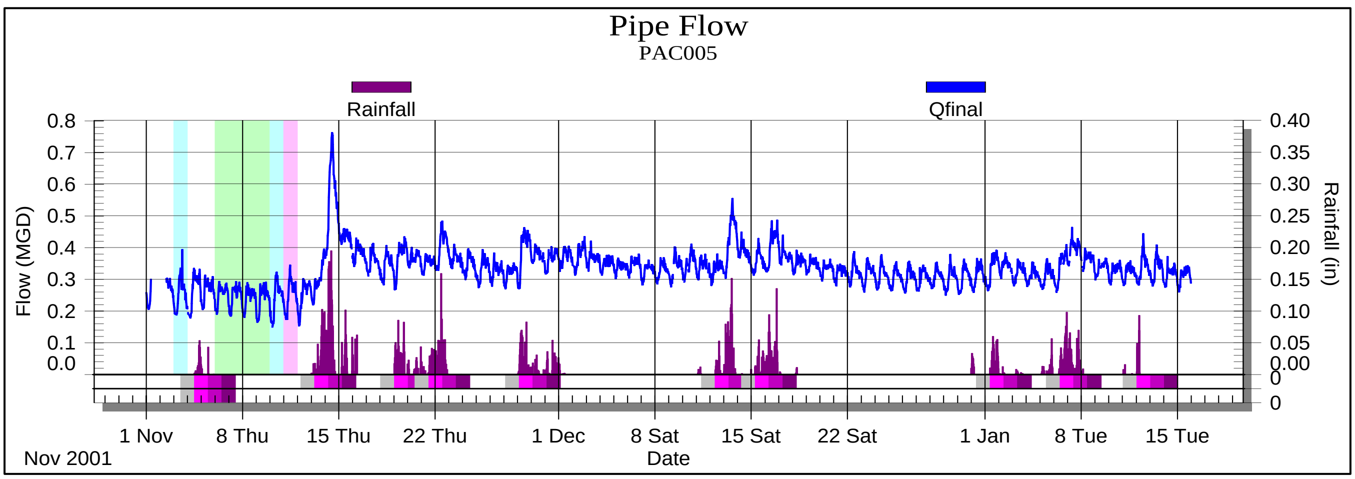
thunderstorm-type of rain event of short duration with a distinct beginning, peak and end. Many of the 10 rain events were over 24 hours in duration without distinct peak rainfall rates.

- 24-hour volume of I/I to 24-hour volume of rainfall (not used this year) - The 24-hour volume-to-volume display is inappropriate because several of the rain events and I/I responses were over 24 hours in length.

a) Interpreting Q to i Diagrams

Mini Basin PAC005 provides an example of how the Q to i diagrams can be used. Figure D15 is the hydrograph of Mini Basin PAC005 and Figures D16 and D17 are Q to i diagrams. The ADDF of the selected dry weekdays shown in the green shaded bands is 0.245 MGD and the estimated base infiltration is 0.156 MGD. (64% of ADDF). The change from the hydrologic fall season to the winter season is apparent by the increase in base flow after the large 5.1-inch storm on November 13, 2001. It is common to attribute this increase to high groundwater or saturated soil and the phenomenon occurred in many Mini Basins.

Figure D15
Hydrograph of Mini Basin PAC005



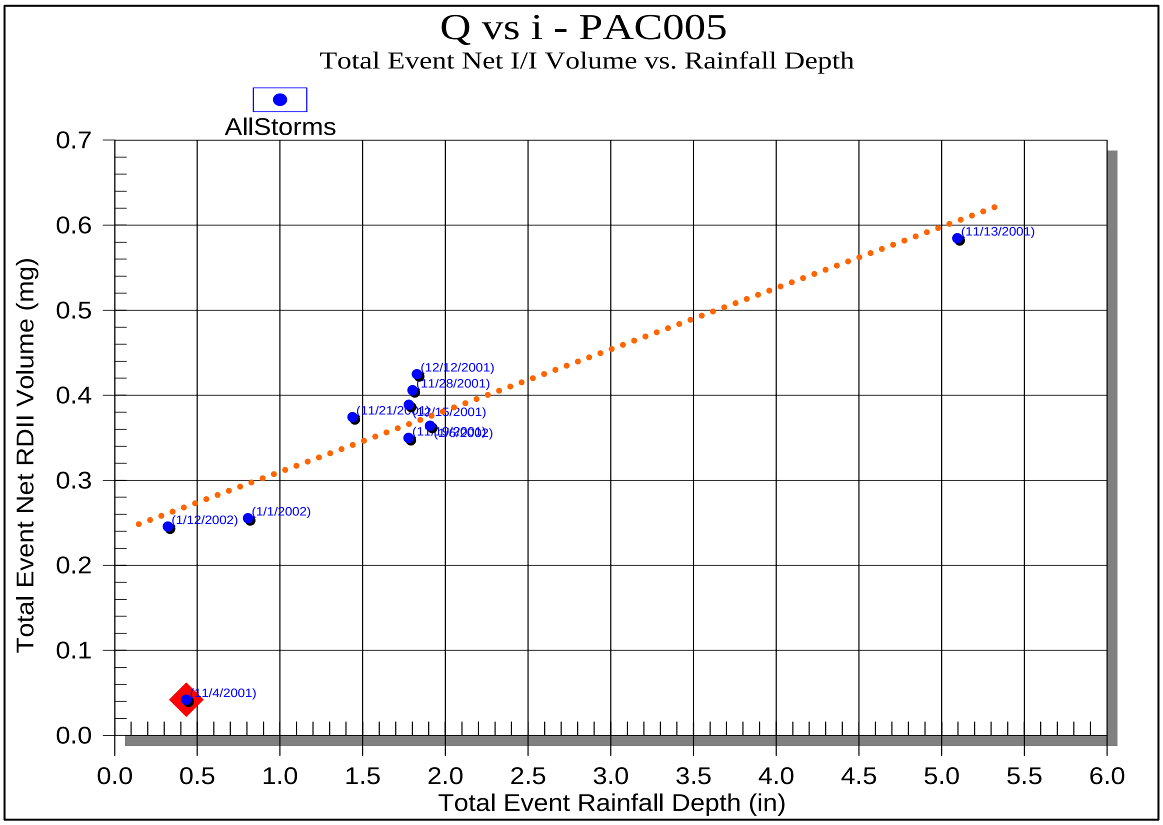
Q to i diagrams offer information not available from the table in Appendix A. The I/I data in the Q to i diagrams are calculated I/I (discussed in D.3.g)) and not Total I/I reported in Appendix A. Calculated I/I is the difference between the measured flow and the dry day flow for that 30-minute period. The base infiltration is included in the dry day flow and therefore is not included in the I/I values.

Also the calculated I/I values are not normalized by acres or by linear feet of sewer in the Mini Basin. The Q to i diagram provides the actual measured I/I as either the peak rate in MGD or as volume in MG.

b) Volume-to-Volume Total Event

The Volume-to-Volume Q to i (Total Event) form shown in Figure D16, plots the rainfall volume of the total event against the volume of I/I during the entire 72-hour event. The 72-hour duration is used to capture initial I/I response as well as the recovery period. Most Mini Basins recovered from a rain event within 72 hours. A longer period may capture I/I from Mini Basins with recovery times longer than 72 hours, but overlapping I/I measurements will often occur if storms are close together. Some users like this form for sizing storage facilities.

Figure D16
Volume-to-Volume (Total Event) Q to i

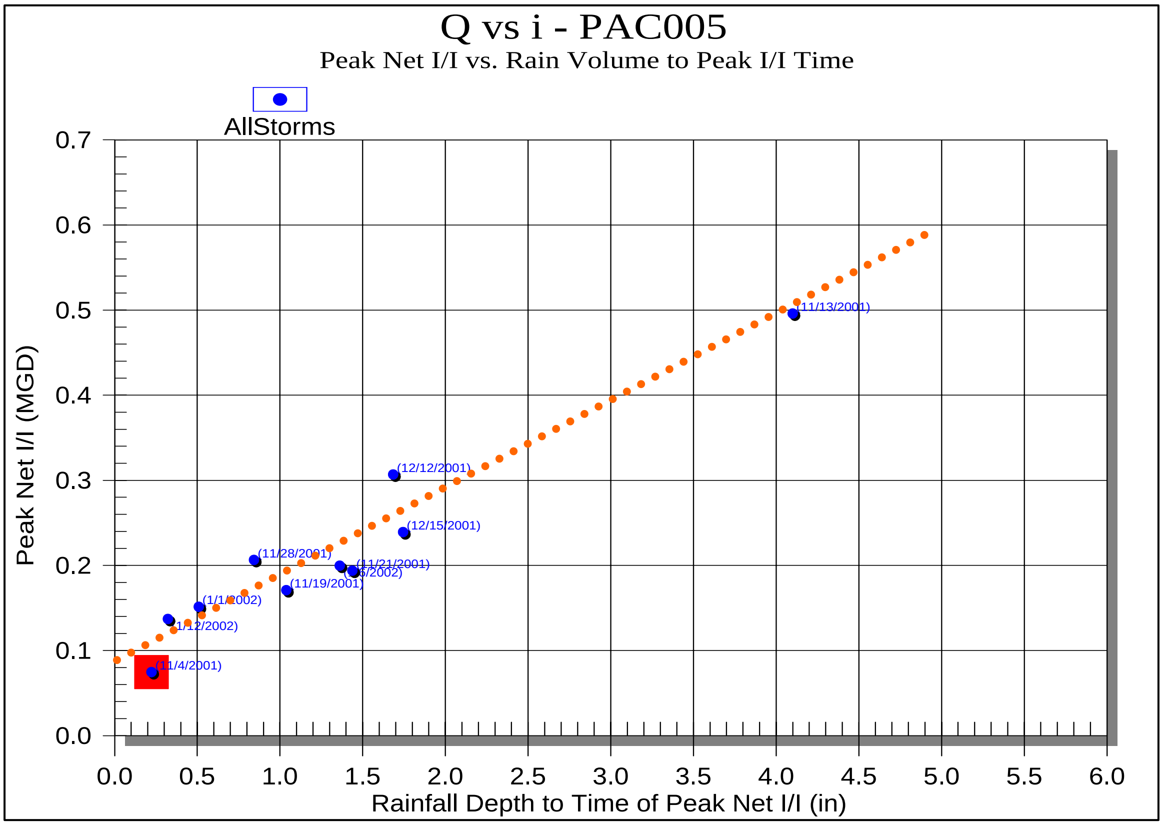


The dashed line represents a reasonable relationship between rainfall and total event volume of I/I in this Mini Basin for all but the first rain event highlighted in red. The first rain event was in the fall season and reflects the distinct difference in flow as seen in the hydrograph in Figure D15. This phenomenon prevents the addition of a best fit line to the Q to i diagrams included in CD#2.

c) Rate-to-Volume

The Rate-to-Volume Q to i form (Figure D17) plots the peak rate of I/I to the rainfall volume falling prior to the time of peak I/I. Some users prefer this form since it recognizes that rain falling after the I/I peak does not contribute to the peak. Note that the peak I/I of the November 13, 2001 rain event occurred after only 4.1 inches of rain fell.

Figure D17
Volume-to-Rate Q to i Diagram

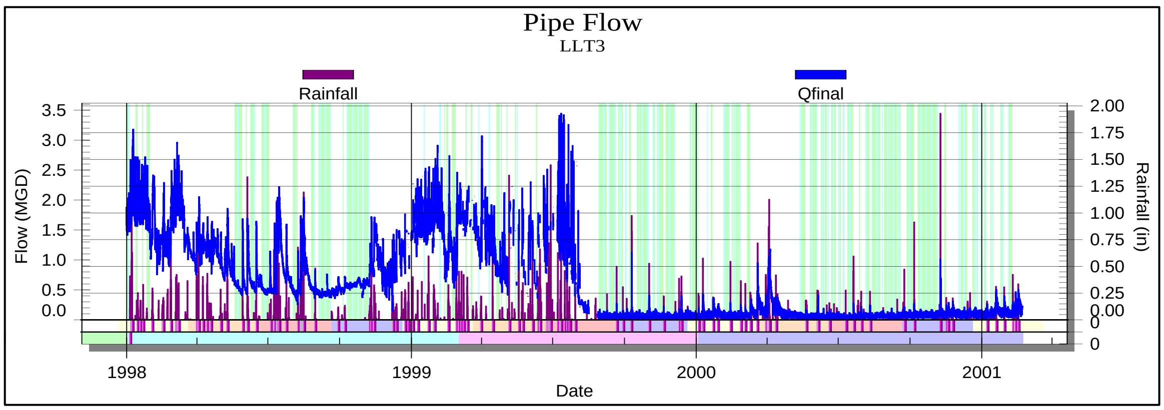


The dashed line represents a reasonable relationship between rainfall and the peak rate of I/I in this Mini Basin. The data point with the red highlight is the November 4, 2001 rain event that occurred during the fall season.

d) Q to i Diagrams for Quantifying Effectiveness of Rehabilitation

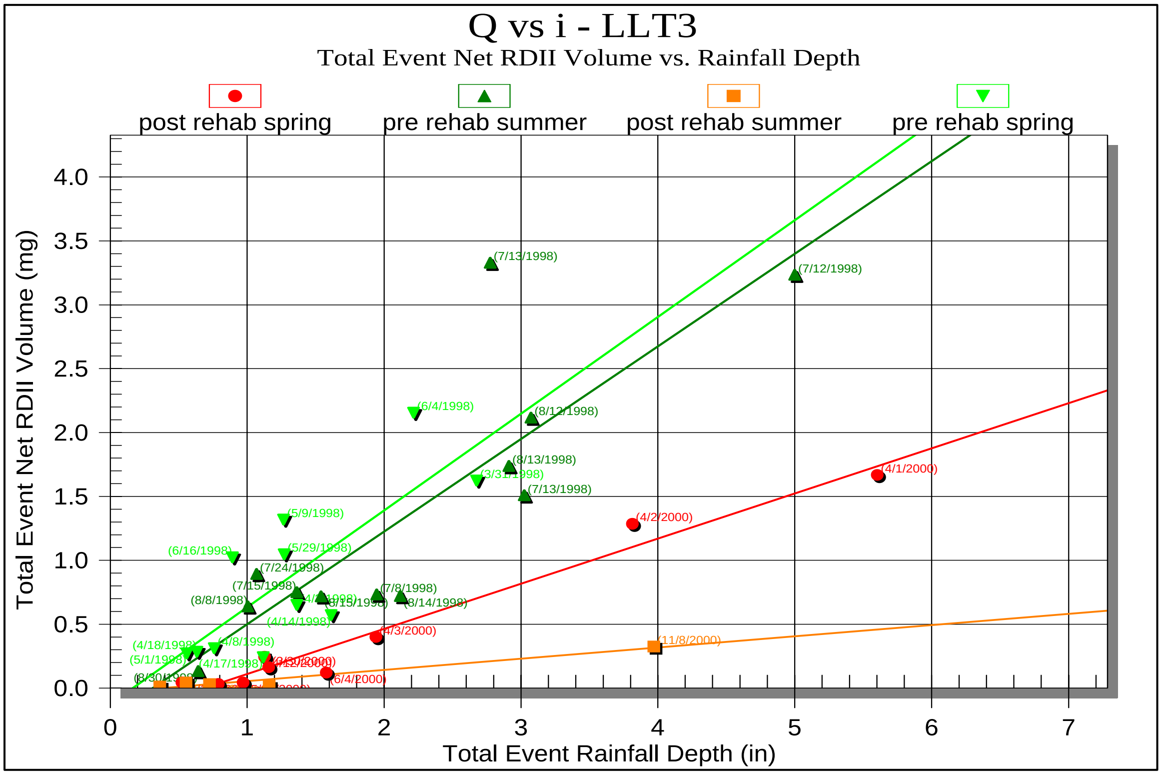
A valuable use of Q to i diagrams is to document the effectiveness of sewer rehabilitation. It is intended that they be used to help quantify the effectiveness of rehabilitation of the ten pilot Mini Basins to undergo rehabilitation as part of this program. For this technique to be implemented flow and rain data from the pilot Mini Basins must be collected for multiple hydrologic seasons both before and after rehabilitation. As an example Figure D18 is a hydrograph of three years of flow data from a basin that was rehabilitated. The rehabilitation occurred in 1999 and resulted in the dramatic change in flow and response to rain. With flow and rain data for multiple hydrologic seasons both before and after rehabilitation, Q to i diagrams can be generated for each season.

Figure D18
Three Years of Flow Data From Rehabilitated Basin



The Q to i diagram in Figure D19 displays 72-hour rain and the resulting 72-hour I/I for the Spring and Summer hydrologic seasons for both before and after rehabilitation. It is expected that diagrams similar to this will be generated for the ten pilot Mini Basins. Flow and rain data must be collected for at least one full hydrological season before rehabilitation and after rehabilitation.

Figure D19
Q to i Diagram for Quantifying Rehabilitation Effectiveness



E. Rainfall and the CALAMAR System

The King County service area as shown in Figure E9 is contained in a rectangular area of approximately 1100 square miles (2800 Km^2) in western King County, southern Snohomish County and northern Pierce County, Washington. Much of 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 King County to consider CALAMAR, a well-developed French technology using radar images from the National Weather Service NEXRAD Radar and the County's network of 72 rain gauges for calibration. CALAMAR is provided by RHEA, SA of Nanterre, France and is described in Sections E3 through E7. All rainfall data delivered as part of this Memorandum in Appendix A and in the Q to i diagrams on CD2 are CALAMAR data.

1. Rainfall in Perspective

King County received an above-average amount of rainfall during the monitoring period with 21.3 inches recorded at SeaTac airport for the three months of November 2001 through January 2002. Last year SeaTac recorded 16.8 inches for the same period. During the 76-day flow metering period from November 1, 2001 through January 15, 2002, the King County Service area received between 19 and 22 inches, with the exception of the northern portion of the Alderwood area that received approximately 16 inches. Within King County the northern half of the service area received approximately 19 to 21 inches, while the southern half received approximately 21 to 22 inches.

As reported by the *Seattle Times* on November 16, 2001, new daily rainfall records were set at SeaTac and the Sand Point NOAA rain gauges for the rainfall of November 14, 2001. SeaTac recorded 2.61 inches breaking the old record of 1.26 inches. Sand Point recorded 1.83 inches breaking the old record of 0.24 inches.

On an event-by-event basis, the rainfall varied dramatically over the service area. Rainfall maps for each rain event, as measured by CALAMAR, are included in Appendix B in the document Appendix B\Rainfall Maps\Rainfall Maps.doc.

Eighteen (18) rain events occurred during the metering period, but only 10 events, listed in Table E1, met the criteria of causing a measurable and system-wide I/I response in the sewer network. Several Mini Basins exhibiting significant inflow and infiltration responses throughout the metering period were used as "I/I barometers" to determine if I/I responses were measurable and system-wide. Barometer Mini Basins were BEL024, BOT003, BRR002, KNT032, NUD040, RNT025, and SOO025. The 10 selected rain events were those that created a measurable response in the barometer basins.

