Modeling for Combined Sewer Overflow (CSO) Control in the Murray Basin

DRAFT for DISCUSSION

August 3, 2010

I. Introduction

This memo was prepared by the Murray Basin CSO Beach Project Team for the Murray Community Advisory Group (CAG). The Murray Basin CSO Beach Project (IBIS 423608) is a King County Wastewater Treatment Division capital project whose scope is to design and implement the measures necessary to reduce CSOs at the Murray Pump Station to no more than one event per year in accordance with state and federal requirements. The Murray CAG is a citizen group formed to represent the diverse interests of the community and to advise King County on the best CSO solutions in the Murray basin.

The purpose of this document is to describe why and how hydrologic and hydraulic modeling was used to evaluate and predict frequency of combined sewer overflows (CSOs) in the Murray basin, and to size CSO control approaches to meet CSO control objectives for the basin. This memo is intended to do the following:

1. Provide an overview of the Murray basin for purposes of understanding how storm flows impact the wastewater system. (Pages 2-5)
2. Describe building, calibrating, and running the hydrologic and hydraulic models. (Pages 6-16)
3. Describe how a calibrated model is used to predict flow response over a long-term rainfall average and why there are differences between reported overflows and model output. (Pages 16-19)
4. Describe the steps required to determine the control requirements for the Murray basin and how hydrologic and hydraulic modeling was used to calculate the required storage volume for CSO control in the Murray basin. (Pages 19-20)

Modeling for CSO Control

A model is a formal set of relationships that attempts to represent processes of the real world and to estimate or project the results of those processes. Hydrologic and hydraulic models are created by using mathematical equations to describe how water moves across the land and through different kinds of pipes and equipment over varying topographies. Models enable us to predict how a system will react under possible future conditions that we may not have measured, and they allow us to do control scenarios and predict how effective these control scenarios might be. A model is a simulation of a system. It is only as good as the information that goes into it.

Description of the Murray Basin

The Murray basin is located in West Seattle, north and east of Lincoln Park. The basin has 1,071 pervious and impervious acres. Of these 1,071 acres, one hundred and eleven (111) are sources of stormwater that are likely connected to the combined sewer system based on GIS data[1]. One hundred (100) acres, or 90%, of the sources of stormwater in the combined sewer are located on private property.

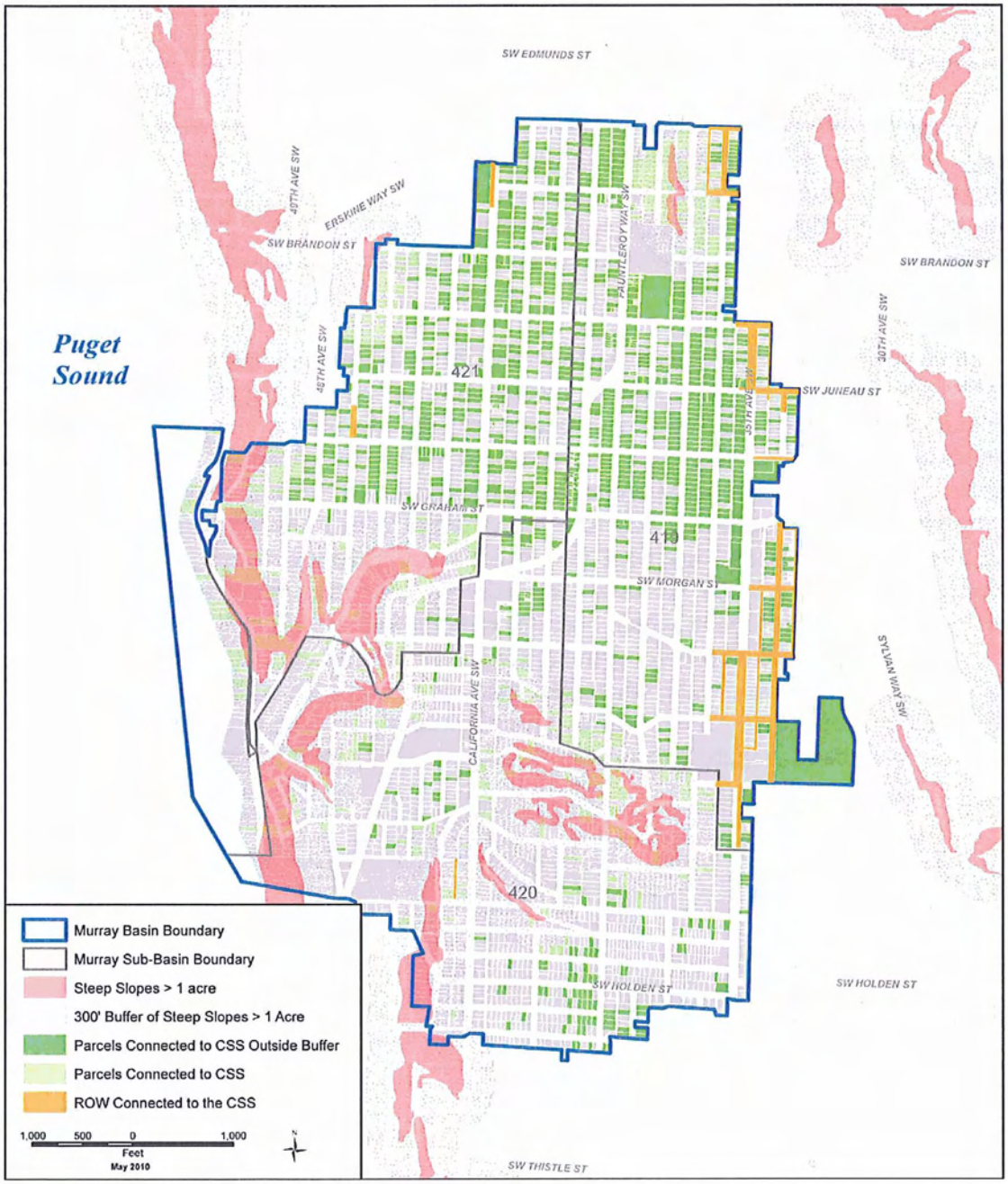
The combined sewer system in the Murray basin converges at the bottom of the basin at the Murray Avenue Pump Station in Lowman Beach Park. The Murray pump station also receives flow from the upstream Barton Street Pump Station, located south of Lincoln Park.

Table 1. Estimated Number of Acres of Impervious Surfaces in the Murray Basin Connected to the Combined Sewer System

Impervious Surfaces	Acres
Residential roof areas	48
Residential impervious	16
Non-residential roof areas	16
Non-residential impervious	20
Streets	11
Total	111

[1] The areas were estimated by analyzing the city of Seattle's GIS data , which closely matched the impervious area estimated in the hydrologic/hydraulic analysis.

Figure 1: Murray Basin Map



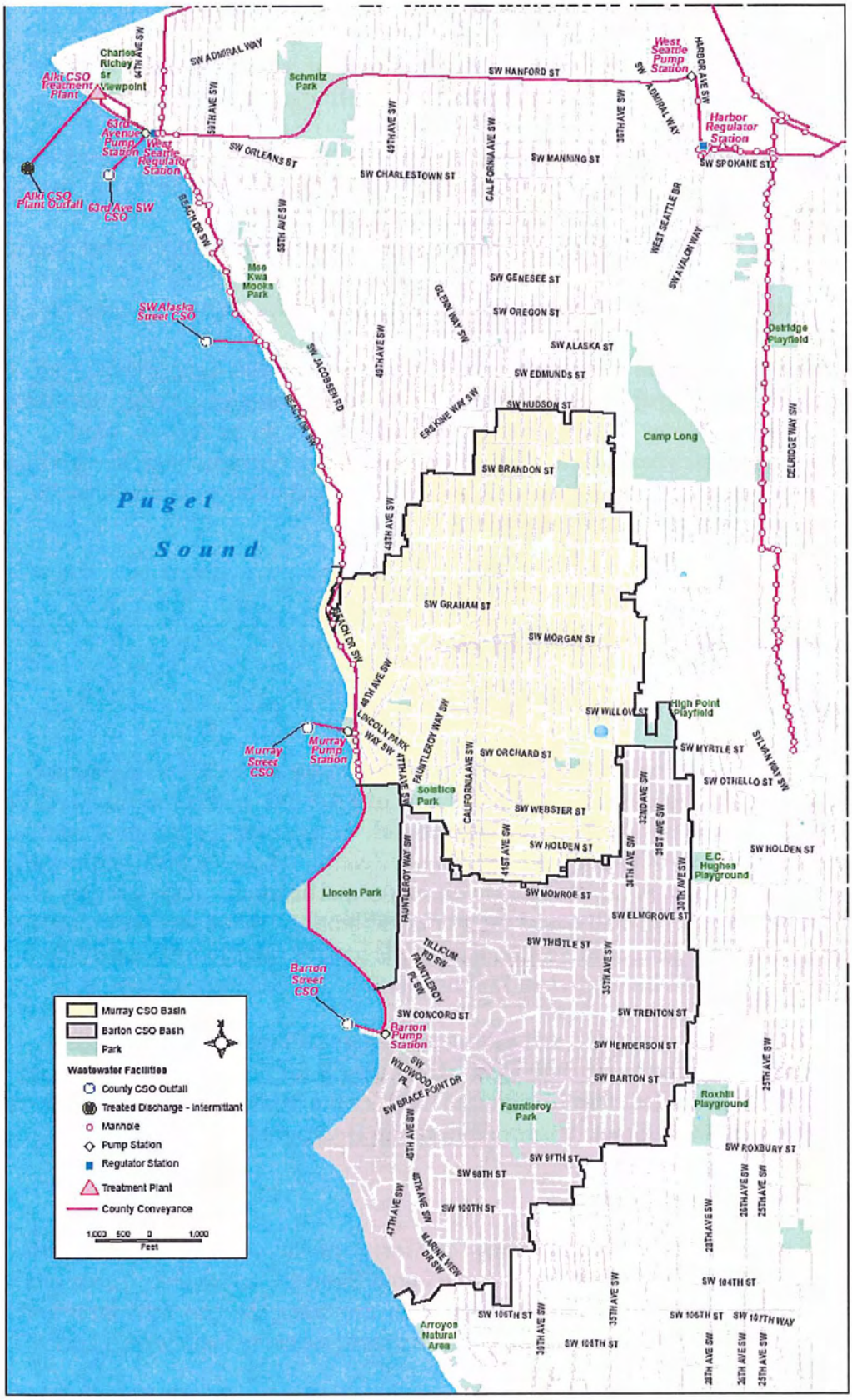
How are Murray Sewage and Stormwater Flow Conveyed?

