Chapter 6

Modeling and Monitoring Inflow Reduction Programs.

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The purpose of this chapter is to discuss the methods and issues related to modeling and monitoring the inflow reduction programs currently being implemented by the City of Portland as part of its Combined Sewer Overflow (CSO) Facilities Plan. The inflow reduction programs consist of the disconnection of roof downspouts from the combined system and the installation of infiltration sumps for residential stormwater runoff.

The Storm Water Management Model (SWMM) is used to track the performance of the sump and downspout disconnection programs. This chapter describes the modeling of these sumps and downspout disconnections in SWMM, current monitoring and modeling practices for the City, concerns and limitations of modeling and monitoring, and recommendations for further monitoring. There are several concerns and limitations in modeling and monitoring these conditions accurately. The primary concern of this effort is to be certain that the inflow reduction technologies are performing as expected.

6.1 Background

Portland, Oregon is served by a large combined sewer system that transports both sanitary and stormwater. The combined sewer system area covers approximately 27,000 acres (11,000 ha). The interceptor system is designed to carry three times the average dry weather flows to the City's wastewater

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treatment plant. During wet weather, the remaining combined sewage overflows into the Willamette River and the Columbia Slough. The combined system discharges annually about six billion gallons of overflow on average to the Willamette River and the Columbia Slough. The City of Portland and the Department of Environmental Quality (DEQ) signed an agreement called the Stipulation and Final Order (SFO) that was designed to reduce combined sewer overflows (CSO) by 94% over a 20 year period. The CSO Facilities Plan calls for implementation of storage, treatment and inflow reduction programs with a capital cost of \$700 million. The inflow reduction programs include removing stormwater from the combined sewer system by installing infiltration sumps and disconnection of roof downspouts from the sewer system. The performance of the sump and downspout disconnection program is being tracked using the City's monitoring system as well as being modeled by the City staff using SWMM.

The City of Portland's combined sewer system consists of 41 basins and three interceptor systems. The current Portland CSO SWMM models use 140 Runoff, Transport and Extran files for simulating Portland's combined system. The modeling system was last calibrated in the summer of 1992, before the implementation of the inflow reduction programs. Portland's CSO SWMM models were calibrated using rainfall and sewer level data collected throughout the combined sewer system area. The city maintains 27 rainfall gages and 66 Sewer Level Remote Telemetry (SLRT) locations that measure depth of flow on a continuous basis. There are 41 rainfall files created for each storm simulated for the entire combined sewer system using the 27 rainfall gages.

6.2 Inflow Reduction Techniques

Simulations performed indicate that Portland's combined sewage consists of approximately 80% storm water. The annual average inflow generated is estimated to be 9,900 MG ($37 \times 10^6 \text{m}^3$) per year in 2040. Inflow reduction techniques are designed to remove storm water from the combined system and reduce the volume and frequency of CSO events. Two of the inflow reduction techniques include installing infiltration sumps and disconnection of roof drain downspouts. Analysis indicates that approximately 2,000 MG ($7.5 \times 10^6 \text{m}^3$) - i.e. 20% - of inflow per year could be eliminated from the combined sewer system by the installation of sumps. Roof drain downspout disconnection would provide an additional 5 to 10 % inflow reduction for a total of 800 MG ($3 \times 10^6 \text{m}^3$) per year. This 30% inflow reduction along with localized system modifications will result in approximately a 45% reduction in CSO volume annually. As a result, inflow reduction techniques will reduce the size of storage and treatment facilities and lower the overall cost of the CSO program.

Infiltration sumps, shown in Figure 6.1, operate by receiving storm water runoff that previously would have entered the combined sewer system through a storm water inlet. The storm water instead is routed to the nearby infiltration sumps. Infiltration sumps are approximately 30 feet (9 m) deep with perforated walls and granular backfill to allow surface runoff to infiltrate into the ground. The sump system consists of two interconnected chambers. The first one acts as a sedimentation chamber to settle out solids in the runoff. The water then overflows into the second chamber, which is a perforated sump that allows the runoff to infiltrate into the ground. The peak flow rate at which the sump can empty is determined by the permeability of the soil. Sumps are best suited for areas with rapidly draining soils.

Figure 6.1 Infiltration sump schematic.

Reducing inflows by disconnection of roof drain downspouts will be achieved by several methods. Roof drains in sumpable areas can be disconnected from the combined system and piped directly to the gutter where it will enter a downstream infiltration sump. Other disconnection methods include splash blocks and soakage trenches (see Figure 6.2). In areas where drainage is poor, roof drains can be connected to dry wells installed on the residential property.

