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APPENDIX DR-06

Westerly Modeling Report Full Document
(Reference Document)

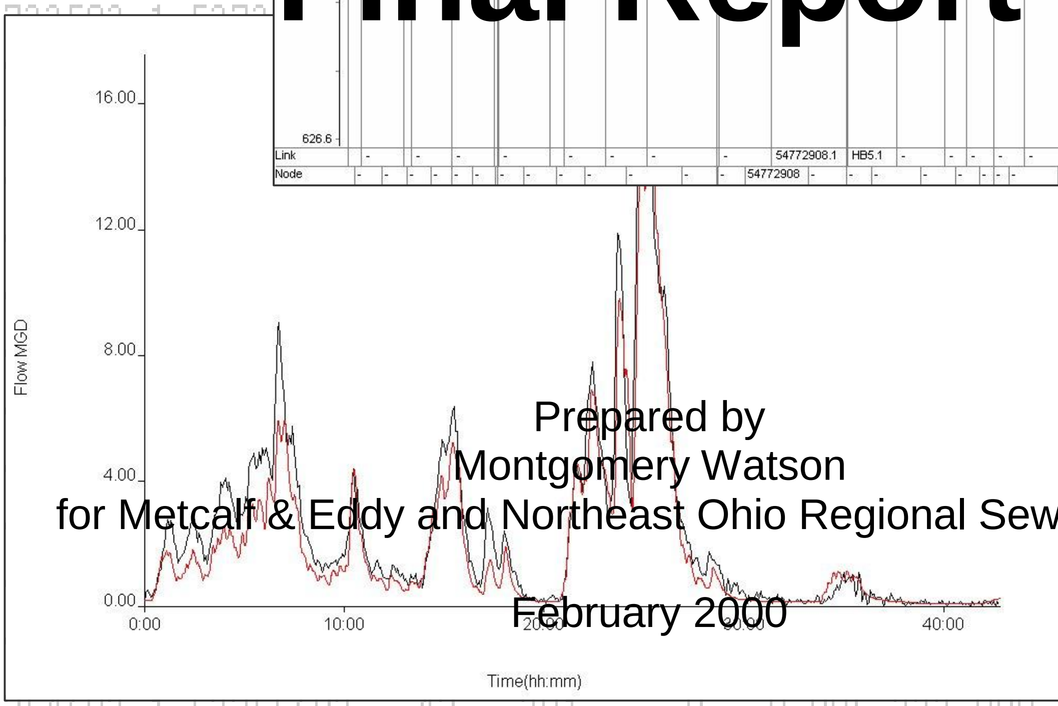
State of Ohio
Department of Transportation
Jolene M. Molitoris, Director

Innerbelt Bridge
Construction Contract Group 1 (CCG1)

Revision Date: August 23, 2006

Westerly CSO Phase II Facilities Plan

Collection System Model Development Final Report



Prepared by
Montgomery Watson
for Metcalf & Eddy and Northeast Ohio Regional Sewer District

February 2000

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1.0 INTRODUCTION

In 1994, the Northeast Ohio Regional Sewer District (District) completed a regional study of Combined Sewer Systems called the CSO Facilities Plan Phase I Study. This study recommended a more comprehensive and consolidated approach to CSO Control in the Westerly Service Area. As a result, the District initiated the Westerly District Combined Sewer Overflow Phase II Facilities Plan. The Collection System Model Development and Verification report is part of the Phase II work undertaken by the District.

Purpose

The Westerly District CSO Phase II Facilities Planning Study, and thus the modeling, involves the refinement of the findings from the Phase I Study. Specifically, the goal of the study was to develop a wet weather long term control plan (LTCP) for the Westerly District that minimizes the CSO impact on receiving waters, as required by Ohio EPA's CSO Policy. To accomplish these goals, the collection system was modeled in greater detail than the Phase I study.

Scope

This report outlines the development and verification of a detailed hydraulic model of the Westerly Service Area collection system. The model was developed as part of Task B – Facilities Planning. The Westerly CSO Phase II Facilities Planning Report contains modeling information about baseline assessment and alternatives analyses.

2.0 WESTERLY DISTRICT COLLECTION SYSTEM DESCRIPTION

The project area is shown in Figure 2-1. This area is located largely in the city of Cleveland and is about 10,000 acres. The District's interceptor system serving the Westerly Treatment Plant is shown on Figure 2-1, also. The four major interceptors include the Northwest, Westerly, Walworth Run, and Cuyahoga River (Low Level). A brief description of each of the interceptors follows the general description of the Westerly Service Area below.

2.1 Service Area Characteristics

The Westerly District service area is a predominantly urban catchment with a mixture of land uses. The catchment contains a large industrial section, well-maintained residential areas, and parkland. Sensitive bathing and recreation areas along Lake Erie, the Cuyahoga River, and Rocky River add a unique quality to this sewer service area.

The topography of the Westerly service area is predominantly flat with the only significant ground slopes found along the Lake's shore and the western boundary with Rocky River. However, the sewer system is drained by gravity with pumping stations only serving local low-lying neighborhoods and the flat areas along the Cuyahoga River.

The collection system contains both a combined and separate sewer area. The separate area lies in the Western portion of the service area and comprises about one-third of the drainage area. The combined sewers drain the remaining two-thirds of the catchment.

2.2 Northwest Interceptor

The Northwest Interceptor is comprised of two segments: (1) a upstream segment that conveys dry-weather flows from western portions of the sewershed to the Westerly Interceptor at the intersection of Lake Avenue and West 117th Street and (2) a downstream segment that conveys only wet-weather flow conveyance from near the W. 117th St. and Edgewater Ave. intersection to the Combined Sewer Overflow Treatment Facility (CSOTF).

This lower segment of the Northwest Interceptor, a 20-foot by 9-foot conduit, begins at the District's Combined Sewer Overflow Treatment Facility (CSOTF) located adjacent to the WWTP and proceeds west across lower and upper Edgewater State Park to Edgewater Drive and West Boulevard (pipe size 20' x 9'). The interceptor then proceeds west along Edgewater Drive to West 117th Street and then south along West 117th Street to a location just north of Lake Avenue (pipe size 120").

At West 117th and Detroit Road, the upper segment of the Northwest Interceptor is diverted to the Westerly Interceptor. Thus, all dry weather flow and a portion of the wet

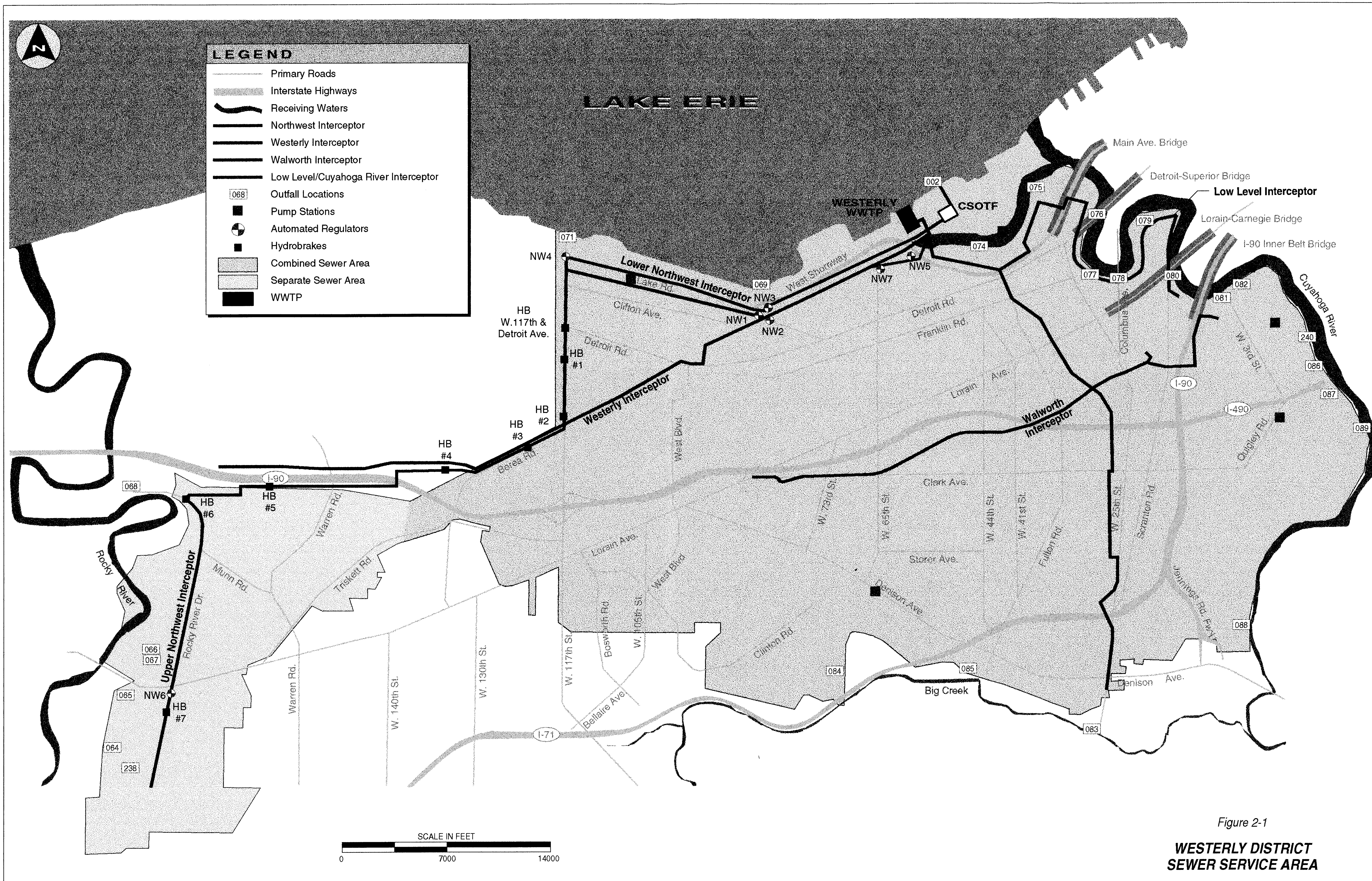

Figure 2-1

WESTERLY DISTRICT SEWER SERVICE AREA

weather flow from the upper portion of the Northwest Interceptor are conveyed to the Westerly Wastewater Treatment Plant through the Westerly Interceptor rather than the lower Northwest Interceptor.

The upper segment of the Northwest Interceptor begins at the vicinity of West 117th St., south of Lake Avenue (pipe size 30"). The interceptor then proceeds south along the east side of West 117th Street to Berea Road (pipe size 30" to 108"). Along Berea Road, the interceptor runs on the south side southwest to Lakewood Heights Boulevard (pipe size 108"). The interceptor then proceeds along Lakewood Heights Boulevard to Bunts Road, south along Bunts to Marginal Road (south of Interstate 90) and then west along Marginal Road to West 159th Street (pipe size 108"). The interceptor then proceeds south along West 159th Street to Fischer Road, west along Fischer Road to Rocky River Drive and south along Rocky River Drive to Puritas Avenue (pipe size 66" to 108").

2.3 Westerly Interceptor

Beginning at the Westerly Wastewater Treatment Plant, the Westerly Interceptor (pipe size No. 4) proceeds south along the line of West 58th to a point approximately 250 feet north of the intersection of Cass Avenue and West 58th Street. At that point, the interceptor (pipe size 6'-6") continues due west to the railroad tracks. The interceptor heads southwest down the railroad tracks to Lake Avenue (pipe size 3'-8'). At Lake Avenue and the railroad tracks, the interceptor goes northwest up Lake Avenue to West 117th Street (pipe size No. 8 to 8'-6").

At Lake Avenue and the railroad tracks, the Westerly Interceptor continues down Desmond Avenue to approximately West 98th Street (pipe size 9'-6") and then south to Detroit Road (pipe size 7'-9"). At Detroit and West 98th the interceptor (pipe size 6') moves west along Detroit to Berea Road. At Berea and Detroit the interceptor turns southwest down Berea Road to Lakewood Heights Boulevard (pipe size 30" to 5'-9"). Here the interceptor turns west down Lakewood Heights Boulevard and continues to Warren Road (pipe size 24"-5').

2.4 Walworth Run

Main Branch

The Walworth Run Interceptor begins at the Westerly Wastewater Treatment Plant and generally follows the West Shoreway to approximately West 33rd Street (pipe size 5'-6"). The interceptor moves down West 33rd Street to Franklin Boulevard (pipe size 5'-6"). At Franklin and West 33rd the interceptor cuts southeast to Woodbine Avenue and West 32nd St. (pipe size 5'-6"). Continuing southeast, the interceptor crosses Whitman Avenue and through the intersection of Fulton Road and Bridge Avenue (pipe size 5'-6"). From this intersection the interceptor moves down West 32nd to Monroe Avenue (pipe size 5'-6"). From this point the interceptor moves southeast to West 30th Street and St. Louis Railroad, and then down West 30th to Trowbridge Avenue (pipe size 2‘-6” to 10’-3”). Gaining Trowbridge Avenue the interceptor (pipe size 5‘-6”) moves down Trowbridge to West 25th Street and then down West 25th to Bradwell Avenue (pipe size 21” to 8‘-9”).

Clark Avenue Branch

From West 30th Street and the St. Louis Railroad, the Walworth run interceptor follows Walworth Run westward to West 55th Street and Walworth Avenue (pipe size No. 5 to 14‘-9”). The interceptor then goes down Walworth Avenue to West 65th Street and Clark Avenue (pipe size 8’ to 9’-6”). The interceptor then goes west following Clark Avenue to Lorain Avenue (pipe size No. 6 to 6’-6”).

Tremont Branch

Beginning at West 30th Street and the St. Louis Railroad the interceptor moves east gaining and following Walworth Avenue to Brevier Avenue (pipe size No. 4 to No. 5). The interceptor goes down Brevier Avenue to Shay Court and then along Kenilworth Avenue, crossing Scranton Avenue, to West 14th Street (pipe size No. 4 to 5’). The interceptor goes up West 14th to the area of University Road, then crosses to Railway Avenue. The interceptor follows Railway Avenue to West 10th Street (pipe size 5’).

2.5 Cuyahoga River (Low Level)

Parting from the Walworth Run Interceptor at West 33rd St. and Detroit Avenue, the Cuyahoga River interceptor heads east along Detroit to approximately West 31st Street (pipe size No. 7). Here it turns northeast to West 29th St. and Vermont Avenue and then up West 29th to the Sewage Pumping Station at Division Avenue and West 29th St. (pipe size No. 7). From the pumping station, the interceptor (pipe size 36”) follows River Road to Elm Street. From this intersection the interceptor moves down Elm to the Main Street Bridge level and follows the Main Street bridge until it passes Sycamore Street (pipe size 36”). Bisecting the area between Riverbed Street and Sycamore Street the interceptor crosses Winslow Street and moves to Washington Street (pipe size 36”). Upon reaching Washington Street the interceptor heads towards the river to Riverbed Street (pipe size 36”). At Cathan Avenue the line crosses to Detroit Avenue at the Sycamore level. Gaining Detroit Avenue the interceptor follows Detroit, crossing under the Detroit-Superior Bridge and gains Riverbed Avenue (pipe size 36”). The interceptor follows Riverbed Avenue and at Columbus Road follows Carter Road to Scranton Road (pipe size 24” to 5’). From this intersection the interceptor proceeds down Scranton Road to University Road and then down University Road to the area of the Inner Belt Freeway (pipe size 24” to 5’).

3.0 COLLECTION SYSTEM MONITORING PROGRAM

The Westerly District Flow and Rainfall Monitoring Program was conducted from April through mid-August, 1997. ADS Environmental Services performed the actual monitoring for the program, while Metcalf and Eddy and Montgomery Watson provided coordination and technical assistance for site selection, meter calibration, and data quality assurance and control. Further description of the flow and rainfall monitoring program is presented in the Sewer System Evaluation Survey Report, dated July 1998.

A total of 106 flow monitors and 7 rain gauges were installed to collect data about the flows in the sewer system and rainfall event information. Figure 3-1 presents the graphical locations of the flow monitors and rain gauges installed for this study. (This large figure can be found folded and placed in the map pocket at the end of this document.) Table 3-1 lists the street locations of flow monitors and rain gauges. Table 3-2 summarizes the rainfall events recorded during the flow monitoring period.

Figure 3-2 shows the coverage of each rain gauge in the Westerly Service Area. The rain gauge coverages were determined using Theissen's polygon method. The Theissen polygon method determines the area representation of a rain gauge in a rain gauge network. Thus, for modeling purposes, all sewer-sheds in a rain gauge polygon receive the rainfall recorded at that gauge.