During dry weather, wastewater from residences and commercial, industrial, and institutional buildings in West Seattle is collected and conveyed in City of Seattle-owned pipes to King County's regional system. The regional system is designed and maintained to convey the flow to the West Point Treatment Plant where it receives secondary treatment prior to discharge in Puget Sound.

When it rains, stormwater is added to this equation and is conveyed in two ways: (1) through the combined sewer pipes; or (2) through a separate storm sewer system that collects rainfall from streets and buildings. The Murray Basin has a partially separated system, i.e., in most of the basin, storm sewers collect rainfall runoff from the street. In approximately 10 percent of the basin, the rainfall runoff enters the combined sewer.

Combined sewer pipes converge at the lowest point in the Murray basin at the county's Murray Avenue Pump Station, located in Lowman Beach Park. Under normal conditions, the collected flow is pumped by the Murray Avenue Pump station north along Beach Drive where it is conveyed at 63rd Avenue to the West Seattle Tunnel. Flows in the tunnel are pumped to an interceptor line and conveyed through downtown Seattle via the Elliott Bay Interceptor to the West Point Treatment Plant for secondary treatment and discharge into Puget Sound. During storms, if flow exceeds the tunnel's capacity, the flow can be diverted at 63rd Avenue to the Alki Wet Weather Treatment Plant, which operates only during periods of heavy rainfall. At the Alki plant, the flow receives primary treatment prior to discharge off Alki Beach. In extreme storm events, when flow exceeds the capacity of the Murray pump station, an overflow occurs at the Murray pump station through an outfall off Lowman Beach Park. Figure 2 shows conveyance of flows in, through, and out of the Murray Basin.

Figure 2: Murray Conveyance System



II. How Are Control Requirements Determined?

Determining the amount of flow that must be stored or reduced in order to control CSOs to no more than one event per year involves four steps:

1. Measuring existing flows using Barton & Murray pump station flow meters.
2. Performing hydraulic/hydrologic analysis and calibrating the data to measured flows.
3. Using the analysis to predict flow response over a long-term rainfall record (30 years).
4. Calculating storage/conveyance capacity needed for regulatory compliance.

King County WTD uses a computer modeling program called *Runoff/Transport.* It incorporates both a hydrologic and hydraulic model and uses geographic information (GIS) about the Murray drainage basin provided by the City of Seattle. This information includes basin area, slope, impervious area, pervious area, basin width, pipe lengths and sizes, soil parameters, and land use and other parameters which affect sewage flow and stormwater runoff.

Step 1:

Measurement of Existing Flows

Rain Gauges

Rainfall gauges located near the Murray basin were used to collect rainfall/storm information (time, volume, duration). Usually one to three years of rainfall and flow data were used to calibrate the hydrologic model. Within the city limits of Seattle, rainfall records were obtained from the City of Seattle. These records were compared with data collected at WTD facilities to check for malfunctions of the gauges. The closest rain gauge is normally used for model calibration. Since there are more city gauges than county gauges in Seattle, the Seattle gauges usually were used for calibration of the combined system for purposes of the CSO Beach Projects.

City of Seattle rain gauges # 5 and #14 were used to calibrate the Murray basin, which lies between the two rain gauges. See Figure 3 for the locations of the rain gauges. The rainfall data from the gauges used for the Murray basin model is located in a supplemental document, Murray Calibration Hydrographs (attached CD #1).

Flow Meters

The flow meter data used in calibrating the Murray model was from two magnetic flow meters located in the Murray Avenue Pump Station force mains. These meters were installed in early 2007 and are regarded as providing the best flow information available. Magnetic flow meters are generally more accurate than "open channel" meters placed in gravity sewer pipelines.

Six additional meters were placed in the Murray basin between December 2007 and June 2008, to assess flow coming from each sub-area of the Murray basin. This information was used to evaluate how much flow could be captured if storage were located upstream in the basin. It provided information on how much flow could be removed if sewer separation were done in an upstream sub-area.

Figure 4 shows the location of the flow meters in the Murray basin.

The data from the pump station flow meters that was used to calibrate the model is located in the supplemental document, Murray Calibration Hydrographs included here in CD #1. The data from the flow meters in the Murray basin is located in a supplemental document, Murray Basin Flow Meter Data included with this document in CD #2.

Figure 3: West Seattle Rain Gauges

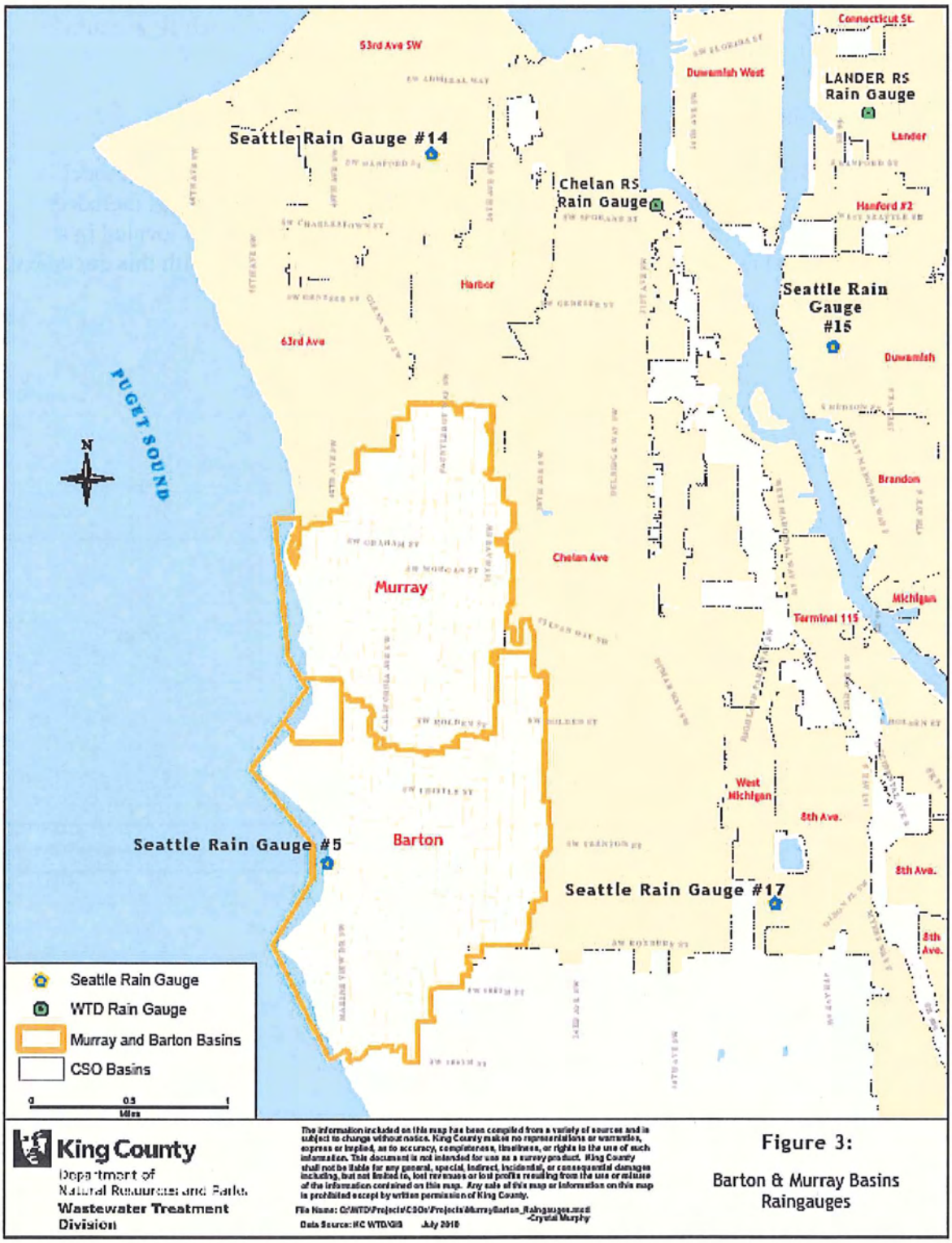


Figure 4: Murray Basin Flow Meters

Meter_ID	MH_Ref	START	END
M_1	068-148	12/02/07	06/12/08
M_1FD	068-156	02/09/08	06/12/08
M_2	068-149	12/02/07	06/12/08
M_2FD	068-245	02/08/08	06/12/08
M_3	068-259	12/02/07	06/12/08
M_4	068-145	12/02/07	06/12/08
M_7	061-301	12/02/07	06/12/08
M_9	068-261	12/02/07	06/12/08

