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Appendix 4-1: CSS Monitoring Program Workplan for Additional CSS Data Collection (April 2008)

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Buffalo Sewer Authority
Phase 2 Long-Term Control Plan

Combined SS Monitoring Program Workplan
Additional Combined Sewer System Data Collection

Prepared by:
Malcolm Pirnie, Inc.

April 2008

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1. Introduction

1.1. Project Background

A *System-Wide Long Term Control Plan for CSO Abatement* was prepared by the Buffalo Sewer Authority (BSA) and submitted to the New York State Department of Environmental Conservation (NYSDEC) in 2004. As part of developing and calibrating a planning-level collection system model to support development of the LTCP, BSA conducted a data collection program. This program included flow monitoring and rainfall monitoring from May 4, 2000 through July 21, 2000. A total of 85 flow monitors were installed throughout the BSA service area. Also, 21 rain gauges were utilized during this same period. Additional collection system model refinement has been suggested based on the NYSDEC and the United States Environmental Protection Agency (USEPA) review of the BSA LTCP.

The model refinement approach was developed based on discussions between the NYSDEC, USEPA and the BSA team. The refined model will be used to estimate CSO flows and volumes for the Receiving Water Model calibration as well as further evaluation of CSO control alternatives. Additionally, the refined model will support preliminary design analysis for the North District (Cornelius Creek) and the Scajaquada District (Scajaquada Tunnel/Delavan Drain/Bird St.) sewer discharge areas.

The model refinement effort will require additional precipitation and in-system flow monitoring. This Combined Sewer System Monitoring Program Plan (Plan) describes the approach that will be taken to collect sufficient additional system flow and rainfall data and defines the monitoring activities to be performed in support of the Collection System Modeling work.

1.2. Scope of This Plan

This Plan describes the locations, equipment and methodologies that will be used to gather flow and rainfall data for the BSA system. The discussion in this Plan includes:

- The flow and rainfall monitoring equipment that will be used.
- The locations of the flow and rainfall monitoring equipment to be installed.
- The duration of the flow and rainfall monitoring.

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2. CSS Monitoring Program

2.1. Introduction

The program includes the installation of meters to record depth and velocity of flows during both dry and wet weather and installation of rainfall monitoring gauges. The objectives of this program are as follows:

- Install depth/velocity meters (monitoring equipment that measures both depth and velocity) at select locations and maximize attempts to successfully measure both variables.
- Attempt to collect data for three qualifying rainfall events with depths equal to or greater than 0.5-inches.
- Install rainfall gauges to collect data concurrent with the flow monitoring program.

These objectives all support the underlying goal of the monitoring program, which is to collect sufficient data to provide further validation of the adequacy of BSA's planning-level collection system model at key system-wide control points. The data collected from this program will supplement the existing data gathered during the previous LTCP preparation efforts that has already been reviewed and used to calibrate/validate the collection system model. During the previous effort, all portions of the model were adequately calibrated to support planning-level applications.

This section describes the specifications and protocols to be followed for the monitoring program, including:

- Flow and rainfall monitoring equipment that will be used;
- Locations where equipment will be installed;
- Recording interval;
- Duration of flow and rainfall monitoring period;
- Programming and calibration requirements;
- Data retrieval and data storage protocols; and
- Maintenance frequency and procedures.

2.2. Flow Monitoring

Flow meters will be installed to record depth and velocity of flows during both dry and wet weather at 17 locations within the BSA system. Locations include both interceptor and trunk sewer installations as well as at overflows.

2.2.1. Flow Monitoring Locations

BSA has identified 17 flow meter locations based on a combination of many factors including:

- Historical knowledge of the system.
- The size of the upstream trunk sewer.
- The activity of the overflow locations.
- The location of previous meters.
- Modeling requirements.
- Selected areas for fast-tracked evaluations and preliminary design.

The following sections detail the preliminary selection of flow monitoring locations identified to support the collection system modeling efforts for this project.