Figure 6.2 Roof drain (downspout) disconnection to a splash block.

6.3 Modeling Infiltration Sumps and Roof Drain Disconnection

Sumps are simulated in the CSO SWMM models by removing the area draining to the sumps from the Runoff subcatchment area. For example, in a 10 acre (4.1 ha) subcatchment, if 3 acres (1.2 ha) drain into a sump, then the Runoff subcatchment area is reset to 7 (2.9 ha) acres. If roof drains are disconnected in an area that is sumped, then the roof area is also removed from the Runoff subcatchment. If roof drains are directly connected to the sewer system, then sumps do not divert roof flow and the roof area remains in the model subcatchment.

Roof area in the model is considered to be 100% impervious. In Portland residential neighborhoods, approximately 50% of the total impervious area is roofs. A revised impervious percentage must be calculated for subcatchments that are sumped but do not have roofs disconnected. For example in our 10 acre (4.1 ha) subcatchment, 3 acres (1.2 ha) drain to sumps, but the roof drains in this area remain connected to the combined sewer system. If the percent imperviousness of the 10 acres (4.1 ha) was 40 %, then the roof area connected to the system, the new subcatchment area and the new impervious percentage are as follows:

Roof area = $(40\% * 3 \text{ acres}) * 50\% = 0.60 \text{ acres at } 100\% \text{ imperviousness}$

New Subcatchment area = $(10 - 3) + .6 = 7.6 \text{ acres}$

New subcatchment imperviousness = $((7 * 40\%) + (.6 * 100\%)) / 7.6 = 45\%$

A spreadsheet was used to calculate the revised subcatchment areas and percent imperviousness required to simulate the sump and roof disconnection programs. A portion of this spreadsheet is shown in Table 6.1.

Specific assumptions and field data are incorporated into the analysis of the inflow reduction techniques. Sumpable areas were determined from soil testing and sump tests. All of these areas will have sumps installed as part of the CSO inflow reduction program. Each subcatchment within the sumpable areas was examined for its particular sumpable portions. Additional field data from plumbing records revealed that the City of Portland already has approximately 5% of roof drains disconnected to streets. The City plans to disconnect at least 46% of the remaining roofs in sumpable areas as part of the CSO inflow reduction program. Following Table 6.1 for subcatchment 1 with an actual area of 3.77 acres (1.53 ha), impervious percentage of 73, and sumpable percentage of 91, the revised area and impervious percentage are as follows:

Pervious Area = $3.77 (1 - .73) = 1.02 \text{ acres}$

Impervious Area = $3.77 (.73) = 2.75 \text{ acres}$

Roof Impervious Area = $2.75 (.5) = 1.38 \text{ acres}$

Non-Roof Impervious Area = $2.75 (.5) = 1.38 \text{ acres}$

Disconnectable Roof Area

(Inflow Reduction Program) = $1.38 (.46) = .63 \text{ acres}$

Roof Area Currently Disconnected to the Street = $1.38 (.05) = .07 \text{ acres}$

Non-Disconnectable Roof Area = $1.38 - .63 - .07 = .67 \text{ acres}$

Revised Pervious Area = $1.02 (1 - .91) = .09 \text{ acres}$

Revised Impervious Area = $(1.38 + .63 + .07)(1 - .91) + .67 = .86 \text{ acres}$

Revised Total Area = $.09 + .86 = .95 \text{ acres}$

Revised Percent Impervious = $.86 / .95 = 90\%$

Only areas draining to sumps are subtracted from the actual subcatchment area. Therefore, the modeled subcatchment areas include only the non-sumped pervious and impervious areas, and roofs not disconnected in sumped areas.

6.4 Current Monitoring and Modeling Practices

In the early 1970's, the City of Portland began to implement a sewer and rainfall monitoring system called HYDRA (Hydrologic Data Retrieval and Alarm). The purpose of the HYDRA system was to monitor the rainfall and resulting sewer flow throughout the combined sewer collection system. The information was then to be used to develop, calibrate and verify mathematical computer models of the combined system. These computer models were to be used for planning and design of the facilities required to control CSOs.

Table 6.1 Calculation of effective area and impervious percent for inflow reduction programs.