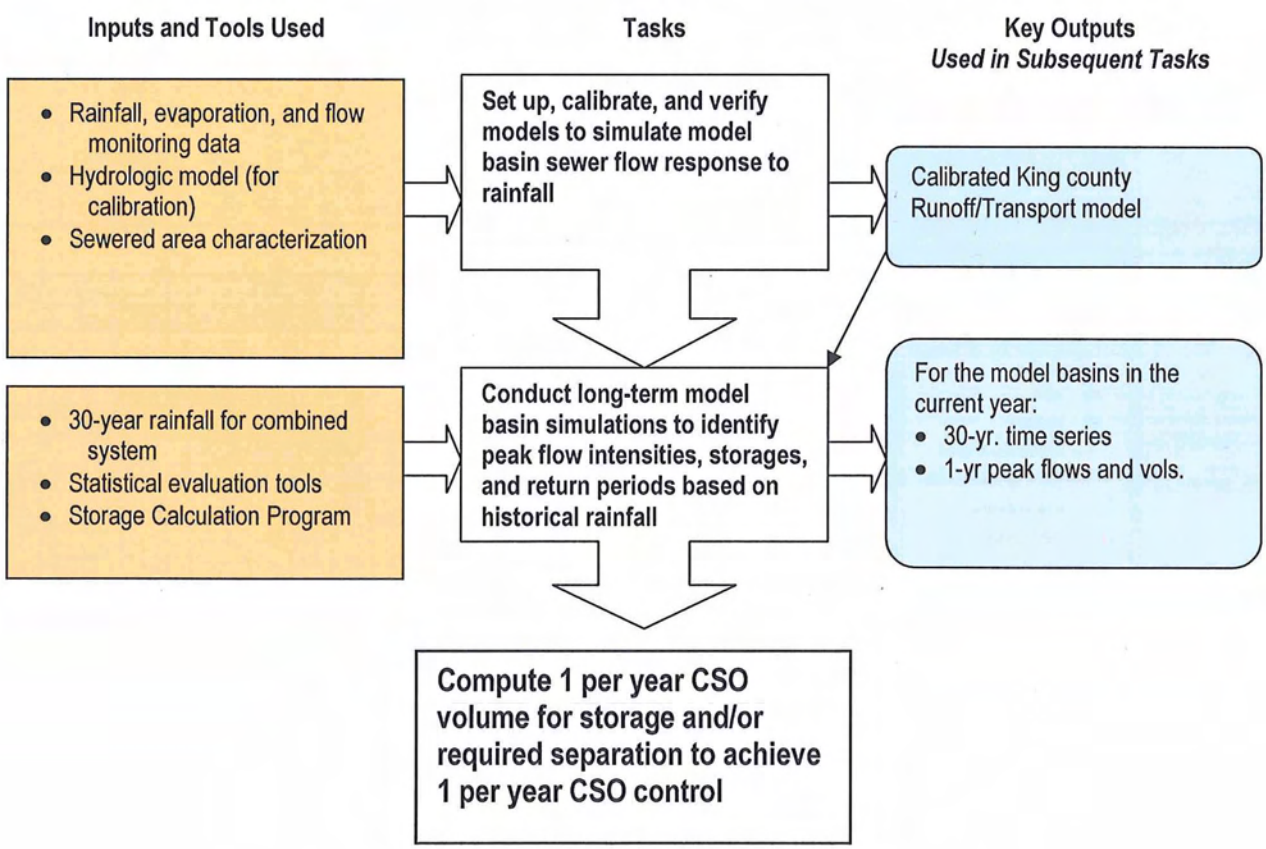
Step 2:

Hydraulic/hydrologic analysis and model calibration

Once the basin parameters (basin area, slope, impervious area, pervious area, basin width, pipe lengths and sizes, soil parameters, land use, etc.) are entered into the computer model, hydraulic/hydrologic analysis is performed using existing historical rainfall and flow data. The model creates an output that is composed of a hydrograph, which is a record of varying flow over a period of time. The model output is compared to measured flow data.

Model parameters are adjusted (calibrated) until there is a good match between the model output and the measured flow. This is an iterative process of adjusting the set of model parameters that optimize statistical measures of fit between observed data and modeled data. It is important to match what is going on in the field in order to gain confidence that the long-term (30-year) model response will adequately simulate what will happen in the field. The procedure for selecting parameter values to calibrate each flow component is complex. It requires a detailed understanding of the relationship between parameter values defined in the Runoff/Transport model and the resulting simulated flow response.

Figure 5. The Model Calibration Process



Dry Weather Calibration

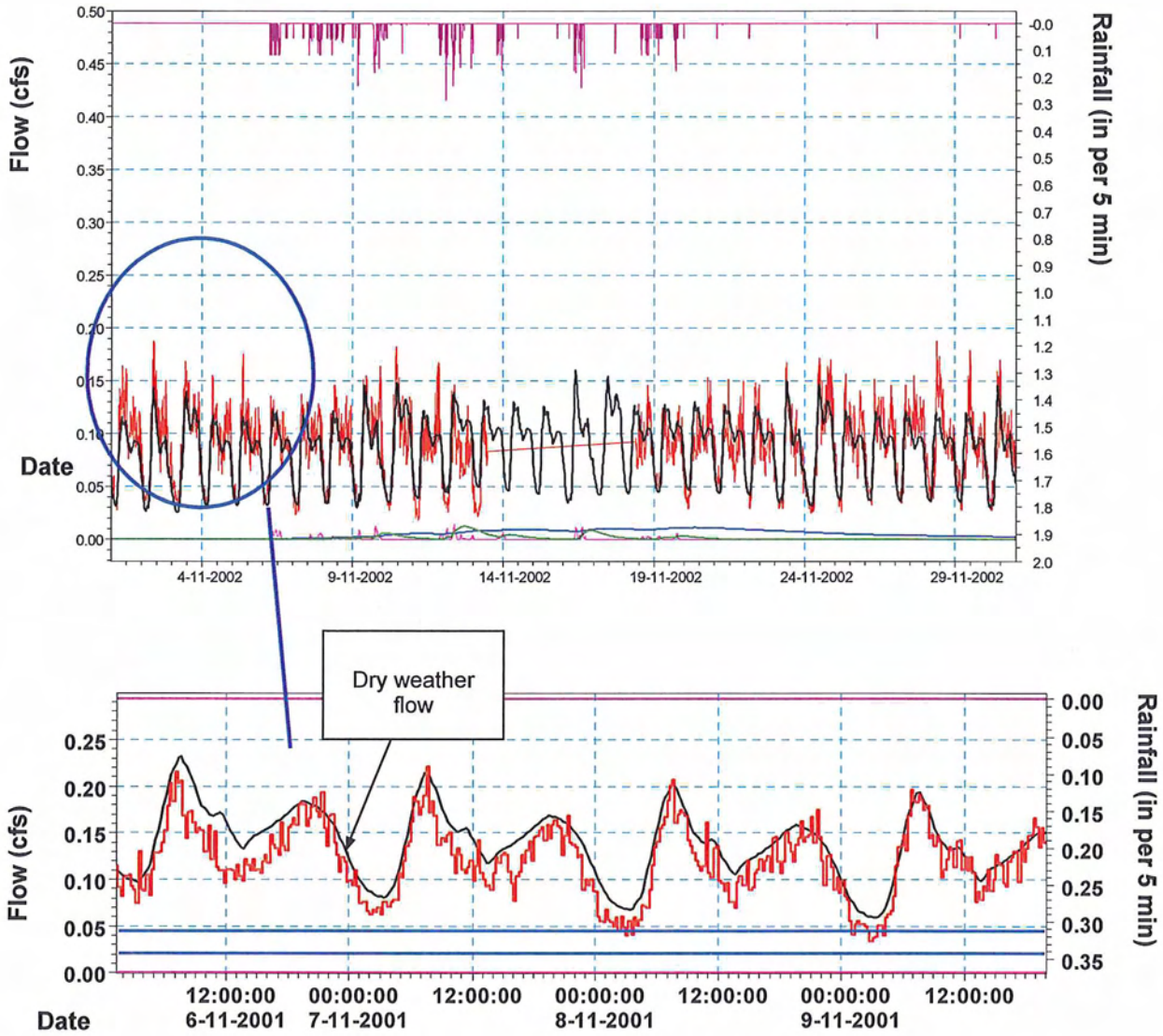
The first step in the calibration process for each model basin is to match simulated flows with flows measured during dry weather. The dry weather flows measured during an extended dry period of the monitoring period (preferably in the summer) are used to define and calibrate dry weather flow input into the model. Dry weather flow is composed of raw sewage and base infiltration[2].

Dry weather calibration is a key step in the overall calibration process to determine what portion of the measured flows are due to a rainfall response and what portion is a result of water use patterns from day to day.