2.2.1.1. Flow Monitoring for the North District (Cornelius Creek Area)

Two flow meters are proposed for placement within the North District to support the Cornelius Creek (CSO 055) evaluations. The meters are placed to capture the data required to validate the collection system model results from previous efforts. Figure 2-1 shows the CSO locations and the proposed monitoring locations. Table 2-1 identifies the monitoring locations in the North District.

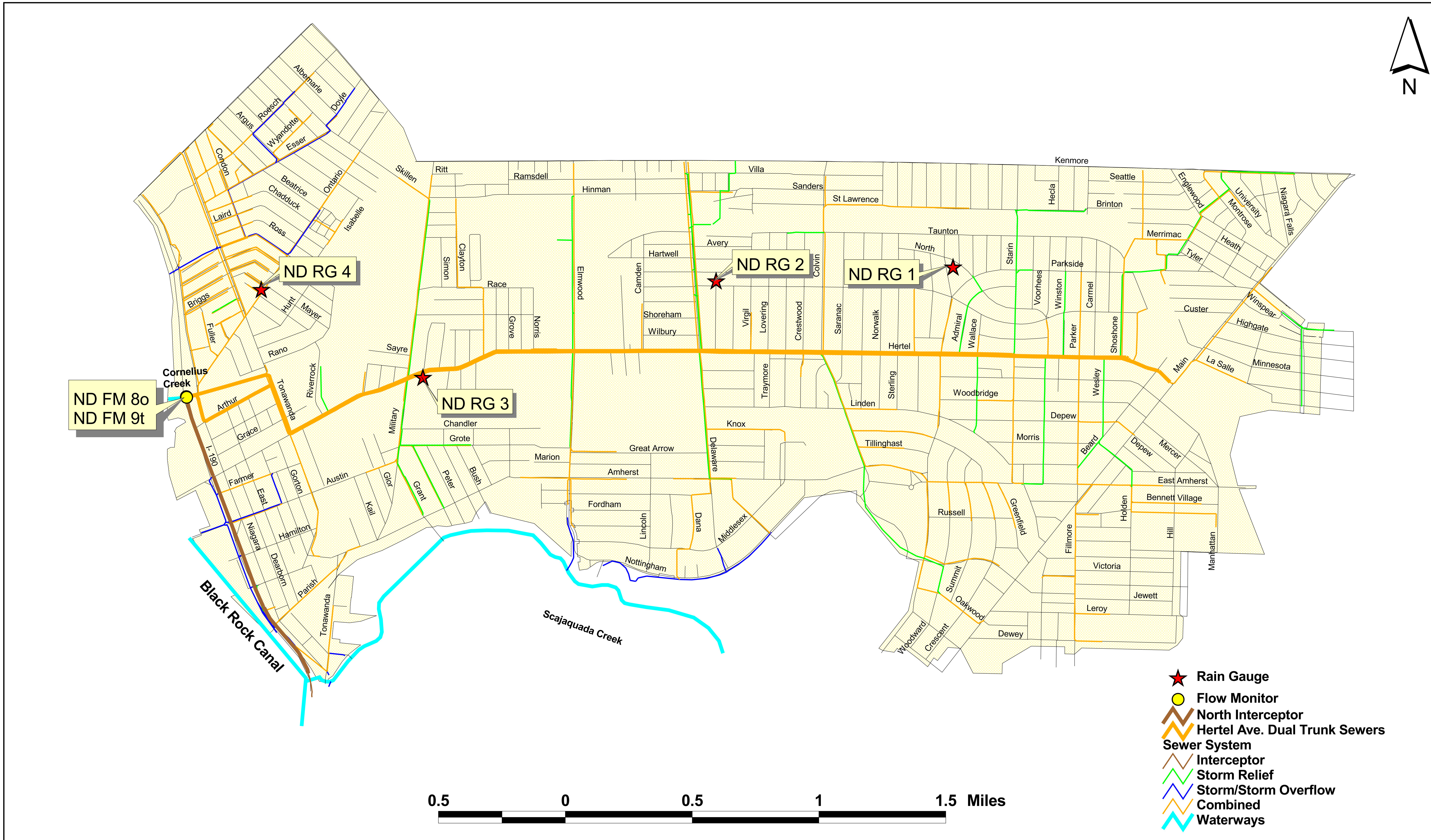
Table 2-1.
North District Monitoring Locations