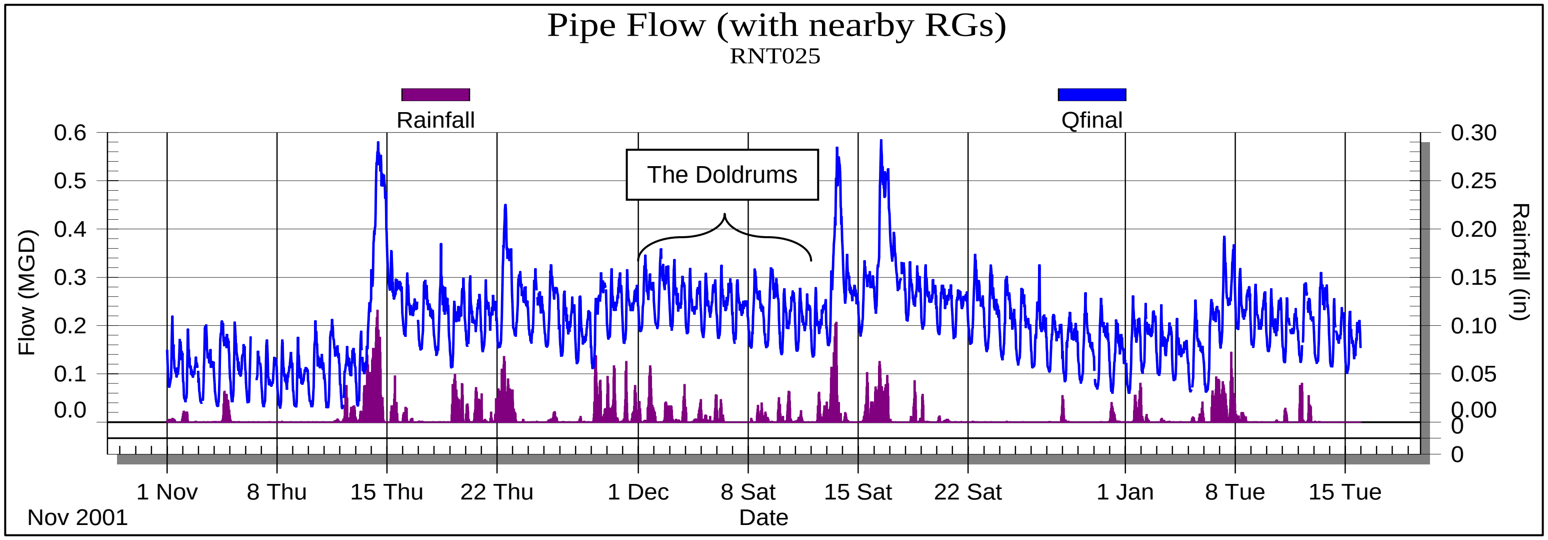
Table E1
Event Start Times and CALAMAR Rain Totals

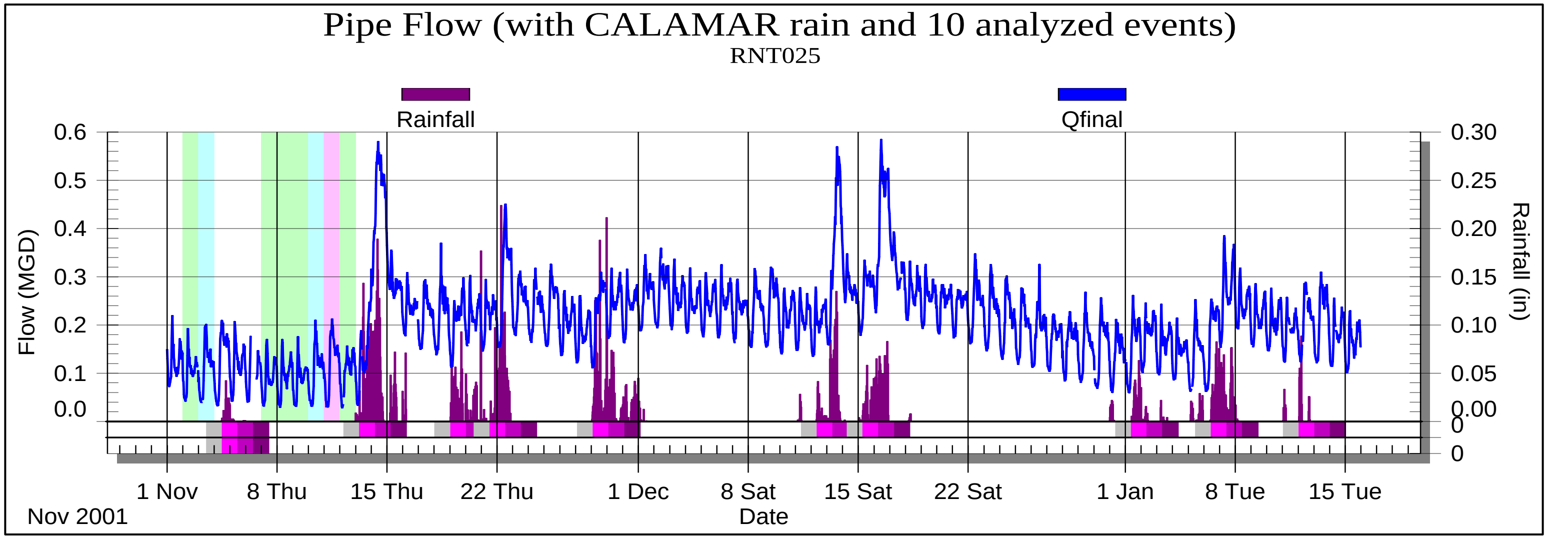
Event Times and Rain Totals Processed by CALAMAR			
Storm	Event Start Time	Minimum Rain	Maximum Rain
1	11/4/01 12:00 PM	0.10	0.62
2	11/13/01 6:00 AM	1.36	5.74
3	11/19/01 1:00 AM	0.92	2.39
4	11/21/01 1:00 PM	0.64	2.86
5	11/28/01 3:00 AM	1.77	3.97
6	12/12/01 9:00 AM	0.64	2.32
7	12/15/01 7:00 AM	1.38	2.90
8	1/1/02 9:00 AM	0.38	0.95
9	1/6/02 11:00 AM	1.03	2.60
10	1/12/02 1:00 AM	0.12	0.97

The Event Start Time in Table E1 is the start time of the I/I calculations throughout the study area. The time selected was the first occurrence of rainfall and significant flow response anywhere in the service area. The rain events did not begin uniformly across the service area and took as long as three hours to affect all Mini Basins. As a result some Mini Basins appear to be "idle" from an I/I perspective at the beginning of the rain event until the rain arrives.

Figure E1 is an example of the flow response from RNT025, which served as a barometer Mini Basin. The top panel shows rainfall from nearby rain gauges and the bottom panel shows the rainfall processed by CALAMAR for the 10 selected events. The period between December 1 and December 12, 2001 is labeled "The Doldrums" on the top panel because it was filled with almost continuous and low intensity rains. The increase in I/I during the doldrums was small and difficult to associate with the preceding rainfall. The I/I response during the doldrums in most Mini Basins was insignificant. Rainfall during the doldrums was not processed by CALAMAR. A sampling of rain gauges indicates that approximately 80% (75% to 85%) of the total rain during the metering period was included in the CALAMAR measurements during the 10 rain events.

Figure E1
Rainfall During the Doldrums was not Processed by CALAMAR



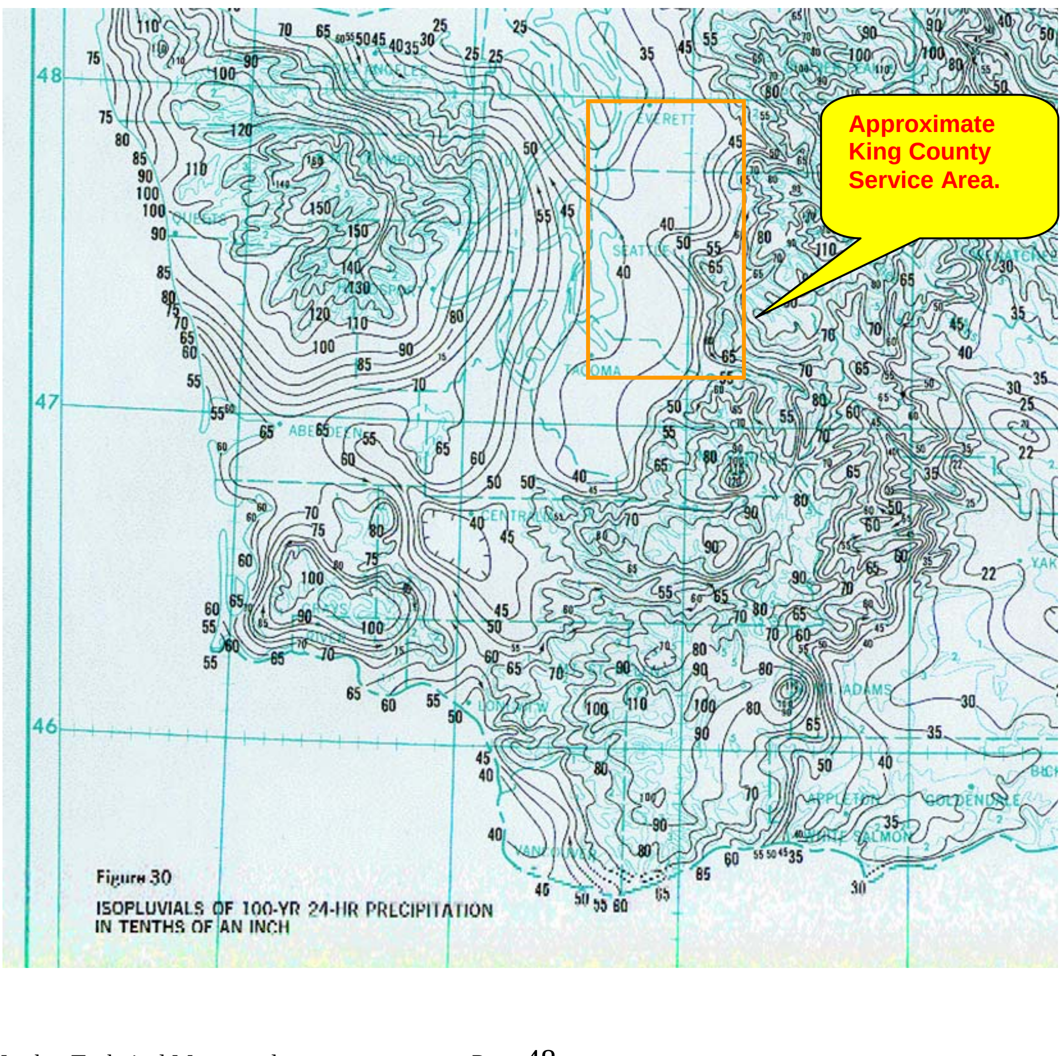


2. Intensity Duration Frequency (IDF) Overview

Understanding the magnitude of rainfall is important to both the measurement of I/I and the calibration of hydraulic models. In addition to knowing how much rain fell, it is important to understand the intensity and return frequency of the rainfall. Rainfall can be evaluated by comparing it to a set of Intensity Duration Frequency (IDF) curves. IDF curves are a statistical summary of many years of historical rainfall data and are unique to a general area. They allow one to answer a question such as, "How often (frequency) does a 3 inch rain (intensity) fall over a 24-hour period (duration)".

IDF data are commonly available in graphic format from the National Weather Service *Rainfall Frequency Atlas of the U.S*. published in 1973. Figure E2 is an Isopluvial (lines of constant rainfall) graph from the Atlas depicting the 24-hour rainfall returning one each 100 years in the in Western of Washington. The Isopluvials are in tenths of an inch. County lines are shown in the background in this graph and King County lines can be seen to the north and south of "Seattle". The isopluvials indicate that a rain of 24-hour duration returning once each 100 years is slightly less than 4 inches.

Figure E2
100-Year Isopluvials in Western Washington (Rainfall Frequency Atlas of the U.S.)



The expected frequency for a given rain is the reciprocal of the probability or chance that the rainfall will be equaled or exceeded in a given year. For example, if a rainfall has a 20 percent chance of being equaled or exceeded each year, over a long period of time the rainfall will be equaled or exceeded on an average of once every five years. This is called the return period or recurrence interval (RI). Thus the exceedance probability equals 100/RI. Table E2 lists the probability of occurrence for standard return frequencies.

Table E2
Return Frequency of a Rain Event versus Its Annual Probability

Return Frequency (Years)	Annual Probability (%) of Event
1	100
2	50
5	20
10	10
25	4
50	2
100	1

The five-year rain event is not one that will necessarily be equaled or exceeded every five years. There is a 20 percent chance that the rain event will be equaled or exceeded in any year; therefore, the five-year rain event could conceivably occur in several consecutive years.

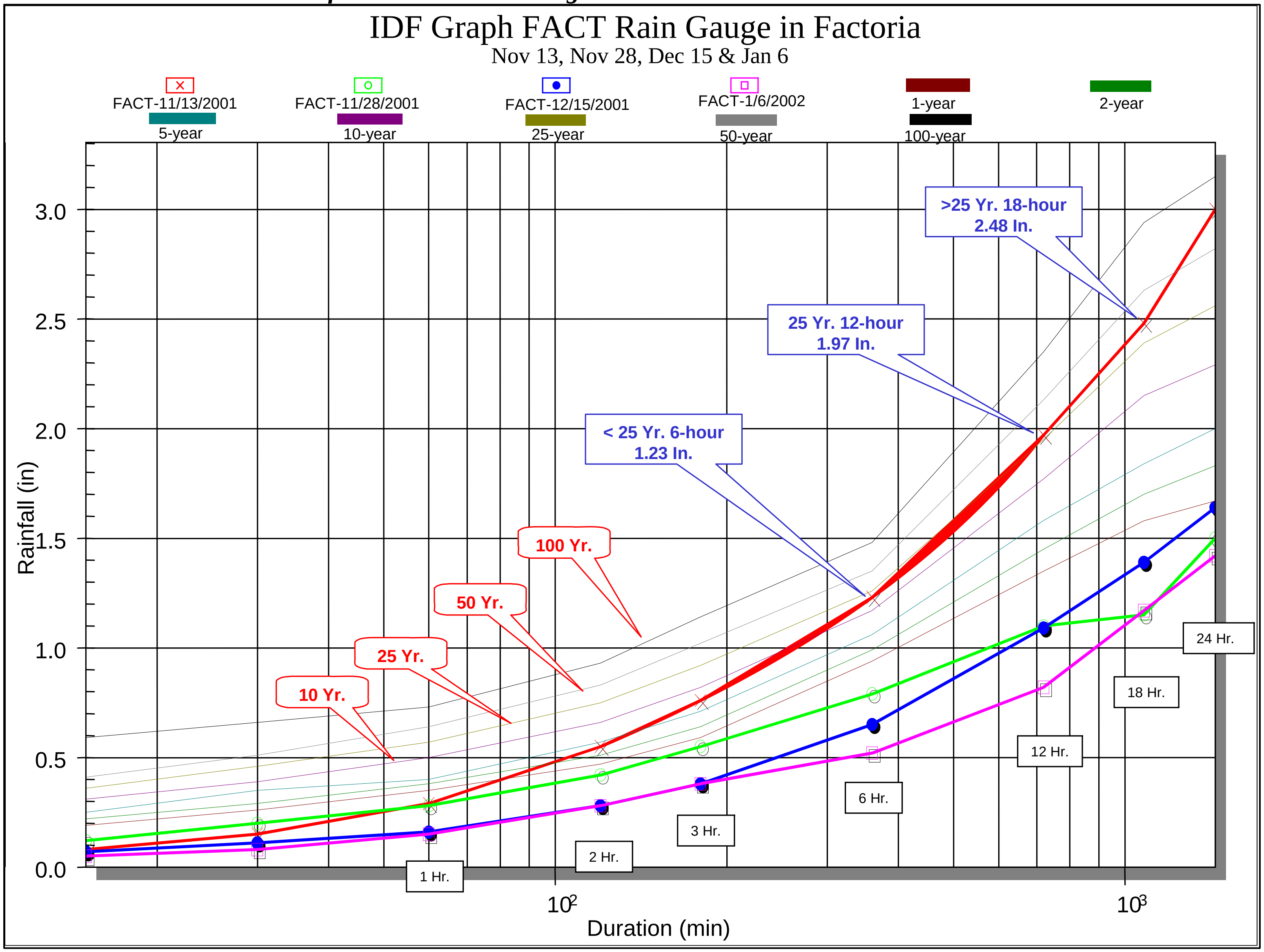
In 1997 the Seattle Public Utilities (SPU) updated the IDF curves that had been prepared by the National Weather Service and published their results in the paper *Recalculating Precipitation Intensity-Duration-Frequency Curves for the City of Seattle.* The effect of the update was to decrease the return frequency of a given rain event, i.e. rainfall that used to be a 15-year event could now be a 20-year event. These IDF curves are based on rainfall in the SPU service area, but for comparison purposes, are used in this Memorandum to evaluate rainfall throughout the King County service area. As a result, the IDF observations made about the rain events are approximate.

Figure E3 is an example of an IDF graph with SPU curves displayed. The set of lightweight curves are a summary of the SPU historical data with the top curve being the 100-year event, the second curve being the 50-year event and so on. The x-axis is a log scale of minutes and the y-axis is the rainfall amount corresponding to the duration (or time step) in minutes. The order and coloring of the lightweight IDF curves are the same on all IDF graphs that follow.

Also plotted are the results of the FACT rain gauge in Bellevue during the rain events of November 13, November 28, December 15, 2001 and January 6, 2002. Rain gauge data are displayed as the combination of duration and the maximum rainfall for that duration. Durations are standard throughout meteorology and are durations of 1 hr. 2 hr., 3 hr., 6 hr., 12 hr., 18 hr. and 24 hours.

These durations are **not** the length of time since the start of the event. For example the maximum rainfall at FACT rain gauge in a 12-hour period during the November 13, 2001 rain event was 1.97 inches or a 25-year, 12-hour event. This 12-hour period could have occurred at the beginning, the middle or the end of the 72-hour measurement period. The return frequency of the other three events was less than once per year.

Figure E3
Data from FACT Rain Gauge in Factoria Plotted on an IDF Curve



a) County Wide Observations

A cursory IDF analysis of both rain gauge and CALAMAR data for the 10 rain events resulted in the estimated maximum return frequency (intensity) shown in Table E3. The duration corresponding to the maximum return frequency is not necessarily a 24-hour duration. For example a rain event may have contained a 4 year 6-hour storm, but less than a 1 year 24-hour storm. There was wide geographic variation for each event and the maximum return frequency shown in the table generally occurred in a small portion of the service area for each event. Also the return frequency values are from the Seattle Public Utilities (SPU) updated IDF curves and are approximate values. The intensities listed in Table E3 did not occur throughout the entire service area. The geographical distribution of these events is mapped in Appendix B\Rainfall Maps\Rainfall Maps.doc.

