PAPER 5

Analysis of the City of Lima RTC System

by

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ANALYSIS OF THE CITY OF LIMA REAL TIME CONTROL SYSTEM UTILIZING A STATE OF THE ART HYDRAULICS COMPUTER MODEL

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INTRODUCTION

The City of Lima, located in northwest Ohio, operates one of the most sophisticated real time control (RTC) systems in the United States. This system, designed in the early 1980s by Floyd Browne Associates and EMA, was designed to utilize available in-system storage to mitigate combined sewer overflows and the subsequent water quality impacts on the Ottawa River (the major receiving water for the City). Recently, due to more extensive combined sewer overflow regulations imposed by the Environmental Protection Agency (EPA), the City of Lima contracted Montgomery Watson to assist them in the development of a Combined Sewer Operational Plan and a Long Term Control Plan (LTCP). The purpose of this two phase study is to develop a comprehensive plan that will satisfy both the Nine Minimum Control and LTCP requirements currently imposed by the EPA.

As part of completing the LTCP for the City of Lima, a computer model is being utilized to develop a complete understanding of the existing collection system hydraulics, and is also being used to evaluate alternatives for achieving compliance with regulatory requirements. Due to the complexity of the City's collection system, the model selected for this analysis is Hydroworks, which provides the capability to analyze real time control systems. Hydroworks, developed by Wallingford Software of the United Kingdom, is a fully dynamic hydraulics model that contains a module specifically developed to analyze RTC systems. Historically, RTC systems have been designed and implemented without the use of a computer model, typically resulting in the need for significant trial and error testing in the field to establish final operational control rules. Having the capability to develop a computer model of RTC systems provides many distinct advantages, one of which includes testing operation control strategies on the computer prior to final design and field implementation. To date, the core part of the City of Lima's RTC system has been successfully modeled using Hydroworks.

SYSTEM OVERVIEW

The first step in the analysis of the City's existing RTC system was to establish a comprehensive understanding of the collection system hydraulics and operational control rules on paper. This was accomplished through field reconnaissance, staff interviews, review of the computer control system, and review of all relevant drawings and system documentation.

Figure 1 provides an overview schematic of the City's RTC system. The system consists of both a separate sanitary and a combined sewer system. The flows from the separate sanitary system drain to the combined sewer system in all cases (typically via a pump station). The combined sewer system serves the older areas of the City, and comprises approximately 1500 ha (3600 acres). Flows in the combined sewer systems drain through a series of laterals and trunks and eventually converge at the Ottawa River Interceptor. Flow in the Ottawa River Interceptor is conveyed to the Baxter Street Lift Station, where it is lifted through the screw pumps to parallel gravity sewers that convey the flow to the wastewater treatment plant.

As can be seen on Figure 1, the RTC system essentially consists of 14 control structures, including the Baxter Street Lift Station, which incorporate both static and dynamic hydraulic control devices. The RTC system can utilize up to 34,000 m^3 (9,283,000 gallons) of available in-system, which is sufficient to hold a design rainfall of about 7.5 mm (0.3 in) without overflowing to the river. The following summarizes the operational objectives of the RTC system:

- Minimize upstream in-system flooding
- Fully utilize available in-system storage prior to spilling at CSO
- Equalize dry weather flows to WWTP

- Minimize RTC gate operations
- Measure CSO discharge to receiving water

The RTC control structures are located within the combined sewer trunk system and along the Ottawa River Interceptor. Three of the structures located in the interceptor, the Lovers Lane, Central Avenue, and McDonel Street control structures, consist of motor operated gates that control flow in the interceptor and discharge of CSOs to the Ottawa River. Flows in the interceptor are controlled by a motor operated sluice gate located at the downstream end of the structures. These sluice gates can be lowered to throttle flows in the interceptor, essentially creating a backwater conditions to utilize available storage upstream of the structure. CSO discharges from the interceptor to the Ottawa River are controlled by motor operated gates that behave as variable weirs. These variable weirs are used to control the timing and rate of CSO discharges during wet weather conditions. Flows in the interceptor are also controlled at the Baxter Street Lift Station with two motor operated sluice gates. Two other structures located on the interceptor, the Heindel Street and Collett Street control structures, contain variable weirs for control of CSO discharge to the receiving water but no interceptor sluice gates. The remaining gate and weir structures, located in the combined trunk sewers, consist of motor operated sluice gates and static weirs for utilization of additional in-system storage.