Dry weather diurnal patterns are established for the weekdays. Diurnal means that there are two peak wastewater flow periods during a typical dry day. See below for a graph depicting 30 days of this pattern (look at the black line). The first peak occurs when large numbers of people rise in the morning, use the bathroom, shower, fix breakfast, etc. and then head for work. This is high peak period for water usage. The second peak occurs when people return home, fix dinner, etc. Each day has this diurnal pattern, with weekdays a bit different than weekends. To calibrate the Murray basin to existing conditions, the amount of dry weather flow is derived from the available measured flow data.

[2] **Infiltration.** Groundwater that seeps into sewers through holes, breaks, joint failures, defective connections, and other openings

Figure 6. Diurnal Flows for Dry Weather Calibration



Wet Weather Calibration

Runoff/Transport wet weather inflow and infiltration (I/I)[3] components can be grouped into three distinct responses: fast response, rapid infiltration, and slow infiltration. Table 2 presents each of the three response types and what components in the Runoff/Transport model are used to characterize that particular response. The model can be calibrated using an automated optimizing program or done by "trial and error". The automated process is preferred, as it usually reduces the time to arrive at a good calibration.

Table 2. Types of Flow Response to Rainfall

Response Type	Flow Characteristics in Response to Rainfall	Suspected Sources
Fast response	Sudden increase in flow. Highly correlated with rainfall intensity.	**Inflow:** catch basins, roof drains, or other direct connections; **Infiltration:** sources that respond rapidly to rainfall, such as shallow side sewers.
Rapid infiltration	Increase in flow during a rainfall event, with gradual reduction in flow over a relatively short period after the event.	**Infiltration:** shallow sources such as laterals, side sewers, foundation drains; and manholes and mains to a lesser extent.
Slow infiltration	Slow increases in flow during a storm; increased flow may take several days or weeks after a storm to decline.	**Infiltration:** deep sources such as manholes and mains; reflects a rising groundwater level.

Actual historical rainfall data is run through the model to compare the output hydrographs with the observed flow data hydrograph. The model is then calibrated (adjusted) until both the hydrographs match.

Figure 7 is an example of a simulated storm hydrograph and the components of the model: dry weather flow, base infiltration, measured rainfall, and wet weather conditions.

Figure 8 is an example comparing measured flow to modeled data and includes the various components of the model.

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[3]**Inflow** Stormwater that rapidly flows into sewers via roof and foundation drains, catch basins, downspouts, manhole covers, and other sources.

Infiltration Groundwater that seeps into sewers through holes, breaks, joint failures, defective connections, and other openings.

Figure 7. Simulated Flow Components

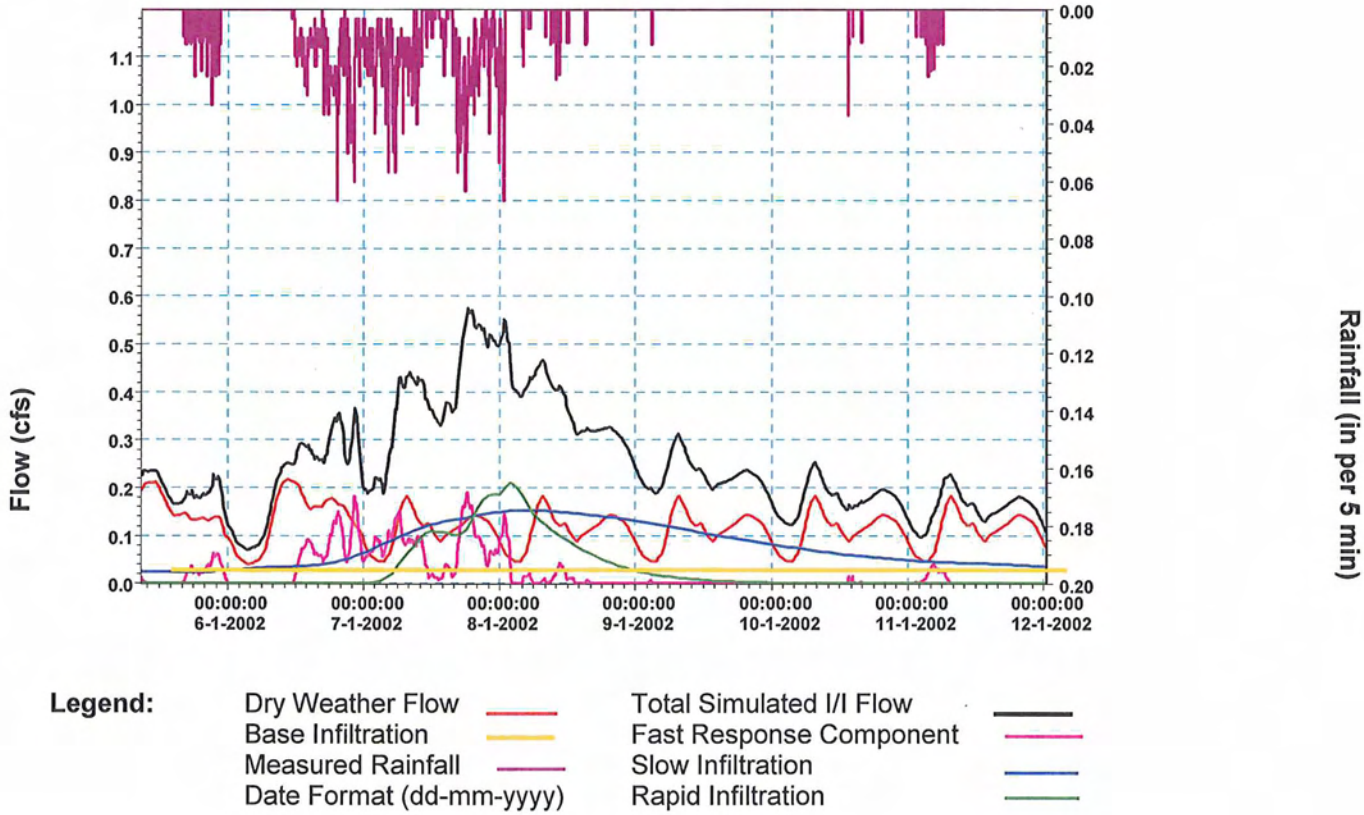
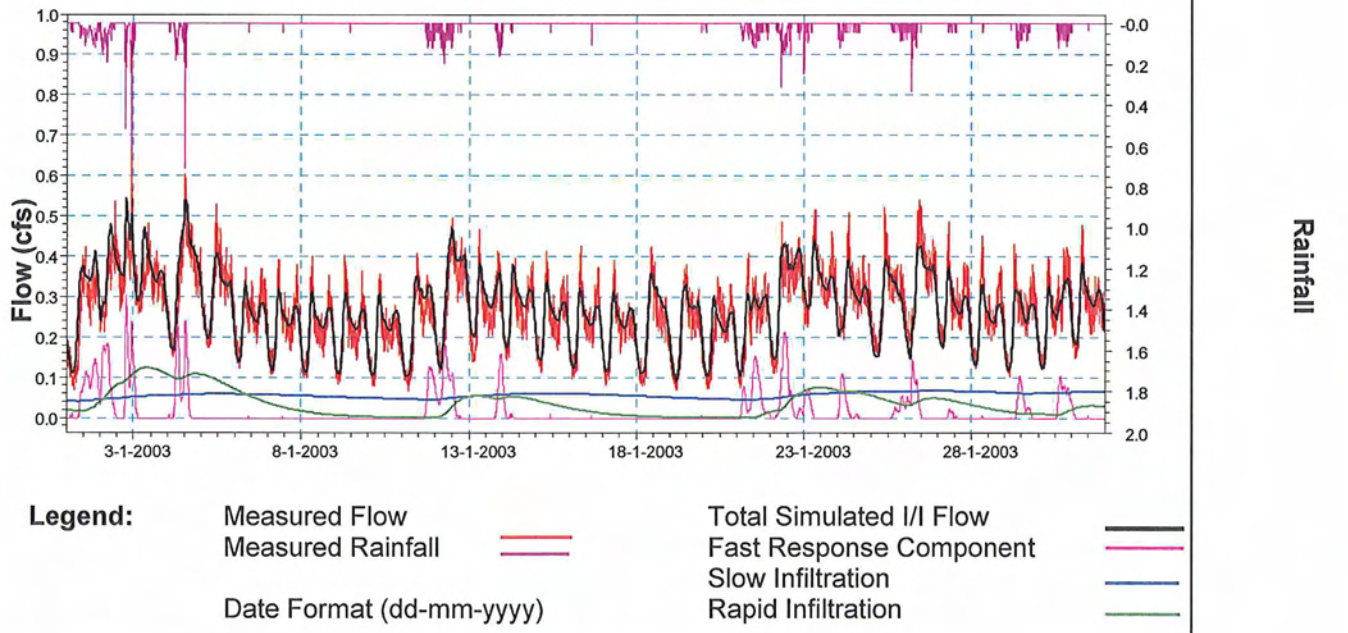


Figure 8. Comparison of Modeled Flow Data to Measured Flow Data



The following Figure 9 (shown in two parts) presents the calibration results for the Murray Avenue Pump Station basin. The numbers below the horizontal axis of the graphs correspond to the eight storms listed in Table 3 that were used to calibrate the model.