	Variable	A	B	C	D	E	F	G	H
	Equation				A(1-C)	A(C)	.5E	.5E	* .46F
Subcatchment Number	Inlet Node Number	Actual Area (ac)	Percent Sumpable	Actual Percent Impervious	Actual Pervious Area (ac)	Actual Impervious Area (ac)	Roof Impervious Area (ac)	Nonroof Impervious Area (ac)	Disconnectable Roof Impervious Area (ac)
1	2006	3.77	91%	73%	1.02	2.75	1.38	1.38	0.63
2	2002	3.77	89%	53%	1.77	2.00	1.00	1.00	0.46
3	2003	3.77	89%	49%	1.92	1.85	0.92	0.92	0.42
6	2006	5.58	91%	53%	2.62	2.96	1.48	1.48	0.68
7	2006	4.33	50%	70%	1.30	3.03	1.52	1.52	0.70
8	2008	5.33	100%	40%	3.20	2.13	1.07	1.07	0.49
9	2009	8.65	100%	40%	5.19	3.46	1.73	1.73	0.80

	Variable	I	J	K	L	M	N
	Equation	** .05F	F-H-I	D(1-B)	(G+H+I)(1-B)+J	K+L	L/M
Subcatchment Number	Inlet Node Number	Roof Area Currently Diverted to Street (ac)	Nondisconnectable Roof Impervious Area (ac)	Revised Pervious Area (ac)	Revised Impervious Area (ac)	Revised Total Area (ac)	Revised Percent Impervious
1	2006	0.07	0.67	0.09	0.86	0.96	0.90
2	2002	0.05	0.49	0.19	0.65	0.84	0.78
3	2003	0.05	0.45	0.20	0.60	0.80	0.75
6	2006	0.07	0.72	0.23	0.92	1.16	0.80
7	2006	0.08	0.74	0.65	1.89	2.54	0.74
8	2008	0.05	0.52	0.00	0.52	0.52	1.00
9	2009	0.09	0.85	0.00	0.85	0.85	1.00

* The City of Portland is assuming a 46% roof drain downsput disconnection rate

** Reviewing of plumbing cards shows that 5% of roof drain downsputs are already disconnected

The HYDRA system began operation in 1976 collecting rainfall from 26 raingages. Each gage records at a 5 second interval allowing the system to measure and record rainfall rates of up to 7.2 inches/hour (184 mm/h). The gages were originally set on a 3-mile (4.8 km) grid that covered the entire city sewer service area. Today, the raingage network is still fairly intact, although many of the gages have been moved for maintenance purposes.

Flow monitoring is performed throughout the City's collection system using the SLRT system. The SLRT system uses bubbler tubes to measure and record the depth in a sewer pipe on continuous 5-second intervals. Estimates of the flow rate through the pipe are then derived from the depth measured using a version of the Manning equation. The SLRT system originally consisted of 41 installations located throughout the sewer system in an attempt to monitor key locations in the system. The original locations were selected based on previously known capacity problems. Many of the SLRT stations have been moved over time to locations with better hydraulic conditions to obtain a more accurate measurement of the flow depth.

One of the key aspects of Portland's monitoring system is that the data is collected via remote telemetry. The original HYDRA rainfall and SLRT stations were first connected to dedicated telephone lines where the readings were transmitted back to the central computer every 15 seconds. The current system reads the data every 5 seconds but stores the information on-site and is sent back to the central computer via radio transmitter. The radio system polls the stations about every 20 minutes and transmits the stored data back to the central computer. This current method works well provided the 20-minute wait does not interfere with "real-time" analysis of the system. Once the data is on the local computer, it is processed and submitted for archiving on the central VAX system. The City has collected about 2 gigabytes of monitoring data (compressed and archived) over the past 20 years.

The current monitoring program will need to be supplemented with more sewer level monitoring stations in locations where additional information is needed on how the system performs. The key locations will be determined from modeling and added to the system for future data collection. Data collection is necessary to verify that the City is meeting its mandated CSO control levels. The Oregon Department of Environmental Quality has established that the Columbia Slough will be allowed to receive CSOs only once every five years during a wet winter season (November through April) and only once every ten years during the summer season (May through October). The rainfall and SLRT data will be necessary to verify this performance level, to verify that the inflow reduction programs are removing the expected amount of flow, and to calibrate the model for designing the final facilities to control CSOs.

6.5 Concerns with Modeling and Monitoring Inflow Reduction

Because of the nature of inflow reduction techniques in minimizing the costs of the overall CSO facilities, it is very important that the actual performance of sumps and downspout disconnections be verified as early as possible. The City has completed its sump program in several basins that overflow into the Columbia Slough. A roof disconnection pilot project that encouraged home owners to voluntarily disconnect their roofs from the combined sewer system was completed in a neighborhood where sumps were installed. The City modeling staff performed an initial calibration on a basin that incorporated both installation of sumps and roof disconnections. HYDRA sewer and rainfall data had been collected in this basin since 1976, and Marsh-McBirney Flo-Totes were installed at different locations in the basin in anticipation of the sump installations and roof disconnections. This basin, therefore, was an excellent candidate for examining the change in flows from the basin over time due to the installation of inflow-reduction measures.

