MONITORING AND MODELING OF DO IMPACTS FROM CSO FACILITY EFFLUENT

Edward Kluitenberg, Senior Project Manager
Applied Science, Inc.
660 Plaza Drive, Suite 2000
Detroit, Michigan 48226

Vyto Kaunelis, Chief Deputy Director
Wayne County Department of Environment, Detroit, MI

Kurt Spieles, Staff Engineer
Applied Science, Inc., Detroit, MI

ABSTRACT

The Rouge River National Wet Weather Demonstration Program (Rouge Project) is evaluating the performance of ten demonstration combined sewer overflow (CSO) control basins in the Rouge River watershed, which is located in the greater Detroit area. Most of the basins are sized significantly smaller than the State's presumptive criteria. For the demonstration basins to be accepted by the State, they must meet specific effluent criteria, and water quality standards must be met downstream of the basins at times of discharge. This paper focuses on how the CSO facility effluent impacts in-stream dissolved oxygen (DO), which is the primary criterion driving the sizing of the CSO basins.

The basin evaluation is completed or underway for nine of ten CSO basins which have been operating for periods ranging from two to four years. The river DO impacts from the CSO basins were evaluated using a combination of basin effluent monitoring, river monitoring and dynamic water quality modeling. The evaluation was complicated by rapidly changing ambient river conditions when the facilities typically discharge.

Using a consensus-based approach, work groups including State personnel, CSO community representatives and consultants have reviewed the CSO basin evaluation results to date and concluded that the demonstration basins can eliminate raw sewage, protect public health and achieve water quality standards, including the dissolved oxygen standard. This demonstration approach to CSO control has been an unqualified success and resulted in a significant savings in costs compared to the presumptive approach.

KEYWORDS

BOD, CSO, demonstration approach, dissolved oxygen, performance evaluation, presumptive approach, river monitoring, river modeling, water quality standards

INTRODUCTION

Recognizing the major costs involved in controlling combined sewer overflows (CSOs) and that other sources of pollution impact water quality, Congress appropriated money through the United States Environmental Protection Agency (USEPA) to Wayne County, Michigan for the creation of the Rouge River National Wet Weather Demonstration Project (Rouge Project) in 1992. The Rouge Project is a comprehensive program to manage wet weather pollution and restore water quality in the Rouge River watershed, which encompasses 467 square miles of urbanized area in the greater Detroit area.

CSO Control Approach and Implementation Status

As of 1994, there were a total of 168 combined sewer outfalls discharging into the Rouge River and its tributaries. At that time the combined sewer service areas comprised 20 percent of the watershed, or nearly 100 square miles. The potential cost of controlling these CSOs with facilities sized based on the State's presumptive criteria was staggering. A court settlement based on the demonstration approach has allowed the Long Term Control Plan (LTCP) for CSOs in the watershed to be implemented in three phases as established through NPDES permits:

- Phase I - elimination of raw sewage and the protection of public health for approximately 40 percent of the combined sewer area
- Phase II - public health protection for the remaining combined sewer area
- Phase III - meet water quality standards in the Rouge River

Under Phase I, six sewer separation projects and ten demonstration CSO control basins were constructed, as shown in Figure 1. The basins were sized based on several different design storms, with most being significantly smaller than required by the State presumptive criteria. The facilities incorporate a variety of innovative technology, special features and operational flexibility in an effort to optimize their effectiveness. The basins capture most wet weather flows for later conveyance to the Detroit Wastewater Treatment Plant, with flows from very large wet weather events receiving screening, skimming, settling and disinfection prior to discharge to the river.

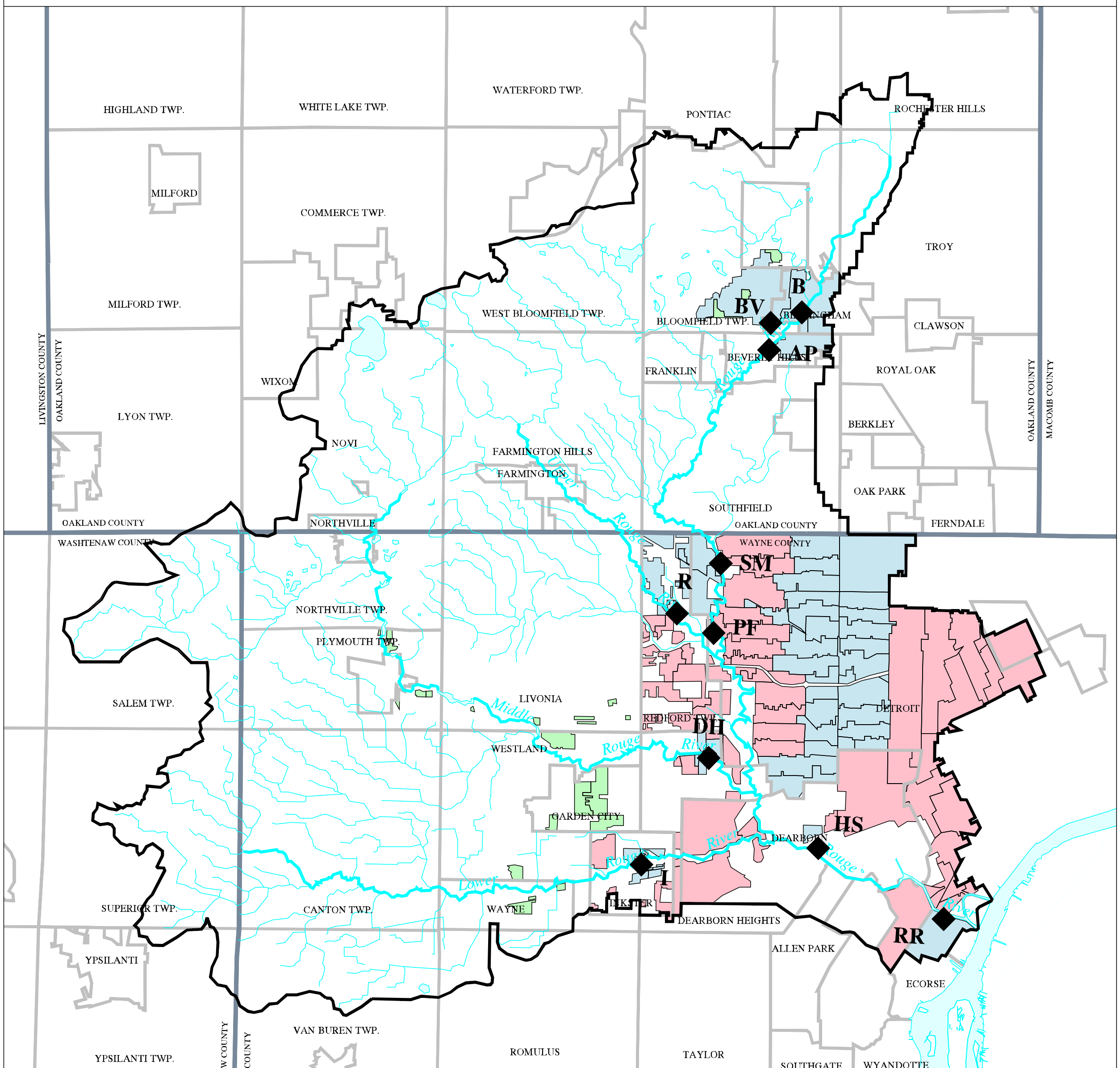
A detailed evaluation study of the CSO control basins is underway to examine the performance of the facilities and the water quality impacts of their discharges. The results of the evaluation study, coupled with efforts to control storm water and other pollution sources in the watershed, will provide the basis for the Phase II and Phase III CSO control program on the remaining CSO sources in the watershed. The information gained from the evaluation of design storms and control technologies will be useful nationwide on determining cost effective CSO controls to meet water quality standards. The results of the CSO basin evaluation and other Rouge Project activities are being widely communicated through a project web site, www.rougeriver.com.