Figure 9. Murray Avenue Pump Station Calibration Results
Part "a" is storm #1 and part "b" is storms 2-8

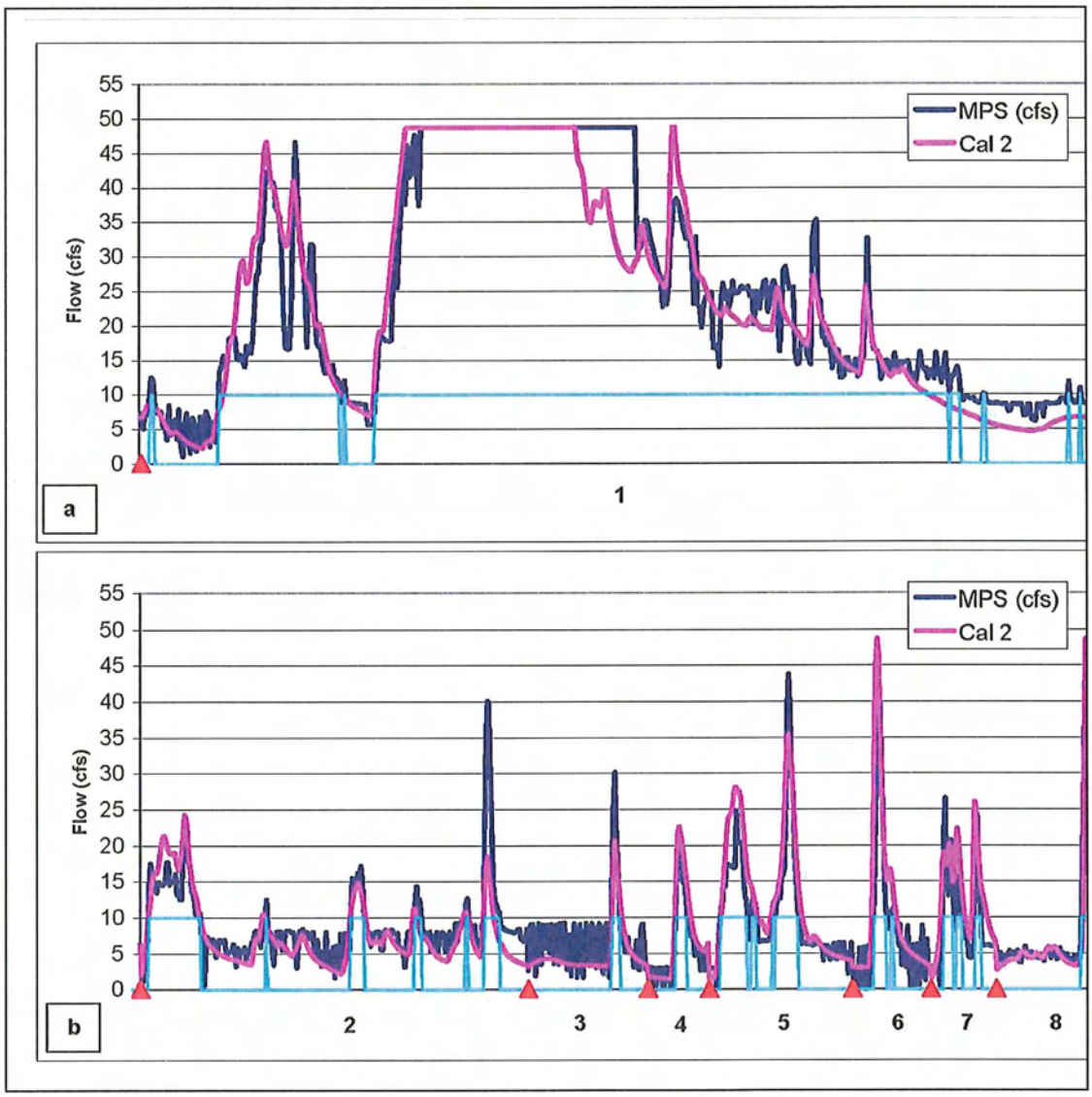


Table 3. Date Ranges For The Eight Events Used For Calibrating The Murray Basin.

Event Date	Peak Flow (mgd)	Event Number
12/2 -12/5/07	> 25	1
1/2/08	11	2
1/19/08	11	3
3/15/08	7	4

3/23/08	23	5
4/8/08	21	6
4/28/08	11	7
6/6/08	> 31	8

The calibrated model is now ready to perform simulations to help determine how much volume needs to be controlled--either by storage or by removing the flows from the conveyance system (demand management).

Step 3:

Prediction of Flow Response Over a Long-Term Rainfall Record (30-Years)

A 30-year extended precipitation and evaporation time series (ETS) is input to the calibrated hydrologic model. The 30-year simulation produces a time series of flows at the basin outlet. This 30-year flow time series can be used to predict flow frequency, which includes estimating the 1-year peak inflow/infiltration (I/I) flow from the Murray basin. The procedure for estimating the 1-year peak I/I flow can be summarized as follows:

1. Develop and calibrate a basin model using rainfall and flow data measured in the basin.
2. Simulate flow response with the calibrated model using the 30-year extended time series (ETS) of precipitation and evaporation as input.
3. Extract and rank the simulated peak overflow volumes.
4. Use the peak overflow volume with the 1-year recurrence period[4] (e.g., the 30th highest volume in 30 years).

What follows is an example of the events that exceed the capacity that will need to be stored. An "event" is defined by comparing flows with rainfall records, as a period preceded by, and followed by, at least 24-hours without rain. Event volume is calculated by summing the area between the hydrograph flow value and the conveyance capacity over the duration of the event.

[4] **Return or recurrence interval** The average number of years between which one would expect a CSO event volume of this size that would occur.

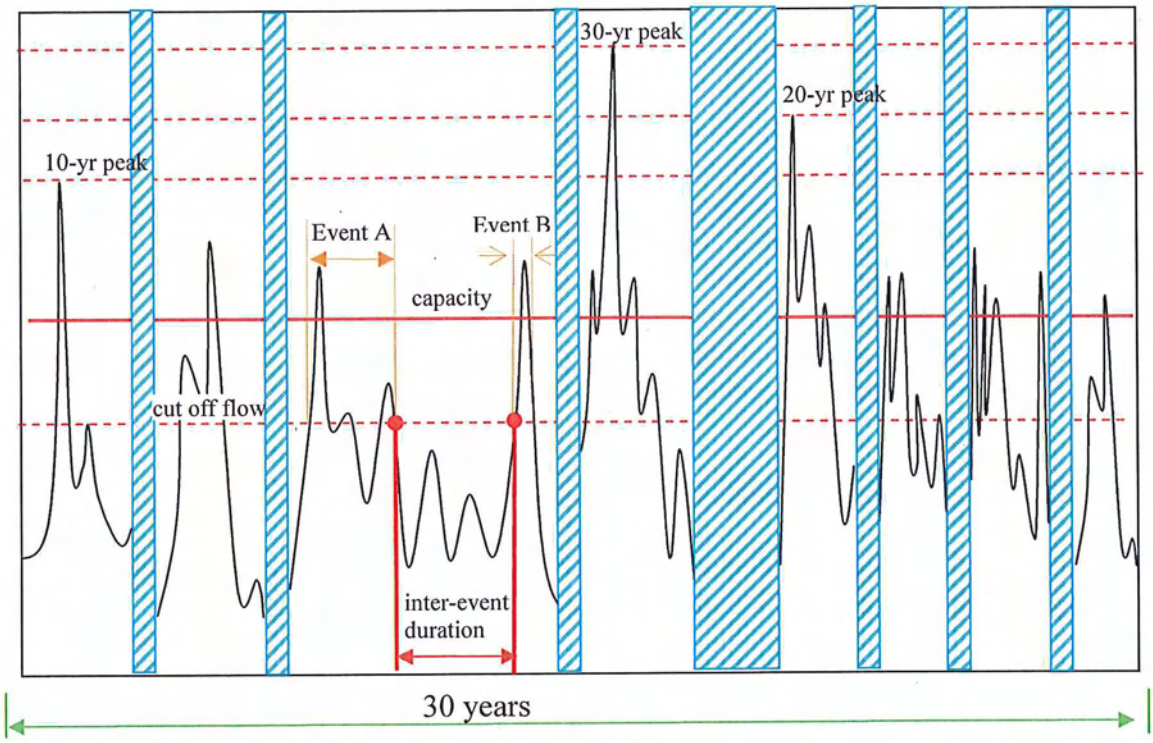


Figure 10. Schematic of a long-term hydrograph

Table 4, excerpted from Attachment A, contains the simulated overflow events during the 30-year simulated period (1978 – 2008). The 30-year simulation was run with the system configuration expected in the future, namely, that the Barton Street Pump Station would be upgraded to 33 mgd and that the Murray Avenue Pump Station will pump 31.5 mgd whenever inflows are equal to, or exceed, that flow rate.

Subset of Table 4. Murray CSO Simulated Overflow Events (flow > 31.5 mgd)

Start Time	End Time	Overflow Volume (MG)	Simulation Year	# Events > 1 MG
6/12/1978 15:40	06/12/1978 16:00	0.059		
7/16/1978 6:00	07/16/1978 8:00	0.386		
9/22/1978 16:50	09/22/1978 19:50	1.776		
10/23/1978 20:50	10/23/1978 21:20	0.140	1978	2
11/3/1978 20:50	11/03/1978 22:50	1.079		
12/4/1978 9:40	12/04/1978 9:50	0.011		

The first column contains the date and time that the overflows begin. The second column contains the end of the overflow event. CSO events are aggregated whenever there is less than 24 hours between the end of one event and the beginning of another. Therefore, there may not be overflows occurring during the entire period between the

time in column 1 and column 2. There may be one or more periods of less than 24 hours in length when there are no overflows.

