Appendix B

Description of Models Used for Metro/King County CSO Planning

King County's approach to modeling has changed over time. This has resulted from improvements in the science of modeling and available models, as well as improved information about the conveyance system. The history of this effort follows. It is also summarized in Table 1.

1979 CSO Control Program

In this program, models specifically developed for the 1976 Metro 201 Facilities plan were used. These included a model known as HYDRO to generate runoff from storms.

HYDRO used a synthetic unit hydrograph technique to calculate surface runoff from rainfall. The synthetic unit hydrograph is a triangular hydrograph of the flow that would result from one inch of rain in a ten-minute period. Unit hydrograph shape was dependent on the shape of the area from which runoff was being calculated. Two sets of independent calculations were performed for impervious and pervious surfaces.

Sanitary sewage flows were represented in the 1979 modeling by diurnal hydrographs adjusted in magnitude based on the land use of individual tributary areas. A base infiltration factor (usually 1,100 gpad, but adjusted for measured flows) was added to compute base sewage flow. Runoff computed by the unit hydrograph technique was then added to base wastewater flows.

The total flow hydrographs computed in each basin of the system were routed through Metro's interceptors using a model known as "NETWORK." NETWORK was a specially developed model using a kinematic wave approximation to the full equations of motion. The kinematic wave approximation does not fully account for backwater effects from pump stations and regulator gates, or any other downstream flow restriction. Thus, a complete description the system operation was not available (the actual impact of throttling back on the Interbay pump station could not be precisely simulated for example). Because flows from the north end of the system were not large, these were simulated as a constant value in development of the 1979 plan.

1986–1988 CSO Control Plan

In the modeling effort for the 1986–1988 CSO Control Plan, consultants used different programs to generate inflow hydrographs from the separated and combined portions of the service area. For the separated sewer area (upstream of the Lake City Regulator) the program LCHYD was used to generate flows from nine sub-basins. A diurnal base flow (e.g., showing two peaks within the same day) hydrograph was developed based on domestic/commercial and industrial populations. A linear relationship was assumed between rainfall and inflow, up to a maximum amount. Infiltration was assumed to be constant for the wet season. A maximum inflow value of 500 gallons per acre per day (gpad) was used for simulating future flows from currently non-sewered areas that were expected to develop and include sewers in the future.

The program LCPRE was used to take into account that peak flows do not occur at the same time in all parts of the system. This lag was incorporated into the simulation.

For the combined system, the program HyDRO72 was used to generate hydrographs from 19 basins in the Northern service Area (NSA). This was a modification of the HYDRO program used in the 1979 CSO control program. Several of the basins in the HYDRO simulation were combined for use in the HYDRO72 model. Furthermore, the length of simulation was increased from24 hours to 72 hours for HYDRO72, which allowed for longer storm events to be simulated.

The same basin parameters from the 1979 CSO Control Program effort were used in the 1986 effort. Despite concerns about the model, a decision was made to continue using the model for continuity with past planning. Five design storms were used to estimate annual CSO volumes and frequencies under existing (at that time) conditions and under future conditions.

The input hydrographs were then used as input to the SACRO (Seattle Area Central Routing Organization) simulation. SACRO simulated the routing of flow through the northern service area (NSA) of the wastewater system. It was designed to give reasonable estimates of the volume of flow through the NSA system. The flow from Interbay Pump Station was assumed to remain the same throughout the study period (1982–2030).

For the wet season, it was assumed that infiltration would remain the same as in the 1981-83 model calibration, at 1100 gpad. HYD72 (similar to HYDROT2) was used to generate synthetic unit hydrographs from 62 basins in the SSA. Seven design storms of varying length and intensities were used to estimate annual CSO frequencies and volumes for the SSA.

The Southern Service Area (SSA) large pipe flow was simulated using SSACRO (South Seattle Area Control Routing Organization). It was developed using primarily SACRO and some of NETWORK. It is based on level pool storage routing concepts and therefore does not accurately represent dynamic wave storage or routing. The program only calculated how the different input hydrographs travel through the system – combining sewer junctions, splitting at diversions, etc. It did not simulate the restriction of flows at the Interbay Pump Station due to flows at the West Point treatment plant exceeding its setpoint, which at that time was 325 million gallons per day.

SSACRO and SACRO basically added up all flows into a particular node (regulator, pump station, etc.), subtracted away that which could be hydraulically conveyed away from the node, and if anything was left, it was either stored or called an overflow. They are mass balance models, and do not compute water surface elevations in the collection system.

The program EBIPRE was developed to simplify and reduce the time involved in routing flows through the Elliott Bay Interceptor. It lagged inflow hydrographs and then combined them to be used in the routing model SSACRO. It also accounted for some of the City of Seattle CSOs and storage projects.

SACE (Seattle Area Combined Sewer Overflow Evaluator) was written to allow rapid testing of alternatives and to determine recurrence periods of overflows for design events. It calculated annual overflows for the wastewater system for the 1942-84 period. The SACE program simply assigned portions of each rainfall event to (l) system capacity; (2) system storage; and (3) rainfall that couldn't get into the sewer. The amount of available storage was increased during inter-event periods to reflect the draining of wastewater from storage. For each rainfall event, the wastewater entering the sewer that could not be contained in “system capacity” or “system storage” was considered to be CSO. There was no simulation of the flow as it proceeded toward the treatment plant.