Basin Evaluation Process and Status

Working with the CSO communities, the Michigan Department of Environmental Quality (MDEQ) established rigorous "Criteria for Success in CSO Treatment" to evaluate whether the

ROUGE RIVER WATERSHED

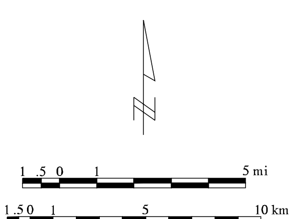
CSO Drainage Area After Phase I



LEGEND

Watershed boundary
Major branches
Tributaries
Community boundaries
County boundaries
CSO areas separated
CSO areas controlled by basins
CSO areas remaining after Phase I
CSO retention treatment basins

AP - Acacia Park retention basin
BV - Bloomfield Village retention basin
B - Birmingham retention basin
DH - Dearborn Heights retention basin
HS - Hubbell-Southfield retention basin
I - Inkster retention basin
PF - Puritan-Fenkell retention basin
R - Redford Township retention basin
SM - Seven Mile retention basin
RR - River Rouge retention basin



\gis\map\wmf\asize\awshed\awcsop1a.emf 06/06/01 demonstration CSO basins met the Phase II goals of elimination of raw sewage and protection of public health, and the Phase III goals of achieving water quality standards. To conduct the evaluation, MDEQ also established several work groups that included State personnel, CSO communities and consultants. The process and criteria established by MDEQ are summarized in a paper presented at WEF Watershed 2000 entitled "Evaluation of In-stream Impacts of CSO Control Facilities."

The basin evaluation is complete or underway for nine of ten demonstration CSO control basins which have been operating for periods ranging from two to four years. Some of the basin performance data, river monitoring data and modeling results have been analyzed for comparison to the various criteria for success. While the evaluation process is ongoing, the work groups established by MDEQ have already evaluated and reached consensus regarding several facilities as follows:

1. The three Wayne County CSO basins (Dearborn Heights, Redford, and Inkster) and the three Oakland County CSO basins (Acacia Park, Bloomfield Village and Birmingham) are meeting the Phase II goals of elimination of raw sewage and the protection of public health.

2. Aside from the total residual chlorine standard which has yet to be evaluated, the Phase III goal of achieving water quality standards at times of discharge is being achieved downstream of the three Oakland County basins and in a portion of the river downstream of the Redford CSO basin. (Additional river reaches and basins have yet to be evaluated.)

Evaluation of Dissolved Oxygen Impacts

This paper focuses on how the dissolved oxygen (DO) standard was evaluated as part of the Phase III goals for the Oakland County and Redford CSO basins. Meeting the DO standard is particularly significant as it is the primary issue driving the size of the CSO basins, and was the biggest concern regarding the acceptability of the demonstration CSO control basins. It is also significant in looking to the future both in the watershed and nationally, to consider whether future CSO control facilities could be designed even smaller than the Rouge Project demonstration sizes and still meet water quality standards. A report containing detailed results of the evaluation has been completed and will soon be available on the project web site.

METHODS

The river DO impacts from the demonstration CSO basins were evaluated using a combination of monitoring and predictive modeling. The predictive models were needed to determine the expected location of any DO sag that might exist, to predict DO impacts between river monitoring locations, and to predict DO impacts where monitoring results were obscured by the impacts of other uncontrolled CSOs. Due to the highly transient nature of observed DO impacts from uncontrolled CSOs, it was necessary to utilize continuous DO monitoring and dynamic, wet weather model simulations to conduct the evaluation.

Monitoring Approach

At least two years of detailed effluent monitoring was conducted at each CSO basin. While the effluent monitoring was underway, continuous DO and flow monitoring were conducted at selected river locations. In addition, grab sampling was conducted at a number of river locations during monitored basin overflow events.

Basin effluent monitoring included flow measurements and water quality sampling conducted by the basin operators during the occurrence of effluent flow at each CSO basin. Continuous river flow and DO data were collected by the U.S. Geological Survey and Rouge Project personnel during the basin effluent monitoring period in order to identify any impacts of the treated basin effluent on river DO. These data were collected between May and October when the most critical DO conditions were expected. Finally, during selected basin overflow events within the basin monitoring period, grab sampling was conducted at a number of sites within the Upper and Main Rouge River.