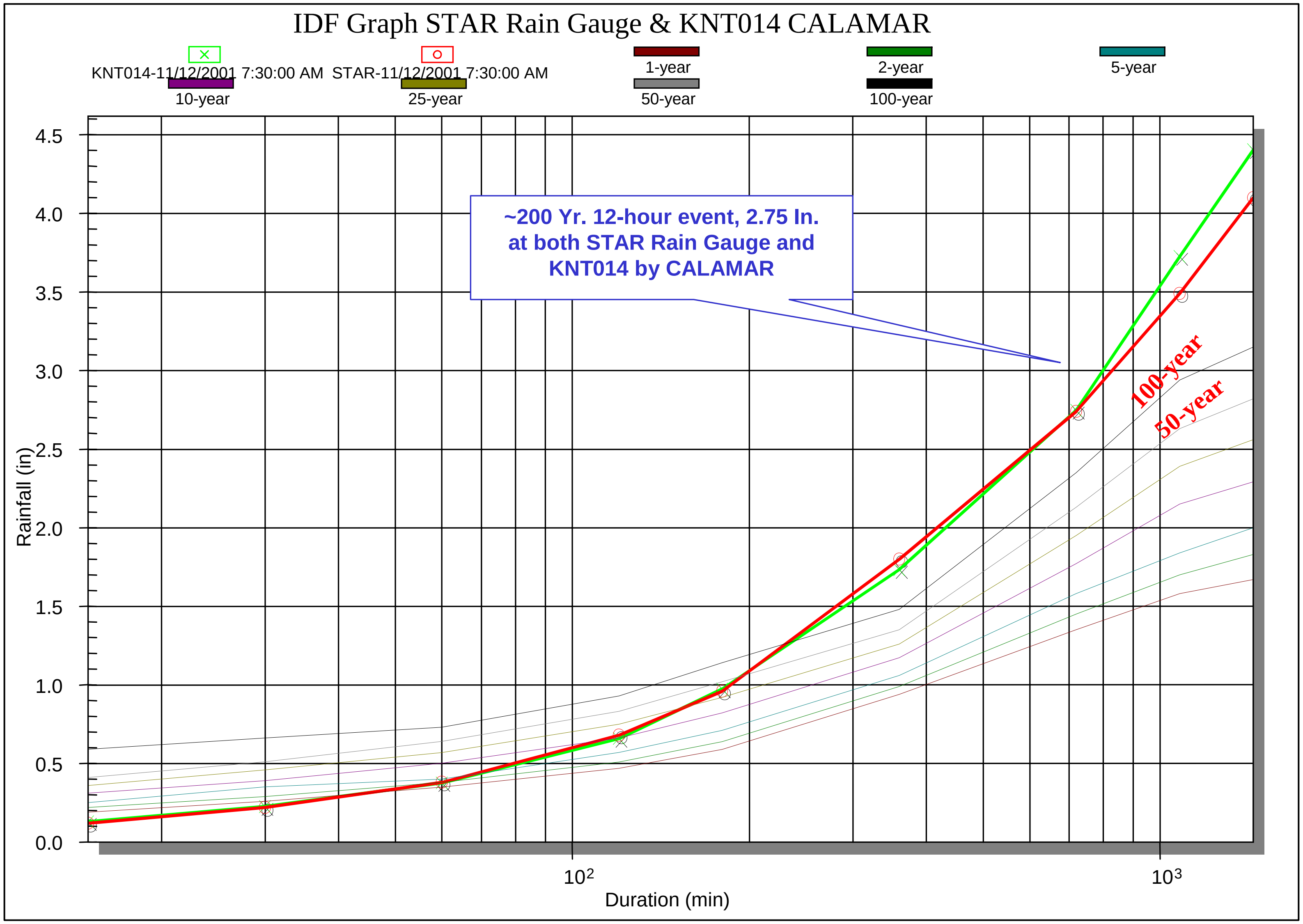
Table E3
Range of Rainfall for 10 Events over Service Area
And Approximate Return Frequency of Maximum Rainfall

Date of Rain Event	Rainfall (Inches)	Return Frequency *
November 4, 2001	0.1 – 0.6	< 1 Year
November 13, 2001	1.4 – 5.2	> 100 Year
November 19, 2001	0.9 – 2.4	< 1 Year
November 21, 2001	0.6 – 2.9	4 Year
November 28, 2001	1.8 – 3.9	50 Year
December 12, 2001	0.6 – 2.3	4 Year
December 15, 2001	1.4 – 2.9	< 1 Year
January 1, 2002	0.4 – 1	< 1 Year
January 6, 2002	1 – 2.6	< 1 Year
January 12, 2002	0.1 - 1	< 1 Year

* Approximate Return Frequency based on SPU Intensity-Duration-Frequency Curves, 1997

The most intense rainfall recorded during the study period was in the Kent area during the November 13, 2001 rain event. Figure E4 is an IFD curve showing data from the STAR rain gauge in Kent and the CALAMAR rainfall on Mini Basin KNT014. The storm intensity exceeded the 100-year return frequency over several durations. Although data are not available to generate the 200-year return frequency line, it appears visually this event could have been a 200-year event had it occurred in the SPU area.

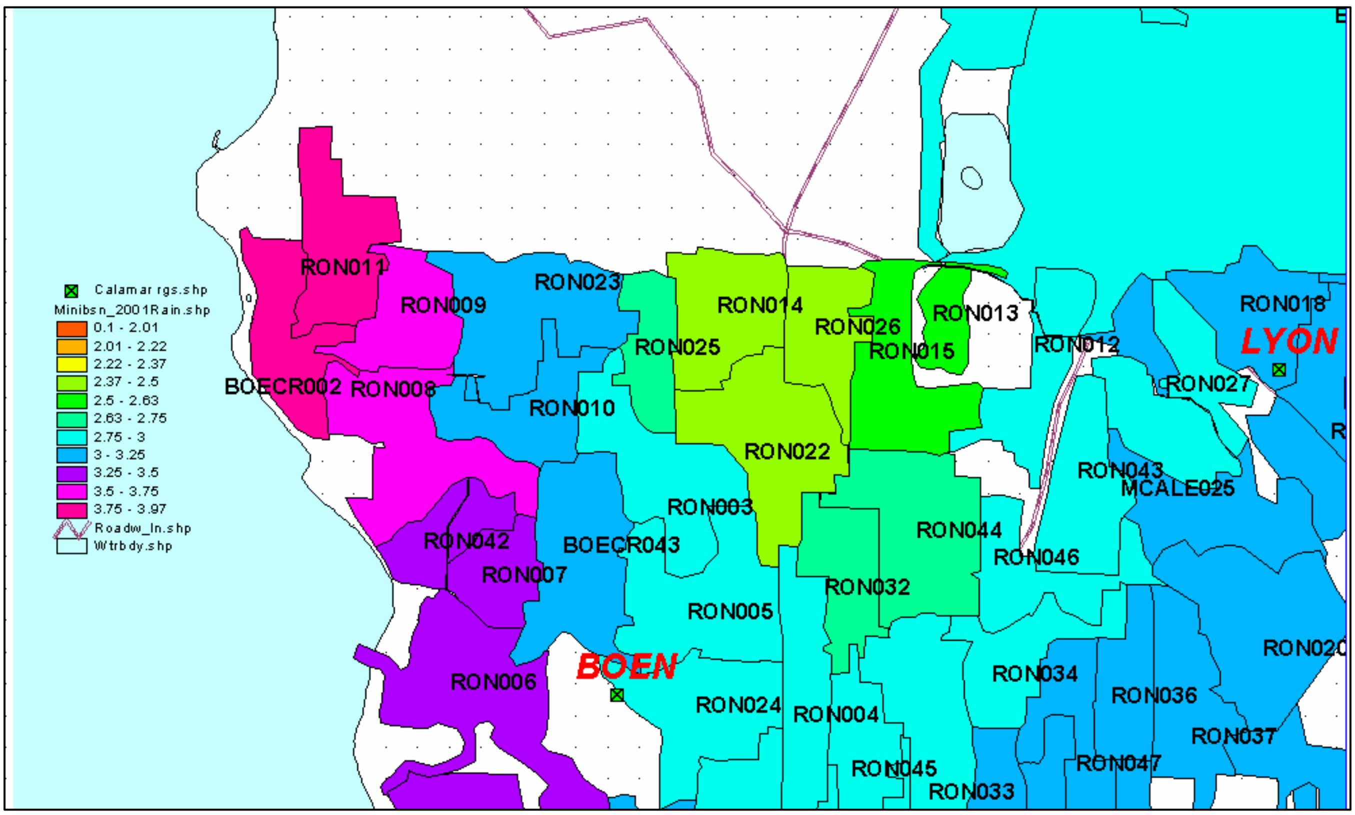
Figure E4
IDF Graph with Data from STAR Rain Gauge in KNT014 from CALAMAR



b) Rainfall Between Rain Gauges

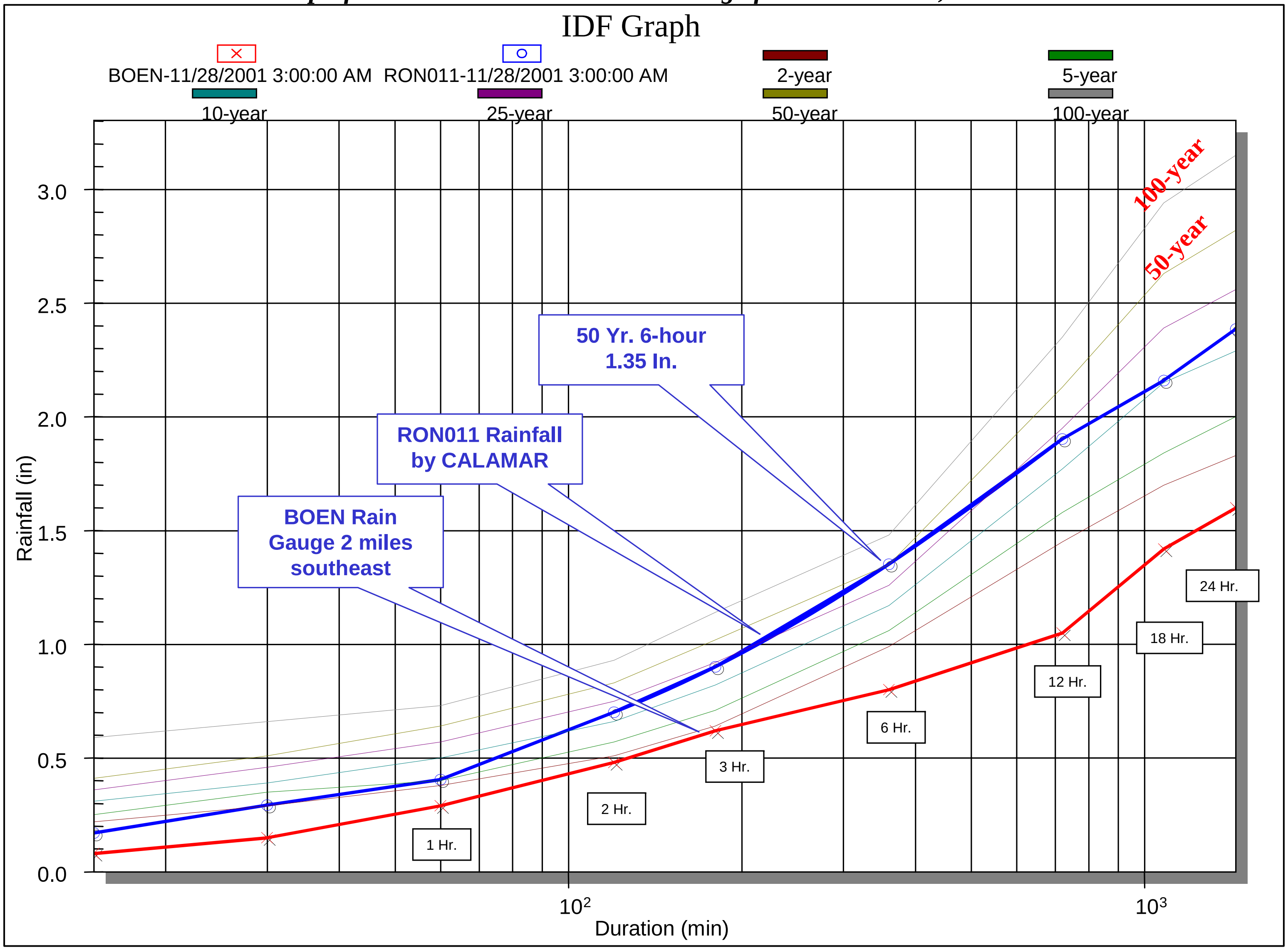
Two important features of the CALAMAR system are that it measures rainfall between rain gauges and spots rain gauges that are inaccurate. Both instances occurred during the November 28, 2002 event in the Richmond Beach area. Figure E5 shows the Mini Basin rainfall in the Richmond Beach area for the November 28, 2001 event. As measured by CALAMAR the two most western Mini Basins, BOECR002 and RON011 received in excess of 3.9 inches for a 72-hour total while BOEN, the nearest rain gauge 2 miles to the southeast, recorded 2.7 inches. CALAMAR measured over an inch more rain in these two Mini Basin than would have been believed by using rain gauges only. In addition CALAMAR showed that the BOEN rain gauge had been underreporting rainfall both before and after this event. It underreported rainfall by over 0.3 inches in this event. The BOEN rain gauge was not used for calibration for this event. See Section E. 6. for a discussion of how rain gauges can become inaccurate.

Figure E5
Rainfall Map of Shoreline Area and Richmond Beach for November 28, 2001 Event



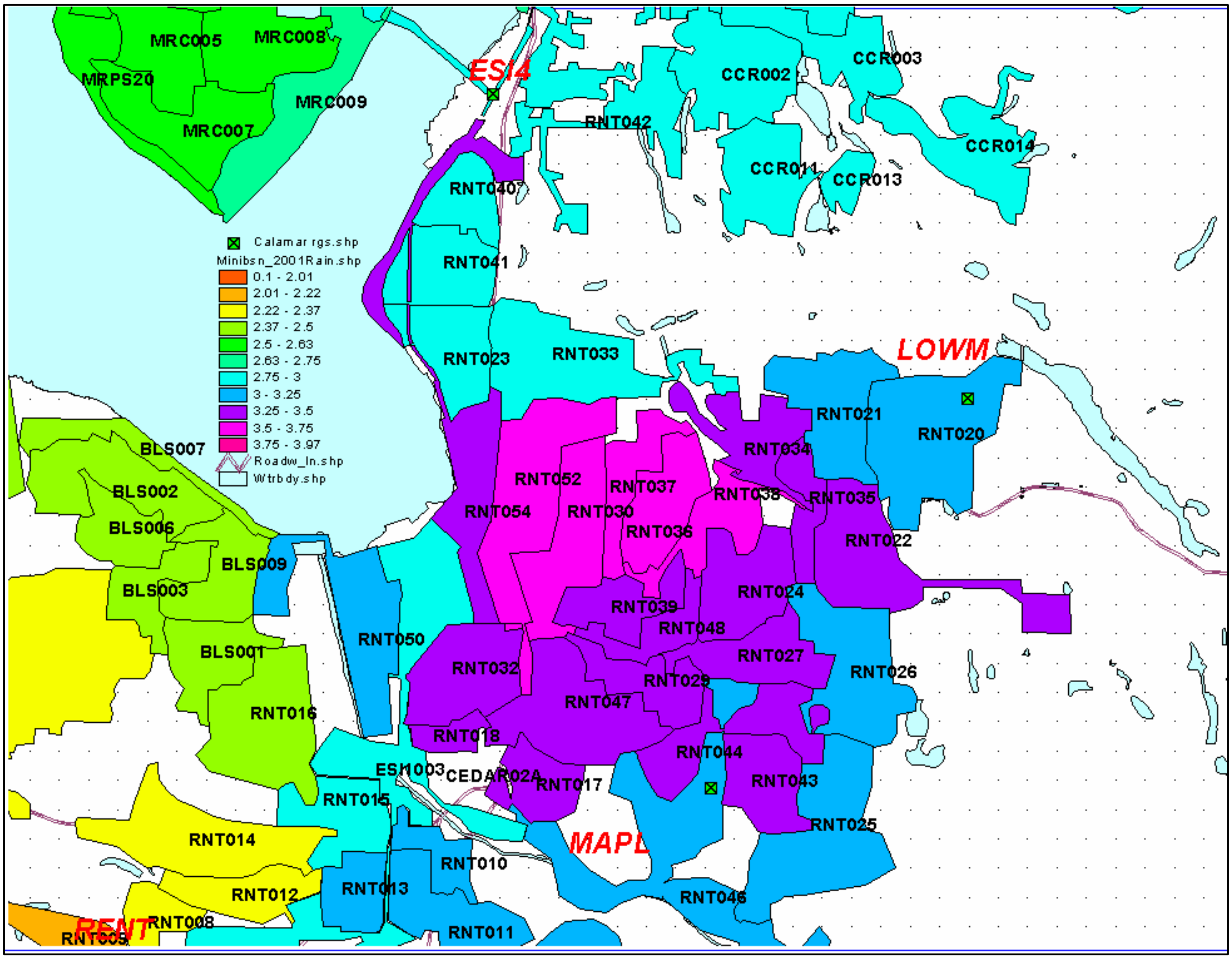
Although the 72-hour rainfall total for Mini Basin RON011 was only 1.2 inch higher than the nearby BOEN rain gauge, it was found that the intensity between the two sites differed considerably. Figure E6 is an IDF graph for rain falling on RON011 and rainfall recorded by the BOEN rain gauge. Mini Basin RON011 experienced a 50-year, 6-hour event while intensity at the BOEN rain gauge was less than a 1-year event.

Figure E6
IDF Graph for RON011 and BOEN Rain Gauge for November 28, 2001 Event



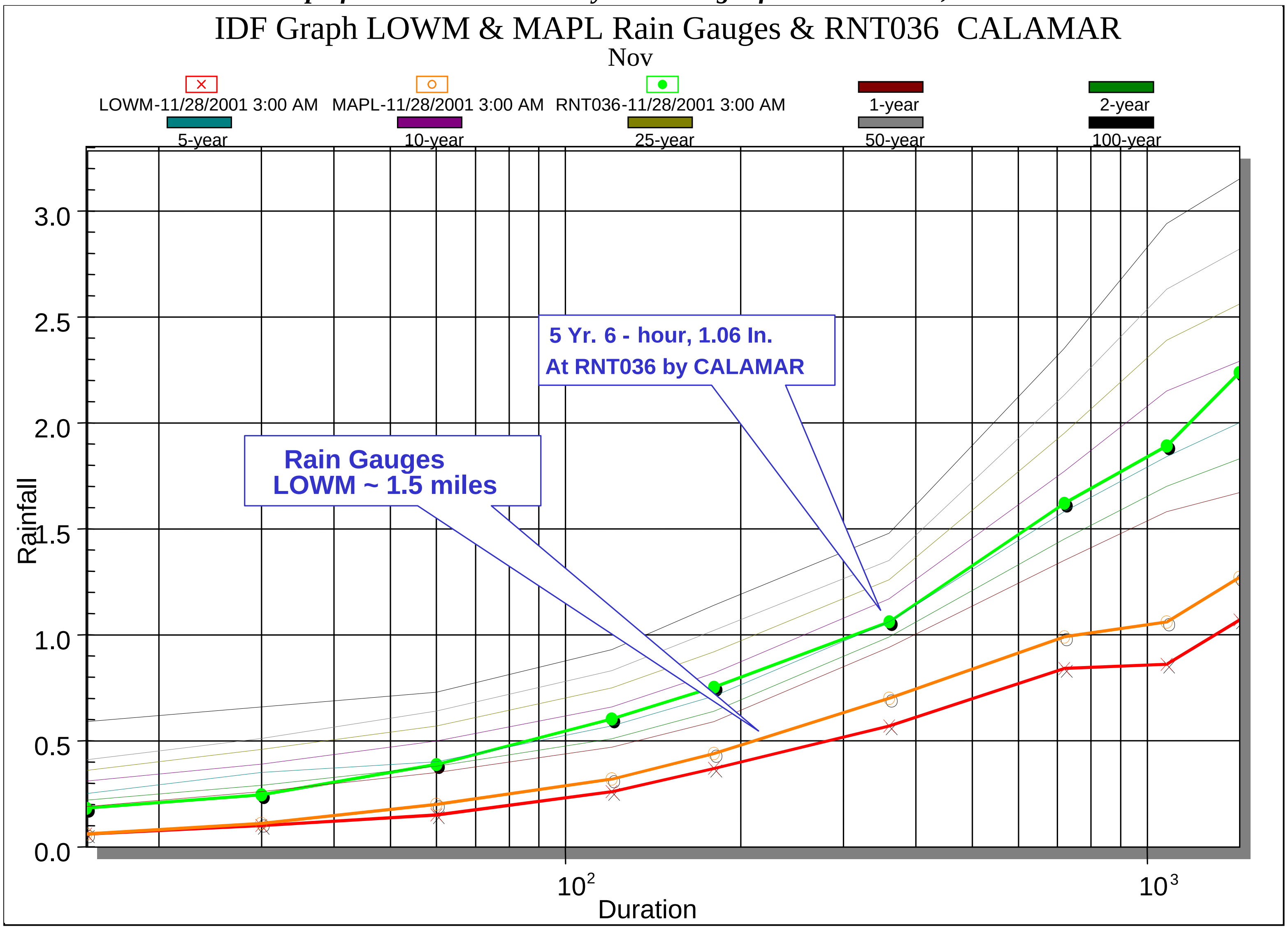
A similar occurrence was spotted in Renton during the November 28, 2001 event. Figure E7 is a rainfall map showing 72-hour rainfall in the Renton area for the November 28, 2001 event and the highest rainfall was measured in several Mini Basins near RNT036 at 3.56 inches. The two nearby rain gauges LOWM and MAPL were approximately 1.5 miles away and each recorded approximately 3.2 inches.