Flow Monitoring Identification Number	Phase I Identification Number	Flow Monitoring Location	Comments
ND FM 8o	ND FM 8o	Cornelius Creek, Overflow, South Side	CSO 055
ND FM 9t	ND FM 9t	Ontario St. near Cornelius Creek, sidewalk	

Note: t = trunk, o = overflow

2.2.1.2. Flow Monitoring for the Scajaquada District

Ten flow meters are proposed for placement within the Scajaquada District to support Scajaquada Drain evaluations. The meters are placed to capture the data required to validate the collection system model results from previous efforts. Figure 2-2 shows the CSO locations and the proposed monitoring locations. Table 2-2 identifies the monitoring locations in the Scajaquada District.



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Phase 2 LTCP

FIGURE 2-1

Flow Monitoring and Rain Gauge Locations - North District

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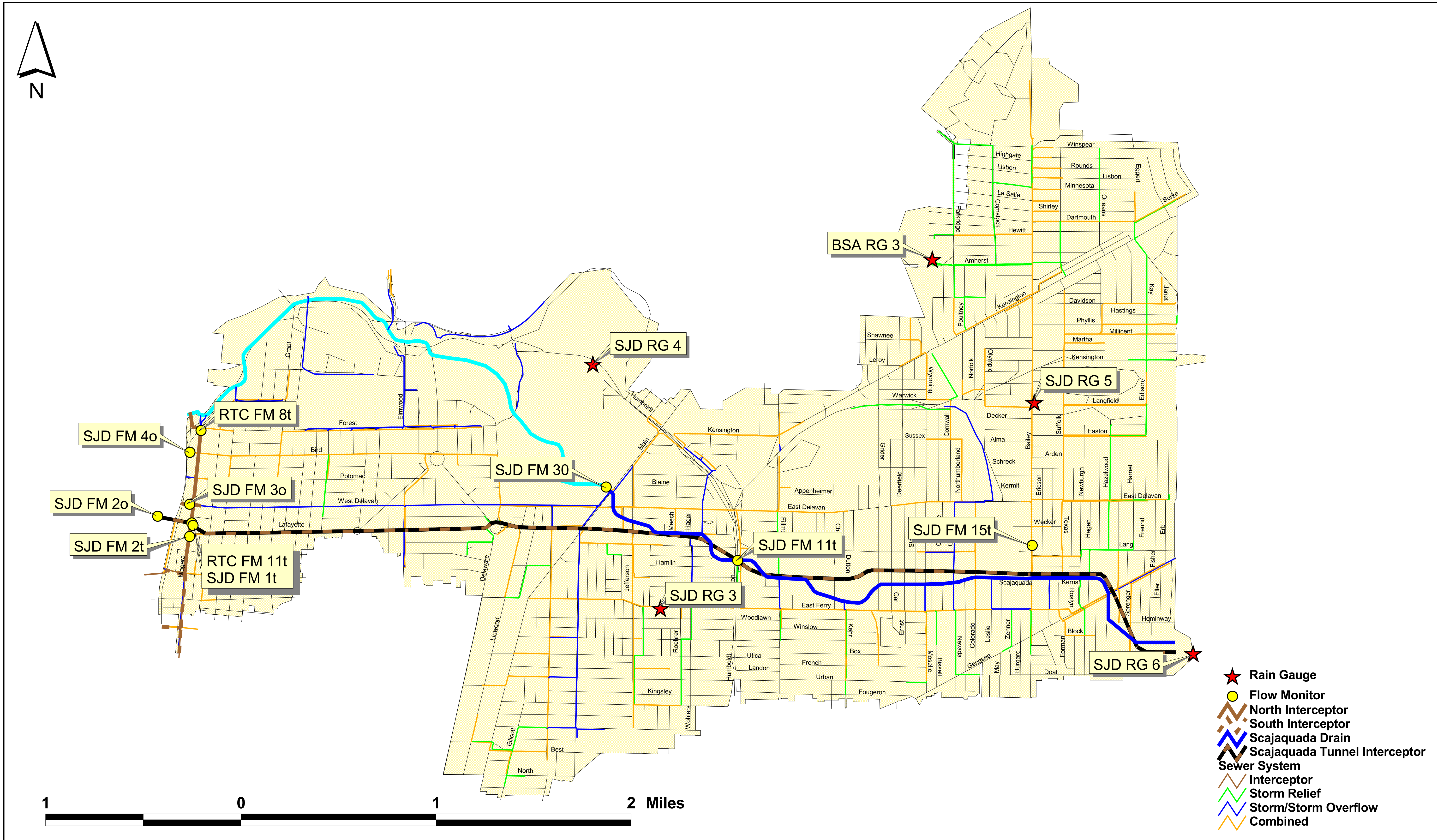