The RTC system can be operated fully automated, fully manual, or some combination of both. Programmable controllers (SLCs) are located in each sewer system control structure. In each control structure located on the interceptor the sewage level, river level and gate levels are continuously monitored. Sewage level and gate positions are continuously monitored at all other control structures. The rate of flow is measured real time at the discharge of the Baxter Street Lift Station and Collett Street Trunk Sewer. All information collected by the monitoring system is fed back to the central programmable controller (PLC), located at the WWTP, via a radio-based SCADA system.

Each remote SLC has control over gates in the structures. The normal operational mode is for the SLC to position the control gates based on system-wide information received from the PLC. If communications fail between these structures, the SLCs will control the gate positions based on local data only, and will give operational priority to the prevention of in-system flooding.

The operation of the RTC system is comprised of the following three control modes:

Mode 1 -	Dry Weather Equalization
Mode 2 -	Wet Weather
Mode 3 -	Dewatering

In Mode 1 (dry weather equalization mode), the operational objective is to dampen dry weather flow diurnal variations to the WWTP. This is achieved by closing one of the Baxter Street Lift Station sluice gates, which control the amount of flow allowed to enter the screw pump wet well, and modulating the other to maintain a constant flow to the WWTP. Because flow can get to the WWTP through either the Baxter Street Lift Station or the Collett Street Trunk Sewer, modulation of the sluice gate is controlled by summing the flows monitored at these two locations to ensure that only average dry weather flow is delivered to the WWTP at all times. During Mode 1, flows in excess of average dry weather flow are stored behind the Baxter Street Lift Station (typically during the day), and are drained back to the WWTP when dry weather flow is below average (typically at night time).

In Mode 2 (wet weather mode), the operational objective is to maximize the use of all available in-system storage during wet weather conditions prior to discharge of combined sewage overflows. This is achieved by throttling flows with the variable sluice gates, both in the interceptor and trunk sewers, while maintaining maximum allowable flows to the WWTP. Each control structure has an associated storage volume assigned to it based in the original backwater computations. The sluice gates are throttled in such a manner that each structure reaches its 100% storage mark simultaneously. The wet weather mode can be invoked automatically by one of the following measured parameters:

- Rate of rise of sewage within the collection system
- Sewage level at control structures

The wet weather mode can also be invoked manually by the system operator when a significant rainfall event has begun or is anticipated.

Each control structure has an assigned control water surface elevation. This elevation designates the safe allowable level of sewage to ensure that in-system flooding does not occur during Mode 2. The variable weir gates that control CSO discharges are usually parked at this elevation such that CSO discharge begins to occur when the sewage levels reach this point. If sewage levels continue to rise above the control elevations, the RTC system will lower the weirs to keep the hydraulic grade line within safe limits. Each control structure has multiple weirs to provide a redundancy in case any one gate fails to move.

During Mode 2, flows to the WWTP are increased by the control at the Baxter Street Lift Station. Ramping of flows to the WWTP occurs and is controlled by the monitored percent utilization of the total system storage. Therefore, if 50% of the total system storage has been utilized, the RTC system will set the Baxter Pumps at 50% capacity (using the influent wet well sluice gates for control). Ramping of flows to the WWTP during wet weather is to prevent a rapid flux in loading to the primary treatment processes.

The automated control will allow the RTC system to leave Mode 2 if one of the following conditions are met:

- The system has not been manually forced into Mode 2 by the operator
- The overall system rate of rise has been below the threshold for at least three minutes
- No independent control structure requires Mode 2 due to a monitored sewage level

In Mode 3 (dewatering mode), the operational objective is to systematically drain the stored wet weather flows such that accumulated solids are flushed to the WWTP. Mode 3 occurs after Mode 2 is fully completed. While in dewatering mode, the control system continually checks for the return of wet weather conditions and will return the system to Mode 2 if any of the wet weather mode criteria are met. While in Mode 3 the system will dewater in a sequenced manner, starting from the downstream end. When the Baxter Street Lift Station has drained the lowest portion of the system storage (below 30% utilization), the McDonel Street control structure will set its interceptor sluice gate to the fully open position, thus draining that portion of the system storage and flushing the accumulated solids. This system will continue to drain in this sequence (moving upstream) until the system has been fully dewatered and returns to Mode 1.

COMPUTER MODEL ANALYSIS

The Hydroworks model was applied to analyze the existing collection system hydraulics, including the RTC system, and to develop alternatives for additional mitigation of CSOs. Hydroworks, a fully dynamic hydraulics model developed by Wallingford Software of the U.K., has been in use in the United Stated for over two years. The model includes a very robust engine for complex hydraulics analysis that can be coupled with a module for real time control analysis and another module for the analysis of sewer system sediments. To date, the core part of the City of Lima's RTC system has been modeled and the operational control modes have been tested with calibrated dry weather flows and synthetic wet weather hydrographs.