Figure E7
Rainfall Map of Renton Area for November 28, 2001 Event



Although the 72-hour rainfall total for Mini Basin RNT036 was only 0.4 inches higher than the nearby LOWM and MAPL rain gauges, it was found that the intensity between the Mini Basin and the two gauges differed considerably. Figure E8 is an IDF graph for rain falling on RNT036 and that recorded by rain gauges LOWM and MAPL. Mini Basin RNT036 experienced a 5-year, 6-hour event while intensity at the two rain gauges was less than a 1-year event.

Figure E8
IDF Graph for RNT036 and Nearby Rain Gauges for November 28, 2001 Event



3. Principles of Radar Technology and CALAMAR

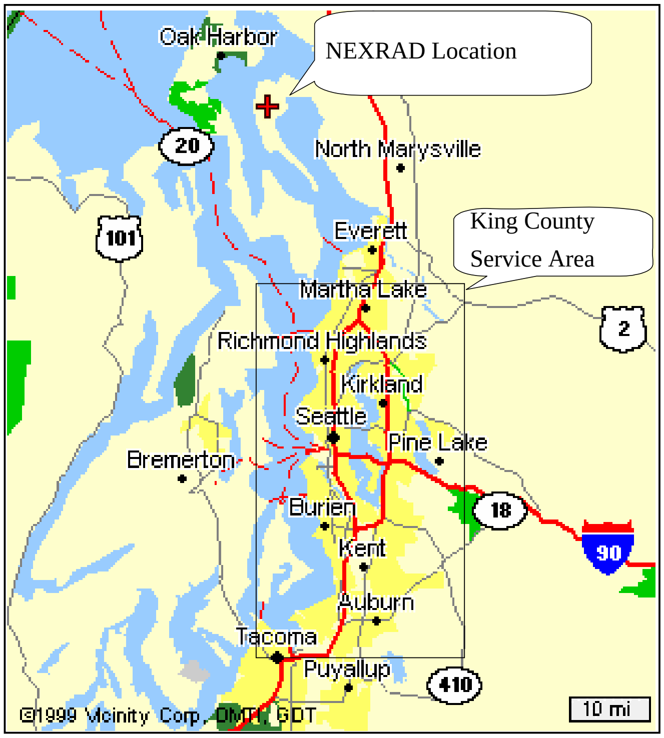
The advent of the National Weather Service's NEXRAD weather radar system provides a major advance in the ability to locate and track rainfall with geographic precision. While the geographic precision of NEXRAD is accurate, its ability to measure the intensity of rainfall is not accurate. With the addition 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 E9 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.

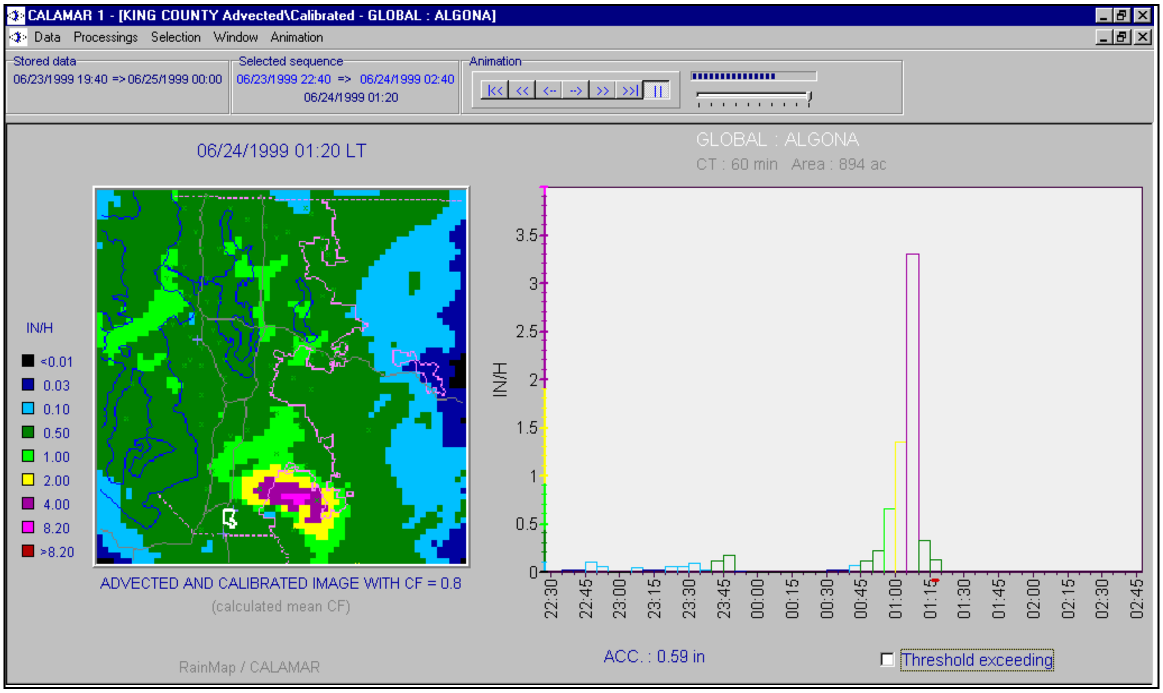
Figure E9
NEXRAD Location



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.

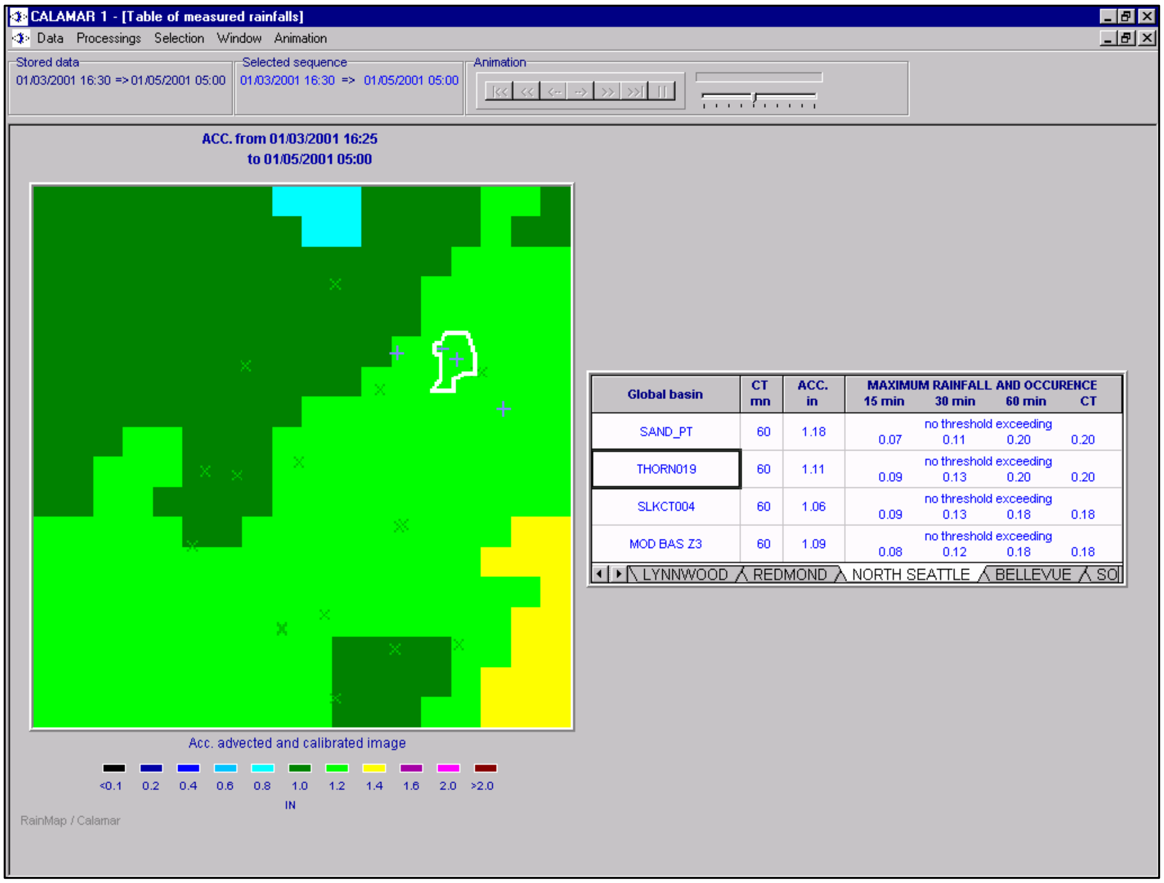
The output from CALAMAR is both graphical and tabular. Graphical views include simultaneous views of the radar image and a hyetograph. Figure E10 provides an example of the radar image on the left and the hyetograph on the right. The image shows a red and yellow rain cell just after it passed over the City of Algona and the hyetograph shows the rainfall intensity in 5-minute steps.

Figure E10
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 E11 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 E11
Accumulated Rainfall for Model Basin THORN019



4. 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. Rain gauge BOTH was relocated approximately 1/4 mile east during the summer of 2001. Table E4 is an inventory of all rain gauges.

Table E4
Rain Gauge Inventory

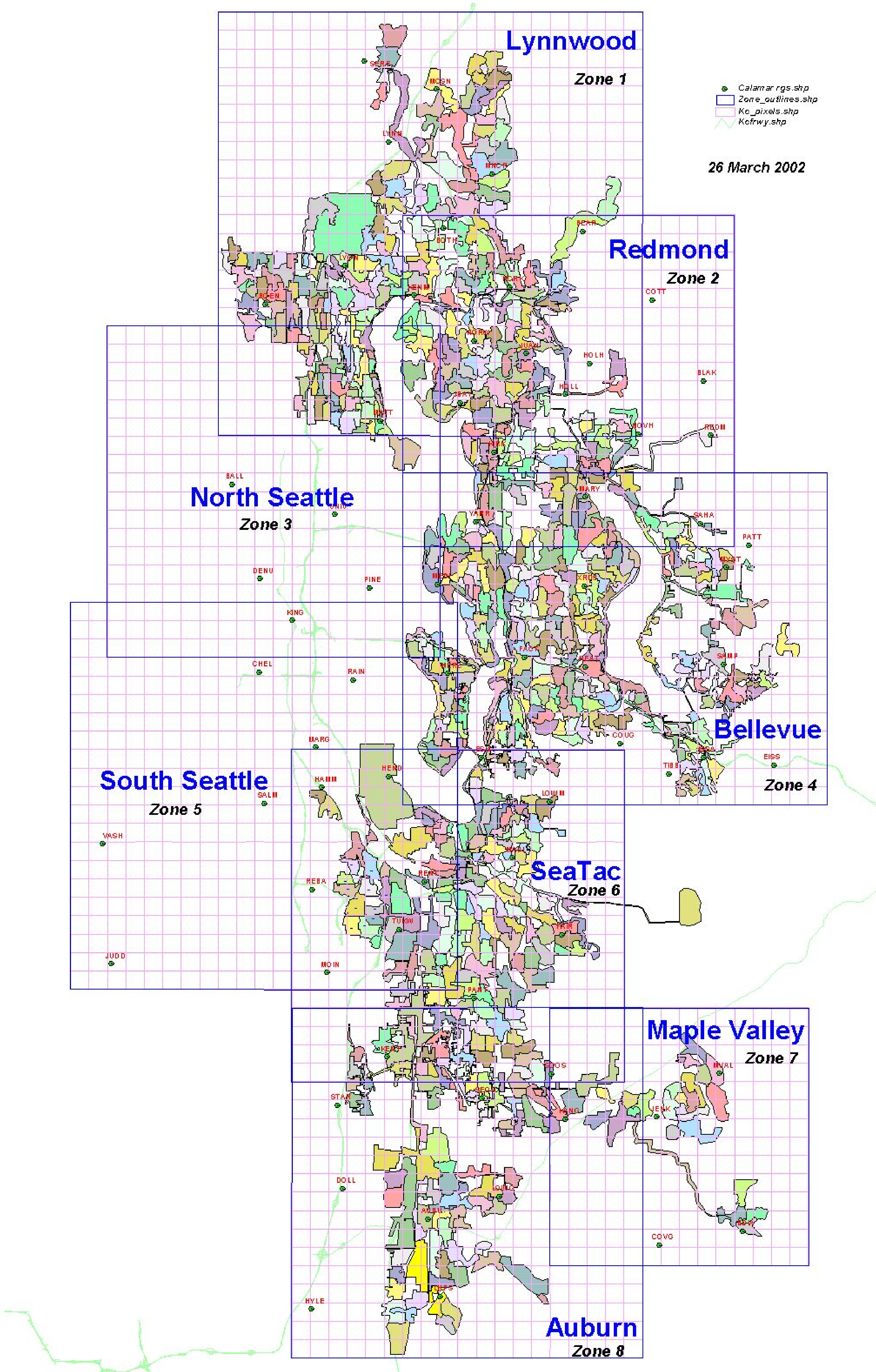
WLRD GAUGE_#	GAUGE_NAME	CALAMAR NAME	DESCRIPTION
02V	Blakely Ridge	BLAK	Blakely Ridge Precipitation, near Redmond.
04U	Boeing Creek	BOEN	Shoreline Community College near Seattle.
02W	Cottage Lake	COTT	At King County Fire Station near Cottage Lake
63Y	Cougar Mountain	COUG	Cougar Mountain Park
09U	Covington 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	East Fork Hylebos
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	City Hall, 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, MH 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			

5. 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 E12. Figure E12 is also included as a JPEG file in the in Appendix D as file calamar_pixels_rg_26mar02.jpg

Figure E12
CALAMAR Calibration Zones

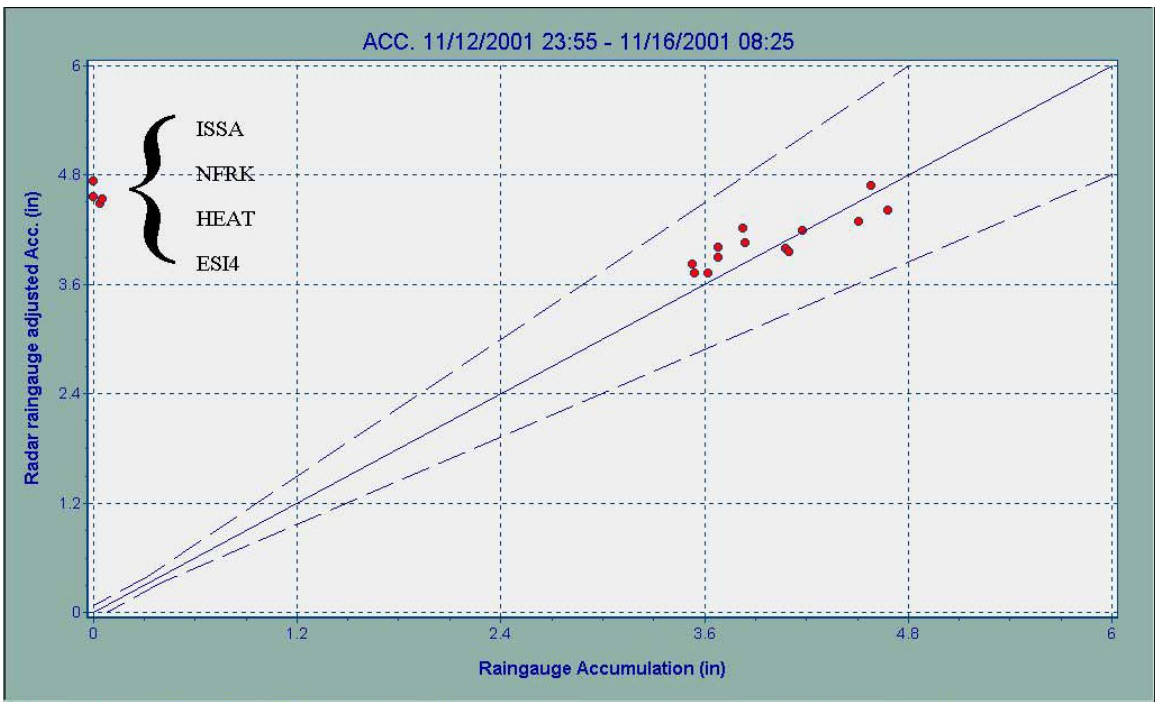


6. Calibration Scatterplots

The basic tool for evaluating the calibration of each zone is a scatterplot displaying the rain gauge accumulation versus radar rainfall accumulation for each rain event. These scatterplots allow dysfunctional rain gauges to be identified so that they were disregarded for the calibration of the zone in which they reside.

Figure E13 is a scatterplot of accumulated rain gauge versus radar rainfall data for the storm event occurring November 13, 2001 produced by CALAMAR for the BELLEVUE Zone. Gauges ISSA, HEAT, NFRK and ESI4 indicate that little or no rain fell at the rain gauge whereas close to a 4.8 inch accumulation was reported by the radar. Gauges ISSA, HEAT and ESI4 were all reported as having operational difficulties at the time of the storm event. NFRK is a rain gauge digitized early in the project, but not used for calibration. All four rain gauges were disregarded for the calibration of this zone for this storm.