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Phase 2 LTCP

FIGURE 2-2
Flow Monitoring and Rain Gauge Locations - Scajaquada District

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Table 2-2.
Scajaquada District Flow Monitoring Locations

Flow Monitoring Identification Number	Phase I Identification Number	Flow Monitoring Location	Comments
RTC8t	RTC8t	North Interceptor, MH D/S of Forest Avenue	
SJD FM 4o	SJD FM 4o	Bird Avenue Overflow At Niagara St.	CSO 004
SJD FM 3o	SJD FM 3o	Delevan Drain Outfall	CSO 006
RTC11t	RTC11t	North interceptor – Brace and Niagara	
SCD FM 2o	SCD FM 2o	Overflow at Niagara Metering Station	CSO 008
SCJ FM 1t	NA	Inflow to Niagara Metering Station	New location
SCJ FM 2t	NA	North interceptor downstream of Niagara Metering Station	New location
SCJ FM 3t	NA	Scajaquada Drain – Downstream end	CSO 053 (Tentative)
SJD FM 15	SJD FM 15	Major overflow to Scajaquada Drain	New location
SJD FM 11	SJD FM 11	Major overflow to Scajaquada Drain	New location

Note: t = trunk, o = overflow

2.2.1.3. Flow Monitoring for South Central District

Five flow meters are proposed for placement within the South Central District to confirm calibration of BSA's planning-level collection system model at key system-wide control points. The meters are placed to capture the data required to validate the collection system model results from previous efforts. Figure 2-3 shows the CSO locations and the proposed monitoring locations. Table 2-3 identifies the monitoring locations in the South Central District.

Table 2-3.
South Central District Flow Monitoring Locations

Flow Monitoring Identification Number	Phase I Identification Number	Flow Monitoring Location	Comments
SCD FM 22o	SCD FM 22o	Smith Street	CSO 026
SCD FM 4o	SCD FM 4o	Albany Street	CSO 012
SCD FM 40o	NA	Hamburg Drain – D/S	CSO 017
SCD FM 41o	NA	Boone Street, West Outlet – D/S	CSO 028
SCD FM 42o	NA	Sloan Drain – D/S	CSO 066

Note: t = trunk, o = overflow

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Phase 2 LTCP

FIGURE 2-3

Flow Monitoring and Rain Gauge Locations - South Central District

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2.2.2. Flow Monitoring Specifications

The flow monitoring will be accomplished using site-specific monitoring equipment from various manufacturers, by the use of continuous monitoring devices incorporating a velocity sensor combined with a pressure depth sensor in order to quantify surcharge depths. The flow meters will collect flow velocity and depth at 5-minute intervals and will compute the flow rate based on the collected data and channel geometry. All data will be collected and verified weekly by the subcontractor for weekly transmittal to Malcolm Pirnie within one week after the data collection. The flow monitors will be checked every week to update flow data, obtain required calibration data, perform required maintenance, and assure proper operation. Flow monitoring data reduction and review will be performed on all data obtained from each flow monitoring location.

The flow meters will be installed by a flow monitoring subcontractor. Based on the preliminary review of the proposals from three subcontractors, GEOtivity Limited (GEOtivity) is tentatively selected for this work (pending review and approval by BSA). Flow monitoring subcontractor will be responsible for quality control of their meters which includes performing weekly calibration testing for depth and velocity as well as equipment maintenance. Flow monitoring subcontractor will be responsible for validation and verification of the depth and velocity data prior to delivery to Malcolm Pirnie.