The third column contains the simulated overflow volume for that event. The fourth column contains the simulation year, and fifth column contains the sum of all overflow events in that year with a volume greater than 1 million gallons. One million gallons is the estimated 1-year overflow volume. This calculation is explained in more detail in Step 4: Calculation of Required Storage/Conveyance Capacity. Model simulation results indicate that a storage tank of one million gallons would result in 29 overflows during the 30-year simulation, thus meeting the regulatory requirement that no more than one event shall occur per year.

Differences between model output and reported CSO events

There will be variations between the model output overflow volumes in Table 4 and the reported CSO events for a variety of reasons:

- **Pump Station Capacity Assumptions.** The actual pumping capacities at the Barton and Murray pump stations during reported events were different than pumping capacities assumed in the 30-year model run. The Murray Avenue Pump Station peaked at about 31 mgd during many of the actual storms, but pumped at only about 24 mgd for most of the overflow events. Pump wear bearings and nose rings have recently been replaced and it is expected that the pump station will maintain 31.5 mgd in the future. The Barton Street Pump Station has a rated capacity of 26 mgd and will be upgraded to 33 mgd after construction of a project that begins in 2012. The model was run assuming these future conditions, not past conditions.

- **Assumptions about the Rain Gauges.** Assumptions are made in the modeling that may not have actually occurred during any given storm event. For instance, the rainfall used in the model is from the nearest rain gauges – City of Seattle Rain Gauges #5 and #14. The model assumes that the rainfall measured at this rain gauge is falling over the entire basin at the same time the rain gauge is recording it. In actuality, these gauges are not in the Murray basin and the rainfall that occurred at these gauges is only an approximation of the rainfall that fell over the Murray Avenue Pump Station basin. The variation in rainfall will contribute to discrepancies between the model and the actual overflow.

- **Power Outages**. The model assumes that all equipment is working properly. Power outages, mechanical difficulties, maintenance activities and pump impeller wear can all affect the performance of a pump station, which will contribute to discrepancies with the modeled results.

- **Wet well measurements.** CSO volumes at the Murray Avenue Pump Station are computed by taking the wet well level and computing flow over a long

weir. Any error in the wet well measurement will result in error in the calculated overflow volume. For very large storms and for high tides, the outfall pipe may restrict the outgoing flow. This restriction has not been factored into the overflow calculation. Therefore, large overflow events likely have been overestimated and therefore, differ significantly from a model result.

- **The model is not an <u>exact</u> representation of the real system**. The model is a prediction. It does not exactly match the response of the real system. There will be discrepancies between the modeled and actual values, even if the above factors are eliminated. During the calibration process, some storms are overestimated and some are underestimated, while trying to match the largest number of storm events as closely as possible. The 30-year simulation of the calibrated model is expected to differ from the real world, but overall, it should provide a reasonable estimate of the range of flows expected to occur in the basin over the long term.

5. In summary, discrepancies between modeled overflow volumes and reported overflows are due to differing[5] assumptions about future conditions, differing rainfall over the basin than that indicated by the rain gauges, operational difficulties in historical events, inaccuracies in level sensors and overflow calculations, and in inaccuracies in the model. However, the 30-year simulation of the calibrated model provides the best engineering estimate of flow volumes to be expected, and is, therefore, used for sizing CSO storage facilities.

Step 4:

Calculation of Required Storage/Conveyance Capacity

The size of a storage facility required to meet overflow goals depends not only on the estimated peak flow volumes, but also on the capacity of the downstream conveyance system and on the shape, length, and timing of the storm event hydrographs. Therefore, an estimate of the peak flow alone is not sufficient for sizing a storage facility.

Once the 30-year simulated hydrograph is produced by the model, the volumes of events can be calculated. Event volume is calculated by summing the area above the conveyance capacity line for the duration of the event (see Figure 10).

The long-term (30-year) hydrograph is run so that all flows significantly above the diurnal peak daily flow during non-event periods are evaluated for potential storage requirements. Any flow with return interval less than 1-year that is above the conveyance capacity (pump station and force main, for instance) must be stored during the event and released when the event is over. The size of storage is

[5] Discrepancies for 2006 & 2007 are described in Attachment B.

dependent on conveyance capacity, i.e., if the Murray Pump Station capacity were actually 26 mgd as opposed to 31.5 mgd, then more of the event hydrograph would have to be stored because less of the flow could be transferred downstream.

Hydrograph volumes above the downstream capacity are computed by the model and ranked by volume. The same simulated overflow events in Attachment A, Side 1, are ranked by order of size and presented in Table 5. Shown below is a subset of Table 5 and includes the first thirty-three simulated CSO events as ranked by overflow size with corresponding return intervals.

The result of the analysis is the derivation of storage-capacity calculations that are used to properly size storage facilities to satisfy the 1-year return period CSO storage requirement.

Table 5: (Subset of Attachment A, Side 2)

Ranked simulated overflow events

Rank (largest to smallest volume)	Overflow Volume w/o Storage (MG)	Return Interval (yr)
1	14.07	30.0
2	9.03	15.0
3	7.08	10.0
4	5.19	7.50
5	4.98	6.00
6	4.74	5.00
7	4.25	4.29
8	3.14	3.75
9	2.86	3.33
10	2.82	3.00
11	2.69	2.73
12	2.51	2.50
13	2.20	2.31
14	2.18	2.14
15	1.99	2.00
16	1.78	1.88

Rank (largest to smallest volume)	Overflow Volume w/o Storage (MG)	Return Interval (yr)
17	1.59	1.76
18	1.56	1.67
19	1.53	1.58
20	1.41	1.50
21	1.33	1.43
22	1.26	1.36
23	1.23	1.30
24	1.20	1.25
25	1.20	1.20
26	1.09	1.15
27	1.08	1.11
28	1.05	1.07
29	1.00	1.03
30	0.99	1.00
31	0.98	0.968
32	0.97	0.938
33	0.94	0.909

The 30th largest event is shown as 0.99 million gallons and is estimated to re-occur (return interval) once per year. Therefore, to meet the regulatory requirement of no more that one overflow per year, the amount of storage required would be 0.99 million gallons.

This storage capacity calculation applies to this location and the specified downstream capacity only. If another downstream capacity was an option, then a new storage capacity calculation would be required for that option.

III. Post Construction Monitoring

After construction is complete, monitoring will be performed to prove that water quality standards are met in the waterway as a result of the project.

Murray is currently monitored for overflow events and volume using Supervisory Control and Data Acquisition System (SCADA – a real-time computer monitoring and control system), pump station wet well level information (measured using an instrument called a bubbler), and a portable flow meter at an inlet pipe overflow line. When the wet well level exceeds the depth to overflow, the system registers that an overflow event has occurred, and the wet well level data is used in a weir equation to calculate the volume of the overflow. Overflows may also occur from the influent line going into the pump station. This overflow is measured directly with a portable flow meter. The portable monitor data is downloaded at regular intervals and entered into the data management system. Measurement of flow in the inlet overflow line signals that an event has occurred of the reported volume. Murray overflows at the outfall are reported as the sum of the wet well and inlet overflow line measurements.

Prior to the coming 2010-11 wet season, the county will install a portable flow meter directly in the Murray outfall pipe downstream of both sources of overflow in an attempt to directly measure all of the overflow from Murray at a single point. The new meter will provide an independent measurement of the total overflow and will verify the measurement from the current locations, at the manhole and wet well.

After completion of the Murray CSO project, the county will continue to measure overflow frequency and volume. Compliance with Ecology's standard of one untreated event per site per year is based upon the frequency of events. Compliance is based on the moving average of 20 years of frequency data. Newly controlled sites like Murray will model the projected performance of the facility under the previous 20 years of rainfall for the compliance measurement. As time passes and monitored data is collected, it will replace modeled data in the moving average.

Supplemental Documents

Provided to the Murray Citizen Advisory Committee on two CDs:

CD 1:

1. Rainfall Data for Murray Basin Modeling - City of Seattle rain gauges # 5 and #14 to calibrate the Murray basin.

2. Flow Meter Data for the Murray Basin Modeling-- The data from the flow meters and the Murray Avenue pump station that was used to calibrate the model.

CD 2:

3. Murray Basin Flow Meter Data -- Meters in the Murray basin were used to assess how much flow was coming from various parts of the Murray basin. They were not used for sizing the 1-year storage volume at the pump station.