Table 3-1: Flow Meter and Rain Gauge Locations

Flow meter	Location	Description
3054R-I	West 25th Street and Columbus Avenue	Regulator inlet
3056R-I	1719 Willey Avenue	Regulator inlet
3070R-D	West 30th Street and Barber Avenue	Regulator dry weather outlet
3070R-I	West 30th Street and Barber Avenue	Regulator inlet
3090R-D	Train Avenue and Barber Avenue	Regulator dry weather outlet
3090R-I	Train Avenue and Barber Avenue	Regulator inlet
WR10-O	near Sycamore Street and Main Street intersection	Cuyahoga River inflow analysis (water depth only)
CSO-1	3780 Rocky River Drive behind Kamms Plaza	Mixed
CSO-2	Beltline at Jennings Road; Dennison Road bridge north of railroad tracks	Mixed
CSO-3	East of Quigley Road at Cuyahoga River (I-490 drainage)	Mixed
CSO-4	Columbus Road and Riverhead (east of bridge north of Carter Road)	CSO
CSOTF	Westerly Wastewater Treatment Plant - CSO outfall conduit	At CSO treatment facility
Lakewood	Lake Avenue and West 117th Street intersection	Regulator dry weather outlet
LL-1	University Road, east of Scranton Road	Regulator inlet
LL-2	2065 Scranton Road	Regulator dry weather outlet
LL-3	Low Level Interceptor along Riverbed Road, west of Columbus Road	Interceptor
LL-4	1200 Division Avenue	Pump station interceptor
NW1D2D	East of Desmond Avenue & Lake Avenue intersection along railroad tracks	Auto regulator dry weather outlet
NW1-I	Near Lake Avenue and Viking intersection	Auto regulator inlet
NW2-I1	On Desmond Avenue and Lake Road	Auto regulator inlet
NW2-I2	On Lake Avenue and Desmond Road	Auto regulator inlet
NW3-D	North of West Shoreway, in Edgewater Park	Auto regulator dry weather outlet
NW4-D	On Edgewater Drive and West 117th Street intersection	Auto regulator dry weather outlet
NW4-I	On West 117th Street between Lake Avenue and Edgewater Drive	Auto regulator inlet
NW5-D	At West 58th Street, north of Cass Avenue	Auto regulator dry weather outlet
NW5-I	At West 58th Street, north of Cass Avenue	Auto regulator inlet
NW6-D	Rocky River Drive between auto regulator NW6 and Northwest Interceptor	Auto regulator dry weather outlet
NW6-I	Northeast corner of Rocky River Drive and Albers Avenue intersection	Auto regulator inlet
NW7-I	Near West 65th Street and breakwater intersection	Auto regulator inlet
NW8-I	Intersection of West 67th Street and Father Caruso Drive	Auto regulator inlet
NWCA	Westerly Wastewater Treatment Plant	CSOTF Center Channel upstream of gate
NWI-1	Rocky River Drive and Westpark Avenue	Interceptor
NWI-2	1601 West 117th Street	Interceptor
NWI-3	South Marginal Road and Warren Road	Interceptor
NWI-T1	11642 Detroit Avenue	Trunk sewer
PS2	1200 Division Avenue	Pump
PS13	Mary Street at West 4th Street	Pump
PS13-D	Marquardt Avenue at West 7th Street	Pump station discharge line
PS13-O	Overflow conduit from Mary Street Pump Station	Cuyahoga River inflow analysis (water depth only)
QC-1	Westerly Wastewater Treatment Plant	Settled Overflow Channel #1
QC-2	Westerly Wastewater Treatment Plant	Settled Overflow Channel #2
SS-1	4335 Rocky River Drive	Separate sanitary
SS-2	4080 Rocky River Drive	Separate sanitary
SS-3	River Edge Road at Fernshaw Avenue	Separate sanitary
SS-4	3646 Rocky River Drive	Separate sanitary
SS-5	3375 Rocky River Drive	Separate sanitary
SS-6	16307 Edgecliff Drive	Separate sanitary
SS-7	16915 Fischer Road	Separate sanitary
SS-8	3155 Rocky River Drive	Separate sanitary
SS-10	3127 West 159th Street	Separate sanitary
SS-11	3137 West Warren Road	Separate sanitary
SS-12	3271 Warren Road	Separate sanitary
SS-13	3355 Warren Road	Separate sanitary
SS-14	3525 Warren Road	Separate sanitary
SS-15	14301 Montrose Road	Separate sanitary
SS-16	East of West 144th Street, south of I-90	Separate sanitary
STORM-1	Near Lorain Road bridge over the Rocky River	Storm water impacted by CSO
STORM-2	Riveredge Road	Storm water impacted by CSO
STORM-3	18111 Larchwood Road	Storm water impacted by CSO
STORM-4	3700 Ridge Road	Storm water impacted by CSO

Table 3-1: Flow Meter and Rain Gauge Locations

Flow meter	Location	Description
STORM-5	Laverne Road and West 168th Street	Storm water impacted by CSO
UO-1	17401 Woodbury Avenue	Sanitary in Over/Under sewer system
UO-1ST	17401 Woodbury Avenue	Storm in Over/Under sewer system
UO-2	16602 Westpark Avenue	Sanitary in Over/Under sewer system
UO-2ST	16603 Westpark Avenue	Storm in Over/Under sewer system
UO-3	15215 Triskett Road	Sanitary in Over/Under sewer system
UO-3ST	15215 Triskett Road	Storm in Over/Under sewer system
UO-4	3573 Warren Road	Sanitary in Over/Under sewer system
UO-4ST	3574 Warren Road	Storm in Over/Under sewer system
UO-5	15618 Munn Road	Sanitary in Over/Under sewer system
UO-5ST	15618 Munn Road	Storm in Over/Under sewer system
UO-6	16205 Munn Road	Sanitary in Over/Under sewer system
UO-6ST	16205 Munn Road	Storm in Over/Under sewer system
UO-7	3118 West 159th Street	Sanitary in Over/Under sewer system
W5B-D	West 45th Street ramp off West Shoreway (behind guardrail)	Regulator dry weather outlet
W5B-I	West 45th Street ramp off West Shoreway (behind guardrail)	Regulator inlet
WR12A-D	Mulberry Street at River Road	Regulator dry weather outlet
WR12A-I	Mulberry Street at River Road	Regulator inlet
WR27A-D	University Avenue at West 7th Street	Regulator dry weather outlet
WR27A-I	West 10th Street at West 7th Street and University Avenue	Regulator inlet
WR27-I	2151 Scranton Road	Regulator inlet - "Big Walworth"
WR34-O	3636 West 25th Street	Regulator wet weather outlet
WR42-O	Lorain Road and West 83rd Street	Flow divider wet weather outlet
WR5-D	West 7th Street at Quigley Road (east of intersection)	Regulator dry weather outlet
WR5-I	West 7th Street at Quigley Road (east of intersection)	Regulator inlet
WR9-D	Intersection of Detroit Avenue, Center Street and Riverbed Avenue	Regulator dry weather outlet
WR9-I	Intersection of Detroit Avenue, Center Street and Riverbed Avenue	Regulator inlet
WST-1	13333 Lakewood Heights Boulevard	Interceptor
WST-2	Berea Road at West 117th Street	Interceptor
WST-3	11600 Berea Road	Interceptor
WST-4	10109 Detroit Avenue	Interceptor
WST-5	11526 Lake Avenue (at West 116th Street)	Interceptor
WST-6	1240 West 58th Street	Interceptor
WST-T1	2181 West 117th Street	Trunk sewer
WST-T2	1463 West 98th Street	Trunk sewer
WST-TB1	3131 West 98th Street	Secondary trunk sewer
WST-TB2	On West 85th Street at Madison Avenue	Secondary trunk sewer
WWR-1	West 25th Street and Trowbridge Avenue	Interceptor
WWR-2	Clark Avenue at West 88th Street	Interceptor
WWR-3	6614 Clark Avenue	Interceptor
WWR-4	Intersection of West 53rd Street and Walworth Avenue	Interceptor
WWR-6	Northeast of Train Avenue and West 30th Street intersection	Interceptor
WWR-7	On West Shoreway, east of West 58th Street	Interceptor
WWR-T1	Trowbridge Avenue and West 31st Street	Trunk sewer
WWR-T2	Junction Road, south of Walworth Avenue	Trunk sewer
WWR-T4	2597 West 41st Street	Trunk sewer
WWTP	Westerly Wastewater Treatment Plant	Influent Channel #1
WWTP2	Westerly Wastewater Treatment Plant	Influent Channel #2

Rain Gauge	Location
RG1	Westerly Wastewater Treatment Plant
RG2	Mary Street Pump Station
RG3	4316 Clark Avenue; Fire Station #24
RG4	4525 Rocky River Drive; Fire Station #43
RG5	15637 Lorain Avenue; Fire Station #39
RG6	9826 Madison Avenue; Fire Station #23
RG7	3544 West 117th Street; Fire Station #33
RG8	Division Avenue Pump Station (District installed)

Summary of Rainfall Events During the Flow Monitoring Period.

DATE	Westerly Rain Gauge													
	Gauge #1		Gauge #2		Gauge #3		Gauge #4		Gauge #5		Gauge #6		Gauge #7	
	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)	Storm Volume (in.)	Approximate Duration (hrs:min)
5/31 - 6/1/97	2.12	36:00	2.36	36:00	2.68	36:00	2.22	36:00	2.9	37:00	2.71	36:00	2.71	36:00
4/12/1997	0.96	17:00	0.96	17:00	0.96	17:00	1.12	16:00	1.12	16:00	1.2	15:00	1.1	16:00
8/16 - 8/17/97	0.95	18:00	1.3	18:00	1.37	18:00	1.98	18:00	2.31	19:00	1.28	18:00	1.64	18:00
5/18 - 5/19/97	0.92	27:00	1.07	26:00	0.81	23:00	0.86	23:00	0.99	23:00	0.94	28:00	0.87	23:00
6/2/1997	0.89	7:00	1.16	6:00	0.78	6:00	0.84	6:00	1.29	6:00	1.06	7:00	1.06	7:00
5/25/1997	0.72	13:00	0.9	17:00	0.87	14:00	0.87	12:00	0.88	13:00	0.83	14:00	0.83	14:00
8/3 - 8/4/97	0.68	15:00	0	0:00	0.62	15:00	0.14	15:00	0.61	15:00	0.6	15:00	0.8	15:00
7/3/1997													0.66	1:00
5/5/1997	0.63	6:00	0.59	6:00			0.4	7:00	0.56	8:00	0.61	6:00	0.55	6:00
3/25/1997							0.51	22:00	0.51	22:00	0.57	23:00	0.57	23:00
8/12 - 8/13/97	0.39	7:00	0.42	7:00	0.46	7:00	0.4	6:00	0.42	6:00	0.54	7:00	0.49	7:00
4/27 - 4/28/97	0.36	10:00	0.42	11:00	0.46	11:00	0.42	10:00	0.53	11:00	0.49	10:00	0.45	10:00
5/29/1997	0.36	7:00	0.42	9:00	0.41	7:00	0.33	10:00	0.39	14:00	0.38	7:00	0.38	7:00
5/3/1997	0.3	12:00	0.37	15:00			0.37	15:00	0.37	15:00	0.36	14:00	0.36	15:00
3/29/1997	0.3	14:00	0.3	14:00	0.3	14:00	0.25	10:00	0.25	10:00	0.33	10:00	0.33	10:00
6/21/1997	0.27	2:00	0.35	3:00	0.33	2:00	0.56	3:00	0.5	4:00	0.39	2:00	0.39	2:00
8/11/1997	0.27	10:00	0.33	10:00	0.47	11:00	0.54	12:00	0.44	10:00	0.3	10:00	0.42	10:00
7/21/1997	0.26	5:00											0.12	5:00
7/2/1997	0.25	1:00											0.02	1:00
7/9/1997	0.25	4:00											0.41	9:00
8/15/1997	0.25	2:00	0.41	1:00	0.42	2:00	0.37	2:00	0.39	2:00	0.16	2:00	0.38	3:00
3/30/1997	0.25	10:00	0.25	10:00	0.25	10:00	0.27	8:00	0.27	8:00	0.31	12:00	0.31	12:00
4/16 - 4/17/97	0.23	35:00	0.23	35:00	0.23	35:00	0.4	35:00	0.4	35:00	0.32	39:00	0.31	34:00
7/26/1997	0.23	3:00											0.44	4:00
6/25/1997	0.21	3:00	0.35	3:00	0.39	3:00	0.51	4:00	0.59	4:00	0.42	4:00	0.42	4:00
5/10/1997	0.19	6:00	0.29	6:00					0.31	6:00	0.21	6:00	0.26	5:00
5/8/1997	0.19	10:00	0.24	11:00			0.16	7:00	0.17	10:00	0.23	10:00	0.16	6:00
6/12/1997	0.18	3:00	0.31	6:00			0.03	2:00	0.06	3:00	0.27	4:00	0.27	4:00
4/22/1997	0.18	9:00	0.18	9:00	0.18	9:00	0.21	10:00	0.21	10:00	0.23	9:00	0.24	10:00
7/1/1997	0.18	3:00											0.3	10:00
6/3/1997	0.17	4:00	0.17	5:00	0.14	5:00	0.17	5:00	0.25	12:00	0.21	4:00	0.21	4:00
6/16/1997	0.17	6:00	0.47	9:00	0.37	6:00	0.17	7:00	0.18	6:00	0.24	7:00	0.24	7:00
7/14/1997													0.2	1:00
6/30/1997	0.14	1:00	0.14	2:00			0	0:00	0.01	1:00	0.02	1:00	0.02	1:00
6/13/1997	0.12	7:00	0.09	5:00			0.18	3:00	0.19	3:00	0.15	3:00	0.15	3:00
8/17/1997	0.12	4:00	0.2	4:00	0.2	4:00	0.25	4:00	0.22	3:00	0.2	4:00	0.21	5:00
5/1/1997	0.11	5:00	0.13	5:00	0.09	7:00	0.11	5:00	0.14	5:00	0.18	5:00	0.15	5:00
5/2/1997	0.11	8:00	0.14	6:00			0.11	6:00	0.13	6:00	0.13	6:00	0.13	6:00
5/30/1997	0.11	5:00	0.09	5:00	0.1	4:00	0.2	7:00	0.2	9:00	0.12	7:00	0.12	7:00
4/23 - 4/24/97	0.1	6:00	0.1	6:00	0.09	5:00	0.21	6:00	0.2	6:00	0.12	6:00	0.21	8:00
6/19/1997	0.08	1:00	0.55	2:00	0.44	1:00	0.28	2:00	0.32	1:00	0.61	2:00	0.61	2:00
5/15/1997	0.07	5:00	0.12	5:00					0.14	6:00	0.11	5:00	0.12	7:00
6/18/1997	0.06	6:00	0.11	11:00	0.1	11:00	0.11	11:00	0.11	11:00	0.11	11:00	0.11	11:00
8/9/1997	0.03	1:00	0.13	2:00	0.19	2:00	0	0:00	0	0:00	0.03	2:00	0.07	2:00
Blank cells mean data were missing or not available.														

* No data is present on the CD-rom for gauges 1,2, and 3.
** ADS considered this event as 2 separate rain events.