The proposed monitoring locations will be field verified by the flow monitoring subcontractor for suitability for meter installation. Final monitoring locations will be identified and photographs and detailed site sketches, along with the GPS-obtained coordinates, will be available prior to implementation of the monitoring program.

2.3. Rainfall Monitoring

Rainfall data is required for the flow monitoring and water quality sampling period to interpret the flow monitoring data and refine the existing collection system model. Rainfall depths will be monitored for the duration of the flow monitoring effort.

2.3.1. Equipment Locations

Twelve rain gauges will be installed for the project. The rain gauges will enable the project team to get an accurate measurement of rainfall within the BSA service area. The locations of the gauges were chosen from the Phase 1 locations that had the most consistent data and are listed in Table 2-4 and shown on Figures 2-1, 2-2 and 2-3.

Table 2-4.
Rainfall Gauge Locations

Phase 1 ID Number	Location Description
ND RG 1	Public School 66, North Drive and Cunard
ND RG 2	Public School 81, Delaware and Tacoma
ND RG 3	West Hertel Elementary School, Hertel Avenue
ND RG 4	Public School 60, Ontario Street
SCD RG 3	Cazenovia Park - Tosh Collins Community Center
SCD RG 4	Colonel Ward Pumping Station - Foot of Porter Avenue
SCD RG 7	U.S. Coast Guard Station – Fuhrman Boulevard
SJD RG 1	Metering Station @ Lafayette St.
SJD RG 3	Police Station @ Glenwood & Main St.
SJD RG 4	City DPW @ Burbank & Delaware Park
SJD RG 5	Firehouse @ Bailey & Collingwood
SJD RG 6	Scajaquada Drain @ USGS Station/Villa Maria

In general, the following installation requirements will be adhered to for rain gauge equipment:

- Gauges will be located in open spaces and away from shielding effects which may be caused by objects in the immediate vicinity.
- Gauges will be installed on a stable, level surface and located in an area that would provide reasonable security of the gauge from vandalism and tampering (roof tops of public buildings, etc.).

To supplement the precipitation data obtained from the proposed 12 gauges, BSA will consider obtaining and utilizing the radar data for the greater Buffalo area as further described in the Collection System Model Refinement work plan.

2.3.2. Equipment Specifications

Remote tipping bucket style rain gauges will be used to measures the amount of rainfall and log the data. The rain gauges are freestanding receptacles for measuring precipitation and contain an open top, which allows rainfall to fall into the upper portion, called the collector. Collected water is funneled to a mechanical device (tipping bucket), which incrementally measures the rainfall accumulation and causes a momentary closure of a switch. As water is collected, the tipping bucket fills to the point where it tips over. This action empties the bucket in preparation of additional measurement. The tipping bucket rain gauges will be supplied by the same flow monitoring subcontractor The resolution of the rain gauges will be set at 0.01 inch of rain and will collect rainfall volume at 5-minute intervals.

2.3.3. Rainfall Gauge Data

Data from all rain gauges will be downloaded by flow monitoring subcontractor weekly for the duration of the flow monitoring effort. The flow monitoring subcontractor will follow standard protocols for maintaining the gauges and collection the data and will be responsible for validation and verification of the rainfall data prior to delivery to Malcolm Pirnie.

2.3.4. Maintenance and Calibration of Equipment

Rain gauges will be inspected, maintained and cleaned weekly, and calibrated monthly, by the flow monitoring subcontractor throughout the monitoring period. Documentation of weekly maintenance activities will be provided to Malcolm Pirnie by the monitoring consultant. These reports will be submitted within a week of the inspection/calibration.

2.4. Monitoring Period

The continuous flow monitoring program will be conducted for a minimum of 12 weeks, between May and August/September. The flow and rainfall program may need to be extended if a sufficient number of qualifying events are not available. Conversely, the program may be ended earlier should sufficient flow and precipitation data be collected before the end of a 12-week period.