The first step in developing a computer hydraulic model of the City's collections system was to establish an appropriate link-node representation and system topology. Hydroworks uses the link-node concept to establish the basic hydraulic conveyance parameters. Within Hydroworks, links are used to represent pipe segments from manhole to manhole, as well as hydraulic control structures including pumps, weirs, and gates. In the case of hydraulic control structures, the links are established as "control links" and the user can then specify the specific nature of each control link (e.g. a variable sluice gate, a screw pump, etc.). The fundamental coordinate data and system connectivity were then transferred to the Hydroworks environment using a predefined format ASCII file.

The next step in the model building process was to collect and enter all relevant sewer system attribute data, including information for each sewer system hydraulic control structure. Figure 2 is a graphical representation of the attribute data input environment within Hydroworks. This particular figure shows some of the hydraulic control links (e.g. variable sluice gates and variable weirs) and the required attribute data for these links. The environment has the look and feel of a spreadsheet, but provides on-line help and guidance for data entry. In the case of head loss coefficients and other common hydraulic parameters, the on-line help provides information on the selection of the proper attribute data. The user also has the option to enter and/or edit attribute data graphically selecting links and nodes in the plan view image. Figure 3 shows a plan view image of the Lima system model. In this figure, the user has selected a variable sluice gate control link for purposes of editing the attribute data.

In the case of the City of Lima's RTC system, the following attribute data was required for the variable sluice gates and weirs within the control structures:

Variable Sluice Gates

- Invert level at gate
- Gate width
- Discharge coefficient
- Initial opening
- Minimum opening
- Maximum opening
- Opening speed (m/s)
- Closing speed
- Minimum operation threshold (mm)

Variable Weirs

- Initial crest elevation
- Weir width
- Discharge coefficient
- Minimum crest elevation
- Maximum crest elevation
- Rising speed (m/s)
- Falling speed (m/s)
- Minimum operation threshold (mm)

In terms of the RTC operational logic, the two critical gate and weir parameters are the speed and minimum operational threshold. The gate and/or weir travel speed, specified in units of meters per second, dictates how fast the control can move, and thus how fast the system can react to variable hydraulic conditions. Many failures of RTC systems are the result of the fact that the system could not quickly react to rapidly changing conditions (e.g. wet weather flow in a combined sewer system). In the case of the City of Lima's RTC system, the travel speed is dictated by the motors and drive mechanisms used to move the gates and weirs. The minimum operational threshold defines the minimum distance that the gate and/or weir must move before the RTC control will actually reposition it. This parameter essentially prevents the hydraulic control from constantly moving (referred to as "hunting" in the RTC industry).

After completing the attribute data entry process, the next step in the modeling process was to define the RTC operational control rules using the Hydroworks RTC module. The data entry environment for the Hydroworks RTC control module is very similar to the attribute data entry environment. The user is prompted to enter required data in specific locations and can access on-line help at any point in the data entry process. Operational control rules can be defined for any of the variable hydraulic control elements in the modeled system. The rules defined in the RTC module are related to specific model elements through the unique ID numbering scheme defined by the modeler. RTC control rules can be defined for any of the model control links including pumps, variable weirs, and variable sluice gates.

Operations control rules are defined in the RTC module using the following four basic building blocks:

- *Ranges* - Ranges are used to define boundary, or trigger points, at which operational control rules can be activated. Ranges can be defined at any location in the modeled system and can be set to look at a variety of parameters including flow, velocity, depth, rate of change in depth, gate positions, etc. In the case of Lima dry weather Mode 1, a range based on flow was set for the influent pipe to the WWTP and was used to define the activation point of the sluice gate controlling flow to the pump wet well.

- *Logic Statements* - Logic statements can be used to combine multiple ranges such that more than one condition must be met before an operational control is activated. The rules are structured using basic logical operators (e.g. and, or, not, nand, etc.)