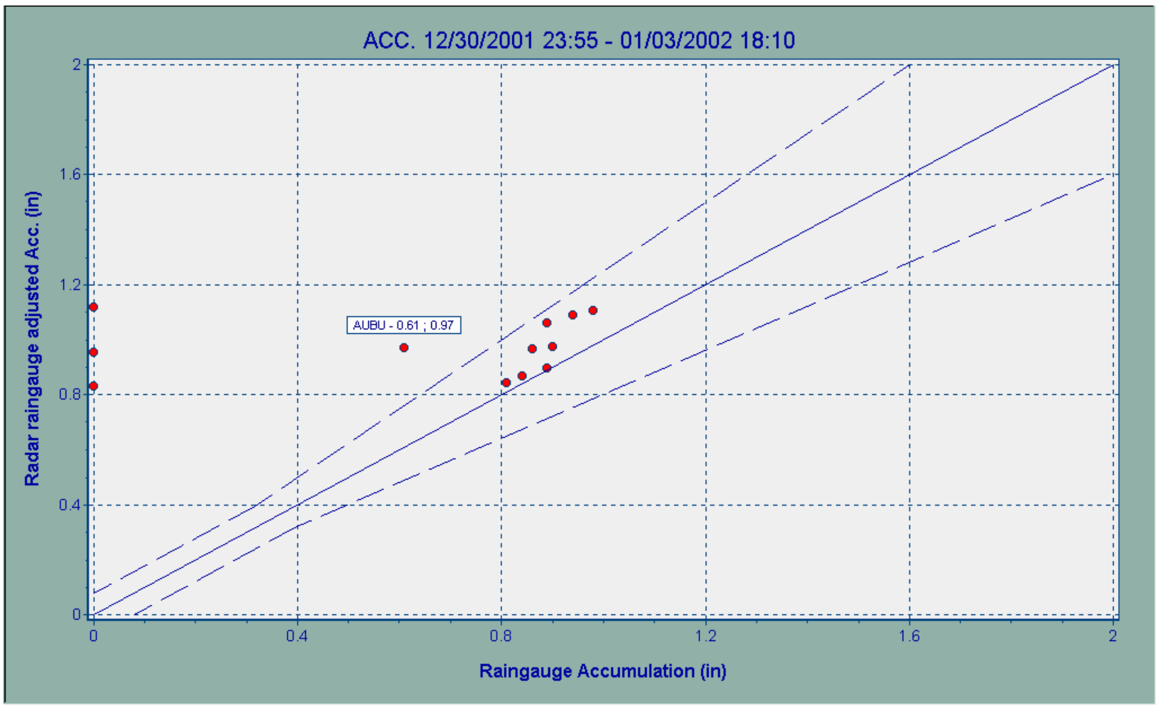
Figure E13
Scatterplot of the Bellevue Zone for the 11/27/2001 Storm Event



A major advantage of using the CALAMAR system to evaluate rainfall is the ability to identify inaccurate rain gauges. Inaccuracies can have several causes including plugged funnels, corroded tipping buckets or being in the "rain shadow" of trees or buildings. Rain shadows exist when a rain gauge is partially obstructed by structures and trees or if nearby buildings significantly alter wind patterns above the rain gauge. Figure E14 indicates that rain gauge AUBU recorded 0.36 inches less rainfall than measured by the radar in the pixel containing the rain gauge.

Figure E14

Scatterplot of the Auburn Calibration Zone for the 12/30/2001 Storm Event

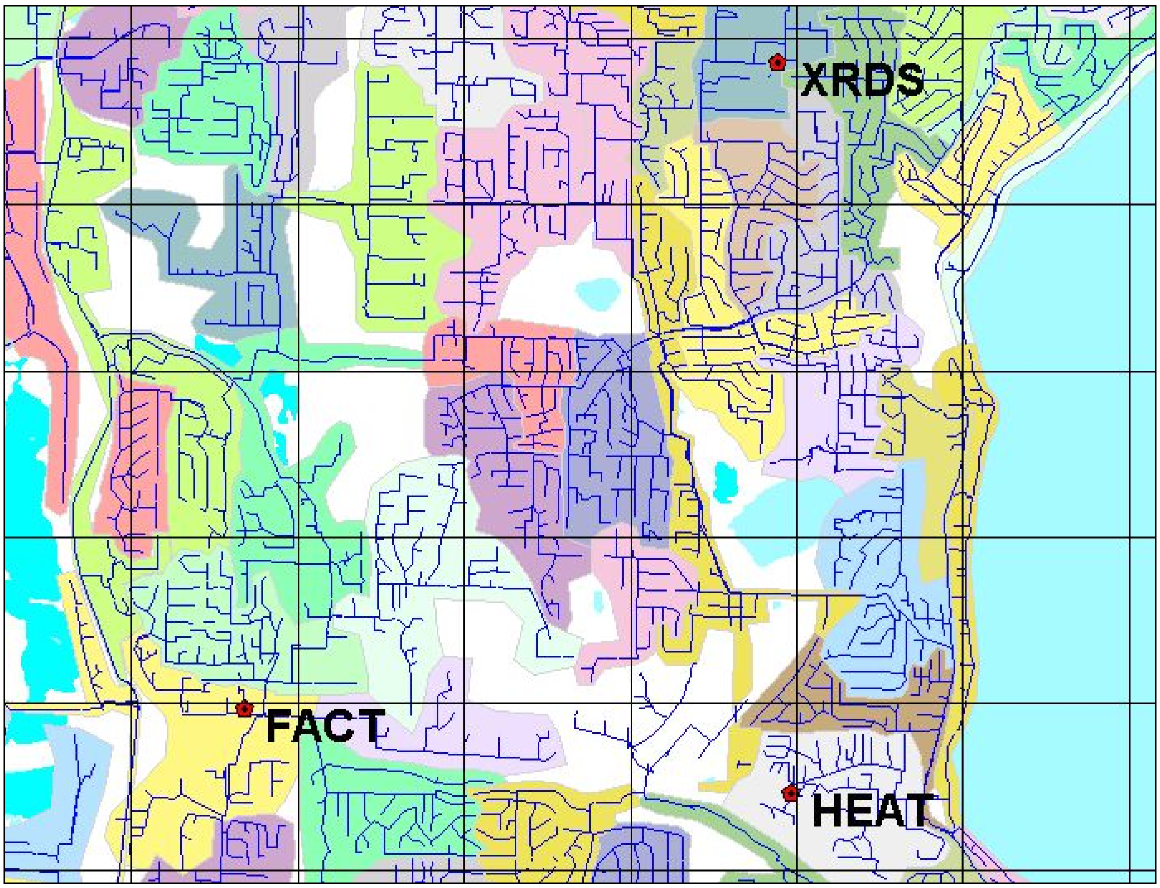


The AUBU gauge was disregarded for the calibration of the AUBURN Zone for the 12/31/2001 storm event.

7. Pixel Rain Data

In its most basic 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 a collection of Mini Basins in the City of Bellevue with 1 Km^2 pixels superimposed is shown in Figure E15. 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 Section E 7.

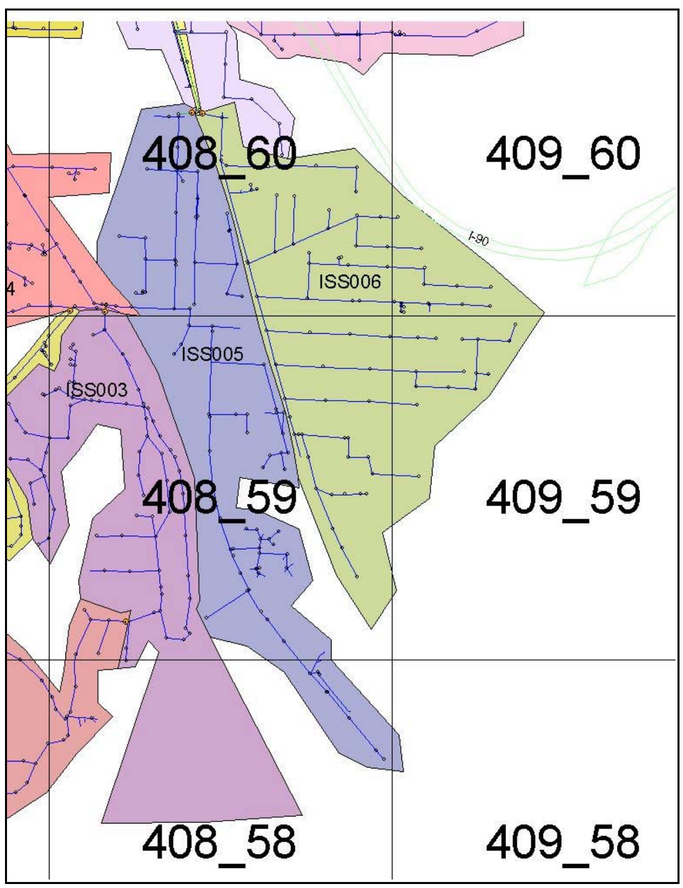
Figure E15
Bellevue Mini Basins, Three Rain Gauges and 1 Km^2 Pixels



8. Conversion from Pixel Data to Mini Basin Rain Data

A rainfall data file was created for each Mini Basin for each of the 10 storms that were analyzed. Most Mini Basins fall into more than a single pixel and the method described in this section was created to determine the average rainfall on each Mini Basin. Figure E16 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. For example the pixel 408_59 is located 408 Km east and 59 Km north of the coordinate starting point.

Figure E16
Mini Basins located in Issaquah and the CALAMAR Pixels Overlaid on the Mini Basins



Many of the Mini Basins are positioned in multiple pixels and the GIS was used to determine the percent of the area of each Mini Basin in each pixel. Table E5 illustrates these percentages for Mini Basin ISS005. The yellow highlighting is on the 5 pixels that contribute rainfall to 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 A.

Table E5
Determination of Percent of Rainfall on a Mini Basin

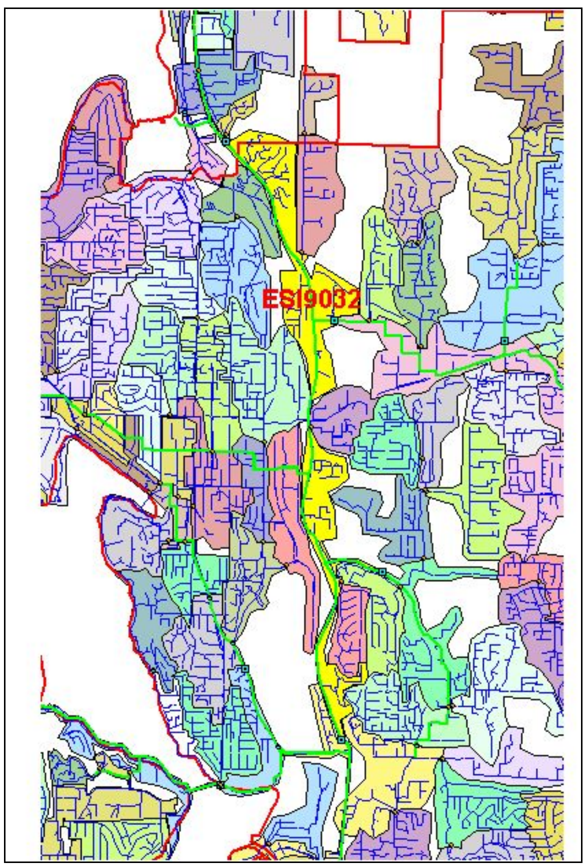
BASIN	PERCENT	EAST	NORTH	PIXEL
ISS004	0.0002	406	60	406_60
ISS004	0.0311	407	59	407_59
ISS004	0.1228	407	59	407_59
ISS004	0.0000	408	59	408_59
ISS004	0.0000	408	59	408_59
ISS004	0.7432	407	60	407_60
ISS004	0.0357	408	60	408_60
ISS004	0.0670	408	60	408_60
ISS005	0.0052	409	58	409_58
ISS005	0.1000	408	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

F. Evaluation of Calculated Flow Results

1. Remnant Mini Basins

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 just upstream of long-term meters on the King County trunk sewers. An example is Mini Basin ESI9032 located in Bellevue and shown as the yellow basin in Figure F1. These remnant Mini Basins 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. Net flow is the flow that results from subtraction between the meter and any upstream meter gross flows. For Mini Basins with no upstream meters the gross and net flows are the same. 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 (423) of the Mini Basins required no subtraction. As a general rule, five (5) or more subtractions may add uncertainty to the I/I calculation. 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 list of meters and upstream subtractions required to calculate net flow for each Mini Basin is included in Upstream_Relationship_2001.xls in Appendix B.

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	15	Total
Mini Basins in category	423	178	94	35	18	7	4	3	4	3	2	1	2	774

3. Base Infiltration

The empirical method for estimating base infiltration (BI) is discussed in Section D and the method depends on the average (ADDF) and minimum flow rates of the average diurnal hydrograph. The presence of pump station cycling can distort the average-to-minimum flow relationship found in normal gravity flow sewers and can significantly distort the BI estimate. Figure F2 shows the hydrograph for 2001 from BEL013, which is heavily influenced by a pump station with lake line flushing.

Figure F2
Hydrograph from BEL013 Showing Pump Station Influence

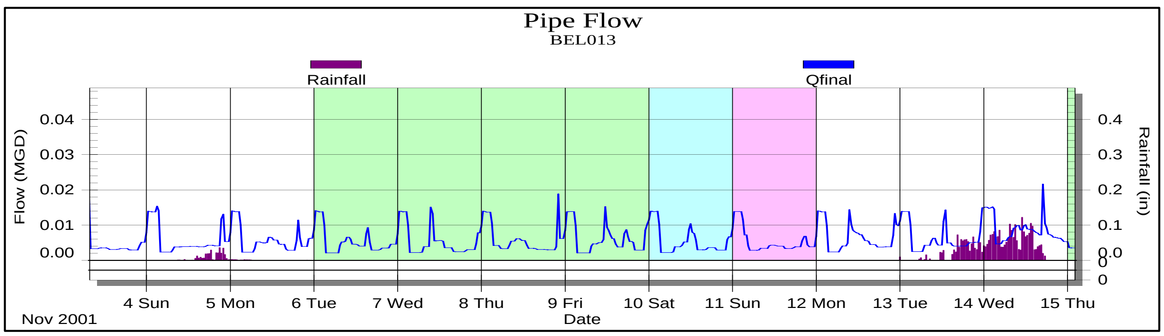
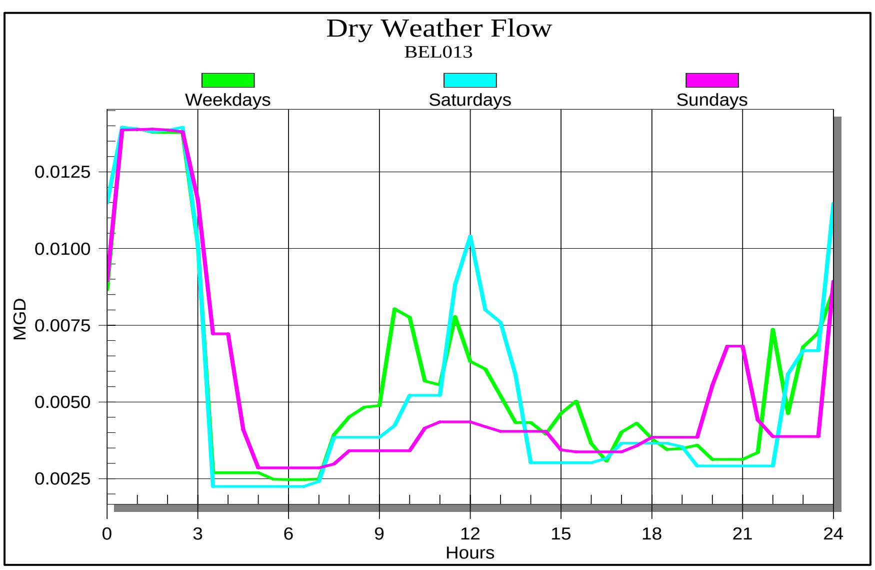


Figure F3 shows the diurnal ADDF hydrograph from BEL013 and the pattern is controlled by pump cycles and is not the smooth shape anticipated by the BI estimation method. The BI estimation method calculates BI at 0.002 MGD. Negative BI values can be calculated from pump station flow as well as from Mini Basins that have multiple upstream meter subtractions. No method for estimating BI is immune to this phenomenon. Negative BI values are reported as zero in Appendix A.

Figure F3
ADDF Hydrograph for BEL013 – BI = 0.002 MGD



4. Peak I/I in 30-minute Intervals

I/I is calculated by subtracting the ADDF from measured flow on 30-minute intervals for a 72-hour period after the start of the rain event. The calculated Peak I/I is the maximum value within the 72-hour period and can be an aberration or an event not related directly to the rain response. An example is shown in Figure F4 in Mini Basin SEA011. The flow during the rain event appears to have experienced a restriction for a couple of hours followed by a rapid increase in flow. The second peak was considered the valid peak, even though it may be due to a temporary upstream blockage.

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.

Figure F4
Significant Increase in Peak I/I in Mini SEA011 Due to Likely Upstream Blockage