Attachment A

SIDE 1

July 21, 2010

Murray CSO Long-term Model Simulation Results
Murray CAG

Assumptions:

Barton PS Capacity	33 (mgd)
Murray PS Pump Capacity	31.5 (mgd)

Simulated Overflow Events (flow > 31.5 mgd)

Start Time	End Time	Overflow Volume (MG)	Year	# Events > 1 MG
6/12/1978 15:40	06/12/1978 16:00	0.059	1978	2
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12/4/1978 9:40	12/04/1978 9:50	0.011		
2/11/1979 18:50	02/11/1979 19:00	0.053	1979	2
4/12/1979 16:20	04/12/1979 16:50	0.235		
9/2/1979 14:30	09/02/1979 15:30	0.909		
10/26/1979 23:40	10/27/1979 15:40	0.257		
12/13/1979 12:40	12/13/1979 12:50	0.042		
12/14/1979 20:50	12/14/1979 23:50	1.586		
12/17/1979 11:40	12/17/1979 18:00	1.234		
1/12/1980 2:20	01/12/1980 3:00	0.183	1980	0
3/11/1980 2:30	03/11/1980 2:40	0.012		
4/14/1980 14:40	04/14/1980 14:50	0.074		
4/19/1980 18:40	04/19/1980 18:40	0.004		
7/11/1980 15:50	07/11/1980 16:30	0.333		
11/5/1980 19:20	11/05/1980 19:50	0.207		
11/6/1980 23:30	11/07/1980 16:10	0.134		
11/8/1980 19:50	11/08/1980 19:50	0.004		
11/19/1980 2:00	11/19/1980 2:10	0.048		
11/21/1980 10:00	11/21/1980 12:20	0.978		
12/26/1980 1:20	12/26/1980 1:30	0.039		
2/19/1981 3:00	02/19/1981 3:30	0.531	1981	1
9/27/1981 14:10	09/27/1981 14:40	0.249		
9/29/1981 3:10	09/29/1981 3:10	0.011		
10/1/1981 19:30	10/01/1981 20:10	0.328		
10/5/1981 22:30	10/06/1981 16:50	4.982		
12/2/1981 4:20	12/02/1981 4:30	0.024		
12/5/1981 5:00	12/05/1981 11:50	0.225		
12/15/1981 11:40	12/15/1981 12:10	0.035		
1/30/1982 18:00	01/30/1982 18:10	0.020	1982	1
2/17/1982 3:20	02/17/1982 4:10	0.314		
10/28/1982 17:00	10/28/1982 18:00	0.108		
11/17/1982 5:50	11/17/1982 7:10	0.541		
12/3/1982 8:10	12/03/1982 14:40	1.556		
1/4/1983 21:20	01/04/1983 21:20	0.001	1983	0
1/27/1983 9:10	01/27/1983 9:30	0.078		
2/17/1983 14:20	02/17/1983 14:30	0.072		
3/12/1983 13:50	03/12/1983 14:00	0.138		
8/11/1983 7:10	08/11/1983 7:50	0.256		
8/29/1983 20:50	08/29/1983 23:20	0.152		
9/10/1983 12:20	09/10/1983 13:00	0.158		
11/3/1983 0:50	11/03/1983 13:10	0.096		
1/2/1984 2:50	01/03/1984 2:20	0.440	1984	1
11/1/1984 13:20	11/02/1984 10:10	1.048		
6/7/1985 6:00	06/07/1985 6:20	0.054	1985	0
10/20/1985 3:30	10/20/1985 3:40	0.043		
10/22/1985 10:40	10/22/1985 11:40	0.256		
1/18/1986 8:20	01/18/1986 21:10	9.025	1986	2
10/25/1986 3:10	10/26/1986 15:50	2.196		
11/5/1986 20:30	11/05/1986 20:30	0.007		
11/23/1986 6:20	11/23/1986 7:00	0.069		
11/27/1986 3:40	11/27/1986 3:40	0.010		
1/28/1987 3:40	01/28/1987 4:20	0.297	1987	1
1/31/1987 23:00	02/01/1987 1:00	0.165		
3/3/1987 14:40	03/03/1987 16:20	1.001		
4/7/1987 21:50	04/07/1987 22:20	0.076		
4/30/1987 19:50	04/30/1987 19:50	0.000		
12/9/1987 15:40	12/09/1987 17:00	0.936		
1/14/1988 10:30	01/14/1988 12:40	0.536	1988	0
5/12/1988 19:50	05/12/1988 20:20	0.126		
5/28/1988 3:30	05/28/1988 3:40	0.093		
10/13/1988 18:30	10/13/1988 19:50	0.422		
11/5/1988 14:20	11/05/1988 15:10	0.071		
11/22/1988 9:00	11/22/1988 12:00	0.743		
8/14/1989 14:20	08/14/1989 14:30	0.117	1989	0
8/21/1989 17:30	08/21/1989 18:00	0.247		
12/2/1989 21:10	12/02/1989 21:50	0.168		
12/4/1989 3:10	12/04/1989 5:00	0.037		
1/5/1990 17:00	01/05/1990 17:20	0.066	1990	2
1/6/1990 23:20	01/07/1990 0:30	0.013		
1/9/1990 5:00	01/09/1990 9:30	2.858		
1/28/1990 12:40	01/28/1990 12:50	0.069		
10/31/1990 18:30	10/31/1990 19:00	0.109		
11/24/1990 6:40	11/24/1990 14:30	2.685		
2/19/1991 5:10	02/19/1991 5:30	0.044	1991	0
4/4/1991 17:40	04/04/1991 17:40	0.000		
7/24/1991 14:30	07/24/1991 14:30	0.004		
4/16/1992 23:00	04/16/1992 23:10	0.006	992	0
9/23/1992 12:50	09/23/1992 12:50	0.011		
12/8/1993 21:00	12/08/1993 22:50	1.201	1993	1
6/7/1994 16:40	06/07/1994 17:00	0.197	1994	0
9/3/1994 10:40	09/03/1994 11:00	0.099		
10/26/1994 13:40	10/26/1994 14:30	0.119		
11/23/1994 0:40	11/23/1994 1:20	0.557		

Simulated Overflow Events (flow > 31.5 mgd)

Start Time	End Time	Overflow Volume (MG)	Year	# Events > 1 MG
1/30/1995 8:20	01/30/1995 8:40	0.045	1995	1
3/9/1995 17:00	03/09/1995 17:30	0.594		
11/28/1995 17:20	11/28/1995 17:30	0.010		
12/12/1995 20:00	12/12/1995 21:00	1.993		
2/8/1996 6:00	02/08/1996 6:20	0.056	1996	2
4/23/1996 6:50	04/23/1996 18:20	0.835		
5/13/1996 1:10	05/13/1996 1:10	0.007		
6/17/1996 20:20	06/17/1996 20:20	0.011		
8/2/1996 16:30	08/02/1996 16:50	0.103		
10/17/1996 18:50	10/17/1996 19:00	0.016		
10/28/1996 16:20	10/28/1996 16:20	0.011		
11/27/1996 16:10	11/27/1996 23:10	1.257		
12/29/1996 9:30	12/29/1996 18:10	4.245		
1/1/1997 12:10	01/01/1997 14:10	1.094	1997	2
3/18/1997 18:30	03/18/1997 21:10	0.325		
4/19/1997 23:10	04/20/1997 0:20	0.047		
4/26/1997 23:10	04/27/1997 0:10	0.823		
5/31/1997 6:10	05/31/1997 10:20	1.204		
7/10/1997 18:20	07/10/1997 18:30	0.092		
10/29/1997 6:30	10/30/1997 5:30	0.146		
8/16/1998 16:10	08/16/1998 16:30	0.192	1998	0
9/25/1998 13:20	09/25/1998 13:40	0.140		
10/3/1998 17:10	10/03/1998 17:20	0.024		
11/20/1998 23:40	11/20/1998 23:50	0.175		
2/6/1999 17:10	02/06/1999 17:40	0.323	1999	1
3/3/1999 5:30	03/03/1999 6:10	0.385		
6/24/1999 2:30	06/24/1999 3:00	0.101		
7/16/1999 5:50	07/16/1999 6:00	0.052		
8/4/1999 7:40	08/04/1999 8:20	0.459		
8/8/1999 6:10	08/08/1999 9:50	4.739		
11/10/1999 15:30	11/10/1999 16:00	0.088		
11/12/1999 3:50	11/12/1999 3:50	0.006		
12/15/1999 11:00	12/15/1999 11:20	0.059		
1/16/2000 14:50	01/16/2000 18:10	2.816	2000	1
10/9/2000 8:30	10/09/2000 8:30	0.017		
12/14/2000 23:10	12/14/2000 23:40	0.344		
6/27/2001 11:20	06/27/2001 11:40	0.071	2001	3
7/15/2001 21:20	07/15/2001 23:30	0.310		
8/22/2001 16:20	08/22/2001 17:50	1.329		
11/13/2001 19:30	11/14/2001 18:30	0.466		
11/28/2001 6:40	11/29/2001 2:20	2.181		
12/13/2001 22:40	12/13/2001 23:10	0.358		
12/16/2001 0:10	12/17/2001 0:30	5.194		
2/21/2002 3:10	02/21/2002 3:10	0.003	2002	0
11/12/2002 21:20	11/12/2002 21:40	0.171		
12/14/2002 15:40	12/14/2002 15:50	0.046		
1/2/2003 18:00	01/02/2003 18:00	0.008	2003	2
1/23/2003 3:50	01/23/2003 4:00	0.038		
10/20/2003 3:20	10/20/2003 18:10	7.084		
11/18/2003 9:10	11/19/2003 6:30	2.513		
12/23/2003 7:20	12/23/2003 8:00	0.324		
1/30/2004 1:40	01/30/2004 2:00	0.139	2004	1
7/12/2004 14:10	07/12/2004 14:30	0.194		
8/22/2004 6:00	08/22/2004 9:10	1.408		
9/11/2004 0:20	09/11/2004 1:10	0.194		
12/10/2004 0:20	12/10/2004 0:50	0.048		
1/17/2005 9:00	01/17/2005 14:20	1.526	2005	1
1/18/2005 16:00	01/18/2005 17:00	0.212		
2/6/2005 13:20	02/06/2005 14:10	0.235		
3/27/2005 1:30	03/27/2005 2:20	0.211		
4/11/2005 20:10	04/11/2005 20:40	0.281		
4/16/2005 6:10	04/16/2005 6:20	0.049		
5/15/2005 7:50	05/15/2005 8:10	0.103		
5/31/2005 18:00	05/31/2005 18:50	0.838		
6/16/2005 23:40	06/16/2005 23:50	0.014		
8/29/2005 13:40	08/29/2005 14:10	0.451		
12/24/2005 2:00	12/24/2005 3:50	0.187		
1/10/2006 2:10	01/10/2006 2:20	0.042	2006	1
1/16/2006 22:50	01/16/2006 23:20	0.343		
1/30/2006 2:00	01/30/2006 2:30	0.021		
2/4/2006 0:30	02/04/2006 0:50	0.129		
11/2/2006 23:10	11/03/2006 0:00	0.167		
11/4/2006 15:50	11/04/2006 17:00	0.013		
11/6/2006 8:20	11/06/2006 10:40	0.972		
11/12/2006 21:30	11/13/2006 5:20	0.076		
12/14/2006 11:30	12/14/2006 18:00	3.135		
12/26/2006 21:30	12/26/2006 23:50	0.138		
1/7/2007 7:00	01/07/2007 7:40	0.268	2007	1
1/8/2007 11:40	01/08/2007 12:30	0.743		
5/21/2007 19:50	05/21/2007 20:30	0.992		
8/20/2007 6:50	08/20/2007 6:50	0.021		
8/26/2007 4:40	08/26/2007 5:00	0.072		
9/4/2007 8:00	09/04/2007 9:00	0.403		
11/16/2007 0:50	11/16/2007 0:50	0.002		
11/17/2007 12:40	11/17/2007 12:50	0.028		
12/2/2007 23:00	12/03/2007 21:50	14.070		
4/8/2008 18:20	04/08/2008 18:30	0.030	2008	0
6/6/2008 16:20	06/06/2008 17:30	0.941		