- *Controllers* - Controllers are used to define which hydraulic structures will be controlled and in what fashion they will be controlled. Within Hydroworks, the modeler can choose to control hydraulic elements using incremental controllers or proportional/integral/differential (PID) controllers. Using and incremental controller, the modeler must define the increment at which variable hydraulic control structures are adjusted each time the operational control rule is activated, and also the frequency at which the controller can be activated. In the case of Lima's RTC system, the hydraulic control elements are operated using PID logic. When using a PID controller, the modeler must define the range and/or logic statement what activates the controller, the time interval at which ranges and logic statements should be checked (which relates to the RTC system monitoring frequency), and the appropriate coefficients utilized in PID algorithms. PID coefficients for Lima's RTC system were obtained from documentation of the City's computer control system.

- *Rules* - Rules are used to establish the set points for which the PID controllers will control. In the case of Lima's dry weather equalization mode, the set point was the average dry weather flow measured at the WWTP influent pipe. Using incremental controllers, the rules are used to define the increment at which hydraulic structures will be adjusted every time the operational control rule is activated.

When all of the RTC operational control rules have been defined, the modeler is ready to begin testing the control rules under a variety of flow regimes. Based on the experience with the Lima study, it is strongly suggested that the modeler build and test the RTC rules one step at a time. The RTC file can get very large very quickly, and the debugging process is quite difficult, if not impossible, if the modeler is unsure of any individual operational control rule. In the case of Lima's RTC system, the development of the RTC rules were phased around the three operational modes (dry weather equalization, wet weather, and dewatering).

RESULTS

To date, the core part of Lima's RTC system has been modeled successfully. Upon completion of the RTC operational control rules for the dry weather equalization mode, the model predicted that the Baxter Lift Station sluice gate will modulate or "hunt" at an undesirable rate. During dry weather flow, the model showed a saw-tooth hydrograph bounding about average dry weather flow at the point where flow enters the WWTP. Figure 4 shows this saw-tooth hydrograph. Detailed analysis showed that the sluice gate was too large to modulate dry weather flow at average within an acceptable limit of gate activity. Conversations with the City of Lima's operational staff confirmed that this gate does in fact modulate at an unacceptable rate, and that this action has caused the gate motor drive assembly to fail at an unacceptable rate (usually the result of worn bearings). This confirmation provided an initial calibration basis for the dry weather operational control rules defined in the model.

RTC rules for the wet weather and dewatering modes have also been completed. Although these results have not yet been calibrated against flow monitoring data, the model is predicting gate activity similar to what is documented in the field. The RTC rules will continue to be refined as the calibration/validation process continues. Figure 5 shows a profile view of the system in wet weather mode. The hydraulic grade line is at the point where each control structure has achieved it 100% storage mark, and CSOs are just beginning to discharge to the receiving water.

The calibrated model of Lima's existing RTC system will be used as a foundation for assessing capital alternative for additional mitigation of CSOs. As part of the study, a detailed receiving water quality model is also being developed such that the impacts of reduced CSO loads can be defined and compared to the desired receiving water quality objectives. The results of the collection system and receiving water quality models are scheduled to be completed in late 1996.

CONCLUSIONS

The following us a summary of conclusions from the City of lima RTC system modeling based on the work completed to date:

- Analysis of RTC system adds a significant degree of complexity to dynamic hydraulic modeling. Modelers who work in this are should have a high level of understanding of the theory and practical realities of complex hydraulics. With the addition of variable hydraulic control elements, model instabilities are much more difficult to identify and resolve. Fortunately, the hydraulic engine of Hydroworks is very robust and model instabilities are rare, provided the user has input reasonably accurate attribute data.

- One of the distinct advantages of Hydroworks is the ability to model complex hydraulic elements as they exist and not being forced to model the hydraulic equivalent of the element. The practice of modeling hydraulic equivalents is fairly common when dealing with dynamic models that easily go unstable. The inherent danger is when the modeler defines a modeled equivalent that is not truly equal, or incorrectly assumes that the modeled element is hydraulically equivalent under all flow conditions. Minimizing the number of hydraulic equivalents provides for a much more robust model.

- RTC systems, and the ability to analyze them with computer models, provide the means to fully explore the optimal utilization of existing collection system infrastructure, such as in-system storage. In many cases engineers write off such alternatives as in-system storage or strategic diversions because of a limited ability to assess the concepts of RTC. As in the case of Lima, RTC has provided an extremely cost effective means to mitigate the impacts of CSOs on receiving water quality.