2.5. Storm Events

It is not possible to define formal requirements for storm events prior to a monitoring program, as the actual experienced events are dependent on future weather patterns. However, the goal of this program is to collect flow monitoring data from three representative storm events having the following characteristics:

- Rainfall duration of ranging from 2 hours to 8 hours. A 6- to 8-hour duration is representative of an average time of concentration in the City's overall collection system; therefore, shorter durations will highlight the response in individual CSO service areas.
- Depths equal to or greater than 0.5-inches. 0.5 inches represents an approximate depth threshold for events that typically cause widespread overflow at major overflows in the system.
- Rainfall distributed evenly across drainage area (or use of the project rain gage network to record non-uniform rainfall).

A goal for specific antecedent conditions before a validation event is not relevant to the BSA modeling approach, as the collection system model was calibrated in continuous mode. This calibration approach accounts for the full range of antecedent conditions experienced during the monitoring period, and is the preferred approach for models that will be used for continuous simulations.

Note that while the above goals for storm events are reasonable, BSA is not stating that meeting the above goals is necessary for a successful monitoring program. For example, a monitored rainfall event of less than 0.5 inches may result in activation of all or most monitored overflows; in that case, the event may be perfectly suitable as a validation event. Furthermore, in the event that fewer than three 0.5-inch events are monitored, it is still possible that adequate data will be collected to meet the monitoring plan's objective.

3. Data Submission and Review

3.1. Data Review and Validation

Following receipt of the data from the flow monitoring subcontractor (i.e., after their standard preliminary data QA/QC check), additional data review and analysis will be performed by Malcolm Pirnie. The purpose of the review is to identify any data issues as quickly as possible (and initiate corrective action by the flow monitoring subcontractor), and prepare the data for use in subsequent model validation.

Malcolm Pirnie's data review and analysis will use three categories of data screening procedures, or checks:

1. **Check for data accuracy:** This procedure reviews data to determine if one or more sensors (depth and/or velocity) behaved inconsistently during an event. Scattergraphs are an important tool used in performing this check. After collection of the first round of data, a depth versus velocity scattergraph will be developed. Based upon a review of the data, it will be determined whether the site has hydraulic characteristics conducive to meeting the objectives of the study. If appropriate, a recommendation will be made to change the monitoring configuration, equipment, or location.

   This check will be performed promptly as each weekly dataset is obtained. The scattergraph of the data obtained since the last download will be plotted and overlaid on the scattergraph of the previous data. Data problems associated with sensor fouling or drift will be identified and the field maintenance crew alerted for appropriate action.

2. **Check for data drops:** Data drops are periods where the data record simply disappears. These periods are a result of clear equipment failure.

3. **Check for unreasonable rainfall/runoff relationships:** The rainfall/runoff relationship varies continuously during a wet-weather event, but there are some fundamental rules in this relationship that should be exhibited in the data. First, the volume of wet-weather flow measured at a point in the system cannot exceed the volume of rainfall that fell on the basin tributary to that point (and in most cases will be significantly less). Second, the in-system flow response should be proportional to the size of the rainfall event; as rainfall events get larger, the in-system response should in general get larger. There are clear exceptions to this second rule, depending on e.g. antecedent conditions, but the general trend should be evident.

3.2. Data Storage

Malcolm Pirnie is responsible for final storage of flow monitoring and rainfall, made up of the transmittals from of final data from the flow monitoring subcontractor. In addition to the data, the flow monitoring subcontractor is responsible for transmitting copies of all installation reports, maintenance reports, and sampling field logs and summary sheets to Malcolm Pirnie for inclusion in the project master files.

Appendix 4-2: Collection System Model Refinement Workplan (April 2008)

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Buffalo Sewer Authority

PHASE 2 LONG TERM CONTROL PLAN

Collection System Model Refinement Workplan

April 2008

INDEPENDENT ENVIRONMENTAL ENGINEERS, SCIENTISTS AND CONSULTANTS

MALCOLM PIRNIE

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Buffalo Sewer Authority
Phase 2 Long-Term Control Plan

Collection System Model Refinement Workplan

Prepared by:
Malcolm Pirnie, Inc.