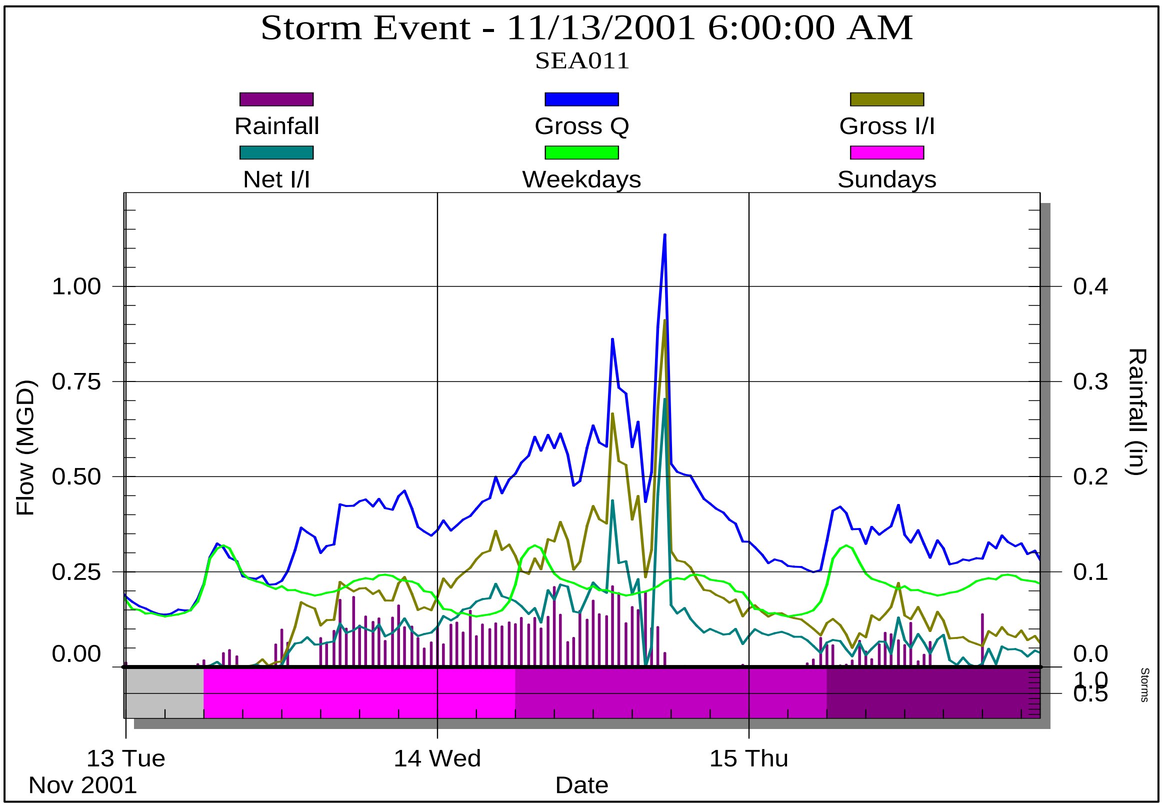
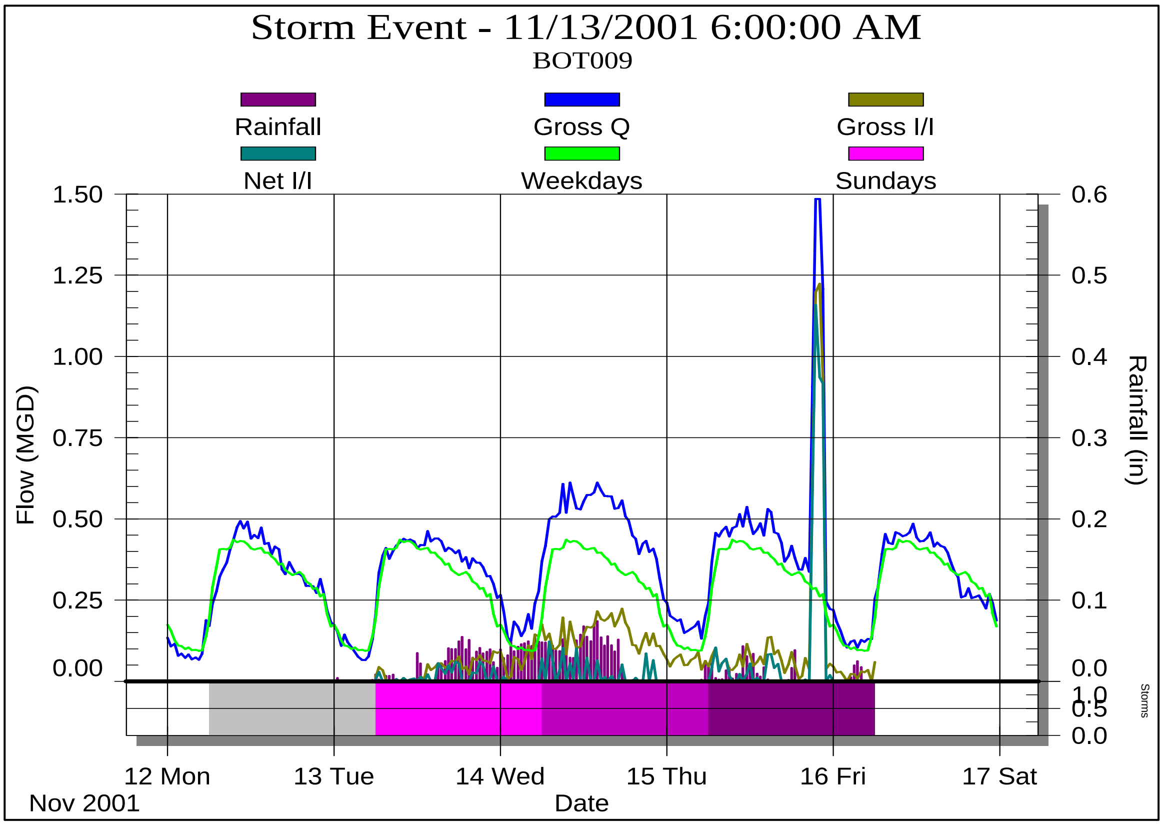


Figure F5 shows a large spike near the end of the 72-hour period due to pump station operations. Several nearby affected meters recorded this spike and backup. This dramatic peak was spotted and considered not to be associated with the rainfall. A more correct peak was selected earlier in the 72-hour period. A comment is made in the "Notes" table in Appendix A if an alternate peak is selected.

Figure F5
Momentary Spike from Pump Station Operations Can Affect Calculated Peak I/I

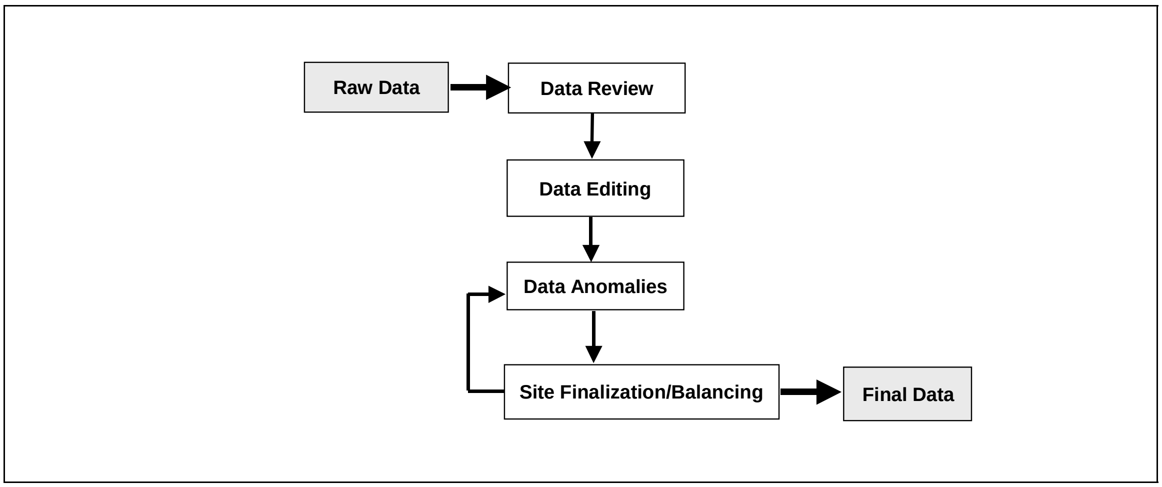


G. The Process for Analyzing Flow Data

Raw data collected by flow meters undergoes 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



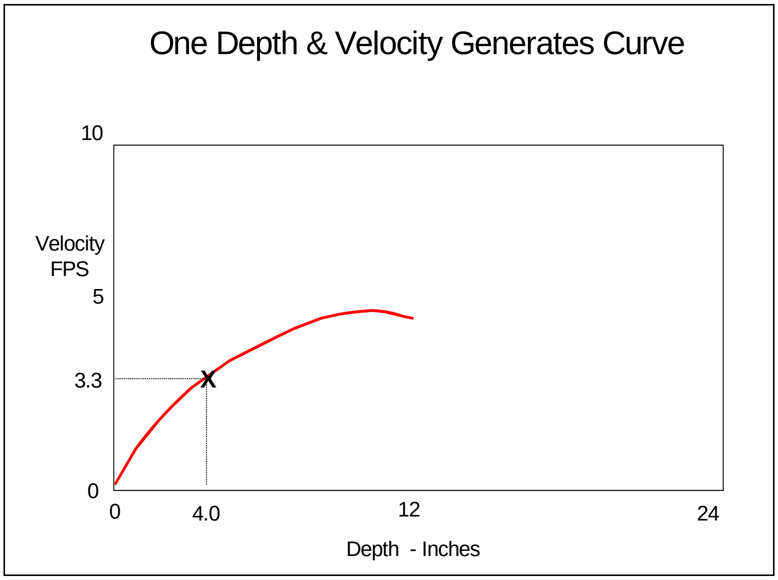
1. Scattergraphs for Understanding and Editing Flow Data

A technique has been developed within the last 8 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. This section is intended to provide an introductory background to 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
Manual Field Measurement Establishes Pipe Curve

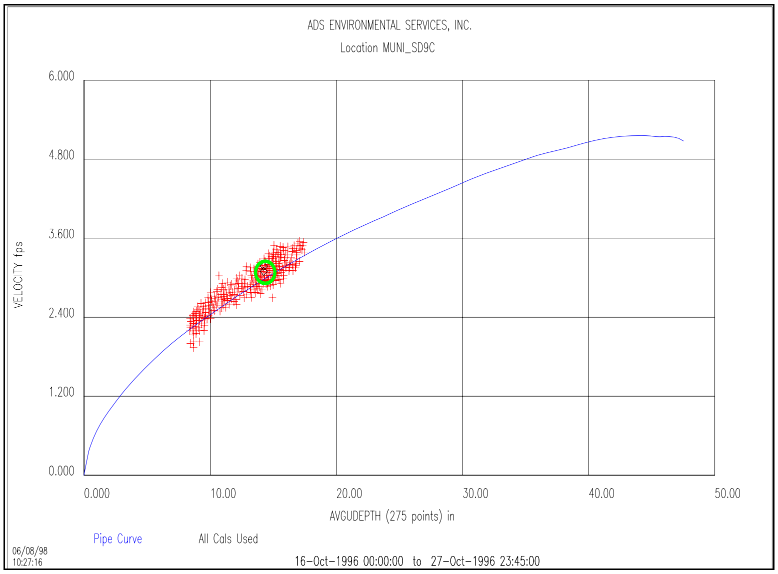


The theoretical Manning equation often does not represent the actual hydraulics in many pipes, however, it is sufficient as an approximate standard against which actual data points can be compared. The plot of paired depth and velocity readings from an open channel flow meter over several days should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



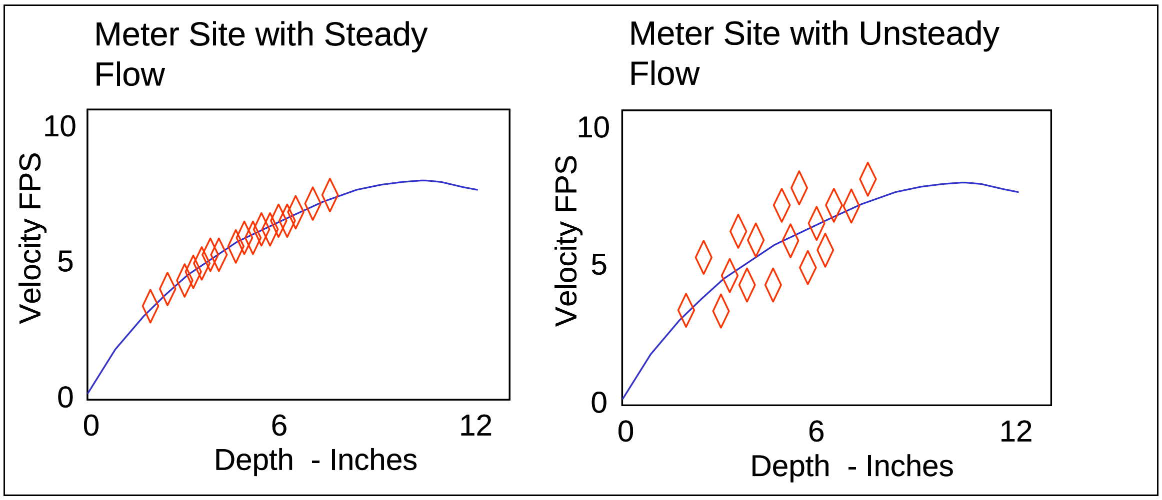
The highly linear grouping of the data indicates that the meter is collecting repeatable data. The fact that all three data sets coincide so well indicates the meter is also accurate.

Note that the 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 indicates 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 that with a cycling pump station upstream.

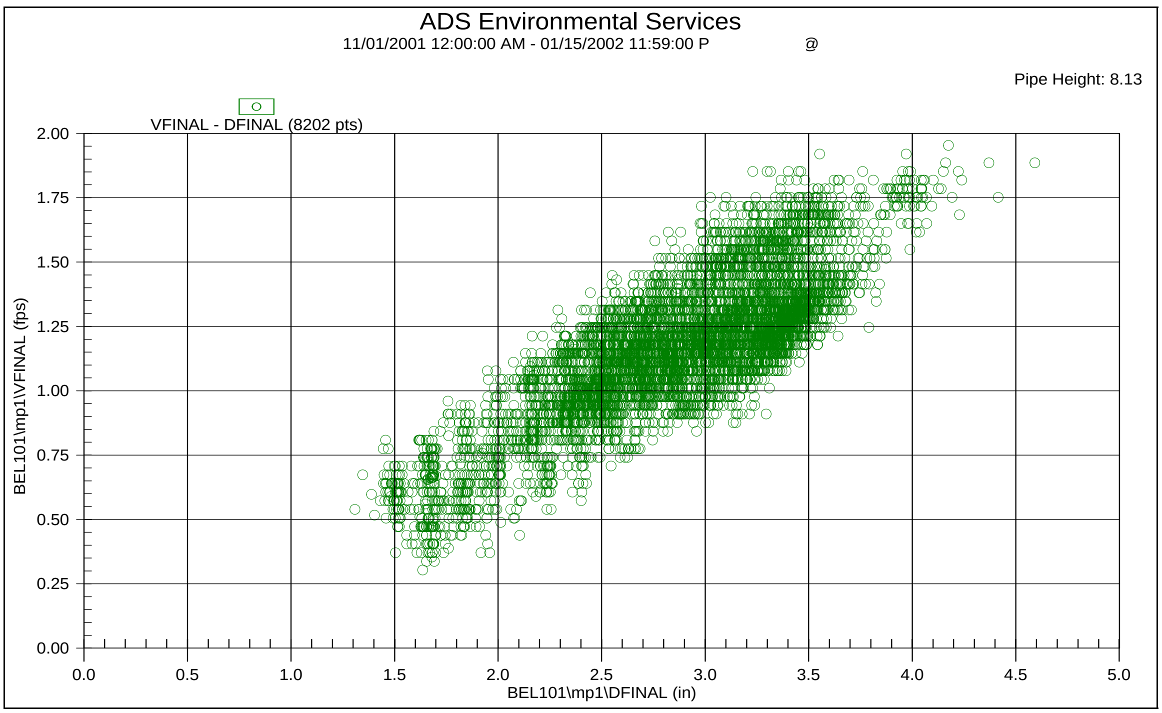
Figure G4
Steady Versus Unsteady Flow Effects on Data Presented in Scattergraph Format



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 BEL101 located in the City of Bellevue. 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 often downstream of the meter and in this case was not identified by the field crew.

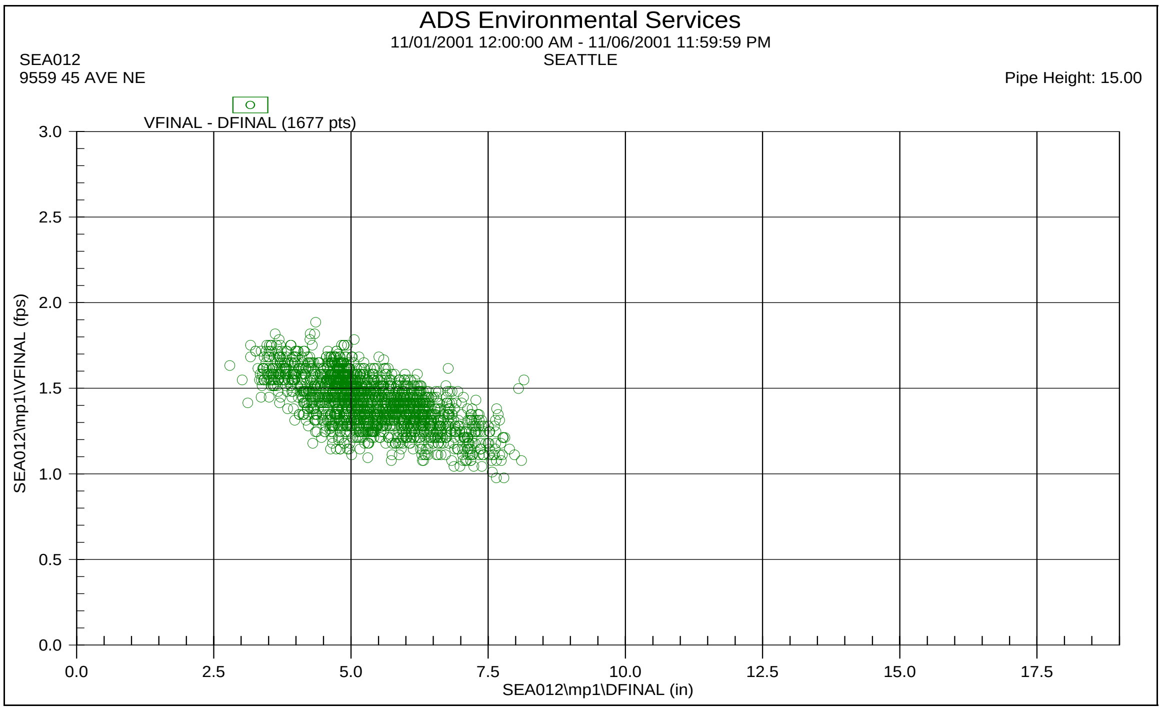
Figure G5
Effect of Shifting Debris and Silt on Data Presented in Scattergraph Format



d) Downstream Hydraulic Bottleneck

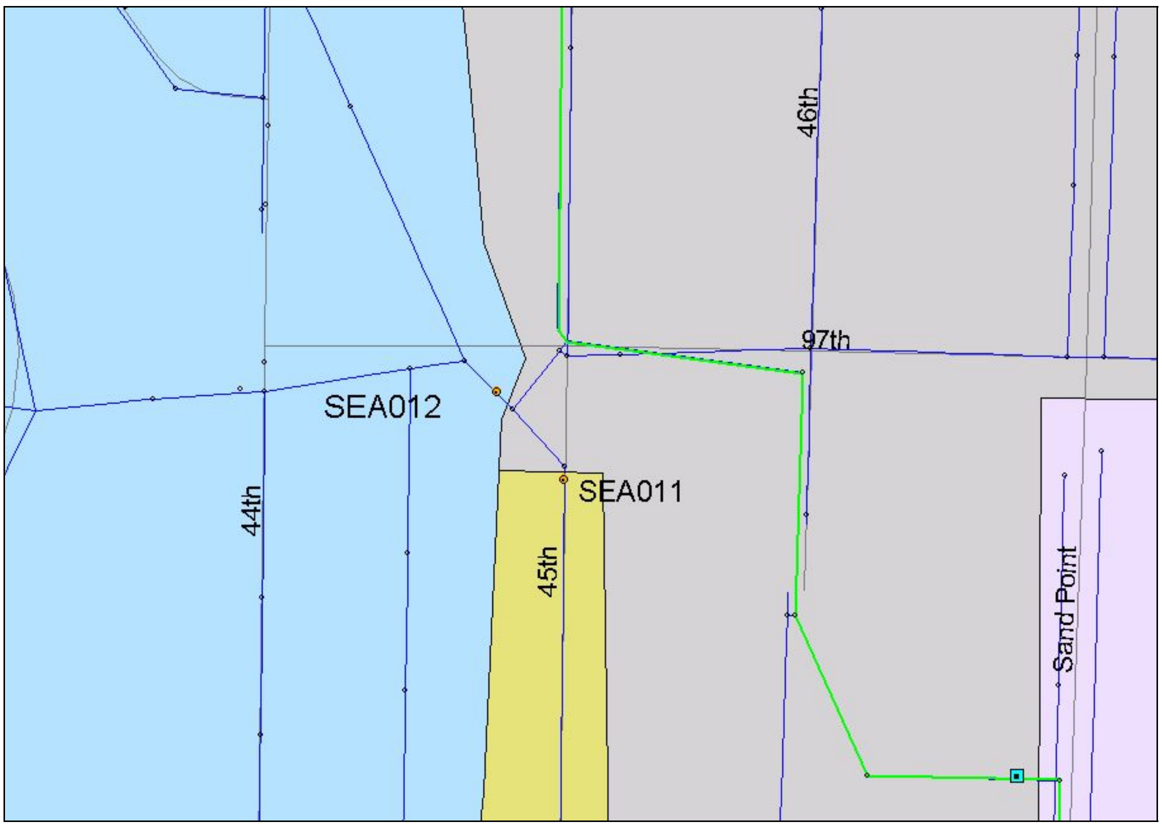
There are several metering sites at junctions with two or more incoming lines into the same manhole. These junctions often form hydraulic bottlenecks, which prevent either line from carrying full capacity. The characteristic pattern is a decrease or steady velocity with an increasing depth. Figure G6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