Table 3-2: Summary of Rainfall Events During the Flow Monitoring Period

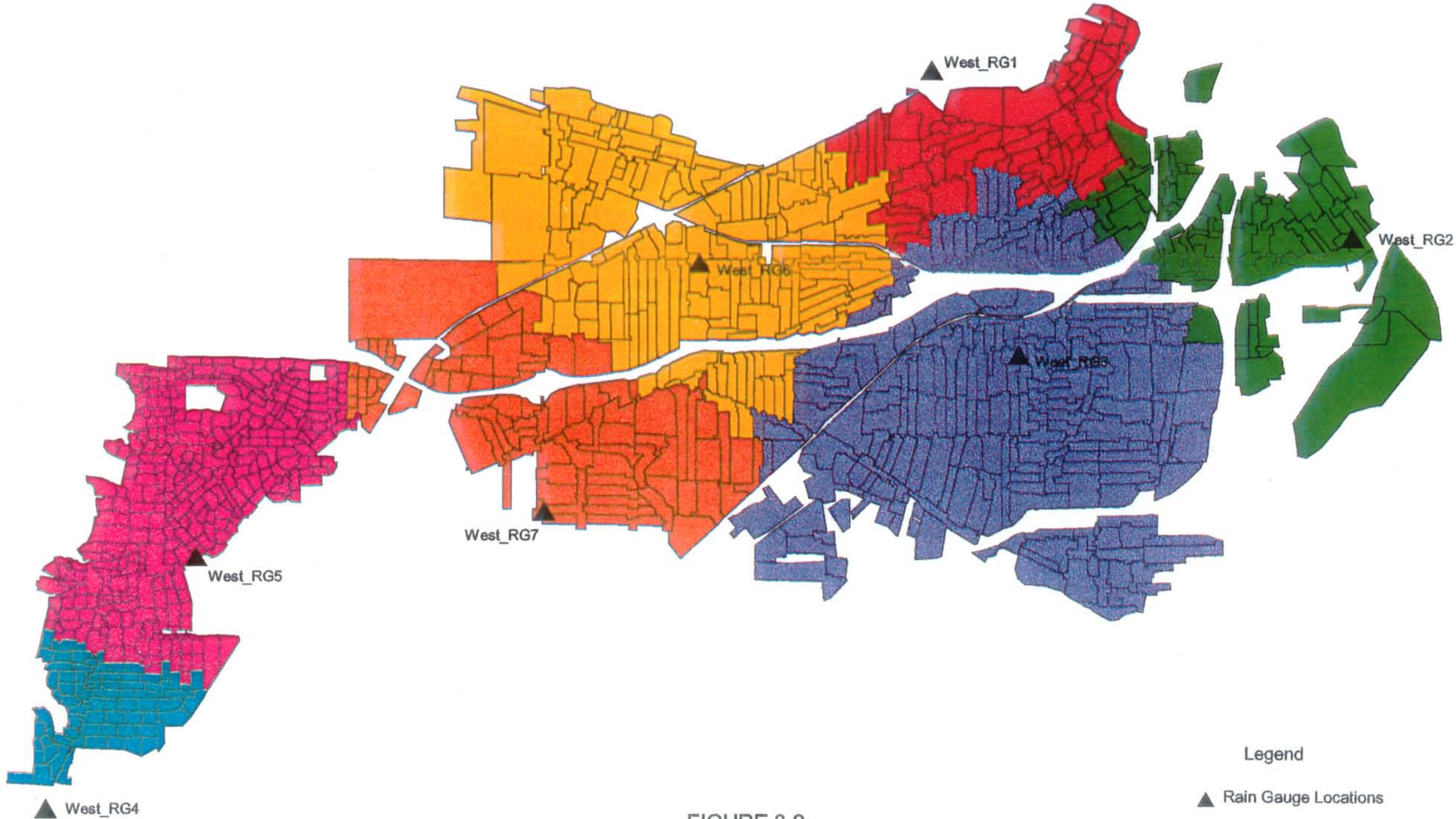

FIGURE 3-2
DISTRIBUTION OF RAINFALL
BASED ON RAIN GAUGE LOCATIONS
WESTERLY DISTRICT
PHASE II FACILITIES PLAN

4.0 COLLECTION SYSTEM MODEL DEVELOPMENT

4.1 Model Choice and Description

Phase I study modeling of the Westerly District was performed with Storm Water Management Model (SWMM) for the combined area and contained only the interceptors and some tributary trunk sewers. This study-level modeling was not sufficiently detailed to adequately simulate the dynamic nature of the Westerly Collection System, specifically the automated regulators. For the Phase II study, HydroWorks, a commercially available hydraulic collection system model, was chosen to evaluate the Westerly District. HydroWorks was selected specifically because hydraulic structures operated by Real Time Control (RTC) can be explicitly modeled. This was an important consideration given the plethora of control structures in the Westerly collection system, including the Combined Sewer Overflow Treatment Facility (CSOTF) and 7 automated regulators with Fabridams.

4.2 Model Development Approach

For SSES and modeling projects, data management has been a tedious and difficult task in the past. For the Westerly CSO Facilities Plan, data was managed through the use of ArcView® Geographic Information Systems (GIS) and associated databases. Many sources of data were used to define the sewer system: City of Cleveland sewer maps, orthophotos, entry and non-entry manhole inspections, and other information. All of the data sources were used to inventory, characterize, and hydraulically evaluate (model) the sewer systems tributary to the Westerly Wastewater Treatment Center. A separate document is being prepared and will explain the data management tools developed for the Westerly CSO Facilities Planning Project. However, the following paragraphs provide some brief information.

<u>Data Management</u>

ArcView® holds information in three associated files (*.shp,*.shx,*.dbf). The shape file (*.shp) stores all the graphic information for each individual graphic object (point, line, polygon). The index file (*.shx) holds links between graphics and databases. The database file (*.dbf) holds all the information associated with a graphic object. For instance, a line represents a pipe; thus, the information contained in the database file includes pipe shape, diameter, length, material, slope, invert, etc.

The data for the sewer system modeling resides in four associated files:

1. WS1NODE.*** contains manhole information, including ground surface elevations;

2. WS1LINK.*** contains pipe information, including shape, size, material, and invert elevations;

3. WS1AREA.*** contains information about the sewer-sheds and their hydrologic characteristics;

4. WS1CONT.*** contains information about control structures such as weirs, orifices, pump stations, automated regulators, and HydroBrakes; and

ArcView® Tools

Several tools were developed to facilitate the management of the GIS and databases for this project. Specifically, a stand-alone data entry program was written that interacts with the ArcView® data tables and eases the data entry process. This program generates an interactive form that mimics the manhole inspection forms used by the field inspection crews. Hydraulic data, necessary for modeling, also are entered via the form. Thus, all sewer data for the project are held in a family of database tables, linked and fully accessible through the program. This program is called the Sewer Asset Manager (SAM) and was specifically developed for the Westerly CSO project to facilitate data entry. In addition, SAM will be made available to the District for querying and modifying the sewer data in the GIS, once this study is completed.

Besides SAM, other tools were developed to aid the modeling process. These include:

- downstream and upstream tracing tools for checking connectivity;
- area delineation tools for delineating sewer-sheds; and
- a sewer profile drawing tool for validating the sewer data.

Except for the sewer profile drawing tool, all tools will be provided to the District with the closure of this project.

4.3 Definition of Sewer Network for Modeling

Prior to the development of the collection system model, the portion of the system to be modeled was determined. The GIS mapping database developed through the Sewer System Evaluation Survey (SSES) portion of the Westerly District Phase II Facilities Planning Project was used to define the extent of the entire collection system. Then, the sewer network for modeling was defined using the following criteria:

- Combined Sewer Interceptors: Westerly, Walworth Run, Northwest, and Cuyahoga River (Low Level);
- All combined sewer trunk lines downstream of static flow dividers or regulators (regardless of diameter);

- Combined sewer trunk lines and tributary lines in special areas of concern (for example, upstream of flooding areas or bottlenecks);
- Overflow pipes from the flow divider, static regulator, or automated regulator to the discharge point (either a downstream point in the system or the receiving water);
- Separate sanitary sewers in the over / under areas greater than or equal to 8 inches in diameter, and the storm sewers above these sanitary pipes;
- Stormwater pipes in the over / under areas that discharge to the receiving water.
- The Westerly Wastewater Treatment Center and CSOTF.
- Major stormwater discharge routes to the receiving water from the separate sanitary areas.
- Any portion of the system needed to insure accurate modeling of the automated regulators and other control structures, particularly if the time of concentration from an area affected regulator operation.

Based on the selection criteria, the sewer network for modeling included all pipes in the separate sanitary areas and pipes 24" in diameter and larger in the combined sewer area.

4.4 Model Simplification

Advances in both computer hardware and software technology have limited the need for simplified models due to long simulation times and disk space limitations. Information is available in the GIS to include every pipe in the sewer network as defined for modeling. However, some model simplifications have virtually no effect on the model results and were made to the Westerly model to reduce its complexity. One such simplification is the elimination of "through" manholes, where the pipe diameter and slope remain the same and no new flows are added to the system. The following criteria were used to determine the necessity of manholes (nodes) in the model network:

- All manholes that receive hydraulic loads from contributing areas;
- All junction manholes at junctions;
- All manholes where pipe shapes change from upstream to downstream;
- All manholes where the pipe sizes change from upstream to downstream;
- All manholes where the pipe gradient changes between the upstream pipe and downstream pipe;
- All manholes where flow monitors were installed;
- All manholes upstream and downstream of flow monitors;
- All manholes receiving hydraulically loaded with industrial flows in the model;
- All manholes containing control structures, such as pumping stations, regulators, tanks, etc.;
- All manholes with steps in invert level between the incoming and outgoing pipes (within 0.2 feet) (ensures that the correct gradients are used in the model and that and hydraulic restrictions are not simplified out of the model).

The Westerly model was simplified to a network containing 2,833 nodes, 2,861 links, 37 outfalls, and 224 controls (including weirs, invert plates, HydroBrakes, automated regulators, and pumping stations). Figure 4-1 shows the simplified sewer network that was modeled. (This large figure can be found folded and placed in the map pocket at the end of this document.)

4.5 Delineation of Sewer Basins and Contributing Area

When developing a collection system model, sewer basins are used to determine the amount of flow that enters the sewer system. These basins are used to determine both the population tributary to the sewer system at various locations and the potential area from which the sewer system receives runoff flows. For the Westerly Collection system model, 1,327 sewer basins were defined to represent flows from the Westerly Service Area.

The primary factor considered for delineating contributing areas was the time of concentration or the amount of time taken for rainfall to hit the ground, runoff, and enter the sewer. If drainage areas are too large, model simulations will not reflect the time of concentration. Generally, the following items are considered when drainage areas are delineated:

- Ground surface contours that affect overland flow;
- Natural boundaries, such as rivers;
- Streets, highways and railroads;
- Property boundaries; and
- The extent of the collection system in the area.

Table 4-1 briefly summarizes the types and numbers of drainage areas delineated for the Westerly District along with a few relevant statistics typically reported for drainage areas. Appendix A contains the full table of drainage areas and the hydrologic parameters determined for each area. The hydrologic parameters are discussed later in this chapter.

In the separate sanitary area, two areas were drawn, one on top of the other (exact replicas), to represent the sanitary flow and rainfall-induced infiltration into the sanitary pipe and the runoff into the storm pipes. The "sanitary" area produces rainfall-induced infiltration/inflow for the sanitary sewer and the "storm" area produces runoff for the storm sewer. This ensured that no more than 100 percent of an area drained into the sewer network. Figure 4-1 also shows the delineated drainage areas for the Westerly Collection System model.

Northeast Ohio Regional SEWER DISTRICT

MONTGOMERY WATSON

M&E Metcalf & Eddy
An Air & Water Technologies Company

REV. No.	DESCRIPTION	DATE	BY	CHK'D

DATE:
DRAWN BY:
CHECKED BY:
APPROVED BY:

FIGURE 4-1
MODEL NETWORK & SEWER-SHED DELINEATIONS
WESTERLY DISTRICT
PHASE II FACILITIES PLAN

NEORSD CONTRACT No.

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Table 4-1. Drainage Areas for the Westerly Collection System Model

Area Type	No. of Areas	Total Area (Acres)	Population	Area-Weighted Percent Impervious	Area-Weighted Percent Pervious	Total
Combined	648	7,440	126,205	56	40	96
Sanitary	341	1,318	28,643	5	11	100
Storm	338	1,318	-	51	33	

Note: The sanitary and storm areas are duplicated, thus the sum of their percentages equals 100 percent. When the combined areas were delineated, some large areas near the waterfronts were included that drain directly to the watercourses rather than to the combined sewer system. Therefore, less than 100 percent of some of the combined areas is tributary to the collection system.

4.6 Dry Weather Flow

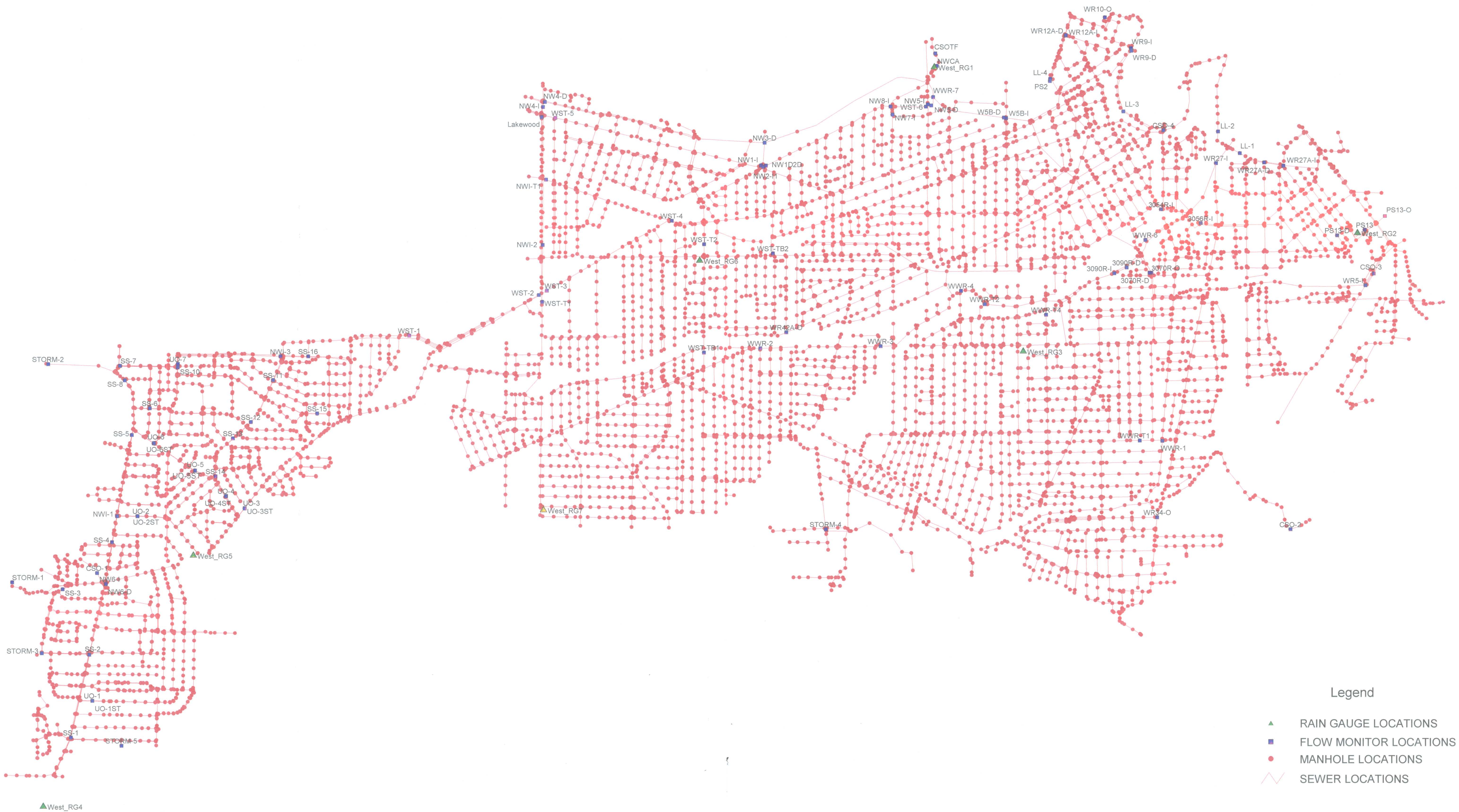
Dry weather flows in the collection system are comprised of three distinct components: wastewater, infiltration, and river or lake inflow. Wastewater includes sanitary flows generated by population water usage and includes commercial and industrial wastewater. Infiltration results from groundwater entering the collection system through cracks in the pipes, joints, and manholes. The dry weather infiltration also can result from broken water supply mains. River and lake inflow to the collection system occurs when the water level in the river or lake rises above the invert level of an outfall pipe or the crest elevation of a weir.

Wastewater Flows

The wastewater or sanitary component of dry weather flow was determined using population data, per capita wastewater generation rates, and billing records of industrial and commercial sewer customers. In addition to the amount of wastewater generated, the diurnal pattern of flow was determined using flow monitoring data.

Base Flow Development for Residential Land Uses

1990 Census Population data for the Westerly District service area was obtained as a TIGER Line 95 GIS coverage from the Unites States Department of Commerce Bureau of the Census. This coverage when “intersected” with the sewer basin coverage provides population estimates for each sewer basin by land use classification including residential and commercial / industrial. The model then uses this population estimate, together with a per capita wastewater generation estimate to determine wastewater flows from each sewer basin. The wastewater generation rates used for residential



Northeast Ohio Regional SEWER DISTRICT

MONTGOMERY WATSON

M&E Metcalf & Eddy An Air & Water Technologies Company

REV No	DESCRIPTION	DATE	BY	CHK'D

N W E S

DATE:

DRAWN BY:

CHECKED BY:

APPROVED BY:

FIGURE 3-1
RAIN GAUGE & FLOW MONITOR LOCATIONS
WESTERLY DISTRICT
PHASE II FACILITIES PLAN

NEORSD CONTRACT No.

SHEET No. OF

areas in this study were 115 gallons per capita per day and 150 gallons per capita per day. These two per capita wastewater generation rates reflected different water usage among the residential areas. This topic is discussed in further detail under "Diurnal Flow Pattern Development within this section.

Base Flow Development for Industrial/Commercial Land Uses

Major industrial and commercial flows were determined by inspection of sewer billings. Facilities discharging more than about 23,000 gallons of wastewater per day were included as additional wastewater flow inputs to the model. For these 33 industries, artificial sewer basins with a small (insignificant) population were created to simulate industrial flows.

An artificial population with a high per capita wastewater generation rate was used to represent the industrial flows in each of these artificial sewer basins. These flows are uniformly distributed to simulate weekday working hour periods. A constant industrial per capita wastewater generation rate (23,000 gallons per capita per day) was used to simulate the anticipated total daily flow from the facilities. The anticipated daily flows were obtained from discharge permits. Table 4-2 presents the artificial populations, the model simulated flows, the actual industrial permitted flows, and their input locations.