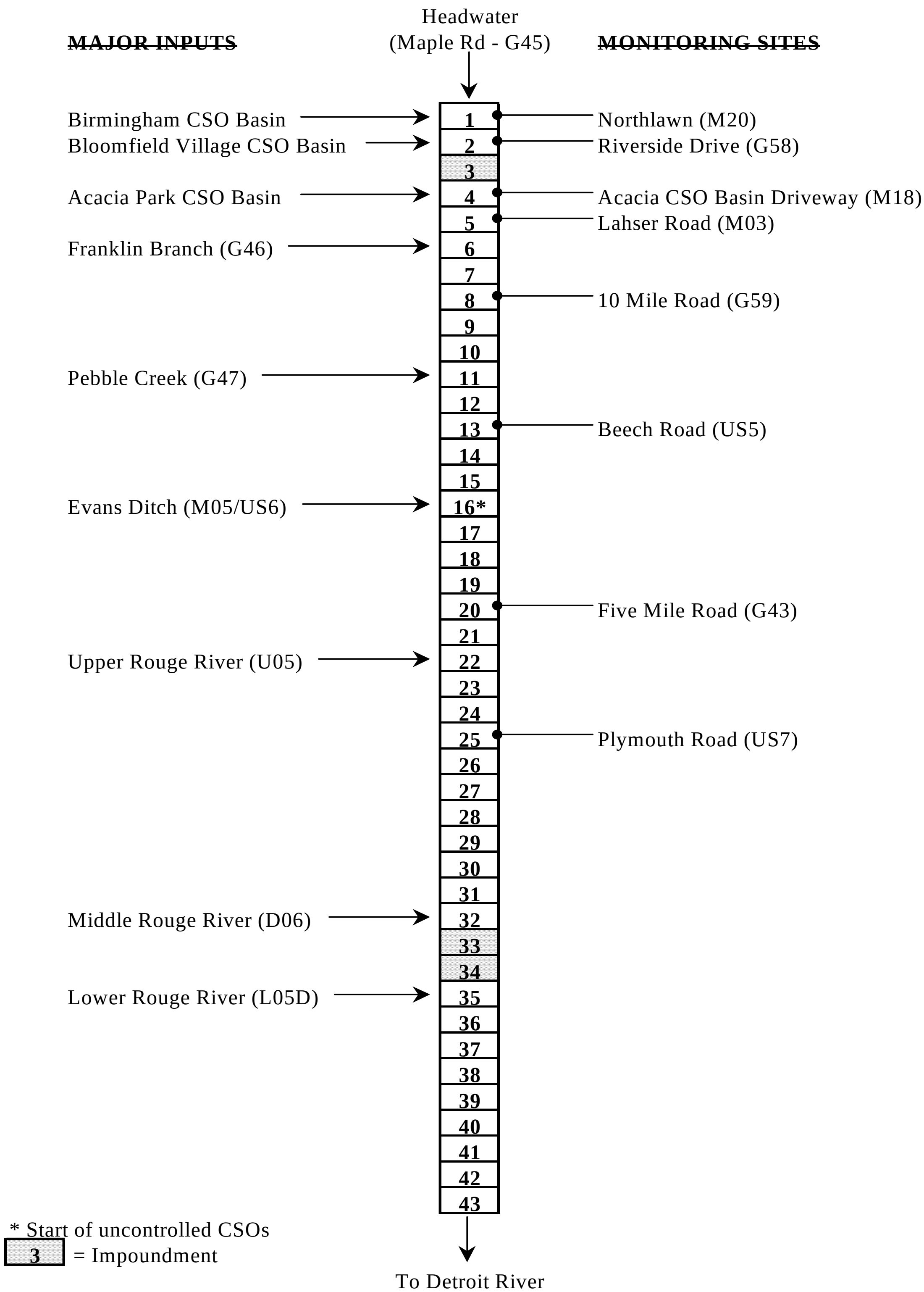
Modeling Approach

To supplement the monitoring data, an existing predictive model of the Main Rouge River previously developed by the project was adapted for purposes of the CSO evaluation. The adapted one-dimensional model is capable of performing dynamic simulations of river hydraulics, DO and 5-day carbonaceous biochemical oxygen demand ($CBOD_5$) given time-varying flows and pollutant loads from various sources. The model includes the following components:

- A river hydraulics model developed using the TRANSPORT block of USEPA's Storm Water Management Model (SWMM);
- A river water quality model developed using the EUTRO block of USEPA's Water Quality Analysis Simulation Program (WASP); and
- A storm water runoff model developed using the SWMM RUNOFF block, to estimate flows and loads entering the river models from wet weather sources for which measured data are not available.

The Main Rouge TRANSPORT model represents the physical characteristics of the river and routes the various flows which enter the river before, during and after a wet weather event. The TRANSPORT model computes hydraulic data including flow, depth, volume, and velocity for use in the WASP water quality model. Using a modified Streeter-Phelps approach, the WASP model predicts in-stream DO and $CBOD_5$ concentrations during wet weather events given time-varying loads of $CBOD_5$ and DO. The WASP model segments have a one-to-one correspondence to the TRANSPORT model segments, and are shown schematically in Figure 2 along with the locations of major tributaries, CSO basins and impoundments.

Figure 2
Main Rouge River DO Model Schematic



RESULTS AND DISCUSSION

Monitoring Results for Oakland County CSO Basins

As shown in Table 1, A total of nine overflow events occurred during the evaluation period at one or more of the Oakland County CSO basins, with five of those occurring after 100 percent CSO control in the Main Rouge was achieved in April 1998. Three of the nine events involved rainfall volumes and hourly intensities in excess of the 1-year, 1-hour facility design storm. Basin effluent data were collected during each of the nine events and selected results are included in Table 1. Complete basin monitoring results are included in basin evaluation reports submitted to MDEQ.