CATAD Program Improvements—Predictive Control Program Begins

In 1986, a different approach was begun to model the West Point (combined) system, leaving behind the previous model. The effort was to support the development of an optimized real-time control program for the West Point collection system. The Predictive Control Program was to allow the Computer Augmented Treatment and Disposal System (CATAD) to automatically operate regulator gates and optimize in-line storage throughout the entire collection system to minimize CSOs.[1]

As part of this new approach, two new programs were developed to simulate flow through the West Point system. A kinematic wave runoff program was developed to simulate overland flow resulting from rainfall. Flow over both pervious and impervious areas that enters the sewer system was simulated. The West Point system was divided into over 400 basins to simulate this overland flow. This flow was then routed through a kinematic wave transport program, which effectively simulates the lagging and attenuation of flows through the local sewer pipes. The program also computes depths and velocities of flows in each pipe, and is a good approximation of actual conditions as long as there are no backwater effects or hydraulic transients (e.g., hydraulic phenomenon that are short in duration). Unlike previous programs used to model the wastewater, the runoff/transport program is a physically-based model that attempts to directly simulate the flow mechanics of the local sewer system. The program simulates a diurnal base domestic flow and a constant groundwater leakage. Inflow from rainfall induced hydrographs were simulated and input into the appropriate pipes for routing.

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[1] Automatic control by CATAD was implemented in 1974. Predictive Control optimizes it.

Over 70 flowmeters were installed to calibrate the runoff/transport model in the late 1980s.

The model UNSTDY was obtained in 1986 from Colorado State University to simulate the routing of runoff/transport flow hydrographs through the Metro/King County trunks and interceptor system. UNSTDY is a complex, fully dynamic simulation that computes flows, depths, and velocities in all pipes in the system. The full hydraulic equations are solved implicitly which enables it to simulate backwater effects, flow reversals, and gravity waves effectively. This sophistication was required to accurately simulate the in-line storage being utilized throughout the collection system. The model was enhanced to simulate the operation of the regulator gates and pump stations.

UNSTDY was programmed to simulate the regulator system using local control (manual control), the existing Automatic Control, and the new Predictive Control. In early 1992 it was discovered that several of the level sensors (bubblers) were reading incorrectly, and probably had been since installation. The UNSTDY simulation was modified to be able to simulate control structures as they would have been operated if the sensors were reading incorrectly, as well as if they were reading correctly. This option (which simulates flow assuming errors in the levels sensors) is used when simulating conditions under “baseline” (1981 -83) conditions.

The runoff/transport program was enhanced in the early 1990s to include rainfall-induced infiltration into the sewer system. This infiltration can be the largest component of I/I during large storms in the separated portion of the County sewer system. This modification allows King County to simulate the flow from the northern part of the West Point service area much more accurately than had been possible previously.

The 1995 and 2000 CSO Control Plan Updates

For the 1995 CSO Control Update the same seven design storms used in the 1988 plan were used to estimate annual CSO volumes. For the 2000 CSO Control Update, 11-year continuous simulations were used to estimate CSO frequencies and volumes. As each flow transfer or CSO project is constructed, UNSTDY is modified to include that facility. For example, the Hanford/Lander Separation Project is included for simulations past 1990. The Carkeek flow transfer was included beginning in 1994. The Allentown Diversion was included in 1996. The Alki Flow transfer was included in 1998 as was the University CSO Project (Densmore Pump Station). The Denny Way CSO facility, the Harbor CSO transfer to the West Seattle Tunnel, and Henderson/Martin Luther King Way CSO facility are being simulated for 2005 and beyond.

SCADA/CATAD as of CSO Control Program Review

Computer hardware at West Point has been replaced in 2004–2005 for the offsite facilities. Software upgrades have also been done for operating the offsite facilities and for collecting, storing, and retrieving their data. The links and software are currently undergoing QA/QC. New control strategies are being tested and implemented for the facilities that came online in 2005.

Table 1. Summary of Hydraulic Models Used by King County

Decade	Models		Brief Description of Capabilities
	Hydrologic (surface runoff and local system flows)	**Hydraulic** (Metro/KC trunks and interceptor flow)	
1970s	HYDRO		Used synthetic unit hydrograph method for runoff due to rainfall from 58 NSA basins and 62 SSA basins.
		NETWORK	Used kinematic wave approximation for simulating flow through Metro trunks and interceptors.
1980s	LCHYD		Used diurnal base flow and constant infiltration to generate hydrographs from separated areas. Linear rainfall/inflow relationship.
	HYDRO72		Used synthetic unit hydrograph method for 19 basins in NSA.
	HYD72		Used synthetic unit hydrograph method for 62 basins in SSA.
		LCPRE	Lagged the hydrographs from LCHYD to put into SACRO.
		SACRO	A mass balance model that simulated flow through the NSA. (Kept track of flow but didn't solve hydraulic equations for levels.)
		SSACRO	A mass balance model that simulated flow through the SSA.
		EBIPRE	Lagged the hydrographs from HYD72 to put into SSACRO.
		SACE	Estimated total system overflows based on rainfall only.
1990s — 2000s	RUNOFF		Kinematic wave simulation of runoff due to rainfall from > 400 basins. Variable inflow and infiltration based on rainfall and soil conditions. A physically based model.
		UNSTDY	A fully dynamic simulation of flow through King County trunks and interceptors. Computes flows, depths, and velocities in all pipes in the system. Simulates backwater effects, flow reversals, gravity waves, surcharges, etc. Simulates automatic operation of regulator and outfall gates and pump stations. Also, simulates Predictive Control, a computer program that controls the regulator gates to optimize the use of in-line storage. Used seven design storms in early 90s to estimate annual overflows. Now continuous 11-year simulations are run to estimate annual averages.

NSA = Northern Service Area (North of the Ship Canal)
SSA = Southern Service Area (South of the Ship Canal)