Table 4-2. Industrial Flows to the Westerly Collection System

Area Ref. Number	Input Manhole Identifier	Artificial Population(1)	Simulated Model Flow (mgd)	Permitted Industrial Flow (mgd)
1313	CL83749301	1	0.023	0.024
1325	CL78763601	1	0.023	0.029
1311	CL847966J1	1	0.023	0.030
1317	CL79779601	1	0.023	0.031
1318	CL84730001	1	0.023	0.031
1316	CL82723201	1	0.023	0.033
1309	CL82793602	2	0.046	0.041
1302	CL80768601	2	0.046	0.042
1314	CL81754301	2	0.046	0.046
1310	CL87794801	2	0.046	0.049
1305	CL82754601	2	0.046	0.053
1321	CL81807301	2	0.046	0.053
1304	CL82793401	2	0.046	0.054
1307	CL79746601	2	0.046	0.054
1326	CL74738401	3	0.069	0.070
1324	CL80797001	3	0.069	0.071
1315	CL84790001	4	0.092	0.081
1303	CL84720701	4	0.092	0.085
1320	CL78776701	4	0.092	0.097
1319	CL81724301	7	0.161	0.150

Area Ref. Number	Input Manhole Identifier	Artificial Population[1]	Simulated Model Flow (mgd)	Permitted Industrial Flow (mgd)
1323	CL87791601	7	0.161	0.152
1333	CL84720401	9	0.207	0.200
1308	CL79787501	9	0.207	0.203
1335	CL66831401	12	0.276	0.270
1322	CL86798301	14	0.322	0.312
1332	CL80777901	17	0.391	0.400
1338	CL838265J1	20	0.460	0.450
1312	CL83809302	23	0.529	0.531
1306	CL82783101	34	0.782	0.780
1336	CL65795101	35	0.805	0.800
1334	CL82803403	57	1.311	1.300
1331	CL88790901	170	2.415	3.900
1337	CL76761501	174	4.002	4.000

[1] Industrial flows are generated by an artificial population and per capita flow rate.

Diurnal Flow Pattern Development

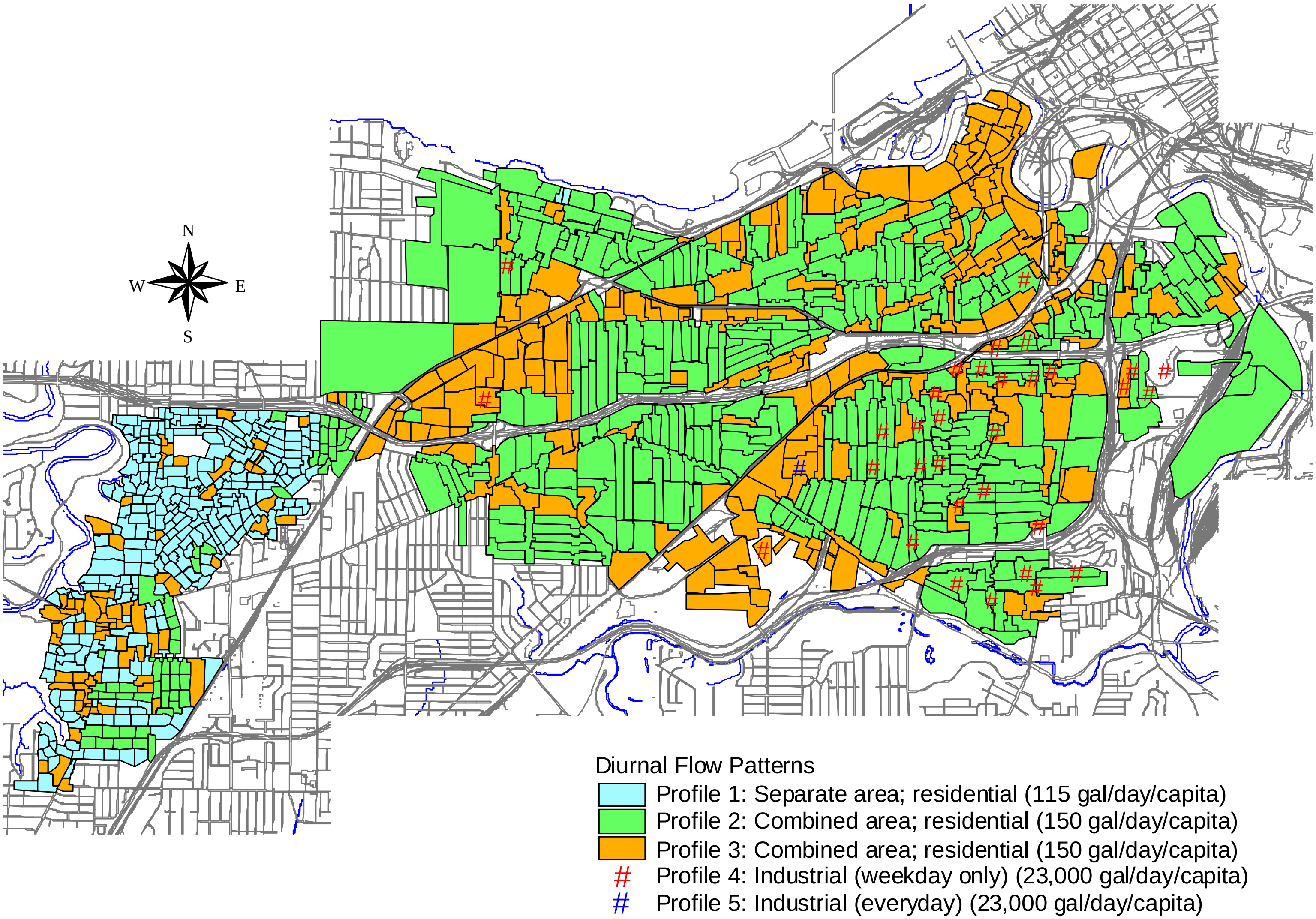
Diurnal flow patterns are important because wastewater flows can vary from 60 percent to 130 percent of the average daily wastewater flow depending upon the time of day. The required data to determine the diurnal patterns include a per-capita flow rate and ratios of the flow at specific times of the day versus the average daily flow for both the weekday and weekend. These data were derived from the flow monitoring data collected for this study. As shown in Table 4-3, five diurnal patterns or profiles were used to represent the diurnal wastewater flows. Three of these profiles reflected the different types of housing in the combined and separate areas. The remaining two reflected industrial wastewater generation including industries that operate only on weekdays and those that operate both weekdays and weekends. By defining the diurnal patterns observed in the collection system, the model simulates a more realistic wastewater flow based on the time of day or the day of the week. Figure 4-2 shows the areas defined under each diurnal flow pattern and their corresponding base flow. Figures 4-3 through 4-12 present the weekday and weekend diurnal patterns for the 3 housing and 2 industrial land use types.

Table 4-3. Diurnal Flow Pattern (Profile) Descriptions

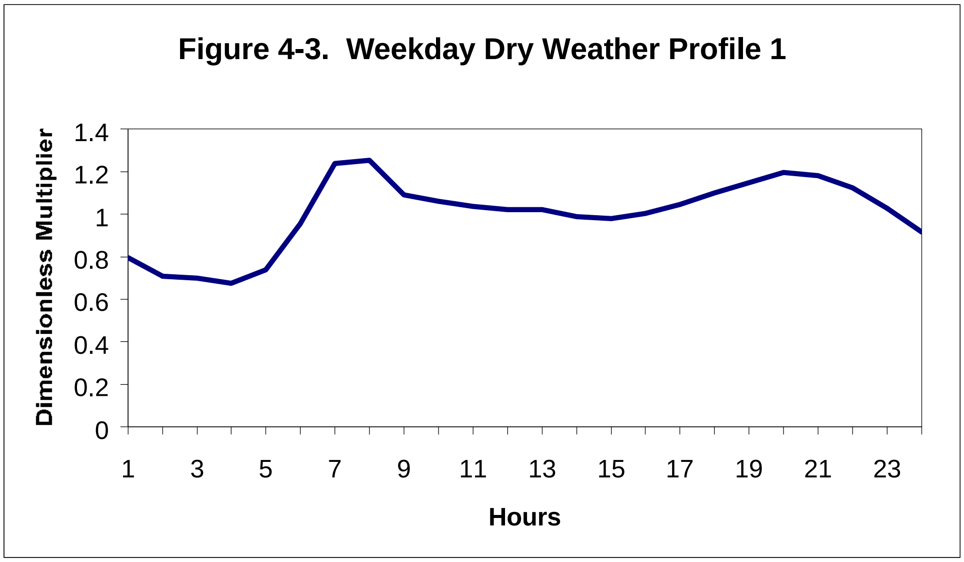
Profile	Description
1	Separate area; residential
2	Combined area; residential
3	Combined area; residential
4	Industrial (week day only)
5	Industrial (week days and weekends)

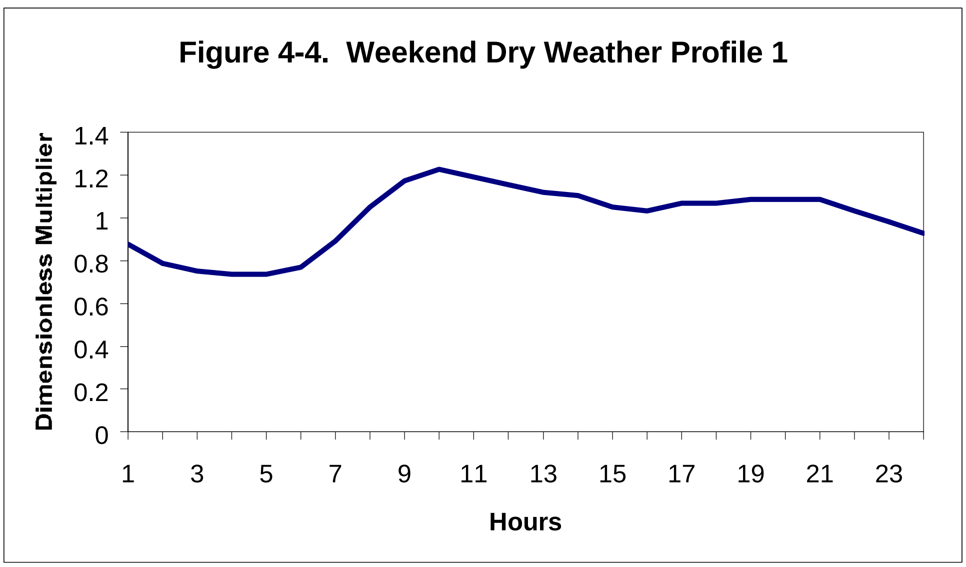
The HydroWorks model uses two files to manage the wastewater flows: the Wastewater Generator file (WWG) and the Land Use Definition file (LUD). The Wastewater Generator file contains the per capita wastewater generation rates and diurnal curves for different land use definitions. The Land Use Definition file contains information about the representative land use types such as the three housing and two industrial types found in the Westerly Service District. Additional information about how HydroWorks uses these two files is found in the Engineer's Guide in the program's help menu.

Figure 4-2 Areas Under Each Diurnal Profile

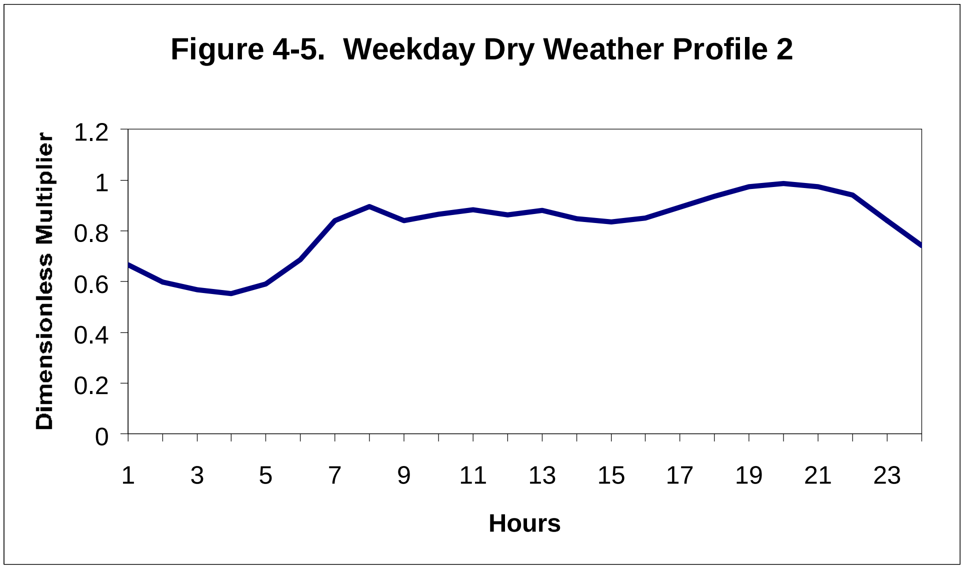


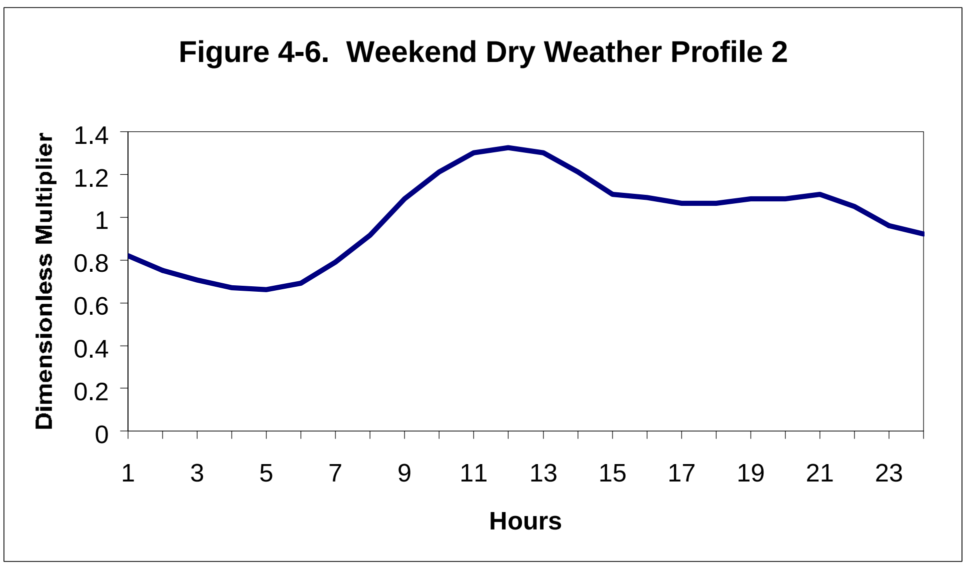
Note: **Figure 4-3 and 4-4 profiles are based upon a population-generated flow of 115 gallon per capita per day (gpcd)**





Note: **Figure 4-5 and 4-6 profiles are based upon a population-generated flow of 150 gallon per capita per day (gpcd)**





Note: **Figure 4-7 and 4-8 profiles are based upon a population-generated flow of 150 gallon per capita per day (gpcd)**

Figure 4-7. Weekday Dry Weather Profile 3

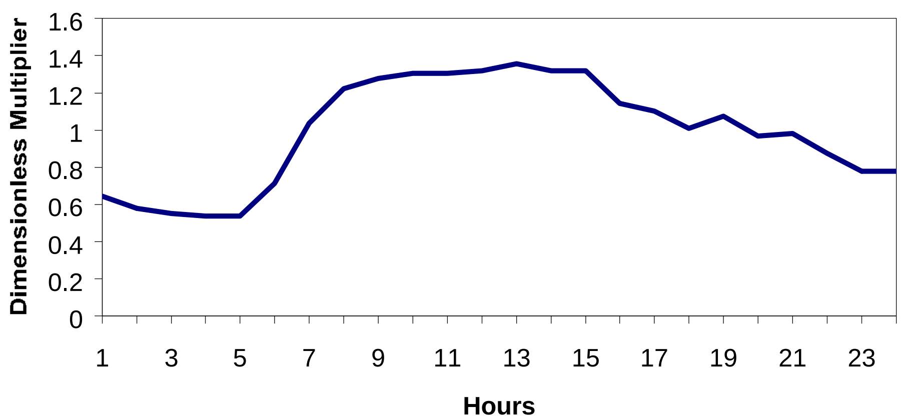
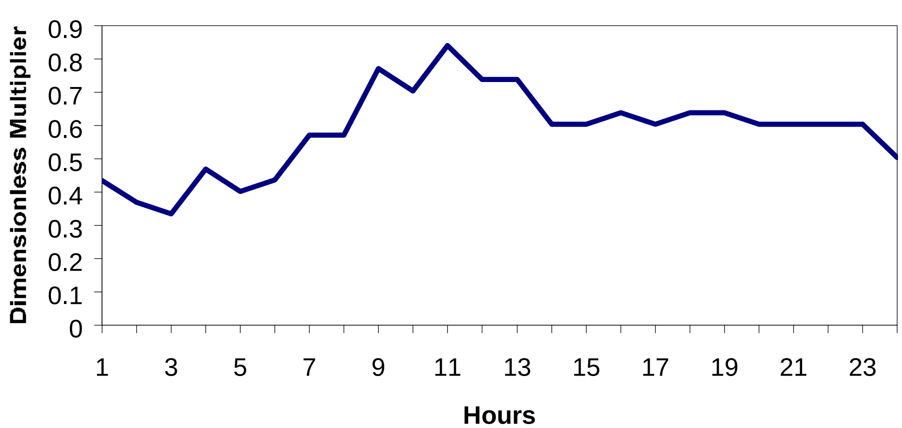