Table 1

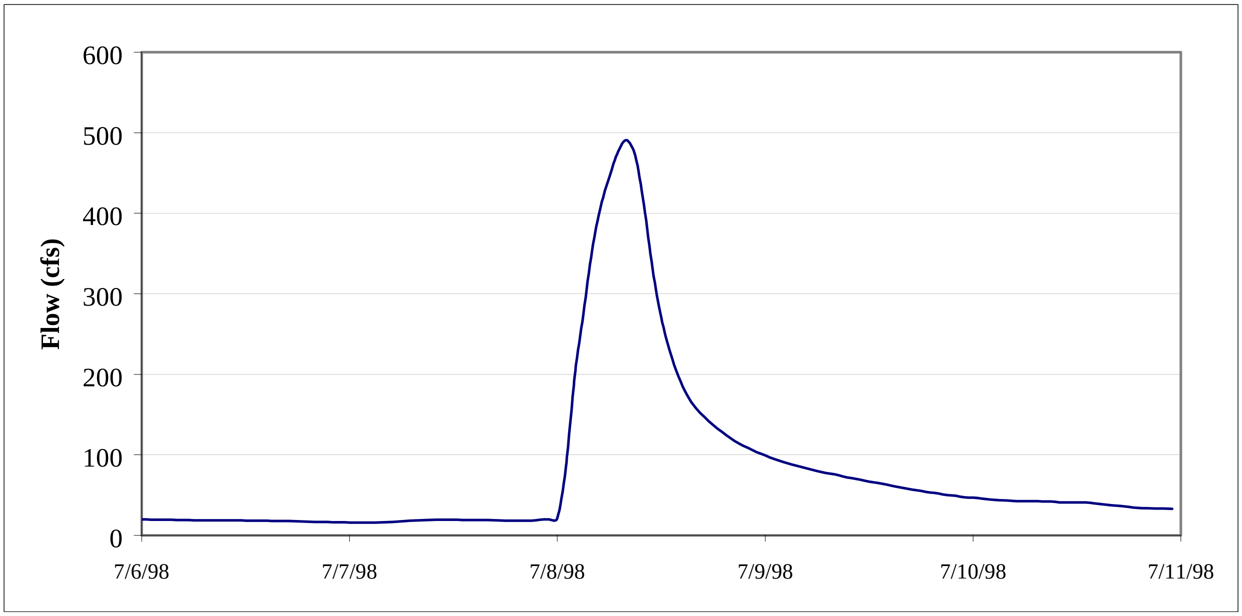
Oakland County CSO Basin Overflow Events and Average Effluent Data

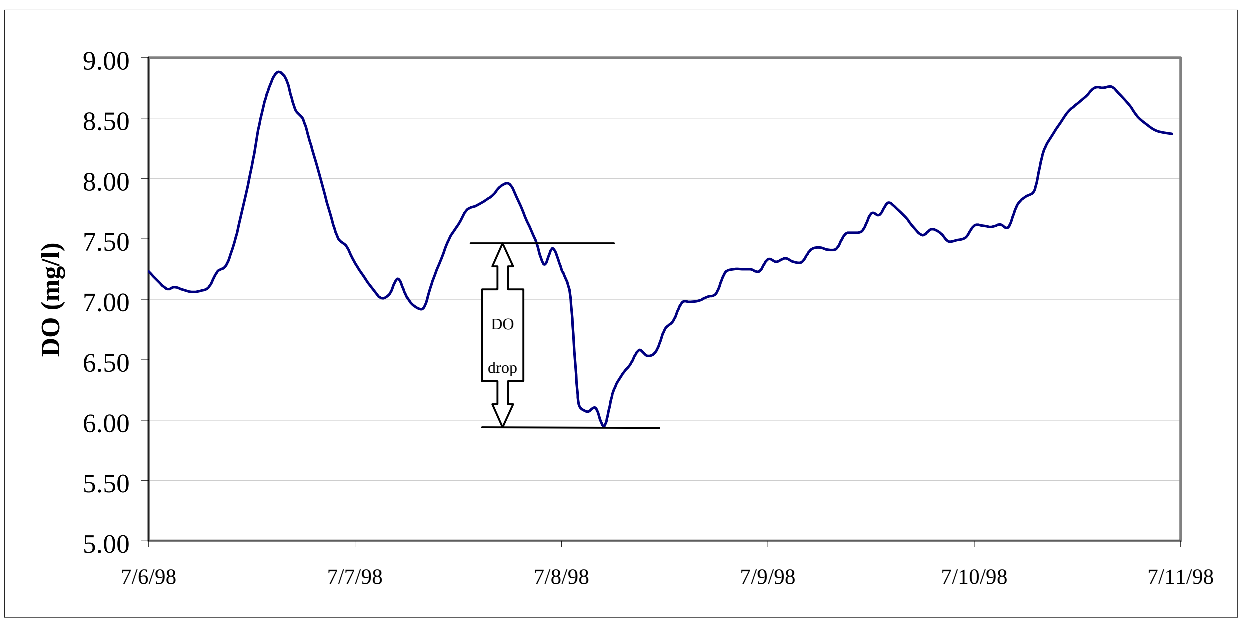
Event Date	Main Rouge CSO Control Status	Average Rainfall (in)	Total Overflow Volume (MG)	Effluent $CBOD_5$ Range (mg/l)	Effluent DO Range (mg/l)	Effluent NH_3 Range (mg/l)
7/2/97	20%	2.24	3.72	-----	6.4 - 7.1	1.60
9/10/97		0.89	2.69	5 - 31	8.6 - 9.0	0.10 - 0.12
2/17/98	70%	2.44	17.16	32 - 53	10.2 - 12.9	0.10 - 0.32
3/9/98		1.33	4.91	5 - 41	11.4 - 12.4	0.10 - 0.14
7/7/98	100%	1.36	4.07	19 - 72	6.1 - 8.6	0.10 - 0.97
8/6/98		5.05	30.02	2 - 73	7.3 - 8.5	0.10 - 0.40
1/22/99		1.26	17.36	5 - 81	11.4 - 13.1	0.13 - 0.77
4/22/99		2.19	22.38	1 - 47	10.3 - 11.2	0.20 - 1.80
6/28/99		1.04	0.13	14 - 91	7.4 - 7.7	0.44 - 6.80

Continuous DO data were collected on the Main Rouge River during the six overflow events which occurred between May and October. These data were collected at one site upstream of the three Oakland County CSO basins, and two sites downstream of the basins. The continuous DO data at each of the downstream sites was used to evaluate the effect of basin effluent on river DO. For each DO meter during each event, the DO response to the wet weather event was calculated as the maximum or minimum DO concentration that occurred in response to the wet weather event minus the pre-event DO concentration. As an example, for the 7/7/98 wet weather event in Figure 3, the DO change would be considered –1.5 mg/l. Several key results are summarized below:

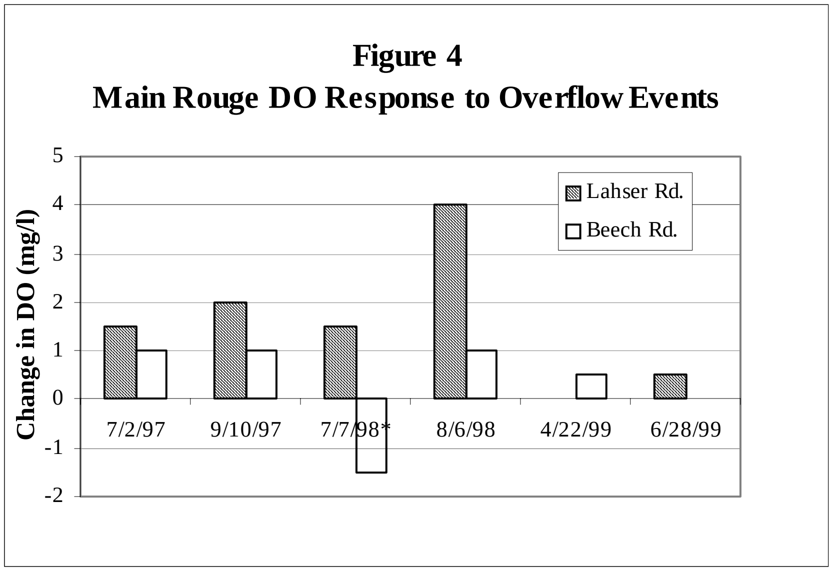
Figure 3

Main Rouge River DO Response at Beech Road - 7/7/98 Event





1. The results in Figure 4 show that the DO actually increased in response to every wet weather event, with the only exception being the 7/7/98 event shown in Figure 3. However, the Oakland County CSO basins were ruled out as a cause for this event based on travel time.



2. For the six events with in-stream monitoring, treated effluent from the Oakland County CSO basins never caused the in-stream DO to fall below the MDEQ in-stream standard of 5 mg/l or below the pre-event DO at the two downstream DO meters.

3. During several overflow events, DO sags (and at least one DO violation) occurred which were clearly not attributable to effluent from the CSO basins. These instances point to the presence of other unknown sources such as sanitary sewer overflows (SSOs).

Modeling Results for Oakland County CSO Basins

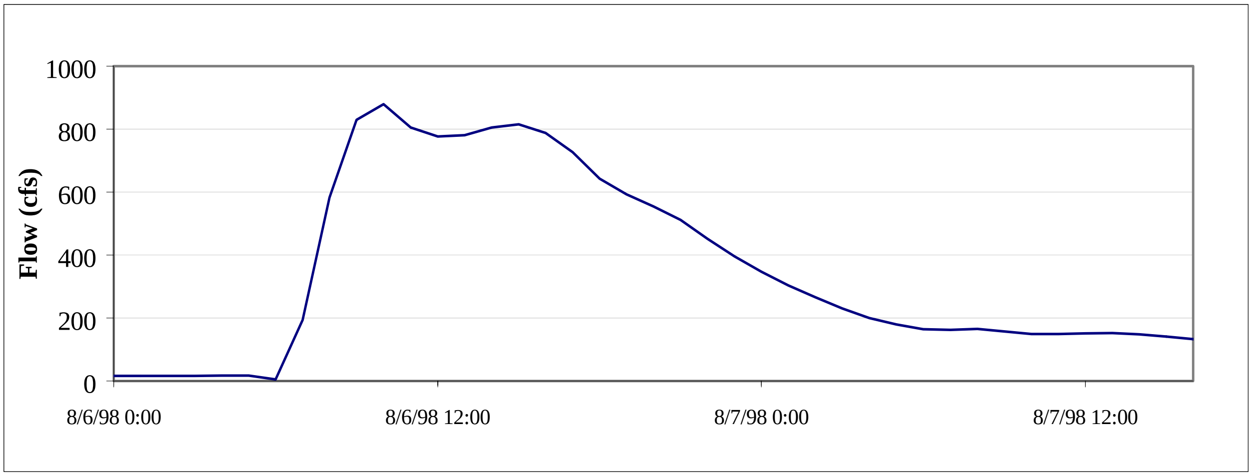
The Main Rouge WASP DO model was used to simulate the 8/6/98 event using the measured effluent flow, DO and $CBOD_5$ from each of the three CSO basins, and similar measurements at several major tributaries and the headwaters. Nitrogenous biochemical oxygen demand (NBOD) was negligible since the basin effluent ammonia concentrations were relatively low, and the effluent is significantly diluted by downstream storm water inputs before exertion of NBOD typically takes place.

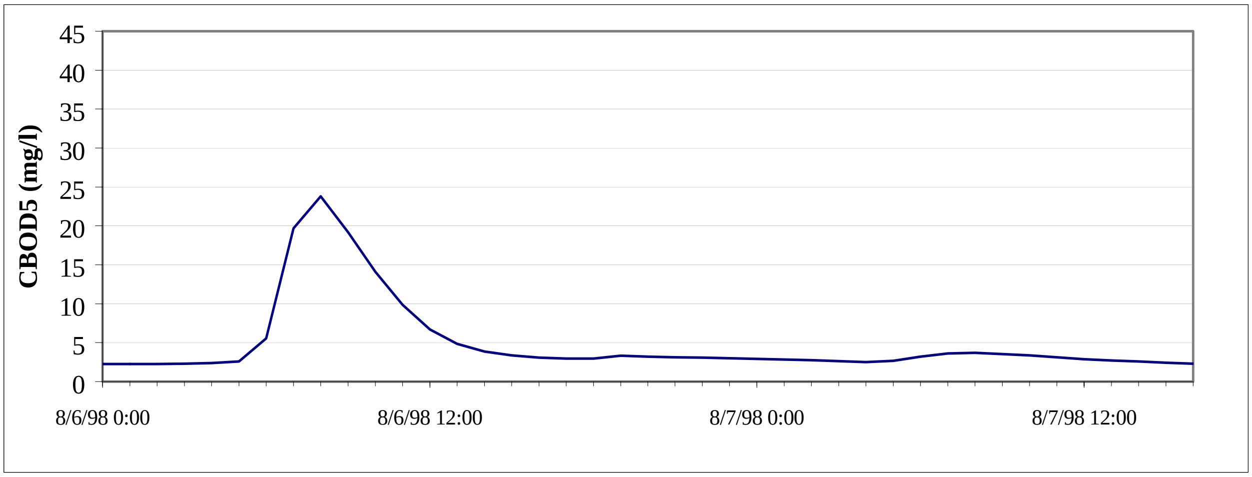
The model was developed with conservative assumptions and measured data were used to verify the conservative nature of the model. Used with this understanding, the model predicts representative river DO concentrations that identify the relative impact of the treated basin effluent on river DO. Several key model results are also listed below, keeping in mind that in-stream $CBOD_5$ concentrations in the model were generally lower than measured in-stream $CBOD_5$ concentrations.