- Computer models that are capable of analyzing RTC systems, such as Hydroworks, provide engineers with a very powerful tool for analyzing this technology as an alternative for mitigation of collection system problems. These models also provide engineers with the capability to fully optimize existing RTC systems by providing them with the ability to analyze multiple hydraulic conditions in a very short period of time. In many cases, RTC systems are implemented through trial and error testing that occurs in the field after systems are designed and constructed. Unfortunately, it is very difficult, if not impossible, to field test all of the multiple hydraulic conditions that occur in wastewater collection systems, Computer models capable of analyzing RTC systems provide the means to test many more scenarios and allow the engineer to modify designs before the systems are implemented. In the City of Lima, it is apparent that the addition of a smaller variable sluice gate at the Baxter Street Lift Station would provide the means to equalize dry weather flows with fewer operational problems (e.g. gate hunting). Although models capable of RTC analysis did not exist at the time this system was designed, subsequent model analysis has identified and confirmed this problem.

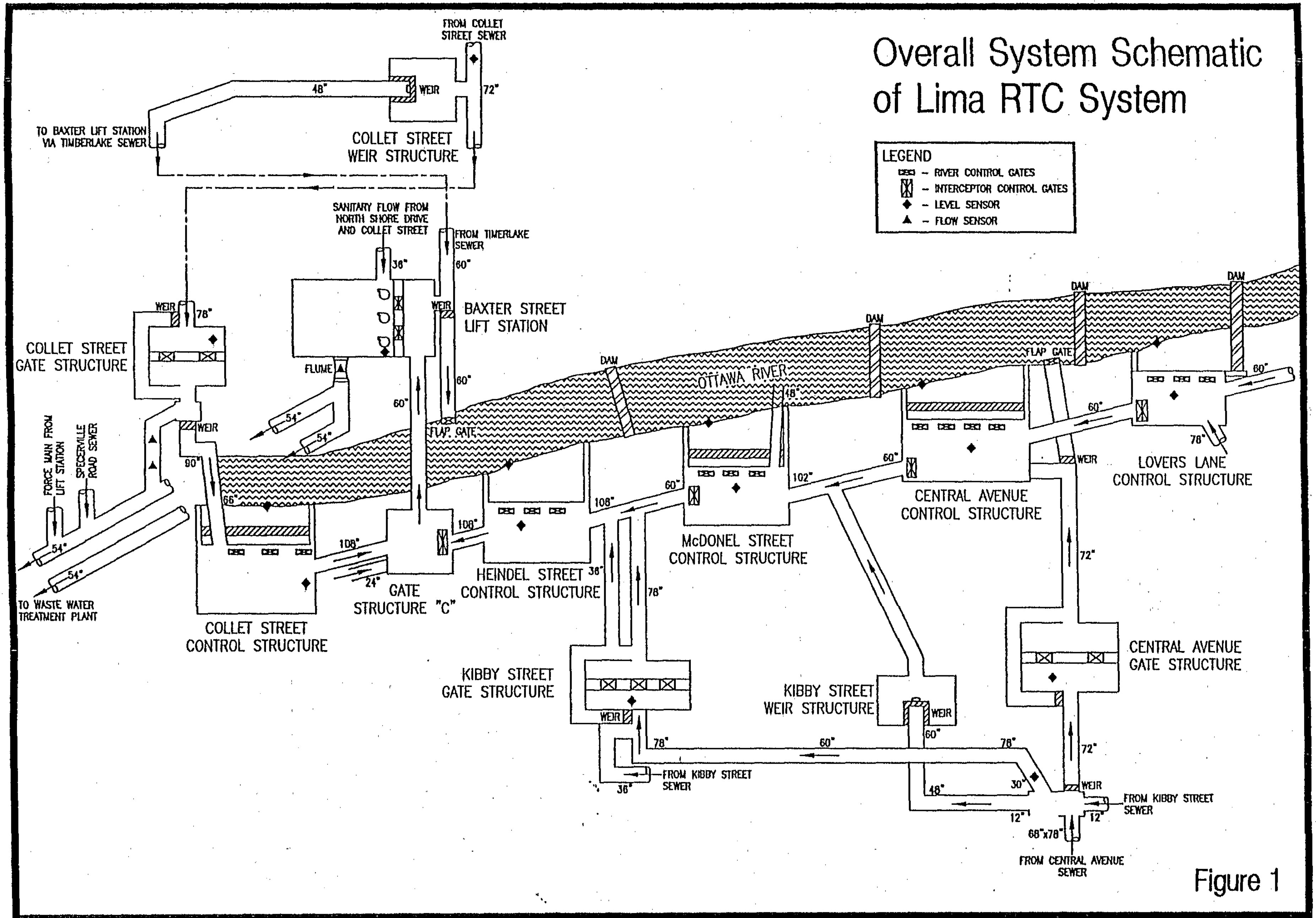

Overall System Schematic of Lima RTC System
LEGEND
– RIVER CONTROL GATES
– INTERCEPTOR CONTROL GATES
– LEVEL SENSOR
– FLOW SENSOR
FROM COLLET STREET SEWER
48"
WEIR
72"
TO BAXTER LIFT STATION VIA TIMBERLAKE SEWER
COLLET STREET WEIR STRUCTURE
SANITARY FLOW FROM NORTH SHORE DRIVE AND COLLET STREET
FROM TIMERLAKE SEWER
36"
60"
BAXTER STREET LIFT STATION
WEIR
78"
COLLET STREET GATE STRUCTURE
FLUME
54"
FLAP GATE