Figure 4-8. Weekend Dry Weather Profile 3



Note: **Figure 4-9 and 4-10 profiles are based upon a population-generated flow of 23,000 gallon per capita per day (gpcd)**

Figure 4-9. Weekday Dry Weather Profile 4

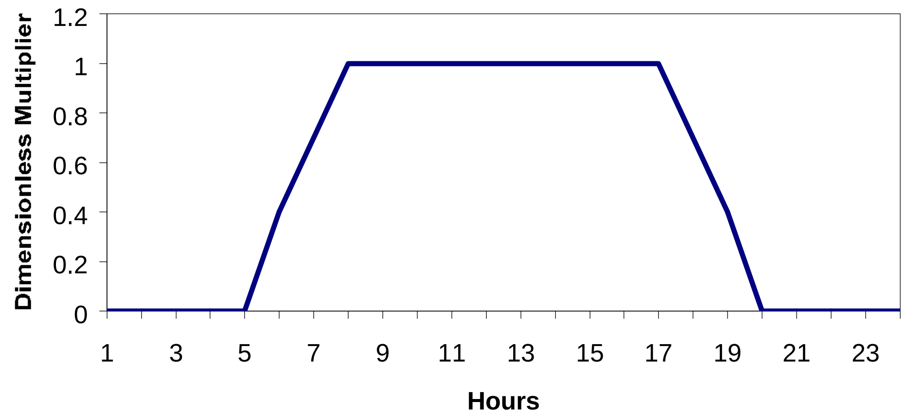
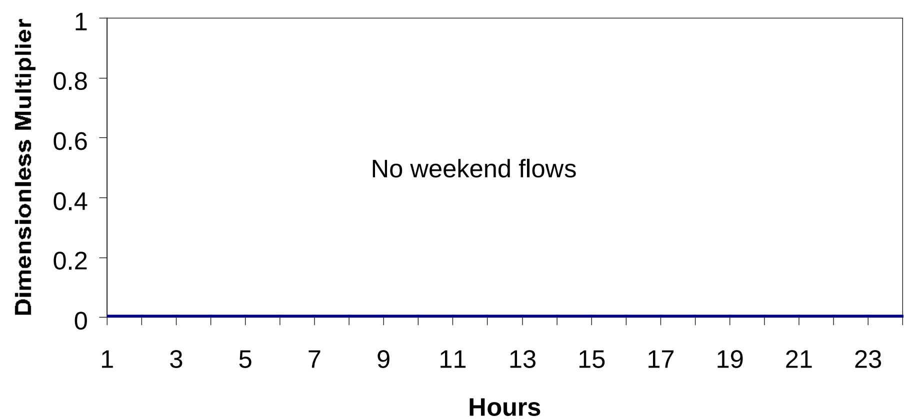


Figure 4-10. Weekend Dry Weather Profile 4



Note: **Figure 4-11 and 4-12 profiles are based upon a population-generated flow of 23,000 gallon per capita per day (gpcd)**

Figure 4-11. Weekday Dry Weather Profile 5

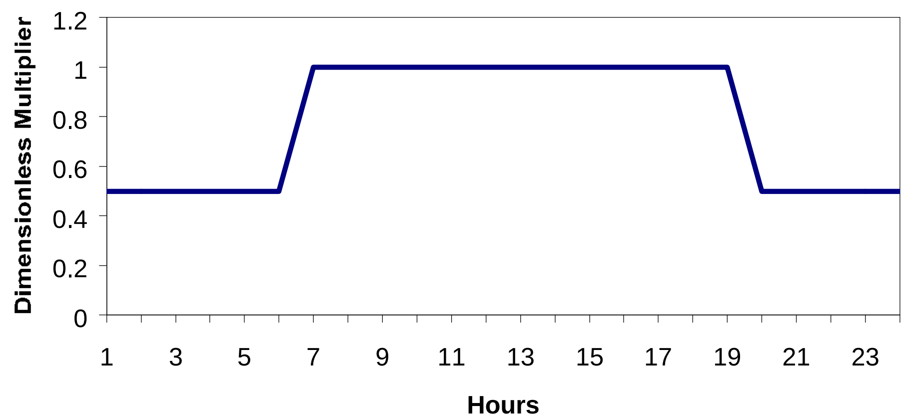
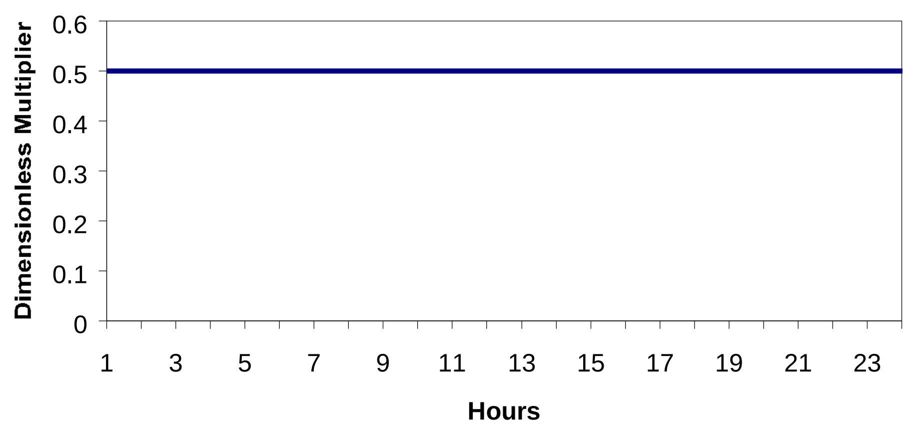


Figure 4-12. Weekend Dry Weather Profile 5



Infiltration

In HydroWorks, infiltration is simulated as a fixed rate of inflow into the sewer system. Whether from naturally occurring groundwater or saturated earth (from a broken water main, for example), infiltration is determined by comparing predicted dry weather flows with observed flow monitoring data. Essentially, infiltration is calculated as the difference between the observed flow and the flow attributable to population and other wastewater sources, during dry weather flow periods and accounting for diurnal variations. For the Westerly Collection system, infiltration was determined during dry weather flow verification as follows:

- If the dry weather flow simulated by the model was less than observed through the flow monitoring data (and not attributable to flows generated by populations or industries), infiltration flows were added to account for the difference.

- If the dry weather flow simulated by the model was greater than observed through flow monitoring data, the population was redistributed to more accurately reflect the observed dry weather flow. Negative infiltration rates were not used.

Flow monitoring data were used from periods where the flow represented base wastewater and infiltration typical of that time of year. Generally, these periods are found when no rainfall had occurred in the previous 3 days. Thus, the infiltration values represented typical groundwater levels or saturated earth during the flow monitoring period, not delayed rainfall-induced flows.

Through the process of dry weather flow calibration, 10.8 mgd of infiltration was found in the Westerly Collection System. Table 4-4 indicates the location, reference flow monitor, and infiltration flows added to the collection system model.

Table 4-4. Infiltration flows in the Westerly Collection System Model				
Area Ref. Number	**Input Manhole Identifer**	**Area Type**	**Flow Monitor Reference**	**Infiltration (MGD)**
390	CL72835801	COMBINED	NW2-I2	2.100
400	CL74856101	COMBINED	NW8-I	2.000
468	CL78802201	COMBINED	WWR-4	2.000
552	CL65785901	COMBINED	WST-T1	1.200
359	CL778255J1	COMBINED	NW5-I	0.800
34	CL837537J1	COMBINED	WWR-T1	0.525
405	CL768419J1	COMBINED	NW7-I	0.400
331	CL72796801	COMBINED	WST-TB2	0.300
516	CL65839501	COMBINED	NWI-T1	0.300
277	CL707749J1	COMBINED	WST-TB1	0.200
939	CL59771702	SANITARY	SS-16	0.200
813	CL53751401	SANITARY	SS-5	0.100
662	CL50708901	SANITARY	SS-3	0.080
715	CL58750501	SANITARY	SS-13	0.080
837	CL56759701	SANITARY	SS-12	0.080
728	CL50658603	SANITARY	NWI-1	0.070
482	CL81879701	COMBINED	WR12A-I	0.060
762	CL54756101	SANITARY	SS-6	0.060
709	CL56749101	SANITARY	UO-3	0.050
484	CL83872401	COMBINED	WR9-I	0.048
684	CL55728601	SANITARY	UO-4	0.040
707	CL57741701	SANITARY	SS-14	0.030
791	CL54765609	SANITARY	SS-6	0.030
924	CL54786201	SANITARY	UO-7	0.030
			TOTAL:	10.783

River and Lake Inflows

For the Westerly District collection system model, river and lake inflows were an important source of flow into the system, particularly along the Cuyahoga River Interceptor. During the SSES portion of this study, field crews observed river and lake water spilling into the system over weirs from submerged outfall pipes. As a result, during an early action project, called the Cuyahoga River Inflow Analysis, it was determined that seven of the Westerly Service Area outfalls were potentially subject to river inflows due to much higher than normal lake levels in 1997. Outfalls with the potential for inflow included 075, 076, 079, 082, 240, 086, and Sycamore Slip (even though collapsed).

River and lake inflows were modeled using river and lake water surface elevations recorded during the flow monitoring period, by specifying depth hydrographs as boundary conditions at the outfalls receiving inflows. The model projected water surface elevations up the outfall pipes. If the water level exceeded the crest of the weir in the overflow chamber, the model calculated a flow rate into the system using standard weir equations. For verification, the actual river / lake levels were used as depth hydrographs. For design and typical year analyses, a standard fixed water surface elevation of 574.5 feet above datum was used. The 574.5 feet is the 95th

percentile water level elevation of Lake Erie, Cuyahoga River, and Rocky River, based on the CRGS datum.

4.7 Wet Weather Flows

Storm flows consist of three major simulated components: dry weather flow (including wastewater, infiltration, and river or lake inflows), runoff from impervious surfaces (including roofs, roads, and pavement), and runoff from pervious areas (such as lawns or other vegetated land areas). Runoff from both impervious and pervious surfaces is simulated using a hydrologic model that calculates the volume of runoff from a rainfall event. Typically, the hydrologic model includes initial losses from depression storage and accounts for time of concentration using the land surface slope and length of flow path.

Hydrologic Model Parameters

For the Westerly Collection System model, the HydroWorks implementation of the SWMM RUNOFF model was used to generate the runoff from pervious and impervious surfaces. SWMM needs the following information to determine the runoff response from rainfall events for the three surface types (Roofs – Type 1; Pavement – Type 2; Grass Areas – Type 3):

- Drainage area
- Percent impervious (types 1 and 2)
- Percent pervious (type 3)
- Effective catchment area width
- Catchment area slope
- Manning's "n" for impervious area (types 1 and 2)
- Manning's "n" for pervious area (type 3)
- Depression storage for impervious area (types 1 and 2)
- Depression storage for pervious area (type 3)
- Initial infiltration rate
- Limiting infiltration rate
- Infiltration rate decay coefficient
- Antecedent conditions

Drainage Area, Width and Slope

The drainage area for each of the sewer-sheds was calculated with the GIS. The method of drainage area (sewer-shed) delineation was discussed in Section 4.5. The width of each drainage area was determined by assuming the area was square; thus, the catchment width was calculated as the square root of the area and the effective catchment width was twice catchment length. Since the drainage areas were delineated to account for the time of concentration, twice the square root of the catchment area was deemed a reasonable estimate of the effective catchment area width. HydroWorks, unless otherwise specified, determines the catchment slope based on the slopes of the ground surface of pipes receiving flows. Therefore, no estimate of catchment slope was necessary as this adequately represented the local ground slope for pavement (type 2) or grass areas (type 3). For roofs (type 1), a standard slope of 5% was used.

Percent Impervious and Area Types

For the Westerly Collection System model, percent impervious was determined as follows:

1. The Westerly District was examined for typical areas;
2. 5 representative areas were defined;
3. The percent of roof (type 1), pavement (type 2), and grass (type 3) was determined for each representative area;
4. The representative area percentages of roof, pavement and grass were applied to all of the drainage areas.

Table 4-1 shows the area weighted percentages of impervious (types 1 and 2) and pervious (type 3). The table of drainage areas in Appendix A lists the percentages of the three area types (roof, pavement, and grass) for each of the 1,327 sewer-sheds.

Manning's "n" Values

The Manning's "n" values for impervious and pervious areas are used by the model to determine the friction losses from overland flow. The Manning's "n" value for roof and paved impervious areas was 0.04 and was the same value used in the Mill Creek study. For pervious surfaces, a Manning's "n" of 0.3 was used, also the same value used in the Mill Creek study.

Depression Storage

Initial losses or depression storage on impervious surfaces were determined based upon the square root of the slope of each drainage area. HydroWorks uses the following equation to determine initial losses from slope:

For impervious areas: $\text{Depression Storage} = 0.04 \text{ inches} / \sqrt{\text{slope}}$

For pervious areas: $\text{Depression Storage} = 0.19 \text{ inches} / \sqrt{\text{slope}}$

The base values of 0.04 inches and 0.19 inches were those used for impervious and pervious minimum depression storage values, respectively, in the Mill Creek Study.

<u>Infiltration Parameters</u>

After initial losses to depression storage are subtracted, 100 percent of the runoff from impervious surfaces reaches the sewer. For pervious surfaces, however, both initial losses to depression storage and infiltration into the ground determine the final volume of runoff from pervious surfaces. Either the Horton or the Green-Ampt method of calculating infiltration is used to determine runoff losses to infiltration. For the Westerly Collection system model, the Horton infiltration method was used.

The Horton infiltration model governs the amount of runoff from pervious surfaces lost through seepage into the ground and soil through a first-order decay relationship. The Horton infiltration model uses an initial infiltration rate, a limiting infiltration rate and an infiltration decay constant to determine the amount of runoff lost into the soil through infiltration. Similar to the Mill Creek Study area, the Westerly District has type D soils. The Westerly District soils are classified as Urban soils predominantly Mahoning. This soil classification is described as poorly drained silty loam and silty clayey loam. As a D class soil, the initial infiltration rate used for modeling was 5 in/hr and the limiting infiltration rate was 0.25 in/hr. The infiltration decay constant was 2/hr (0.00115/ sec). These values represent published data for type D soils and are consistent with the values used for the Mill Creek model.

<u>Antecedent Conditions</u>

The use of antecedent conditions ensures that the state of soil saturation is accounted for over and above its typical drainage characteristics and is particular for each individual storm. The amount of moisture held within the soil would affect the point at which runoff occurs from pervious surfaces (grassland, etc.). If this occurs early on in a wet weather event, such as when storm follow close to one another, then greater runoff will occur than were a storm to occur after an extended dry period.

Antecedent conditions were determined by evaluating the rainfall during the 24 hours preceding the beginning of a wet weather event. The model accounts for antecedent conditions by applying the antecedent rainfall depth to the ground surface and calculating the available depression storage and infiltration capacity.

4.8 Control Structures

The Westerly Collection System Model has over 200 control structures. These structures include the 7 automated regulators (some with Fabridams), 8 HydroBrakes, 7 pump stations, the CSOTF (CSO Treatment Facility), various weirs, flow dividers, and invert plates. Although the modeling of these structures in HydroWorks was generally straightforward, a brief description of most is provided in this Section.

HydroBrakes

Eight HydroBrakes are located in the Westerly Collection System on both the Northwest and Westerly interceptors. Their locations are shown on Figure 2-1, and their street locations are listed below:

HB#1:	1497 West 117th Street
HB#2:	West 117th Street north of Berea Road
HB#3:	12920 Berea Road
HB#4:	Lakewood Heights Boulevard east of West 140th Street
HB#5:	West 153rd Street and South Marginal Road
HB#6:	Riverside Drive and Fischer Road
HB#7:	Rocky River Drive and Chatfield Avenue
HB#8:	West 117th Street and Detroit Avenue

These HydroBrakes were detailed in an EPA report "Controlling Discharge and Storage in a Combined Interceptor Sewer - Cleveland, Ohio (HydroBrakes)", dated July 1987. The report provided information about the locations and discharge characteristics of the HydroBrakes. Each HydroBrake was included in the model as a vortex control device by specifying the stage-discharge curve from this report. These curves are shown in Figures 4-13 through 4-20. The report indicated that a weir was installed at each HydroBrake location to allow overtopping and bypass of the flow control. These weirs also were modeled. In the model, the specified discharge curves have a negative component, which allows for flow reversal through the HydroBrake.