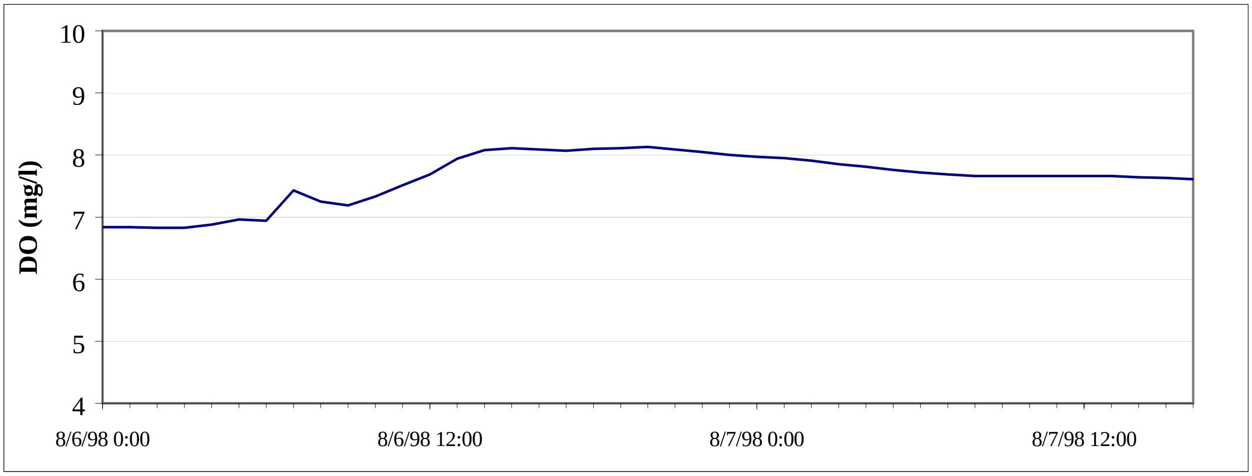
1. A small DO sag is predicted and evident in the model results for about 10 miles downstream of the CSO basins. The DO sag tends to diminish, in part, due to the dilution of other wet weather inputs while moving downstream. Results for one of the model segments is are shown in Figure 5. Since the modeled DO sag follows an initial rise in DO and is fairly small, the low point of the sag never falls below the pre-event DO value, or below the 5 mg/l DO Standard. Since the in-stream $CBOD_5$ concentrations in the

Figure 5

Main Rouge River Model Results at Segment 5







model are generally higher than those measured, the actual DO sag would be even smaller than predicted with the model.

2. In the model the DO sag is clearly visible at the two key continuous DO monitoring sites downstream of the basins. This verifies that the monitoring sites were appropriately selected to detect any actual DO sags that might occur, although not necessarily the minimum DO sag.

3. At the most downstream site, the timing of the model DO sag and the corresponding stream flow compare well to previously measured stream flows at this site and corresponding DO sags caused by uncontrolled CSOs.

4. In the first few miles downstream of the basin, what appears to be a DO sag in the model is primarily caused by the basin effluent DO concentrations being lower than ambient concentrations. However, as distance from the basins increases, exertion of CBOD becomes the primary factor.

Monitoring Results for Redford CSO Basin

As shown in Table 2, A total of 15 overflow events occurred at the Redford CSO basin during the evaluation period. Three of the nine events involved rainfall volumes and hourly intensities in excess of the 1-year, 1-hour facility design storm. Basin effluent data were collected during each of the 15 events and selected results are included in Table 2. Complete basin monitoring results are included in basin evaluation reports submitted to MDEQ.

Continuous DO data were collected on the Upper Rouge River during the five Redford CSO basin overflow events which occurred between May and October of 1998-99. These data were collected at one site upstream of the Redford CSO basin, and one site downstream. As with the Main Rouge, the continuous DO data at the downstream site were analyzed to calculate the DO response at each DO meter. However for some events, the river DO response involved an initial rise in DO concentration followed by a drop to below the pre-event DO concentration. An example is shown in Figure 6 for the 6/12/99 event. For this example, the primary change in DO was considered to be +2 mg/l, with the secondary change in DO being –2.5 mg/l. Several key results are summarized below:

1. The results in Figure 7 show that at the meter downstream of the basin, the primary DO response to every wet weather event was an increase in DO, however three of the five events had a secondary drop in DO to concentrations below the State standard. After further analysis it was shown based on time of travel and recorded basin overflow times that the DO drops could not have been caused by effluent from the Redford basin.

2. For all events with continuous in-stream monitoring, treated effluent from the Redford CSO basin never caused the in-stream DO to fall below the 5 mg/l DO standard at the downstream DO meter. (A DO sag caused by the basin would probably be more