The calibrated model was examined for the Vancouver basin during the early 1980's before sumps and roof-drain disconnections were implemented. The location of Vancouver Basin within the CSO area is shown in Figure 6.3. Vancouver basin has a rainfall gage located at the upper end of the collection system and a SLRT monitor located in the main trunkline just upstream of the basin's major diversion structure. The monitoring system for this basin has had several problems throughout its history due to installation difficulties and vandalism. The specific dates and history of the monitoring system for the Vancouver Basin are shown in Figure 6.4.

The SWMM Runoff and Extran models for the Vancouver Basin were executed for a small storm in December of 1980 to provide one of several calibration runs for pre-sumped conditions. Figure 6.5 shows the calibration plot for the depth in the 36 inch (914 mm) main trunkline. The model matches the measured depth of flow fairly well without any adjustments of runoff or flow parameters. The model fit, estimated to be within 20% for peak flow and volume, is representative of the overall CSO model fit and was judged to be satisfactory for the purposes of CSO planning and pre-design.

The second step in the calibration effort was performed by simulating the sumped conditions before the roof disconnection pilot project under a recent storm. Unfortunately, the sewer level monitor no longer existed within this basin due to maintenance and vandalism problems. The model calibration was then performed using the current existing conditions based on monitoring data from the Flo-Tote located in the trunkline. Plumbing data indicated that the percentage of roofs disconnected before the roof disconnection pilot project was originally assumed to be 5%. However, research conducted during the pilot project

Figure 6.3 Location of Vancouver Basin in the combined sewer system.

determined that there was a higher percentage of roofs disconnected, as many as 30%. The model was used to display the incremental changes in the depth of flow for sumps and roof-disconnections. The resulting calibration plot for an October 1992 storm at the Flo-Tote location is shown in Figure 6.6. This figure shows the model results for three different conditions: no sumps, sumps installed with a roof drain disconnection of 5%, and sumps installed with a roof-drain disconnection of 30%. It is clear from this plot that the sumps have a significant impact on reducing the flows. Predicted depths for the model with sumps installed matches the Flo-Tote depths fairly well. Predicted depths for the model with sumps and roof-drains disconnected is typically lower than the monitored depths. These results show that the model tends to slightly over-predict the reduction in flow due to sumps and roof-drains combined. However, the actual error in the model

Figure 6.4 History of monitoring in Vancouver Basin.

(10%-20%) under pre-sump conditions could easily account for the error in the model under existing sumped conditions.

Based on the Vancouver calibration effort, it was concluded that a more detailed calibration would be required to calibrate the model to existing conditions, measure the effectiveness of sumps, and better estimate the effectiveness of roof disconnections within the 5% level of accuracy. Clearly, a finer degree of detailed data measuring smaller area, localized rainfall, runoff and conduit flows will be required to allow this fine level of accuracy for model calibration and verification.

Other efforts to verify the performance of the inflow reduction measures have not shown an equivalent amount of reduction of wet-weather flows from the installation of sumps. These other efforts have not been as detailed as the Vancouver basin calibration. For these reasons, the City has begun a more detailed investigation and calibration of how sumps and roof disconnections are actually performing. This information will be critical to the upcoming design of CSO facilities in Portland.

Figure 6.5 Calibration plot of Vancouver Basin, December 1980; pre-sumped condition.

6.6 Model Limitations

Modeling can track and verify the expected incremental changes in combined flows due to changes in sumping, downspout disconnection and partial separation. Calibrating the model to more accurately reflect these changes will be critical to the success of the overall CSO Facilities Plan. Lack of sensitivity in the models is a limitation in measuring the effectiveness of inflow reduction techniques. There are several possibilities for an increase of expected flows to the combined system. One is a potential for increased infiltration resulting from higher groundwater tables due to the new sumps. Also, runoff from roofs that are disconnected from the system and released onto splash blocks may flow overland and enter the combined system during large storms. Increased groundwater infiltration will also reduce the effectiveness of inflow reduction projects.