The model simulations were evaluated to ensure that the HydroBrakes where operating correctly by viewing sewer profiles during wet weather events. These profiles show the combined operation of the HydroBrakes to affect storage in the interceptor sewer. The discharge curve for the HydroBrake at West 117th St. and Detroit Avenue was based upon actual and interpretive information contained within the above referenced report.

Figure 4-13. HydroBrake Discharge Curve for W.117 St & Detroit Ave

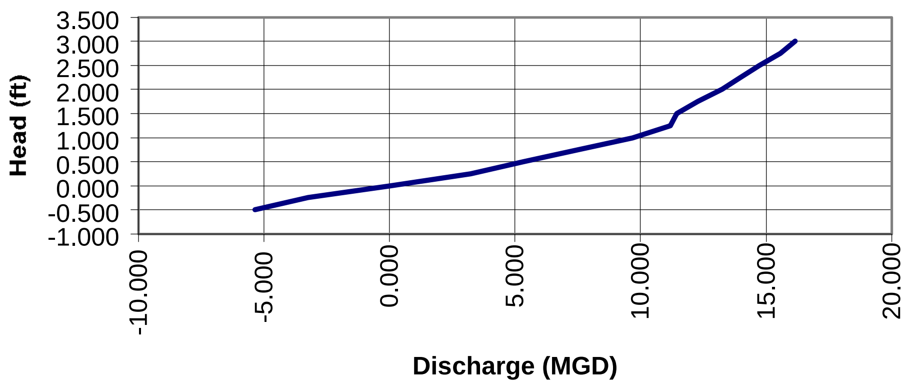


Figure 4-14. HydroBrake Discharge Curve for HydroBrake Number 1

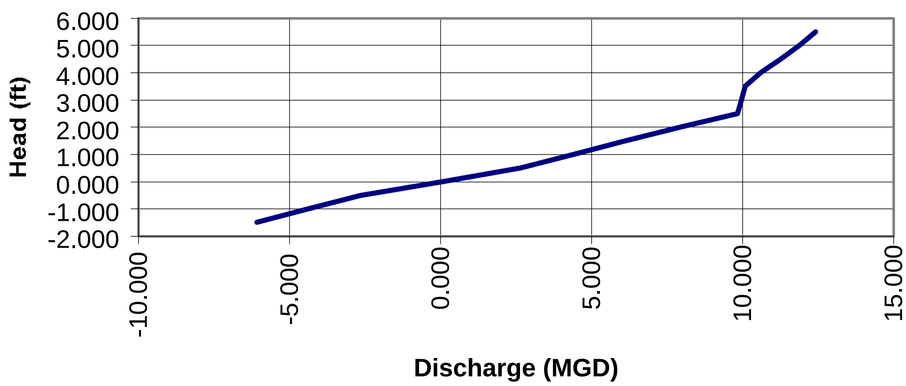


Figure 4-15. HydroBrake Discharge Curve for HydroBrake Number 2

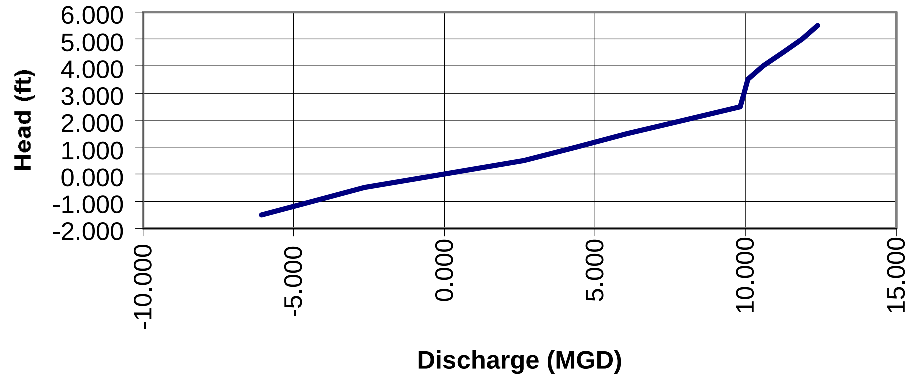
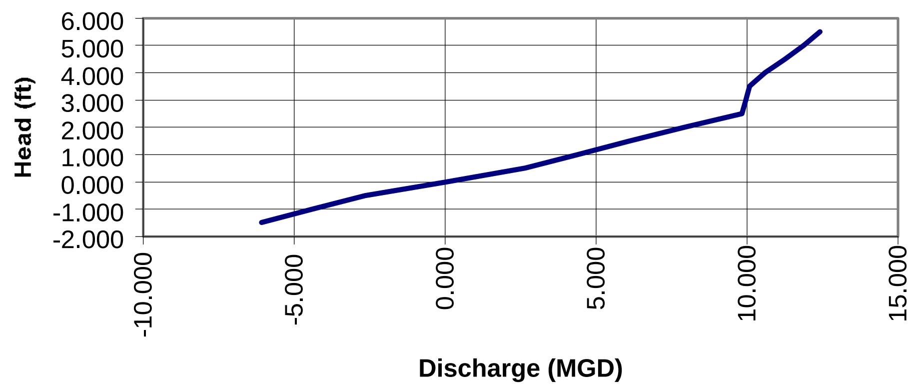


Figure 4-16. HydroBrake Discharge Curve for HydroBrake Number 3



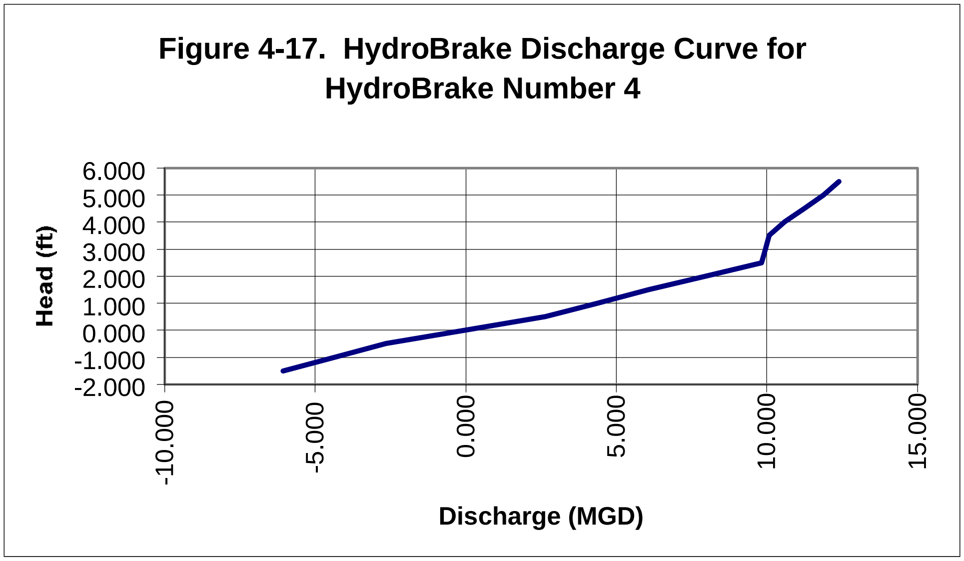


Figure 4-17. HydroBrake Discharge Curve for
HydroBrake Number 4
Head (ft)
6.000
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-10.000
-5.000
0.000
5.000
10.000
15.000
Discharge (MGD)

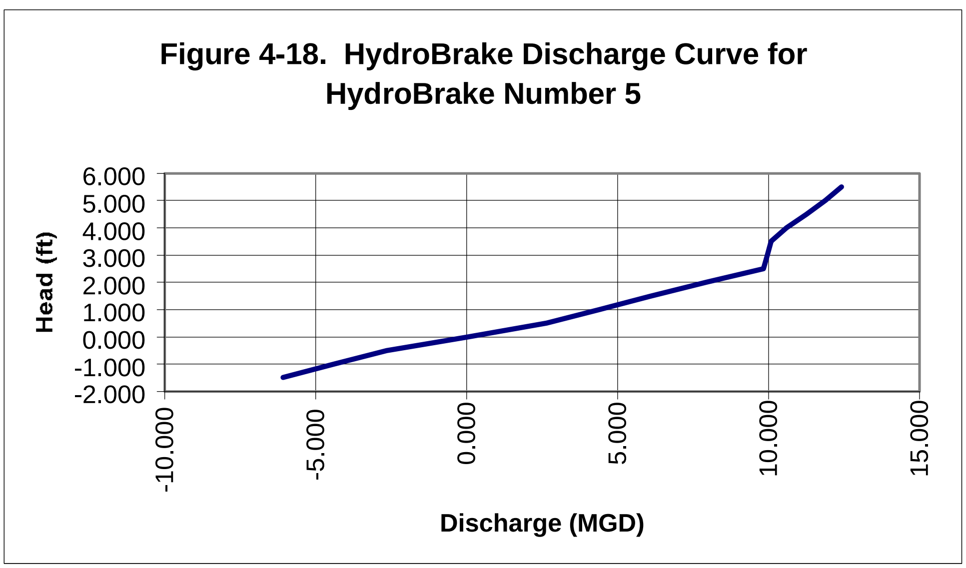


Figure 4-18. HydroBrake Discharge Curve for
HydroBrake Number 5
Head (ft)
6.000
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-10.000
-5.000
0.000
5.000
10.000
15.000
Discharge (MGD)

Figure 4-19. HydroBrake Discharge Curve for HydroBrake Number 6

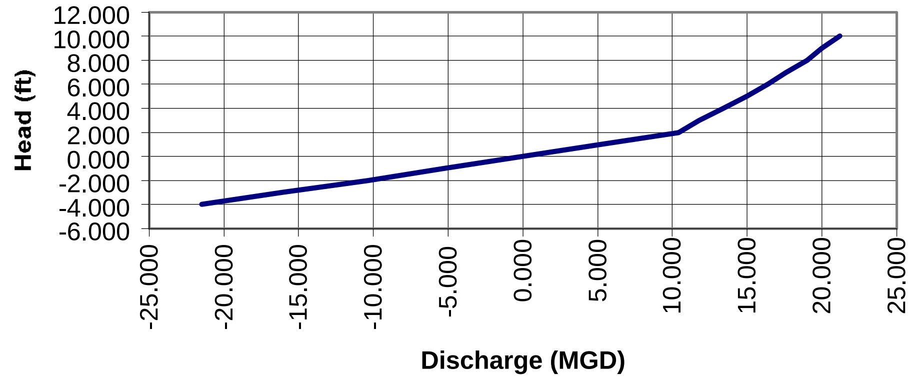
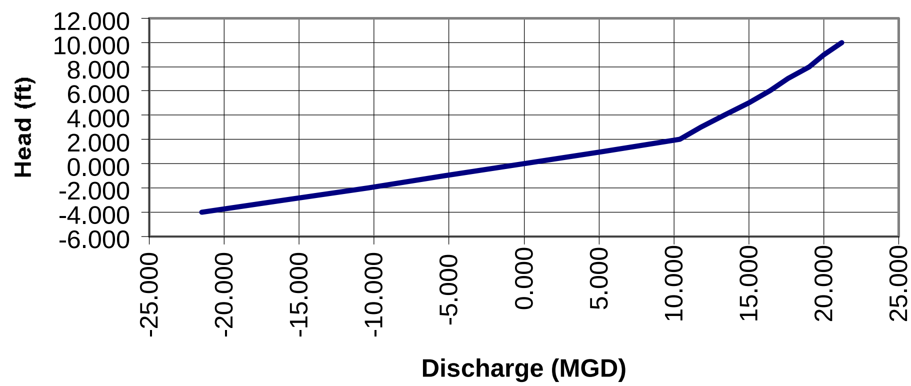


Figure 4-20. HydroBrake Discharge Curve for HydroBrake Number 7



Pumping Stations

Six pumping stations within the Westerly collection system and one at the CSOTF were included in the model. The six (non-CSOTF) pumping stations in the model are:

- West 61st Street and Barberton Avenue;
- Edgewater Drive and West 112th Street;
- West 3rd Street and Service Court;
- Incinerator and Mahoning Avenue;
- Division Avenue; and
- Mary Street.

Of the non-CSOTF stations, the District operates the Division Avenue Pump Station. The City of Cleveland operates all others.

These six pumping stations were modeled as screw pumps, rather than fixed discharge pumps. Screw pumps were used because their solution algorithm uses smoother calculations, reducing model run times. The operating regime of the actual fixed discharge pumps was reflected in the model.

The individual pumping station operational characteristics were accounted for to ensure that the model simulated the appropriate discharge characteristics. The information used to model these pumping stations was based on prior studies and construction drawings. No pumping station tests were conducted for this study. Figures 4-21 through 4-26 present the pump curves used to represent six of the pumping stations.

The pumping station at the CSOTF was modeled as a fixed discharge pump. The operational characteristics were simulated using real time control rules based upon the known operating strategy of CSOTF. For model simulations, it was assumed that the pump at the CSOTF turns on and empties the tanks at a rate of 14 mgd to the headworks when gravity flows arriving at the headworks fall below 49 mgd.

Figure 4-21. Pump Curve for W. 61 St. & Barberton Pumping Station

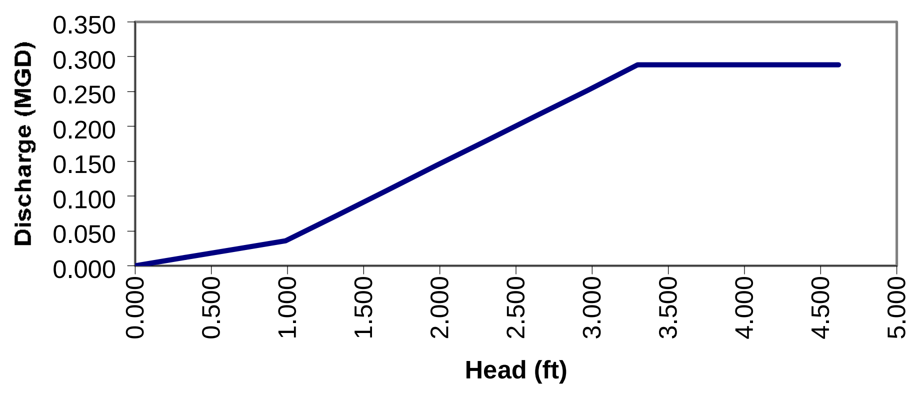


Figure 4-22. Pump Curve for Edgewater Drive & W. 112 St. Pumping Station

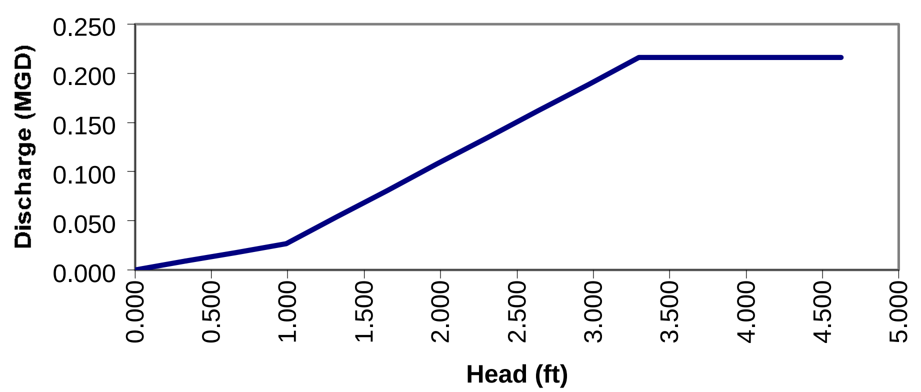


Figure 4-23. Pump Curve for W. 3rd & Service Court Pumping Station

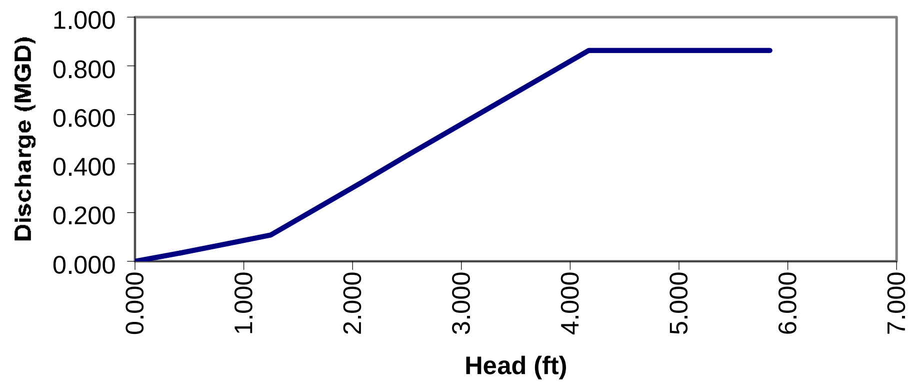
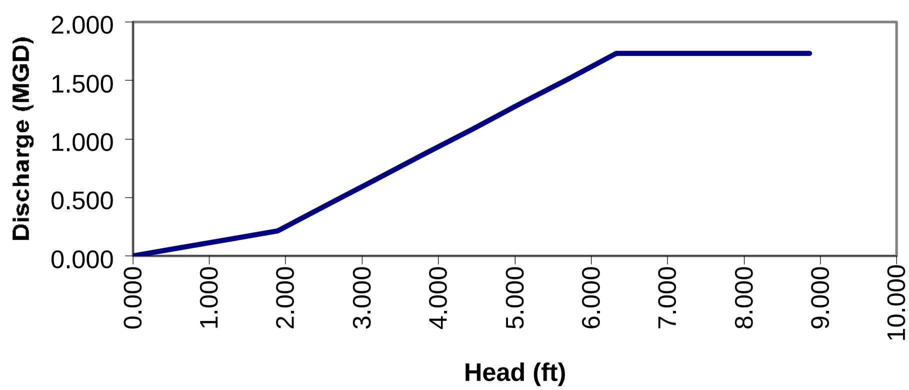