Table 2
Redford CSO Basin Overflow Events and Effluent Data

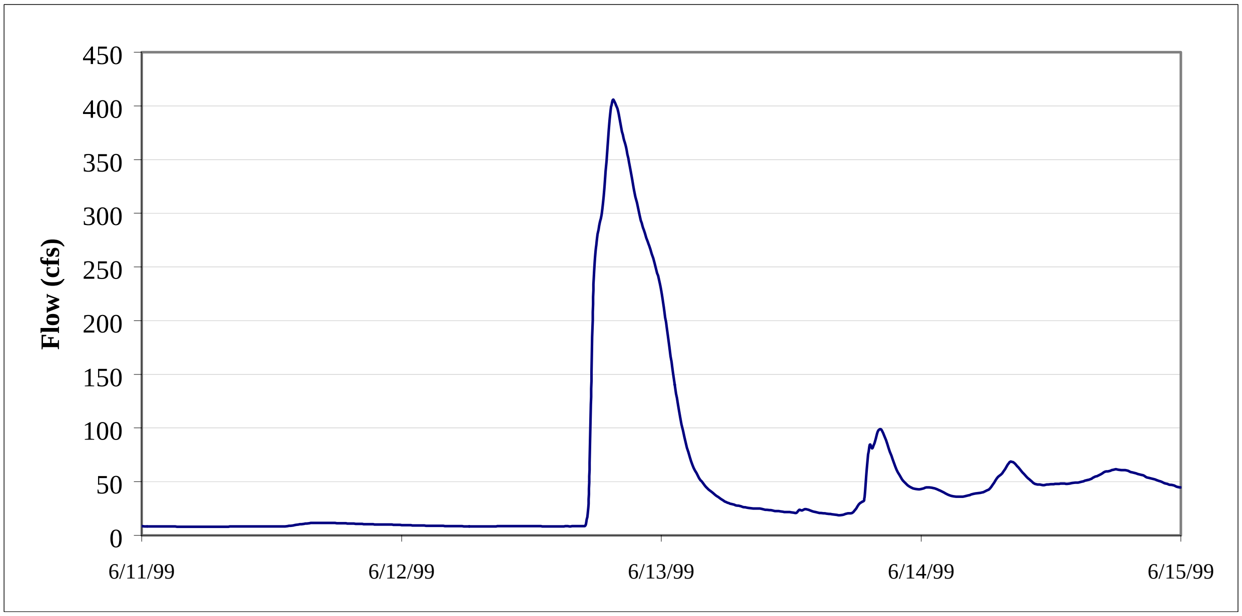
Event Date	Total Rainfall (in)	Overflow Volume (MG)	Effluent $CBOD_5$ Range (mg/l)	Effluent DO Range (mg/l)	Effluent NH_3 Range (mg/l)
6/16/97	0.63	0.10	-----	-----	-----
7/2/97	1.75	8.58	15 - 31	6.1 - 9.0	0.57 - 1.4
7/26/97	0.82	0.16	-----	-----	-----
9/10/97	1.71	0.99	12 - 31	6.0 - 9.4	0.86 - 1.6
1/7/98	0.21	0.79	13 - 25	5.5	0.60 - 0.72
2/17/98	2.42	23.42	2.1 - 53	7.7 - 12.0	0.11 - 3.0
3/9/98	1.05	3.48	12 - 17	8.2 - 8.8	0.62 - 0.85
4/9/98	1.21	0.90	15 - 20	8.5 - 8.6	0.85 - 1.00
8/6/98	3.42	5.92	<2.0 - 25	8.1 - 8.6	0.54 - 1.7
10/7/98	1.86	0.42	11 - 32	6.5 - 9.4	1.7 - 11
1/22/99	1.06	0.23	<2.0 - 12	-----	1.6 - 2.0
4/22/99	1.23	4.86	6.9 - 22	7.8 - 15.0	0.8 - 1.9
6/12/99	2.46	2.07	-----	-----	-----
6/27/99	2.01	0.50	33 - 35	6.2 - 6.5	1.1 - 1.2
6/28/99	0.70	0.05	-----	-----	-----

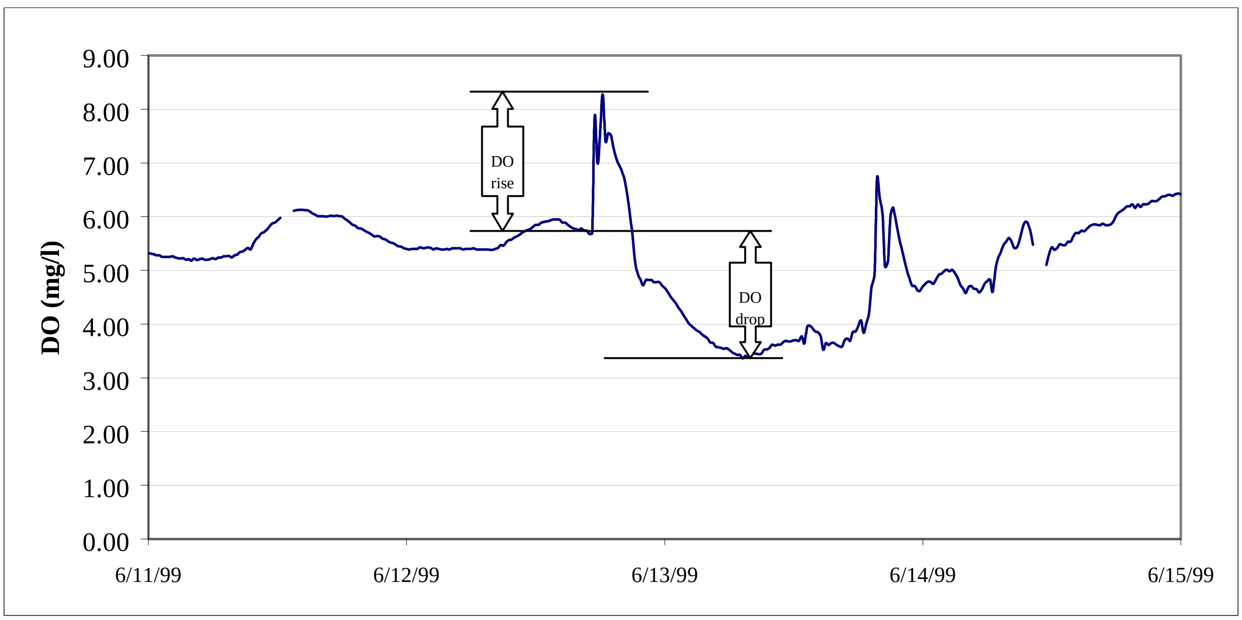
significant at points farther downstream. This can not be demonstrated with DO monitoring due to the presence of other uncontrolled CSOs. Instead, a predictive water quality model will be developed similar to the one developed for the Main Rouge River to assess if any DO sag will occur farther downstream of the Redford CSO basin.)