OTTAWA RIVER
DAM
FORCE MAIN FROM LIFT STATION
SPECERVILLE ROAD SEWER
90"
66"
108"
24"
TO WASTE WATER TREATMENT PLANT
COLLET STREET CONTROL STRUCTURE
GATE STRUCTURE "C"
HEINDEL STREET CONTROL STRUCTURE
McDONEL STREET CONTROL STRUCTURE
102"
CENTRAL AVENUE CONTROL STRUCTURE
LOVERS LANE CONTROL STRUCTURE
KIBBY STREET GATE STRUCTURE
KIBBY STREET WEIR STRUCTURE
CENTRAL AVENUE GATE STRUCTURE
FROM KIBBY STREET SEWER
30"
12"
66"x78"
FROM CENTRAL AVENUE SEWER

Figure 1

Hydroworks Attribute Data Input Environment

HydroWorks Workbench - [Edit : c:\lima\models\dsd\limapid.dsd]

File Edit View Project Model Tools Window Help

Record: 108 of 191 Record Insert: Manual Typing Mode: Ins

Field: 3 of 15 / Sluice gate type

		Link reference	D/S node	Gate type	Invert level	Width	Discharge coeff	Opening	Time delay	U/S set effic
101	Conduit	130_010.1	100_050	1001	CIRC	24				
102	Conduit	100_050.1	100_060	82	CIRC	72				
103	Conduit	100_060.1	100_070	384	CIRC	84				
104	Conduit	140_010.1	100_070	1001	CIRC	20				
105	Conduit	100_070.1	100_080	364	CIRC	84				
106	Conduit	150_010.1	100_080	1001	CIRC	78				
107	Conduit	160_010.1	100_080	1001	CIRC	12				
108	Sluice	100_080.1	LOVEGATI	VSGATE	93.110	5.000	1.50	1.001		
109	Weir	100_080.2	LOVEOUT	VCWEIR	109.514	16.496	0.85			
110	Conduit	LOVEGATI	100_090	240	CIRC	60				
111	Conduit	170_010.1	100_090	1001	CIRC	24				
112	Conduit	180_010.1	100_090	1001	CIRC	116				
113	Conduit	100_090.1	100_100	295	CIRC	60				
114	Conduit	190_010.1	100_100	1001	CIRC	24				
115	Conduit	100_100.1	100_110	259	CIRC	60				
116	Conduit	200_010.1	100_110	1001	CIRC	18				
117	Conduit	210_010.1	100_110	1001	CIRC	10				
118	Conduit	100_110.1	100_120	784	CIRC	60				
119	Conduit	220_010.1	100_120	1001	CIRC	48				