April 2008

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1. Introduction

1.1. Project Background

A System-Wide Long Term Control Plan for CSO Abatement was prepared by the Buffalo Sewer Authority (BSA) and submitted to the New York State Department of Environmental Conservation (NYSDEC) in 2004. As part of developing and calibrating a planning-level collection system model to support development of the LTCP, BSA conducted a data collection program. The BSA flow monitoring and rainfall monitoring was conducted from May 4, 2000 through July 21, 2000. A total of 85 flow monitors were installed throughout the BSA service area. Also, 21 rain gauges were utilized during this same period. The flow monitoring program is summarized in Table 1-1 below.

Table 1-1.
Monitoring Conducted During LTCP Model Development and Calibration

District	Number of In-System Monitors	Number of Overflow Monitors
North	10	3
Scajaquada	14	7
South Central	30	22

Data from this program was used to calibrate a planning-level model to support BSA's LTCP development process. The data collection, model calibration, and model application followed the incremental and iterative approach outlined in the CSO Guidance:

> *"The permittee may use an incremental approach, initially using simple screening models with limited data. These results may then lead to refinements in the monitoring and modeling plan so that the appropriate data are generated for more detailed modeling. Another option is to use a simpler CSS model for the whole system and selectively apply a more complex sewer model to portions of the system to answer specific design questions."* From "CSO Guidance for Monitoring and Modeling," Section 4.1.2.

Additional collection system model refinement has been suggested based on the NYSDEC and the United States Environmental Protection Agency (USEPA) review of the BSA LTCP. BSA used a planning-level CSS model for the whole system as part of developing the LTCP, and will selectively apply a more complex model (supported as appropriate by additional local calibration) to portions of the system to answer future advanced planning and design questions. The model refinement approach was developed based on discussions between the NYSDEC, USEPA and the BSA team.

The refined model will be used to estimate CSO flows and volumes for the Receiving Water Model calibration as well as further evaluation of CSO control alternatives. Additionally, the refined model will support preliminary design analysis for the North District (Cornelius Creek) and the Scajaquada District (Scajaquada Drain/Tunnel/Delavan Drain/Bird Avenue) sewer discharge areas.

1.2. Scope of This Plan

This Plan describes the objective of model refinement and the model validation process to be used for the BSA system.

2. Collection System Model Refinement

2.1. Model Validation Objective

The purpose of model calibration and validation, according to the CSO Guidance, is described in the following excerpts (emphasis added):

> *"Model calibration and validation are used to "fine-tune" a model to better match the observed conditions and demonstrate the credibility of the simulation results. An uncalibrated model may be acceptable for screening purposes, but without supporting evidence the uncalibrated results may not be accurate. To use model simulation results for evaluating control alternatives, the model must be reliable."* From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.

Specific to validation, the Guidance describes the following purpose:

> *"Validation is important because it assesses whether the model retains its generality; that is, a model that has been adjusted extensively to match a particular storm might lose its ability to predict the effects of other storms."* From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.

However, no specific calibration or validation procedure is provided in, or required by, the Guidance. In fact, the Guidance explicitly states that there is no single approach to any part of the monitoring and modeling process:

> *"Because each permittee's CSS, CSOs, and receiving water body are unique, it is not possible to recommend a generic, "one-size-fits-all" monitoring and modeling plan in this document."* From "CSO Guidance for Monitoring and Modeling," Section 4.2.

Therefore, while the *purpose* of calibration and validation is clear, and a constant in the modeling industry, the Guidance clearly supports the position that the *approach* to calibration and validation varies with the complexity of the modeled system, size of the model, and purpose of the model.

One of the few quantitative procedural suggestions for calibrating and validating LTCP models is in Section 7.4.2 of the "CSO Guidance for Monitoring and Modeling:"

> *"The Combined Sewer Overflow Control Manual (U.S. EPA, 1993) states that "an adequate number of storm events (usually 5 to 10) should be monitored and used in the calibration." The monitoring period should indeed cover at least that many storms, but calibration and validation are frequently done with 2 to 3 storms each."* From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.