Total # overflows < 1 MG in 30 years = 29

July 8, 2010

Murray Basin Overflow Ranking
Murray CAG

SIDE 2

Rainfall Record

Start	End	Elapse (yr)
6/8/1978	6/8/2008	30.0

Rank (largest to smallest volume)	Overflow Volume w/o Storage (MG)	Return Interval (yr)
1	14.07	30.0
2	9.03	15.0
3	7.08	10.0
4	5.19	7.50
5	4.98	6.00
6	4.74	5.00
7	4.25	4.29
8	3.14	3.75
9	2.86	3.33
10	2.82	3.00
11	2.69	2.73
12	2.51	2.50
13	2.20	2.31
14	2.18	2.14
15	1.99	2.00
16	1.78	1.88
17	1.59	1.76
18	1.56	1.67
19	1.53	1.58
20	1.41	1.50
21	1.33	1.43
22	1.26	1.36
23	1.23	1.30
24	1.20	1.25
25	1.20	1.20
26	1.09	1.15
27	1.08	1.11
28	1.05	1.07
29	1.00	1.03
30	0.99	1.00
31	0.98	0.968
32	0.97	0.938
33	0.94	0.909
34	0.94	0.882
35	0.91	0.857
36	0.84	0.833
37	0.84	0.811
38	0.82	0.789
39	0.74	0.769
40	0.74	0.750
41	0.59	0.732
42	0.56	0.714
43	0.54	0.698
44	0.54	0.682
45	0.53	0.667
46	0.47	0.652
47	0.46	0.638
48	0.45	0.625
49	0.44	0.612
50	0.42	0.600
51	0.40	0.588
52	0.39	0.577
53	0.39	0.566
54	0.36	0.556
55	0.34	0.545
56	0.34	0.536
57	0.33	0.526
58	0.33	0.517
59	0.33	0.508
60	0.32	0.500
61	0.32	0.492
62	0.31	0.484
63	0.31	0.476
64	0.30	0.469
65	0.28	0.462
66	0.27	0.455
67	0.26	0.448
68	0.26	0.441
69	0.26	0.435
70	0.25	0.429
71	0.25	0.423
72	0.24	0.417
73	0.24	0.411
74	0.23	0.405
75	0.21	0.400
76	0.21	0.395
77	0.21	0.390
78	0.20	0.385
79	0.19	0.380
80	0.19	0.375
81	0.19	0.370
82	0.19	0.366
83	0.18	0.361
84	0.17	0.357
85	0.17	0.353
86	0.17	0.349
87	0.17	0.345
88	0.17	0.341

Storage + Overflow

Storage

Rank (largest to smallest volume)	Overflow Volume w/o Storage (MG)	Return Interval (yr)
89	0.16	0.337
90	0.15	0.333
91	0.15	0.330
92	0.14	0.326
93	0.14	0.323
94	0.14	0.319
95	0.14	0.316
96	0.14	0.313
97	0.13	0.309
98	0.13	0.306
99	0.13	0.303
100	0.12	0.300
101	0.12	0.297
102	0.11	0.294
103	0.11	0.291
104	0.10	0.288
105	0.10	0.286
106	0.10	0.283
107	0.10	0.280
108	0.10	0.278
109	0.09	0.275
110	0.09	0.273
111	0.09	0.270
112	0.08	0.268
113	0.08	0.265
114	0.08	0.263
115	0.07	0.261
116	0.07	0.259
117	0.07	0.256
118	0.07	0.254
119	0.07	0.252
120	0.07	0.250
121	0.07	0.248
122	0.07	0.246
123	0.06	0.244
124	0.06	0.242
125	0.06	0.240
126	0.05	0.238
127	0.05	0.236
128	0.05	0.234
129	0.05	0.233
130	0.05	0.231
131	0.05	0.229
132	0.05	0.227
133	0.05	0.226
134	0.05	0.224
135	0.04	0.222
136	0.04	0.221
137	0.04	0.219
138	0.04	0.217
139	0.04	0.216
140	0.04	0.214
141	0.04	0.213
142	0.04	0.211
143	0.03	0.210
144	0.03	0.208
145	0.02	0.207
146	0.02	0.205
147	0.02	0.204
148	0.02	0.203
149	0.02	0.201
150	0.02	0.200
151	0.02	0.199
152	0.01	0.197
153	0.01	0.196
154	0.01	0.195
155	0.01	0.194
156	0.01	0.192
157	0.01	0.191
158	0.01	0.190
159	0.01	0.189
160	0.01	0.188
161	0.01	0.186
162	0.01	0.185
163	0.01	0.184
164	0.01	0.183
165	0.01	0.182
166	0.01	0.181
167	0.01	0.180
168	0.00	0.179
169	0.00	0.178
170	0.00	0.176
171	0.00	0.175
172	0.00	0.174
173	0.00	0.173
174	0.00	0.172
175	0.00	0.171

Murray Ave. Pump Station Overflow (Reported vs. Modeled) Comparison (2006-2007)

Reported Overflows		Model-simulated Overflows		Volume Difference (Model - Reported) (MG)	Possible Reasons for Differences
Date	Volume (MG)	Date	Volume (MG)		
	0.000	1/10/06	0.042	0.042	
	0.000	1/16/06	0.343	0.343	Leak in Barton Force main discovered the next day. Murray PS was not receiving intended flow from Barton.
		1/30/06	0.021	0.021	
	0.000	2/4/06	0.129	0.129	Break in Barton force main limited flow from Barton PS. This was not simulated in model.
6/2/06	0.039			-0.039	
11/4/06	0.217	11/3/06	0.167	-0.037	
		11/4/06	0.013		
11/6/06	2.85	11/6/06	0.972	-1.873	
		11/13/06	0.076	0.076	
12/11/06	0.420			-0.420	Either rain gauge 5 or 14 failed and/or data from one was patched into the other. Rainfall used by model likely was not a good estimate of what fell on the Barton and Murray basin.
12/13/06	3.28	12/14/06	3.14	-0.825	Power outage occurred at Pump Station. Power outage was not simulated in model.
12/14/06	0.68				
12/26/06	0.009	12/26/06	0.138	0.129	
1/2/07	0.001			-0.001	
1/7/07	0.003	1/7/07	0.268	0.265	Wet well water level likely in error (level at weir height for 3 hours). The reported overflow volume was most likely underestimated due to a level sensor error.
	0.000	1/8/07	0.743	0.743	Very high spatial variability in rainfall. The rainfall over the basin probably was lower than what was input to the model.
	0.000	5/21/07	0.992	0.992	Either rain gauge 5 or 14 failed and data was input from another gauge. It is very likely that the rainfall used in the model is not a good estimate of what fell on the basin.
7/2/07	0.003			-0.003	Power outage occurred at Pump Station. Power outage was not simulated in model.
	0.000	8/20/07	0.021	0.021	
	0.000	8/26/07	0.072	0.072	
	0.000	9/4/07	0.403	0.403	Rain gauge 5 failed and data was replaced with rainfall data from rain gauge 17. The wet well level flattened at weir height, so it appears that an overflow occurred. Probably the level sensor reading was scaled too low and did not produce an overflow event.
	0.000	11/16/07	0.002	0.002	
	0.000	11/17/07	0.028	0.028	
12/2/07	107.4	12/3/07	14.07	-93.33	Reported overflow calculation did not account for outfall capacity. Reported overflow included calculated overflow up to 316 mgd, when outfall could only pass about 60 mgd. It also appears that the weir level used in the overflow calculation was too low. Correcting for these 2 factors results in an overflow calculation of about 20 MG.