Start | HydroWorks Workbe... | Microsoft PowerPoint - [Pr... | 4:10 AM

Figure 2

Hydroworks Graphical-Based Editing

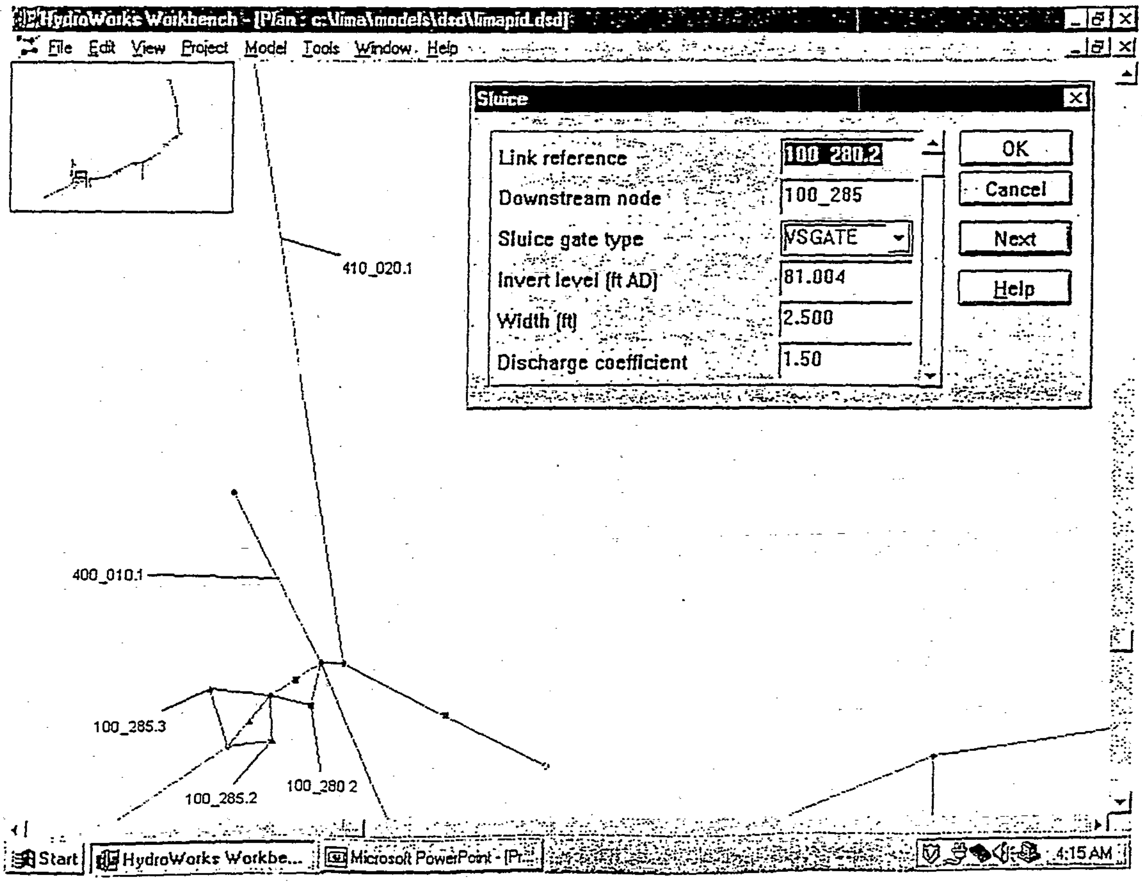


Figure 3