Figure 4-24. Pump Curve for Incinerator & Mahoning Ave. Pumping Station



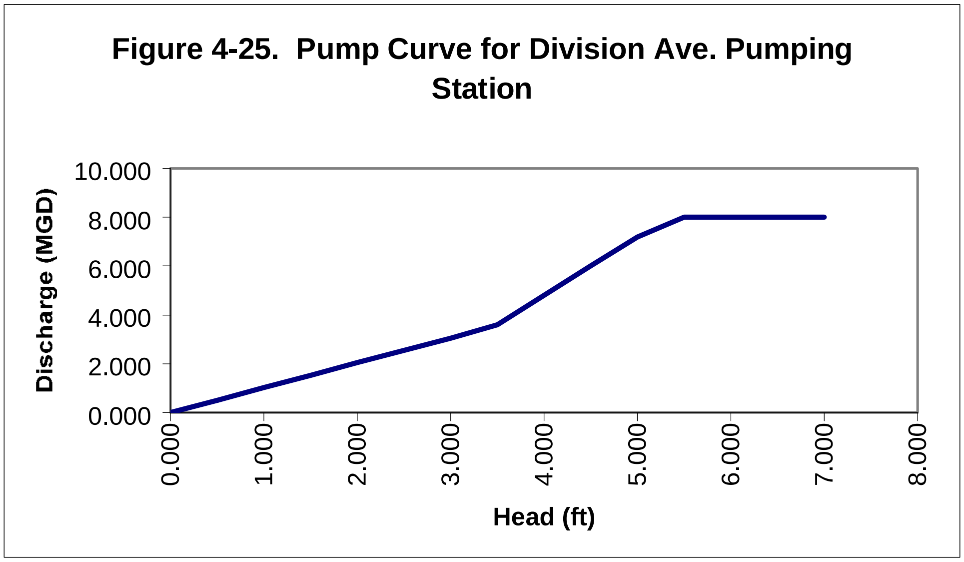


Figure 4-25. Pump Curve for Division Ave. Pumping Station
Discharge (MGD)
10.000
8.000
6.000
4.000
2.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
Head (ft)

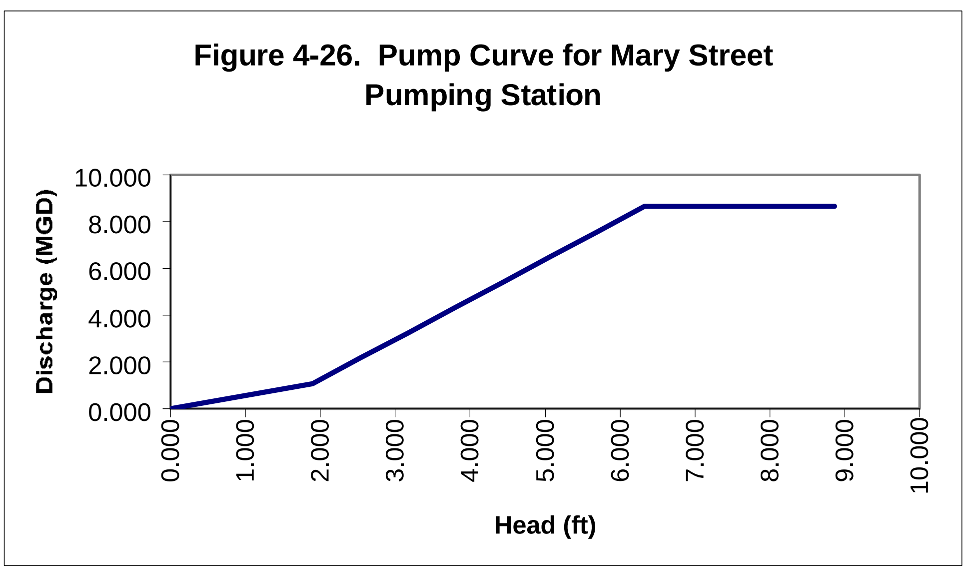


Figure 4-26. Pump Curve for Mary Street Pumping Station
Discharge (MGD)
10.000
8.000
6.000
4.000
2.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
Head (ft)

Regulators and Flow Diversions

Regulators and flow diversions were modeled based upon CSO Phase I survey information that had been verified or updated during this project. Typically, these control structures were fixed weirs or orifices (holes in the base of a pipe where flows drop into another sewer). Instances of pipes leaving manholes at higher elevations were modeled as such rather than as weirs. A few abandoned Brown & Brown mechanical regulators were simulated with appropriately sized pipes and orifice openings.

Auto Regulators

Seven automated regulators were included in the model of the Westerly collection system. The District supplied information about each automated regulator for modeling, including PID coefficients and digital data of their operation. Some flow monitoring data was also collected in the vicinity of the automated regulators. Construction drawings were used to ensure that correct chamber sizes and weir elevations were incorporated into the model.

The District's automated regulators are typically comprised of a gate controlling flow to the WWTP and a Fabridam controlling the overflow. The gates were controlled by Real Time Control (RTC) rules developed for this project, but based on the desired gate operation. The Fabridams were modeled as variable crest weirs and also controlled with RTC rules. The automated regulators included in the model were:

- Lake Ave. and Viking Ave. (NW1);
- Lake Ave. and Desmond Ave. (NW2);
- Edgewater Park (NW3);
- West 117th Street and Edgewater Drive (NW4);
- West 58th Street and Cass (NW5);
- Rocky River Drive and Lorain Avenue (NW6); and
- West 65th Street and Breakwater Dr. (NW7).

Table 4-5 summarizes the real time control rules for CSOTF and each automated regulator. In general, these facilities are controlled using Proportional Integral Differential (PID) logic algorithms that (1) vary gate positions and (2) inflate / deflate bladder-type dams based on flow depths within the interceptor and trunk sewers. Two coefficients govern the PID algorithms: a proportional coefficient and a differential coefficient. The proportional coefficient directly governs the total range in the movement of a gate. For example, a larger proportional coefficient suggests that the gate will have a larger reciprocating range. The differential coefficient governs how much change in gate position can occur within each sensing interval.

Real Time Control Parameters												
Auto Regulator ID	Type	Control in Model	Speed of Gate Movement (in/s)		Measurement Location	Control Method	Measurement Interval (seconds)	Proportional Coefficient	Differential Coefficient	Level to Maintain (ft)	Depth to Maintain (ft)	Comments
			positive direction	negative direction								
NW1	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	627.511	n/a	On overflow line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	3.501	On DWF line
NW2	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	628.633	n/a	On overflow line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	3.501	On DWF line
NW3	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	599.577	n/a	On DWF line to mobilize storage
	Gate	Variable height gate	0.20	0.20	upstream of gate	PID	60	0.01	1.36	595.790	n/a	On overflow line
NW4	Fabridam	Variable crest weir	0.20	0.20	downstream of fabridam	PID	60	-0.01	1.36	n/a	10.499	On DWF line to mobilize storage
NW5	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	630.671	n/a	On overflow line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	1.499	On DWF line
NW6	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	748.836	n/a	On overflow line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	1.001	On DWF line
NW7	Fabridam	Variable crest weir	0.20	0.20	in regulator chamber	PID	60	-0.01	1.36	623.439	n/a	On overflow line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	2.599	On DWF line
	Gate	Variable height gate	0.20	0.20	downstream of gate	PID	60	-0.01	1.36	n/a	4.000	On DWF line
CSOTF	Gate	Variable height gate	0.20	0.20	in CSOTF tanks	PID	60	-0.01	1.36	583.929	n/a	Main gate into CSOTF tanks from channel
	Gate	Variable height gate	0.20	0.20	in main channel	PID	60	0.01	1.36	584.330	n/a	Overflow gate from main channel
	Pump	Pump (fixed capacity)	n/a	n/a	at headworks (2m downstream)	PUMP	Continuous	n/a	n/a	n/a	n/a	Pumps to activate when flow in Headworks falls below 49 MGD. Pump discharge 14MGD

Table 4-5: Real-Time Control Parameters

Combined Sewer Overflow Treatment Facility (CSOTF)

The CSOTF, a storage and treatment facility for excess wet weather flow, was included in the Westerly collection system model and controlled by RTC rules. Two automated gates control the flows into the storage tanks and flows through the main channel to the Lake. In addition, when flow to the WWTP drops below 49 mgd, the stored sewage is pumped back to the WWTP for treatment before release to Lake Erie. The base flow allowed through the WWTP was limited to 50 mgd based on information supplied. This initial flow rate was increased to 100 mgd under baseline conditions.

Over-Under Sewers (Invert Plates)

The Westerly collection system service area is partially served by separate sanitary sewers. In the separate sanitary area, the storm and sanitary sewers were constructed in a "common trench" with a shared manhole for access at some locations. At manholes shared between the storm and sanitary sewer an invert plate provides access to the sanitary sewer for maintenance (vacuuming or jetting). Figures 4-27 and 4-28 show the invert plates and the configuration of the storm and sanitary sewers at shared manholes.

During the SSES portion of the Phase II study, field crews inspected each manhole in the separate sanitary area to determine the location, size, and condition of the invert plates. A total of 264 invert plate manholes were found in the Westerly District collection system. Their conditions were as follows:

- 55 plates missing
- 46 plates damaged
- 23 plates seated improperly
- 140 plates intact

Since both the storm and sanitary sewers were modeled, the invert plates were represented as an orifice from the sanitary sewer to the storm sewer. The orifice discharge coefficient and opening size were correlated to the condition of the invert plate.

During a rainfall event, flow travels in the storm sewer until an invert plate is encountered. If the invert plate is damaged or dislodged, the flow from the storm sewer enters the sanitary sewers. At some point, the sanitary sewer usually becomes surcharged and flow then travels from the sanitary sewer into the storm sewer through the invert plate openings.

The operational characteristics of the invert plates were fully represented by the orifices used in the model. Specifically, both directions of flow were simulated (from the storm sewer into the sanitary sewer –inflow- and from the sanitary sewer into the storm –

surcharge and contamination). However, the model does not handle the following

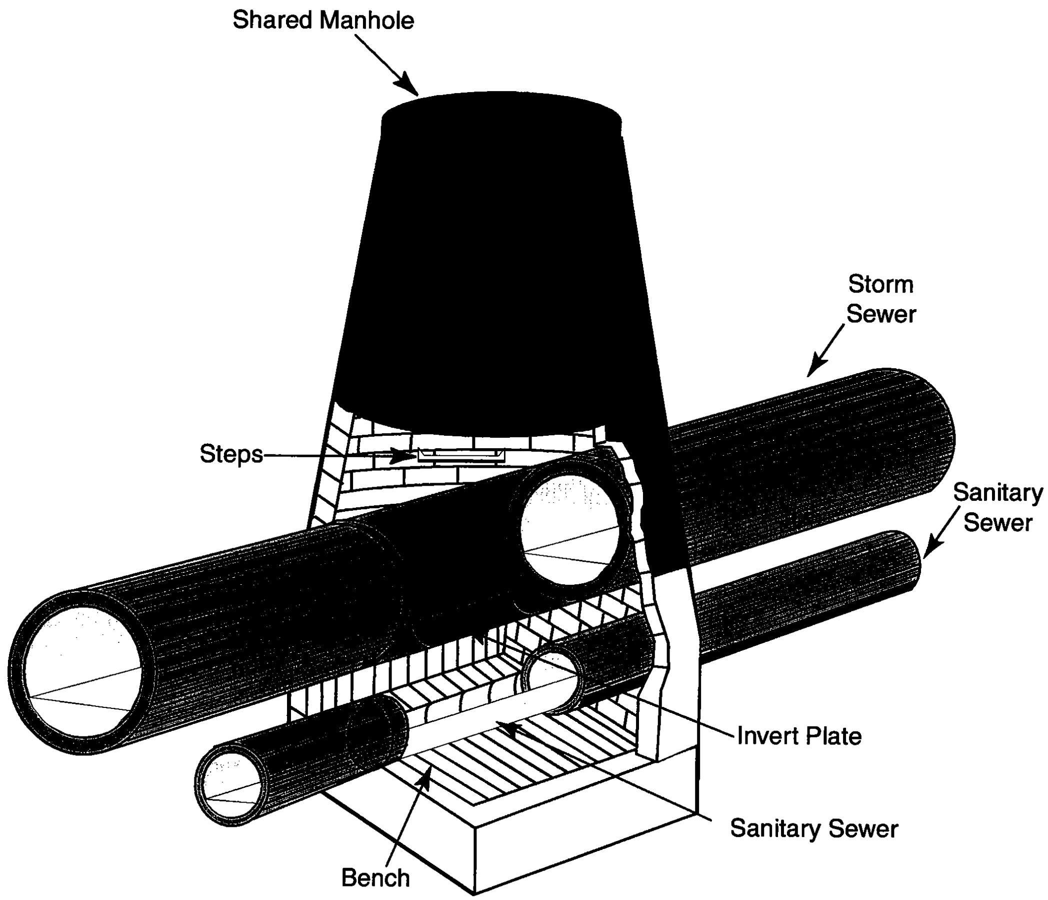
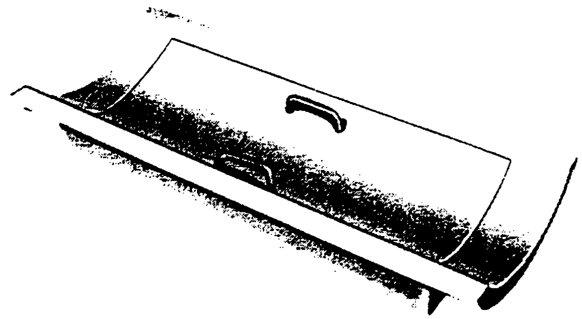


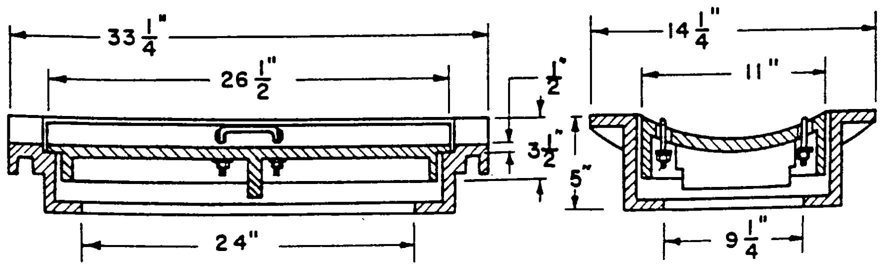
FIGURE 4-27

DIAGRAM OF OVER/UNDER SEWER

Figure 4-28. Detail of Invert Plate in Over/Under Sewers



Orthogonal Rendering



Cross-sectional Diagrams

scenario: where sufficient velocity is attained, the flows in the storm sewer could "jump" an invert plate opening. Although, in theory, the invert plate may act as a leaping weir, the only areas affected would be the uppermost portion of the over-under system during the beginning of a storm. Once a storm begins, most of the sanitary sewers in the over-under area become surcharged from inflows through upstream invert plates and "spill" flow back into the storm sewers. This scenario is considered to be a minor model limitation; therefore, this model arrangement was considered satisfactory for simulating invert plates.

5.0 COLLECTION SYSTEM MODEL VERIFICATION

5.1 Verification Events

The model of the Westerly District collection system was verified using two dry weather and three wet weather flow events. The event details are shown in Tables 5-1 and 5-2.

Table 5-1. Dry Weather Flow Verification Events

Date	Duration (hours)	Day
April 26, 1997	24 hours	Saturday (Weekend)
June 11, 1997	24 hours	Wednesday (Weekday)

The flow monitoring data was examined to find days where the flows were at the base flow rate without rainfall derived infiltration/inflow. The above dry weather flow days were chosen because no rainfall occurred during the two previous days and the flows were approximately equal to the expected base flow.