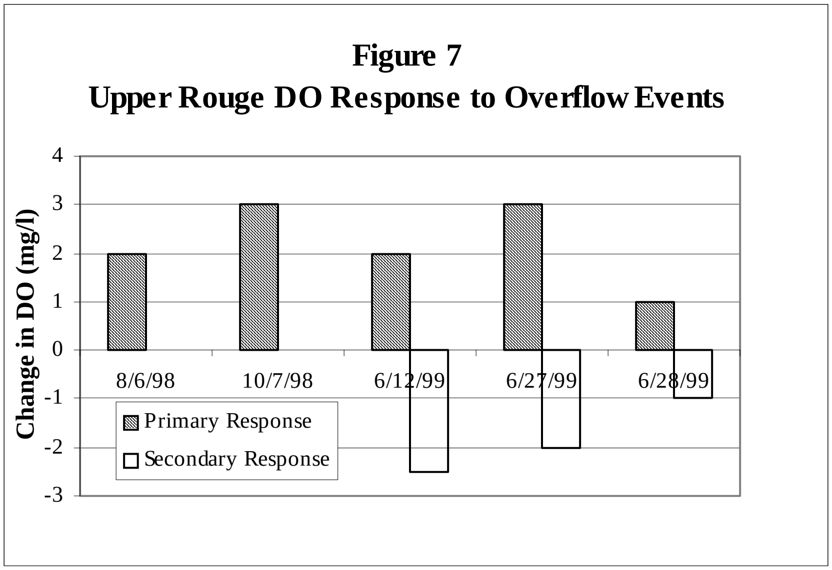
3. During several CSO basin overflow events, DO sags and violations occurred which were clearly not attributable to effluent from the CSO basin. DO sags also occurred upstream and downstream of the Redford basin during 17 non-overflow events, with DO falling below the standard for more than half of these events. These instances point to the presence of other unknown sources such as SSOs.

Figure 6

Upper Rouge River DO Response at 5 Mile Road - 6/12/99 Event







Water Quality Trends

Before implementation of the LTCP began in 1994, the DO standard was frequently exceeded in CSO-impacted reaches of the Rouge River and its tributaries. Implementation of the Phase I CSO control projects and other watershed management measures has resulted in significant improvement in river conditions. In river reaches now free of uncontrolled CSOs, exceedances of the DO standard have been eliminated except for those caused by SSOs or illicit connections, which will soon be eliminated.

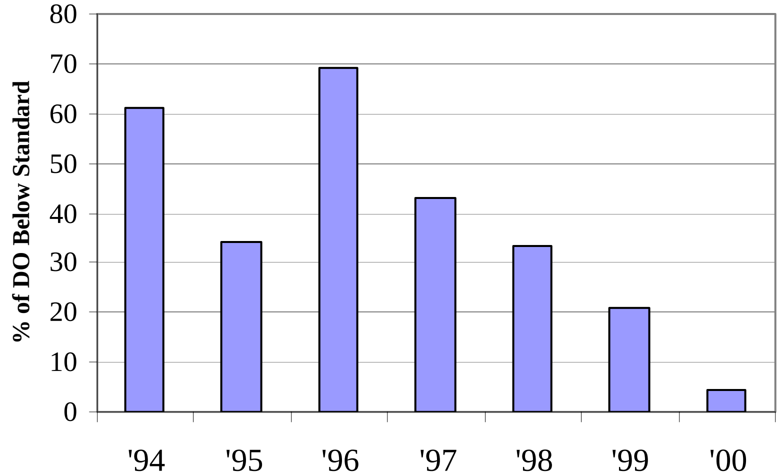
While the continuous DO data collected since 1994 have been an imporant part of the CSO evaluation, they are also revealing long-term trends of improving water quality. These trends are even evident in areas with significant remaining uncontrolled CSOs upstream. As shown in Figure 8, on the Lower Rouge River the percentage of continuous DO data below the State DO standard dropped from nearly 70 percent in 1994 to 4 percent in 2000. The improvements can be attributed to upstream CSO control projects and a variety of other watershed management measures and changes.

CONCLUSIONS

1. Work groups have reached consensus with MDEQ that the first six CSO basins evaluated are meeting the Phase II goal of protecting public health and eliminating raw sewage. They have also concluded that the first three CSO basins, and the partial evaluation of a fourth basin completed to date, are achieving MDEQ-defined criteria for achieving water quality standards at times of discharge, except for meeting the TRC standard yet to be evaluated.

2. CSO basins can be significantly smaller than required by the State's presumptive criteria, and if operated and maintained properly, can result in the attainment of water quality standards. While compliance with the water quality standards for TRC has yet to be evaluated, this is not an issue that affects the sizing of CSO basins.

Figure 8
Lower Rouge River DO Improvement
at Military Road



3. The implementation of the demonstration approach to CSO control has been a tremendous success and resulted in hundreds of millions of dollars in savings compared to the cost of the presumptive approach.

4. A combination of monitoring and predictive modeling is serving as a valuable tool in demonstrating that the state DO standard is being met downstream of CSO basins. While such efforts carry a cost, it is easily justified compared to the potential savings when using the demonstration approach to CSO control. The monitoring may have a secondary benefit of revealing other pollution sources such as SSOs and illicit connections, as was found at both locations evaluated by the Rouge Project.

5. If the quality of an uncontrolled CSO can be adequately characterized, the data could be used with the modeling approach described herein to predict the basin size required to meet the DO standard for given design storm events.

6. The evaluation of the Phase I CSO control facility is providing valuable information for use in sizing future CSO control facilties in the Rouge watershed and other communities.

ACKNOWLEDGEMENTS

The Rouge River National Wet Weather Demonstration Project is funded, in part, by the United States Environmental Protection Agency (EPA) Grant #X995743-01, 02, 03, 04 and 05 and #C995743-01. The views expressed by individual authors are their own and do not necessarily reflect those of EPA. Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official EPA approval, endorsement, or recommendation.

REFERENCES

Hubbell, Roth & Clark, Inc. (2000) Retention Basin Evaluation for the Acacia Park CSO RTB.

Hubbell, Roth & Clark, Inc. (2000) Retention Basin Evaluation for the Birmingham CSO RTB.

Hubbell, Roth & Clark, Inc. (2000) Retention Basin Evaluation for the Bloomfield Village CSO RTB.

Kaunelis, Vyto, C. Johnson, and E. Kluitenberg. (2000) Evaluation of In-stream Impacts of CSO Control Facilities, *WEF Watershed 2000*.

Rouge Stream Data Committee (2001) Rouge Stream Data Committee Interim Report.

Wade-Trim/Associates (2000) CSO Basin Evaluation Report – Township of Redford Retention Basin, Interim Final Report.