Results of RTC Dry Weather Equalization Mode Analysis

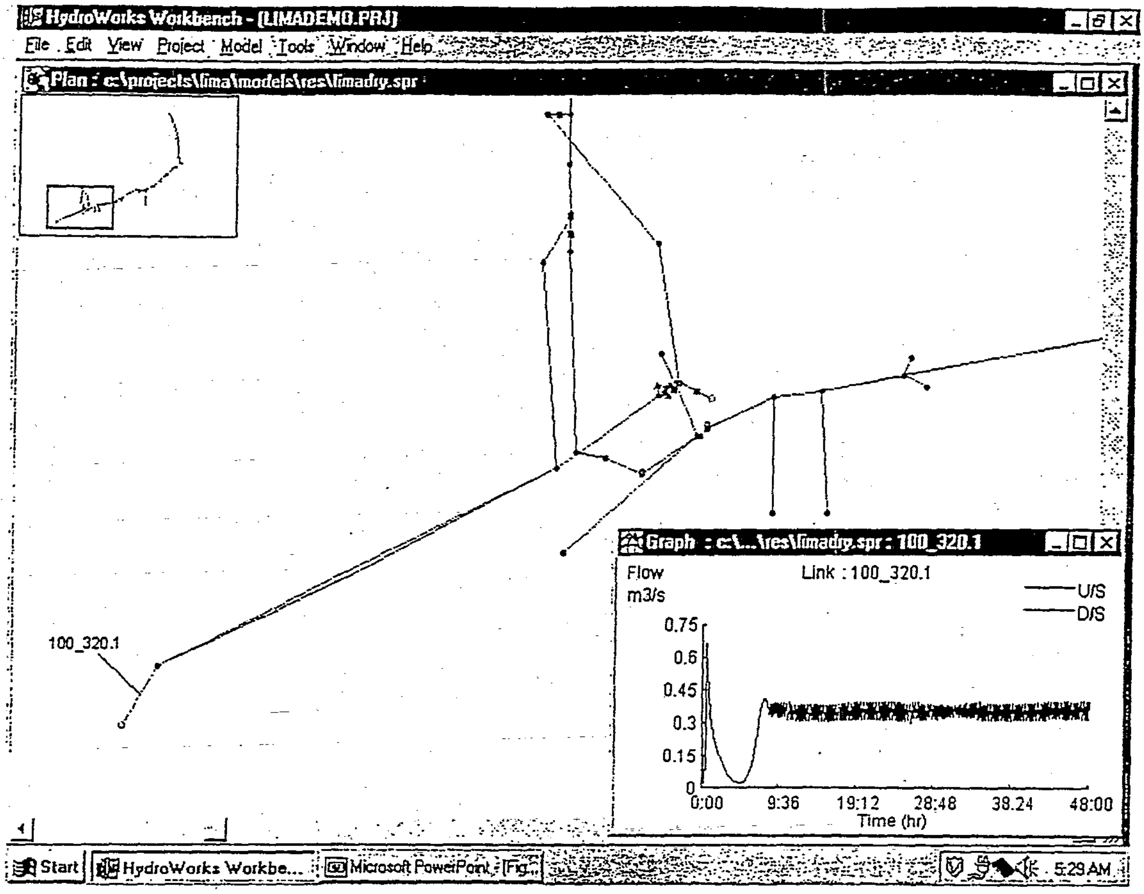
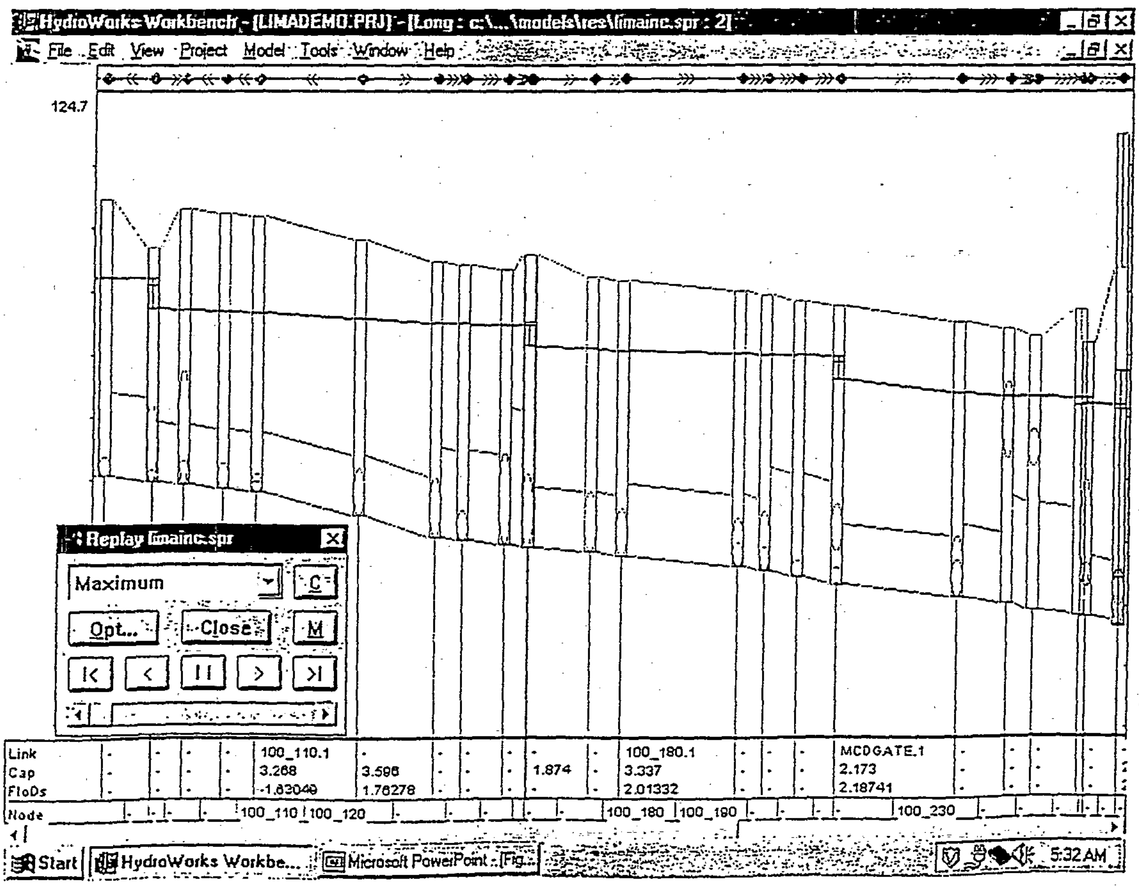


Figure 4

Results of RTC Wet Weather Mode Analysis



Figure