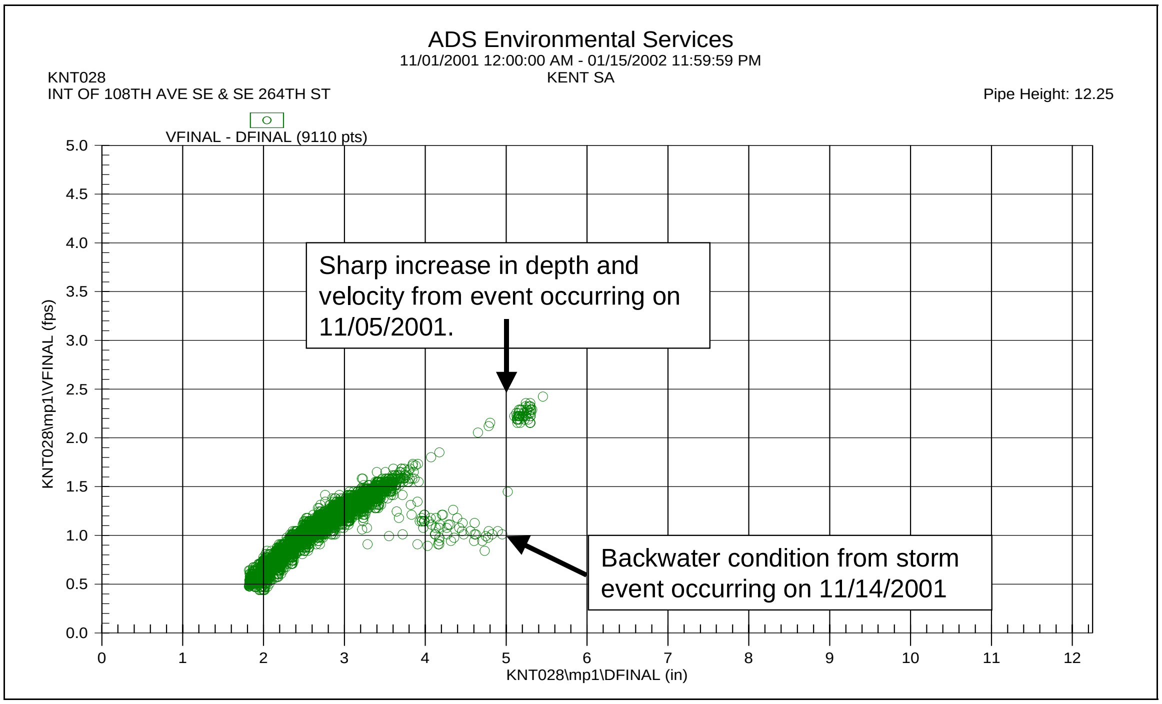
Figure G7
Location of Mini Basin SEA012



e) Unusual Hydraulics

The meter in Mini Basin KNT028, in the City of Kent, captured two distinctly different flow patterns during the monitoring period. A sharp increase in depth and velocity (not to the point of surcharge) occurred on November 5, 2001 with no apparent hydraulic loss. However during the November 14, 2001 storm event a backwater condition appeared at depths greater than approximately 3.5 inches. Both conditions are shown in Figure G8.

Figure G8
Scattergraph of both Steady Flow and Backwater for KNT028



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. c).

b) Data Editing

Conditions such as a build up of debris or surcharging can result in the sensor equipment becoming fouled. When this occurs the data collected is not a valid representation of the depth and/or velocity at the site. For this reason the data is 'edited' to ensure that only valid data is used in sequential quantity and I/I calculations. Data uptime of 1ess than 100% indicates that some information was considered invalid and not used for quantity or I/I calculations. The remainder of this Section describes how

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. 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. Data that does not indicate a repeatable depth versus velocity relationship or a standard hydraulic condition may be considered invalid. 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. The concentration of data in the red circle was not a repeatable depth condition (the higher depths only occurred for a few days during the monitoring period with no corresponding magnitude of increase or decrease in velocity).

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

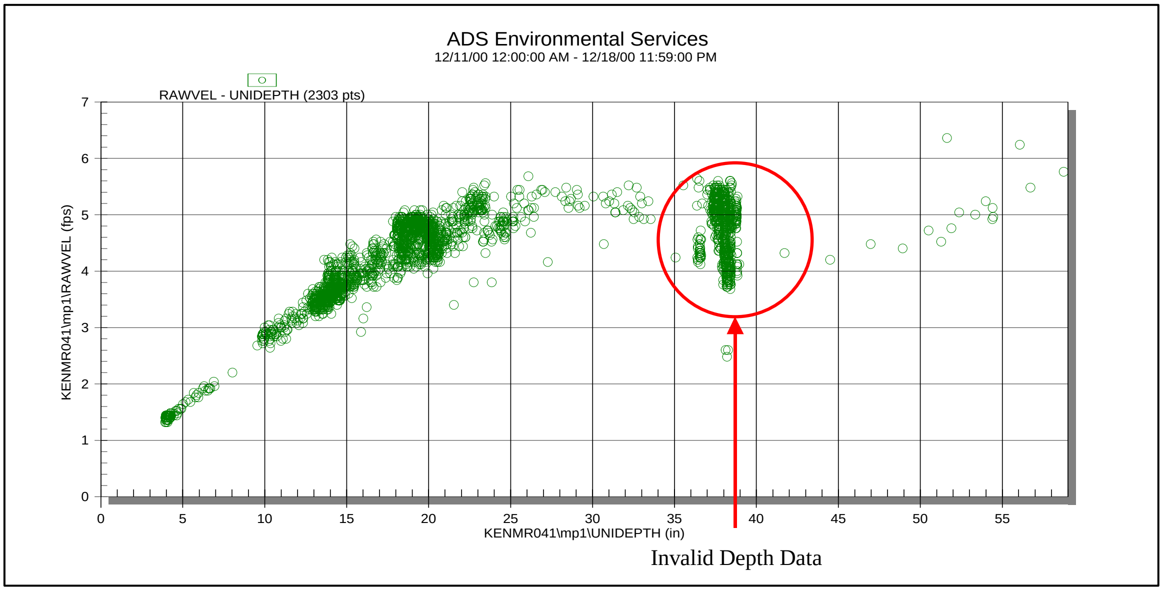
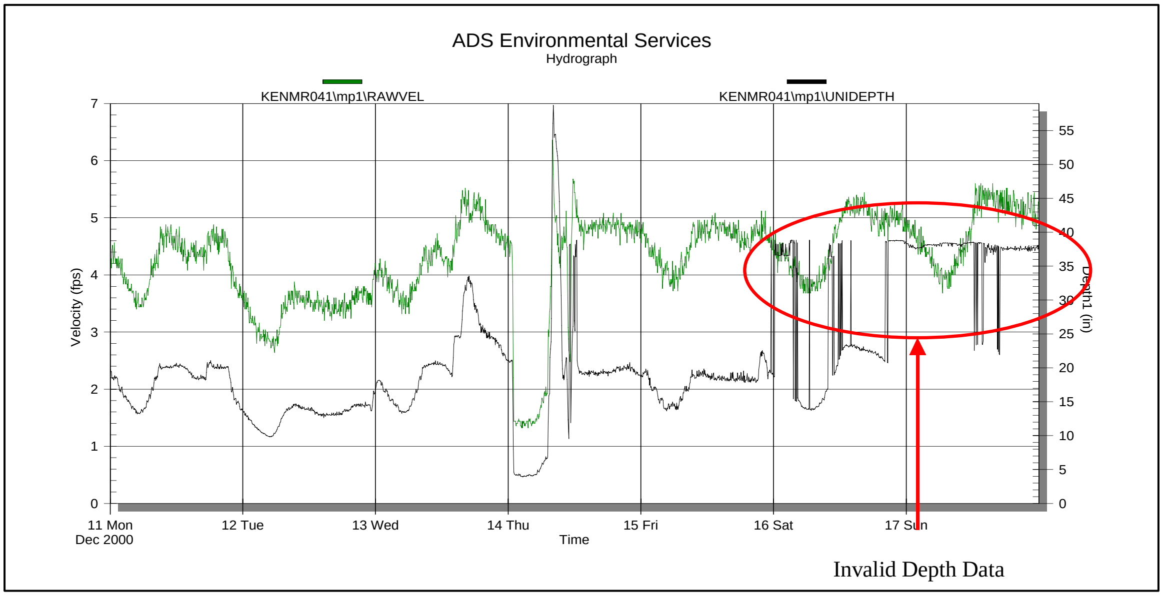


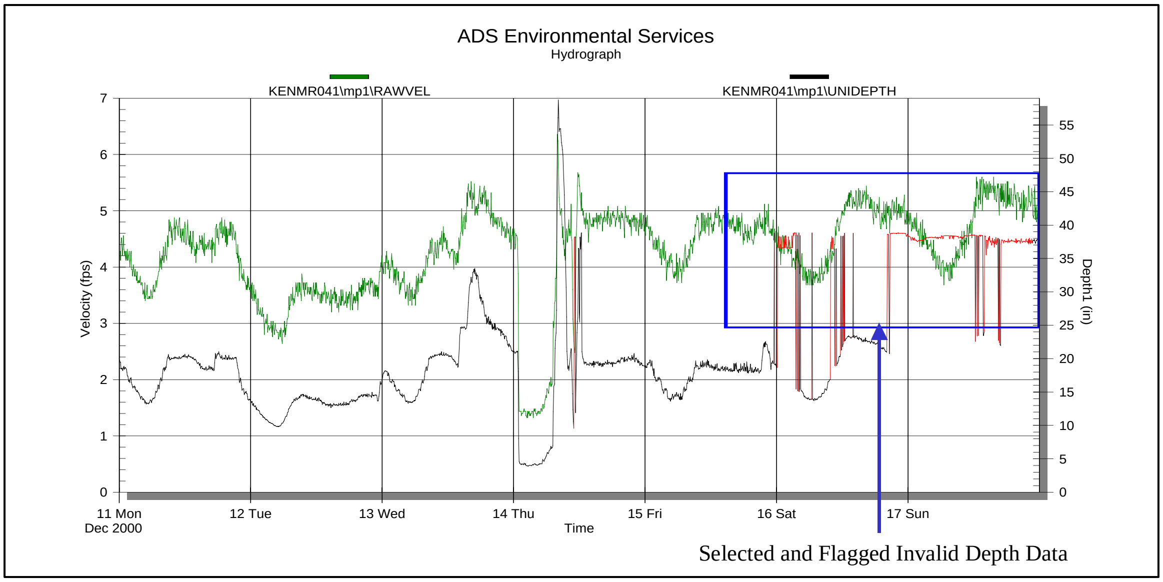
Figure G10 displays the same data as Figure G9, but in hydrograph format.

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.

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 concentration of data in the red circle was not a repeatable velocity condition (the lower velocities only occurred for a few days during the monitoring period with no corresponding magnitude of increase or decrease in depth). The invalid velocity data are the result of a sensor that became fouled. Figure G13 displays the same data, but in hydrograph format.

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

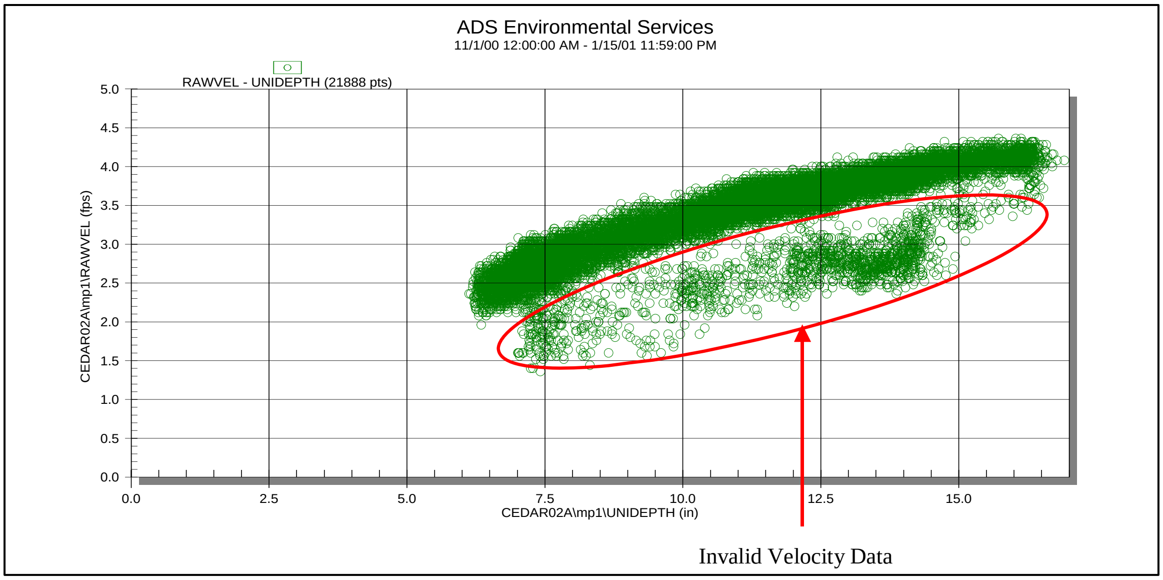
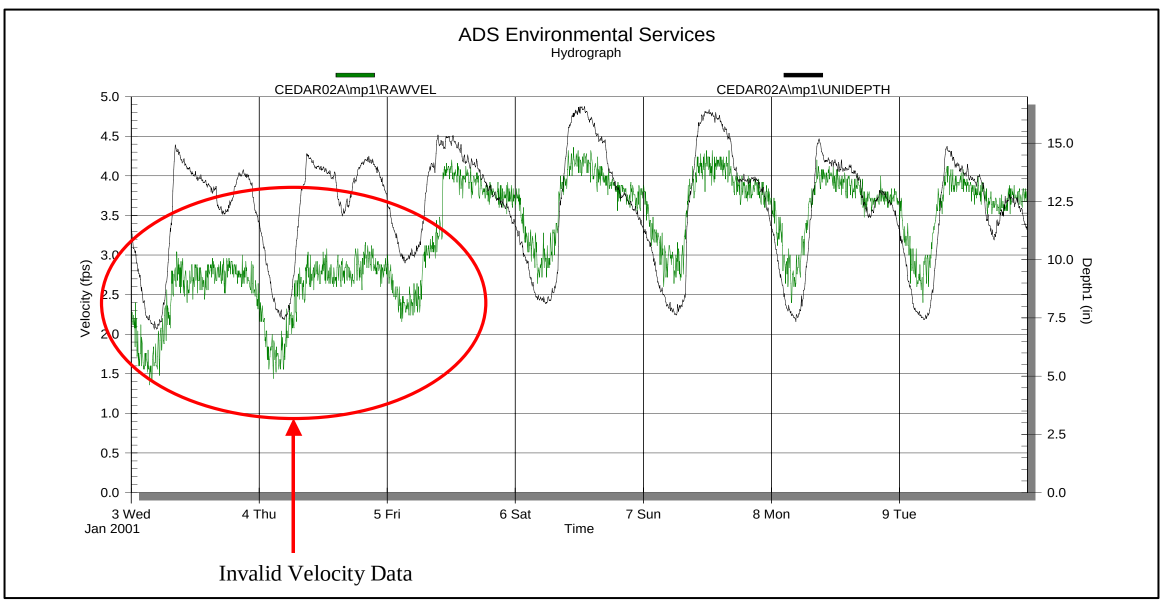


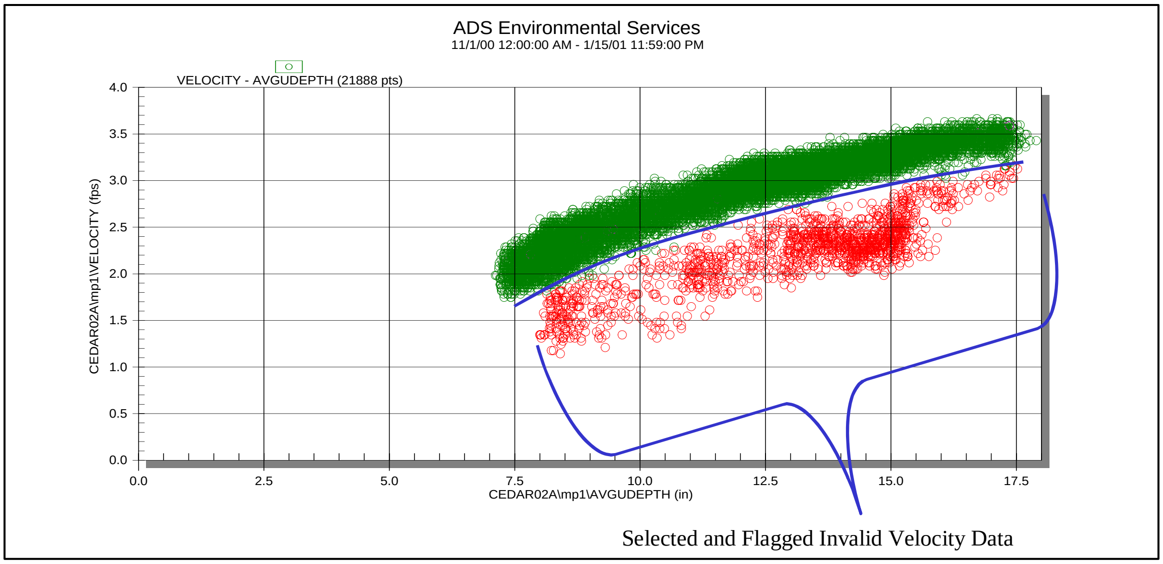
Figure G13
Hydrograph of Invalid Velocity Data due to Debris on Velocity Doppler Sensor



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. c).

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 curve is fit to the scattergraph of valid data that best 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

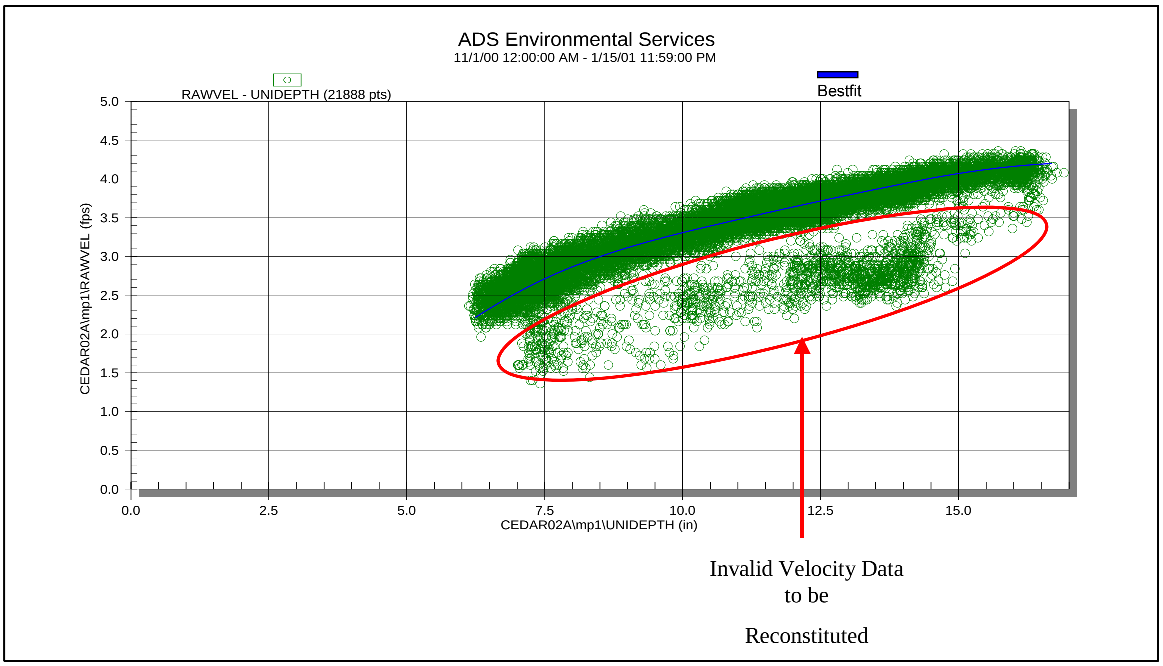


Figure G16 is an example of invalid velocity data being reconstituted. The magenta points on the blue best-fit line are the reconstituted velocity data points previously identified in Figure G15.