This incremental increase in flow may not be seen with a model that is not calibrated to a higher degree of accuracy. However, accurately simulating the combined sewer system will have a significant impact on future facilities being designed for the CSO program. One such facility is a consolidation conduit that will collect overflows and transport them to a treatment plant. The conduit will be designed to accommodate the extreme SFO design storms (one overflow every ten years in the summer and one storm every five years in the winter). Larger storms will overflow into the river. Designing the consolidation conduit for

Figure 6.6 Calibration plot for Vancouver Basin, October 1992; post-sump condition.

lower than actual future flows will result in an increase in the number of overflows predicted and result in fines. Implementing an ineffective inflow reduction program could also increase costs. Over-design of the consolidation conduit could also occur. Due to lack of confidence in modeling results and uncertainties in the inflow reduction programs, the consolidation conduit would be sized larger. If the inflow reduction techniques are effective then the consolidation conduit will be over-designed. The amount of effort required to model the sewer system and the proposed alternatives accurately will save the City considerable money in its CSO program. Potential sedimentation that will occur when large pipes are no longer flushed with storm water is another concern. Maintenance costs would increase due to sedimentation problems.

6.7 Recommendations

Based on the results of calibration efforts similar to the Vancouver basin exercise discussed here, it was determined that a more aggressive and accurate calibration program would be required to confidently track the performance of the inflow reduction programs. The new calibration program, which is summarized below, will incorporate a higher degree of detail in data collection and monitoring rainfall, dry weather flow, and groundwater infiltration. The duration of the monitoring period will likely be about two years. In addition, the calibration program will be applied to two or three basins where past HYDRA, SLRT and rainfall data exist. This is needed to provide sufficient variety and coverage of data that will allow the results to be applied to all the CSO basins.

Rainfall Monitoring

In each basin to be used for the detailed calibration there will be two to three rainfall gages located at strategic points in the basin: one just upstream of monitoring locations and others where the basin geometry or rainfall pattern significantly changes. The rainfall gages do not need to be permanent devices, but they should remain in one location for the duration of the monitoring program. An existing HYDRA raingage will be preferred if one is installed in the appropriate location for the calibration effort.

Sewer Flow Rate and Depth Monitoring

Monitors such as Marsh-McBirney Flo-Totes or ISCO's Doppler probes will be installed at key locations to provide measurements of depth, velocity and flow rate. The most critical location is just upstream of major diversion structures which are the most important locations for the model to be calibrated. A flow monitor may still be required at the diversion structure even if a SLRT currently exists there in order to verify the SLRT depths and estimated flow rates.

Other critical locations for flow monitors would be in conduits downstream of an area where a known amount of sumps, roof drain disconnections and/or partial separation has been implemented. Subcatchments with more available data or known characteristics should have higher priority for being selected as a monitoring site. Another criteria for selecting a monitoring site is the subcatchment size. There should be a range of subcatchment sizes to match other basins where similar conditions exist. This will allow the modelers to apply the same corrections to similar basins. There is a minimum limit on the size of the basin that will be useful, typically about four to six blocks. In addition, accurate dry weather flow patterns will be needed to show good calibration during the low periods of a storm as well as to quantify any significant increase in infiltration and inflow.

Groundwater Monitoring

One of the greatest concerns facing the inflow reduction projects is the potential for increased infiltration resulting from groundwater tables that are higher than currently seen due to the new sumps. It will be necessary to include groundwater piezometers or sample wells to measure the fluctuations in the groundwater table. The groundwater monitors will be placed at the centers of the subcatchments that are being calibrated.

Field Data Collection

The data collected for roof drain disconnections, sumps and partial separation should be as detailed as the model. Therefore, it will be necessary to have data accurate at the minimum subcatchment size (four to six block areas). The roof drain downspout disconnection program uses a database that includes information that could be used by modeling staff. We are working closely with the disconnection program staff so information collected can be easily transferred to the SWMM model and a subcatchment number field be added to the database. Information that will be collected from the roof drain downspout disconnection

program includes the fraction of roof area disconnected from combined sewer system and draining to a sump, splash pad, or local retention facility. Other data needs are: distribution and totals of impervious areas including roofs and streets in sumpable and non-sumpable areas; actual areas draining to sumps; actual conduits or areas with stormwater removed from the combined sewer system due to partial separation, and verification of conduit inverts, sizes and shapes where a problem with available data is identified.

6.8 Conclusion

Modeling can track and verify the expected incremental changes in combined flows due to changes in sumping, downspout disconnection and partial separation. Based on this study it was determined that a more detailed model is required to confidently track the performance of inflow reduction programs. Accurately reflecting these changes will be critical to the success of the overall CSO Facilities Plan. A less sensitive model could result in an increase in project costs due to unexpected high flows.

References

Information provided in this chapter is from actual work done; the references only provided background information. Interested readers are encouraged to write to the City of Portland for further information or to comment on the methodology used.

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