Table 5-2. Wet Weather Flow Verification Events

Date	Duration Ranges (hrs:min)	Rainfall Depths (inches)							Antecedent Depth (inches)	Peak Intensity (in/hr)
		RG 1	RG 2	RG 3	RG 4	RG 5	RG 6	RG 7		
April 12	13:50 - 15:20	0.96	0.96	0.96	1.12	1.12	1.2	1.1	0.0	0.36 – 0.60
May 31	35:00 - 35:55	2.12	2.36	2.68	2.22	2.90	2.71	2.71	0.2	0.48 – 0.96
June 2	4:30 - 5:55	0.89	1.16	0.78	0.84	1.29	1.06	1.06	1.4	0.48 – 1.32

From the 44 rainfall events (see Table 3-1) recorded during the flow monitoring period, only 17 storms had recorded depths greater than 0.2 inches with all rainfall gauges operational. Of these 17 storms, only 7 events had recorded rainfall depths greater than 0.5 inches. However, for one of the seven storms, many of the flow monitors had been removed; therefore, only 6 of the 44 storms were chosen as potential verification wet weather events. Of the 6 events, the three largest volume storms averaged among the 7 rain gauges were chosen as the verification storms.

5.2 Dry Weather Flow

For the two dry weather events, the model predicted flows were compared with the observed flows to determine:

- Modeling anomalies;
- Flow data discrepancies; and
- Manhole or pipe data errors.

The initial modeling results compared well with the observed flow data. Where the model results did not compare well with the observed dry weather flow monitoring data, the connectivity of the model network was re-evaluated. Once connectivity discrepancies were resolved, the distribution of population was re-examined and redistributed as appropriate based on building locations and other information. After the population distribution was investigated, areas deficient in flow were investigated for large sources of trade flow (large sewer users). Several additional industrial flows were added to the model to improve the verification. These flows are listed in Table 4-2. If population distribution or larger trade flow sources did not explain the discrepancies between observed and modeled flows, infiltration flows were allocated throughout the collection system to account for the additional base flow. About 10.8 mgd of infiltration was added throughout the collection system to make up the base flow. Appendices B and C present the hydrographs comparing observed and simulated dry weather flows.

The model was considered calibrated for dry weather flow.

5.3 Wet Weather

After the model was calibrated for dry weather flows, the verification rainfall events were modeled and the results compared with the flow monitoring data. Typically, flows were compared unless the monitoring data was questionable; then, the depths were compared. The objective of the comparison was to ensure that the model adequately represents the runoff response from rainfall events.

The verification process involved identifying discrepancies between observed and simulated flows, investigating the discrepancies, and correcting model parameters. Typical problems evaluated during verification included:

- Under- or over-predicting runoff volumes;
- Inaccurate representation of pump station operation;
- Over-predicting flooding
- Over-predicting surcharging

- Spatial rainfall
- Hydrograph runoff decay
- Under estimating in-system storage

Before investigating discrepancies, the flow monitoring data was evaluated for reasonableness. Some factors that were considered in evaluating the flow monitoring data included:

- whether depth and velocity sensors were operational (with reference to flow, depth, velocity, and scatter graphs);
- whether the sensors recorded similar responses for similar storms;
- if either sensor was blocked by debris;
- if site hydraulic conditions were likely to produce valid data; and,
- if other flow monitors in the vicinity confirm the data (mass balance).

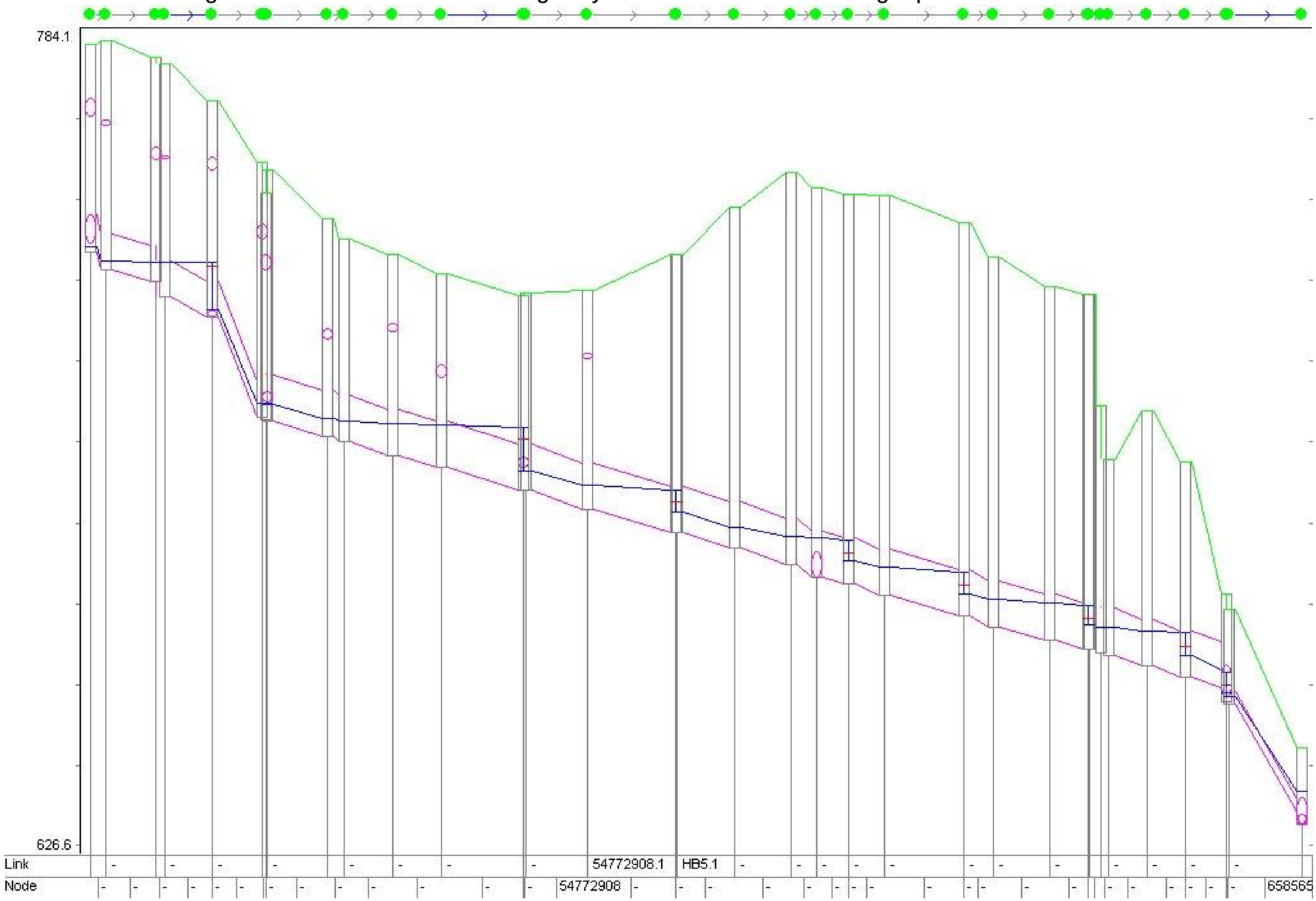
If the velocity data was questionable, but the depth data seemed reasonable, the model was verified with depth data. In the absence of good or reasonable data, the model was not verified with flow monitoring data in that location.

Along with an evaluation of the flow monitoring data, wet weather connectivity (stormwater outlets) and sewer maintenance data were used to evaluate the comparison of simulated and observed flows. For instance, if blockages were suspected, flow monitor inspection logs and sewer maintenance logs were consulted to confirm a blockage existed. Since blockages are temporary they are generally not modeled unless the model could not be verified for other wet weather event simulations. This circumstance did not occur during the Westerly project. All instances where flow monitoring data may have suggested a blockage during a particular storm were verified during other wet weather events.

If evaluation of the flow monitoring data, connectivity, and operational logs, did not resolve the verification, the contributing drainage area percentage impervious allocations were inspected for gross errors (mistakes). Where reasonable, adjustments were made to percent impervious allocations in areas of poor model verification. However, unrealistic changes were not considered or implemented.

Verification proceeds from the upstream areas to the downstream areas. Since the majority of the pump stations, HydroBrakes, and automated regulators were located "downstream" in the system, the operation of these controls was investigated towards the end of verification. To start verification, these structures were simulated as their operational plans indicated. However, as verification proceeded, some minor changes to the original operational rules were made to improve the comparison of modeled and observed flows. For instance, one CSO was known to have a blockage of consolidated sediment. For verification, sediment was added into the model to simulate this blockage. Typically, the hydraulics around the control structures produced unfavorable conditions for recording good flow monitoring data. Therefore, the verification of these structures focused on simulating their operational plan behavior, not necessarily mimicking the flow monitoring data. As an example, Figure 5-1 presents the sewer

Figure 5-1. Sewer Profile Through Hydrobrakes Demonstrating Operational Behavior



profile through the HydroBrakes, illustrating their operational behavior of creating storage in the Northwest and Westerly Interceptors.

Model verification is evaluated by comparing the observed and predicted flows during dry and wet weather flow conditions. For the events during the monitoring period, the predicted flows compared to the observed flows should meet the following criteria:

1) peak flow rate is within +30% and -20%;
2) volume of flow is within +30% and -20%;
3) general shape of both hydrographs is similar; and
4) the above criteria should be met for 2 of 3 storms, unless circumstances at the monitoring locations a) cannot be modeled and are determined to be unimportant, b) are not detrimental to the model, or c) are due to infiltration and can be accounted for in subsequent use of the model.

These criteria are similar to that presented in WaPUG's[1] *Code of Practice for the Hydraulic Modeling of Sewer Systems, November 1993*. Currently, USEPA's *Combined Sewer Overflows: Guidance for Monitoring and Modeling*, dated December 1996, is issued in draft form and provides only vague non-numerical criteria for calibration assessment.

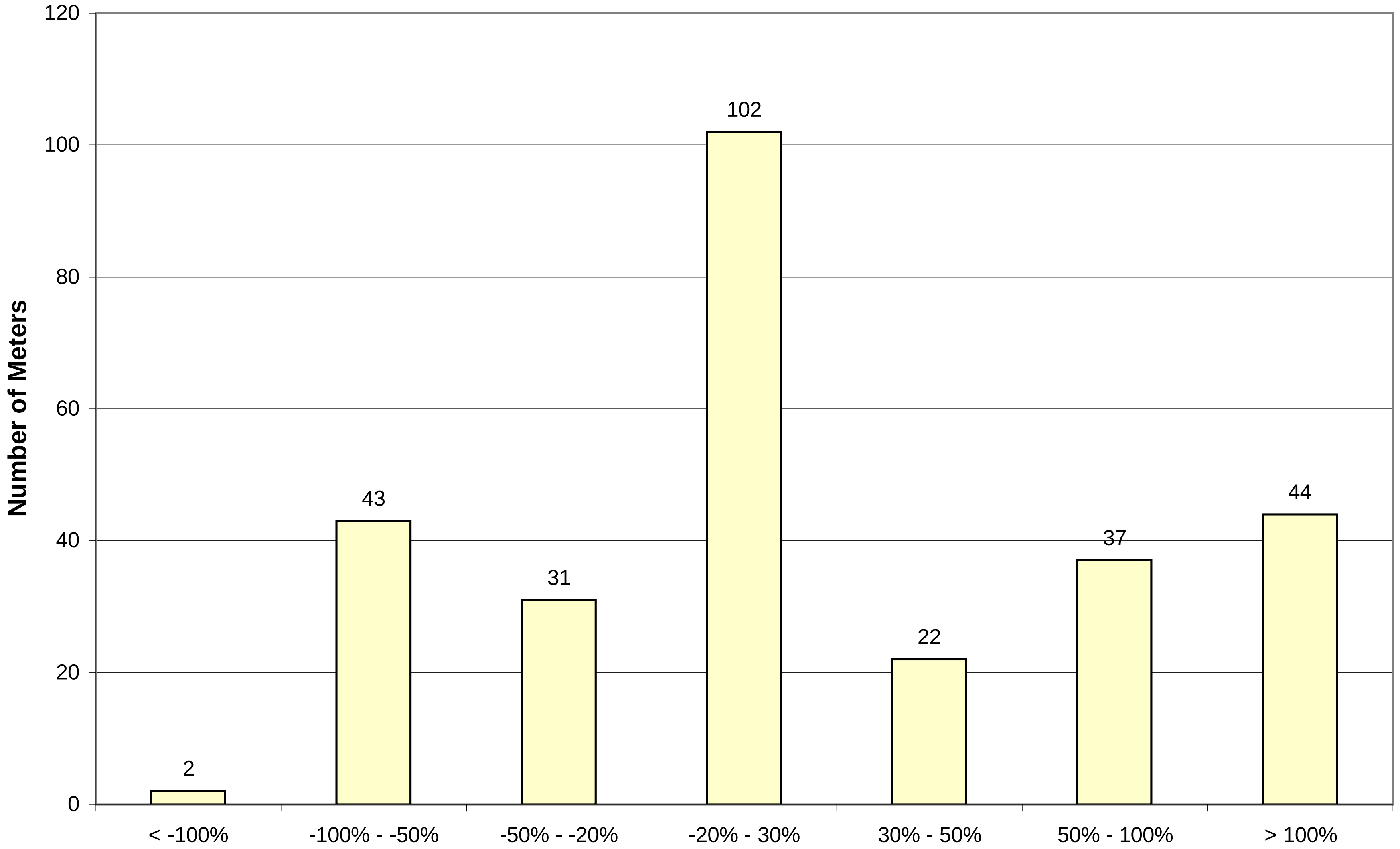
Of the 106 flow monitors, 97 were located in the collection system and used for flow verification. The comparison plots of the model-predicted peak flows, peak depths and volumes relative to corresponding observed values, for the wet weather events of April 12, 1997, May 31, 1997 and June 2, 1997, are located in Appendices D, E, and F, respectively. Appendix G summarizes the verification status of the model for each flow monitor for each wet weather event. Further, it provides an overall model verification conclusion for each flow monitor.

Appendix H further details the information presented in Appendix G by presenting (1) the percent differences between model-predicted peak flows and volumes relative to corresponding observed values and (2) the differences in predicted peak flow depths versus observed flow depths. There are 95 meters that provided flow data in the collection system during the April 12 and May 31 storm events. For the June 2 storm, 91 meters successfully provided flow data. This provides a total of 281 meter-events for evaluation. Figure 5-2 presents of a summary of the percent differences between predicted peak flows and corresponding observed values for the three calibration storms. With respect to peak flow percent differences, most of the values are in the –

[1] WaPUG stands for Wallingford Procedure Users Group, an organization of model users in the United Kingdom. The group meets regularly to discuss modeling, including flow monitoring, model building and testing, calibration and verification, and documentation.

20% to +30% range, and thereby achieve the desired accuracy. The larger differences

Figure 5-2. Peak Flow Comparison - All 3 Events



that exist, however, are typically associated with meter installations on smaller pipes that drain relatively small catchments where flows are highly variable, inconsistent and ultimately difficult to calibrate models. These catchments contribute little to the overall wet weather response in the collection system. Furthermore, other general collection system issues made calibration activities more challenging at some meter installations for some wet weather events. These include:

- Poor flow data (ragging, turbulence, flows too low to be recorded by probes, etc.);
- Operation and maintenance problems, such as blockages;
- Simplified representation of system in peripheral sewer-sheds;
- Over-prediction of flooding and spills in peripheral areas;
- Unknown connections between sewer branches or storm and sanitary sewers;
- Complex interaction between sewers in over / under sewer systems; and
- Complex nature of hydrological processes (non-linear rainfall-runoff relationship).

As a result of these issues, segments of the model are not well verified against some flow meters during some wet weather events. This can be expected in a sewer system as hydraulically complicated as the Westerly District Collection System. Structures with such complex hydraulics during storm flows, such as the automated regulators and invert plates mingling storm and sanitary flows, present difficult site conditions for the collection of valuable flow data. The collected data has been examined in detail and every effort has been made to use this information when possible. In addition to the three verification storms, other collected data was consulted to develop understanding of site characteristics and hydraulic behaviors.

Overall, the model was considered reasonably verified in its prediction of wet weather flows in the system along with the operation of the control structures, particularly the HydroBrakes, automated regulators, and CSOTF. In addition, the extremely complex flow regimes in the separate sewer area with its abundance of invert plates have been calibrated. The District now has a powerful tool with which to evaluate the Westerly Collection System.

5.4 Verification Results

The model was reasonably verified with 2 dry weather and 3 wet weather events. The wet weather events used for verification were the largest storms that occurred during the flow monitoring period. Many of the discrepancies between the model results and the observed data were explained through the investigation of the site hydraulics. In some cases, monitors were installed at locations where the site hydraulics precluded the collection of good data. In addition, some blockages occurred in the system that prevented the collection of good data. The model was not altered to reflect these blockages if they were documented and explainable.

Appendix A

Land Use Codes

Land Use Type	Description
1	Separate area; residential
2	Combined area; residential
3	Combined area; residential
4	Industrial (weekday operation only)
5	Industrial (weekday and weekend operations)

Residential Land Use Codes

Residential Land Use Type	Description
01A	Single family, approx lot size 30 ft x 150 ft
01B	Single family, approx lot size 30 ft x 100 ft
01C	Multi-family, approx lot size 50 ft x 150 ft
02A	Multi-family, approx lot size 30 ft x 200 ft
02B	Multi-family, approx lot size 40 ft x 75 ft
Industrial	Industrial
Multi-Unit Apartment	Multi-Unit Apartment