Figure G16
Reconstituted Velocity Data on a Scattergraph

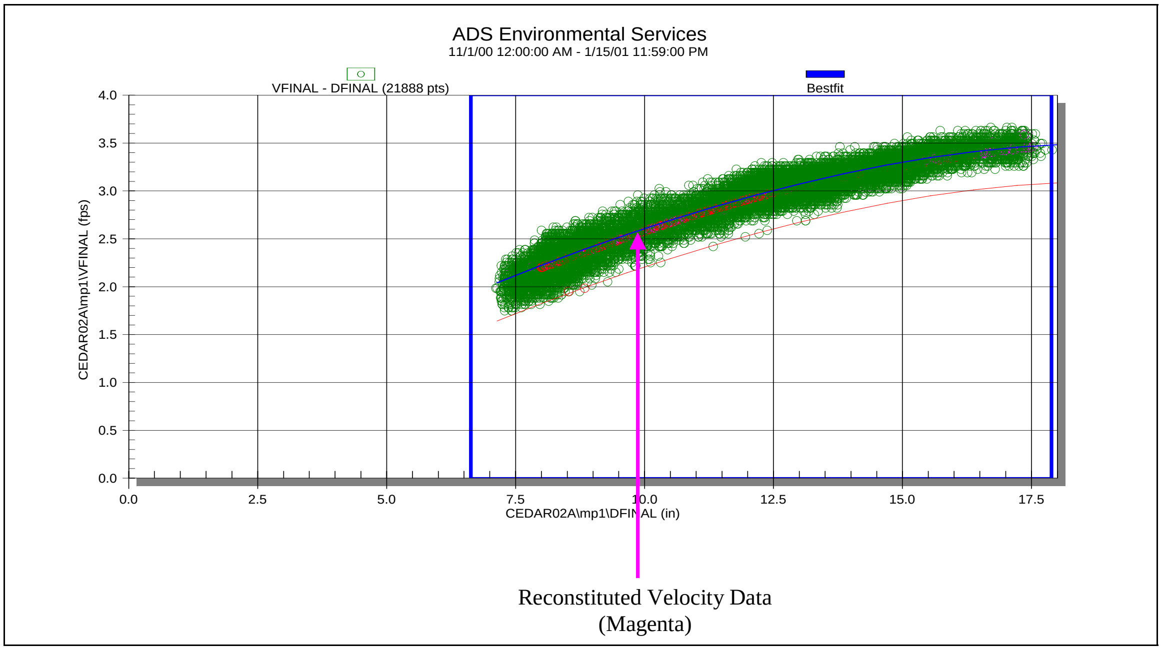
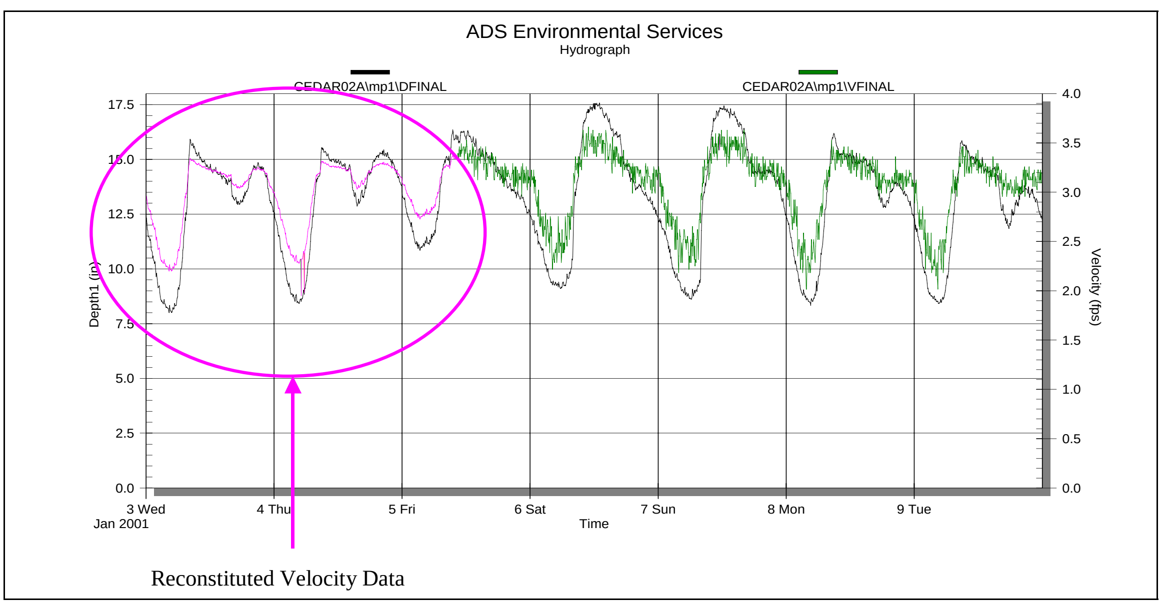


Figure G17 is the hydrograph of the reconstituted velocity data. The magenta velocity data are the reconstituted velocity data (existing data is green). The black data are the depth data that are valid throughout the time period.

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. The effects of the hydraulic conditions at this site were so severe that the site was relocated in 2001/2002.

Figure G18
Data Anomaly Backwater Condition at ABN007 in 2000

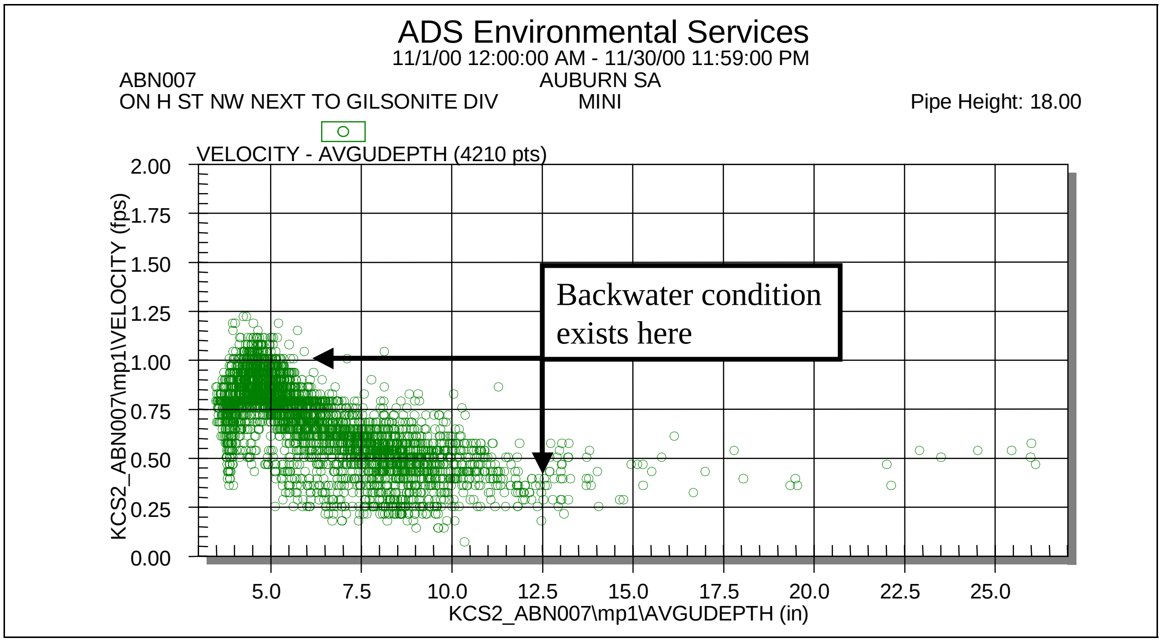


Figure G19
Photo of Outgoing Line at ABN007 in 2000

3. Finalizing Meters

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 identify any unusual hydraulic conditions (such as silt or poor flow channel conditions) that may have an impact on the final measured flow quantity. Confirmations are completed and evaluated by field crews at the meter location and again by data analysts in the office to identify trends or shifts in hydraulic conditions.

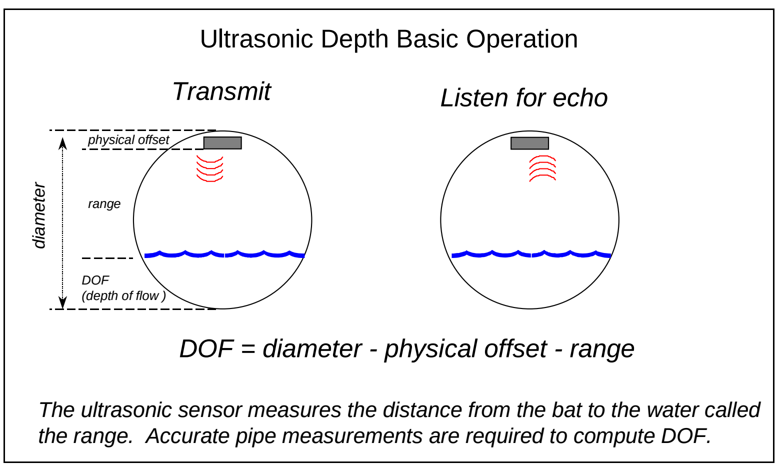
a) Field Crew Confirmations

Manual measurements of flow depth 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 Flow Depth

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 re-measured 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 sub-optimal 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.

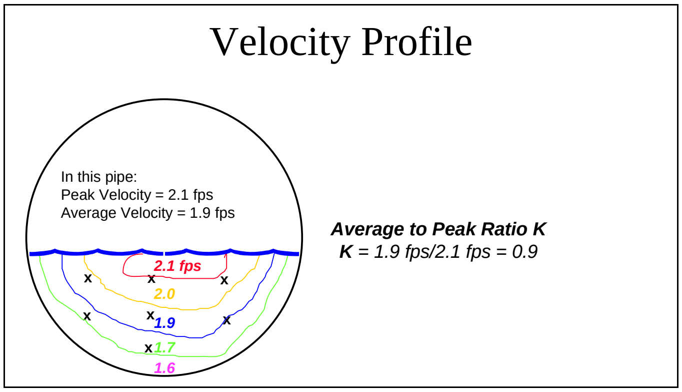
c) Confirmation of Velocity

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. Where it is determined by a field crew that a manual flow measurement with a hand held velocity meter is too difficult, a weir test may be conducted. Weir tests must be conducted in sites where the flow is less than 3 ft/s and is not subject to pump station influence.

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 (based on ADS history) is 0.90. The acceptable range of A/P's is 0.80 – 1.00. Sites with an average depth consistently greater than 5 inches had velocity profiles performed to determine the A/P. Five (5) inches of flow is necessary to ensure enough points in the flow can be measured to calculate a meaningful average. 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.

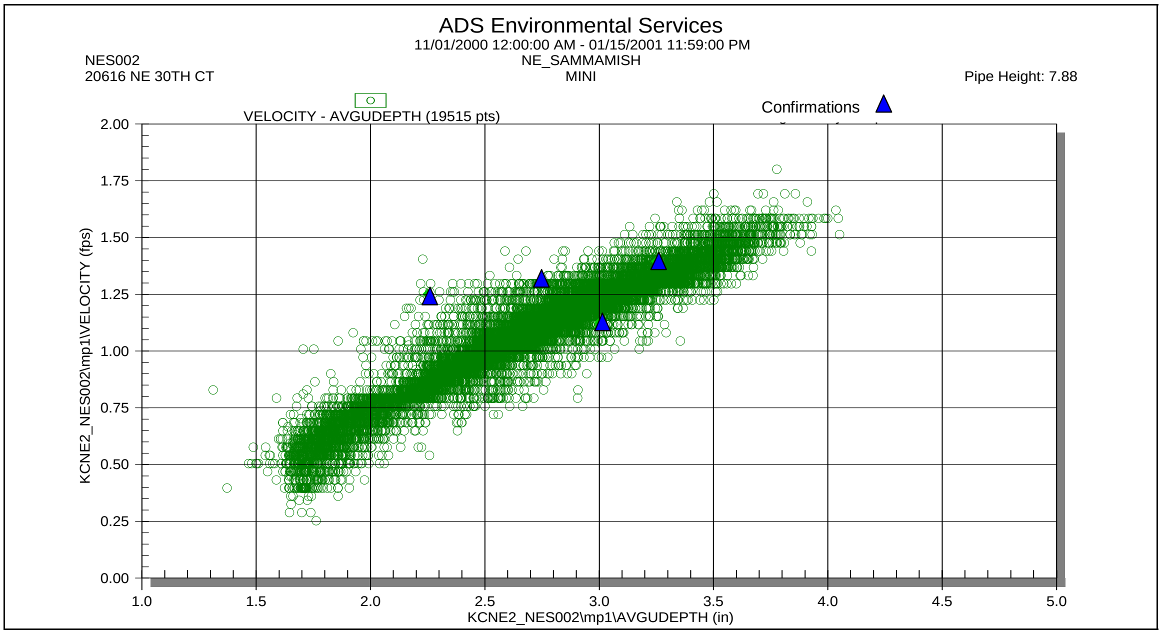
Figure G21
Example Velocity Profile in Sewer



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 (Section G 4) 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 predominantly for this 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 = Cross Sectional Area x Average Velocity X 0.64633

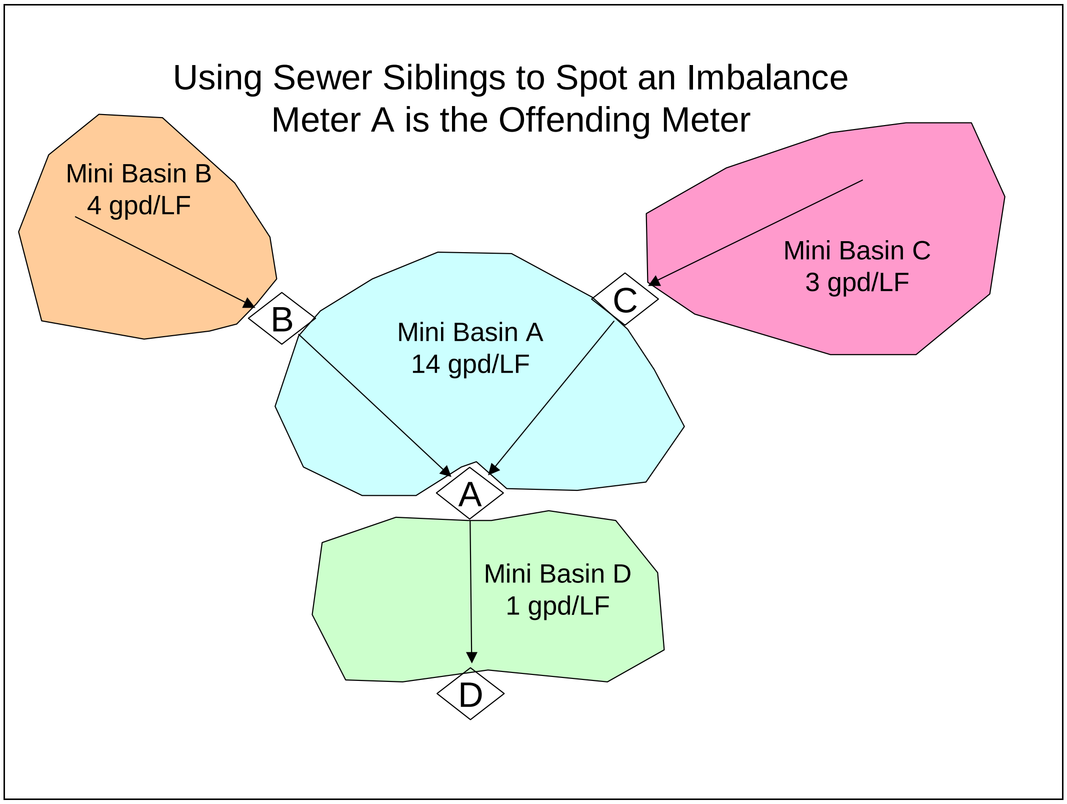
Where:
Q is calculated in Million Gallons per Day
Cross Sectional Area of flow is in Square Feet and
Average Velocity is in Feet per Second.

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 of 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. In addition a determination based on scattergraph analysis is made if unusual hydraulics exist at any of the metering sites.

Figure G23
Using Sewer Siblings to Spot an Imbalance



If a very high (or low) wastewater production value and a poor scattergraph exist for one meter location, Meter A for example, it indicates that an additional level of attention by field crews or the analyst is required. Typically additional field reconnaissance reveals information that can be used to solve an imbalance (for example if it was discovered that the pipe height was measured incorrectly). If no information is obtained to suggest that the measured data are incorrect it is assumed that no exfiltration occurred between the meters and flows are balanced with a single value adjustment to the either the recorded depth or velocity entity. The meters affected by such adjustments are summarized in spreadsheet Finalization.xls.

H. Appendices

This Memorandum is delivered on two Compact Discs (CD). The first CD (CD#1) contains the Memorandum, Appendix A and Appendix B. The second CD (CD#2) contains a two-page Word™ document of graphics for each Mini Basin.

1. Compact Disc 1 (CD1)

a) Appendix A – Total I/I in 30-minute Peak and 72-Hour Volume

Appendix A is an Excel workbook with data sorted by Mini Basin. The estimated Base Infiltration, expressed in GPD/Acre, is added to the measured 30-minute Peak I/I for each rain event to develop the Estimated Total Peak I/I. 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 3 and F 3 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 Appendix A workbook contains a spreadsheet "How to Read Data Sheet" that explains how to read the data and lists the equations used to calculate I/I values.

b) Appendix B

Appendix B contains the following information:

1. Map of Mini Basins

A general location map of all the Mini Basins is in the file MiniBasinmap.pdf and a collection of 19 detailed maps can be accessed through the document Read This PDF Description.doc. The detailed maps are intended to be viewed on-screen and include streets, meter locations and Mini Basin boundaries.

2. Maps of Rainfall Accumulation, Mini Basins

Maps of rainfall accumulation for 10 rain events

3. Upstream Meter Relationships

Upstream Meter Relationships that establishes the meters that must be subtracted to measure net flows for each Mini Basin.

2. Compact Disc 2 (CD2)

a) Graphic Documents

On CD2 open the document named "CLICK HERE!". Graphics for each Mini Basin are presented in a Word document named after the Mini Basin.