The objective of BSA's proposed validation process is to obtain a consensus on validation at critical monitored overflow points and interceptor locations in order to establish the adequacy of the current collection system model as a planning-level tool to support the further development of BSA's LTCP. Further development of the LTCP will be conducted during the Phase 2 alternatives evaluation, requested by USEPA and agreed to by BSA. The validation process will consist of two storm events. Data for these two storm events will be collected during the proposed Phase 2 Flow and Rainfall Monitoring Program. For those locations where the validation demonstrates that the current level of calibration is inadequate for the defined planning-level purposes, the calibration of the current model will be refined.

Concurrent with the validation process, which is being conducted at the request of USEPA, BSA is investing additional effort in their collection system model to support a preliminary design analysis for the North District (Cornelius Creek) and the Scajaquada District (Scajaquada Drain/Tunnel/Delavan Drain/Bird Avenue) CSO discharge areas. While not required by the validation process, this focused effort in a portion of the modeled system will result in information supporting the validation objective.

2.2. Model Validation Process

The existing XP-SWMM collection system model for all monitored CSO Service Areas will be validated using data collected during the Phase 2 Flow and Rainfall Monitoring Program. This validation process will occur by completing the following steps:

- Step 1: Convert Model
- Step 2: Update Hydraulic Model Representation
- Step 3: Identify Validation Events
- Step 4: Run Validation Events
- Step 5: Update Calibration of Model as Needed

2.2.1. Step 1 - Convert Model

The existing model for the Buffalo collection system was developed using XP-SWMM v6.1. Prior to model validation, the existing model will need to be converted to XP-SWMM v10.6. To do this, the existing model will be opened and saved in v10.6. The 1-month 6-hour and 6-month 6-hour 1st-quartile synthetic design storms run during the original existing system assessment will be re-run using the converted model. Any problems encountered during the simulations as a result of the conversion will be documented and corrected. For each of the design storms, peak flow rates and total flow volumes will be documented for each of the 47 CSOs represented in the original model. These values will be compared to the values for the same locations for the v6.1 simulation results. Comparisons will also be done for critical interceptor locations to be determined later. If the percent difference between the v10.6 results and the v6.1 results is less than 10 percent, or if the absolute difference between the results is <0.1 MG for flow volume and 0.1 MGD for peak flow, it will be assumed that the model conversion has been successful. If the differences exceed these values, further work on the conversion of the model may be needed. The extent of the required work will be documented and reported to BSA.

2.2.2. Step 2 - Update Hydraulic Model Representation

Once the existing model has been successfully converted, the next step will be to incorporate any necessary modifications to the model representation of the collection system's hydraulics. Such necessary modifications would include any significant improvement projects or other changes in system configuration which have occurred since the existing model was originally developed. To accomplish this, Malcolm Pirnie will meet with members of BSA's staff to identify the critical system changes that need to be incorporated into the model. During this phase of the project, field investigations may be requested as needed in order to facilitate the update of the model.

2.2.3. Step 3 - Identify Validation Events

Two storm events will be identified from the Phase 2 flow monitoring program for use as validation events. The storm events will be selected based on (1) availability of useable flow data, (2) availability of useable rain gauge data, and (3) size of storm event. For the selected events, rain gauge data will be reviewed for spatial variability. If rainfall for a particular event is found to be sufficiently spatially variable, the purchase of radar rainfall data for the event from a third-party provider (e.g., Vieux and Associates) will be considered in consultation with BSA.

2.2.4. Step 4 - Run Validation Events

Once the validation events have been identified and all necessary data obtained, the events will be simulated using the converted modified existing system model. The measure of success for model validation will primarily rely on producing good visual comparisons to data in terms of peak flow, total volume, and shape and timing of the hydrograph for a range of storm sizes. In general, the standard of success for model validation is lower than for model calibration, since validation is a step that follows calibration and is intended to test whether the model "retains its generality," i.e., to ensure that the model has not been excessively adjusted and customized to a small number of calibration events. The only measure of success specific to validation provided in the Guidance is in Section 7.4.2 (emphasis added):

> *"Validation is the process of testing the calibrated model using one or more independent data sets. In the case of the hydraulic simulation, the model is run without any further adjustment using independent set(s) of rainfall data. Then the results are compared to the field measurements collected concurrently with these*

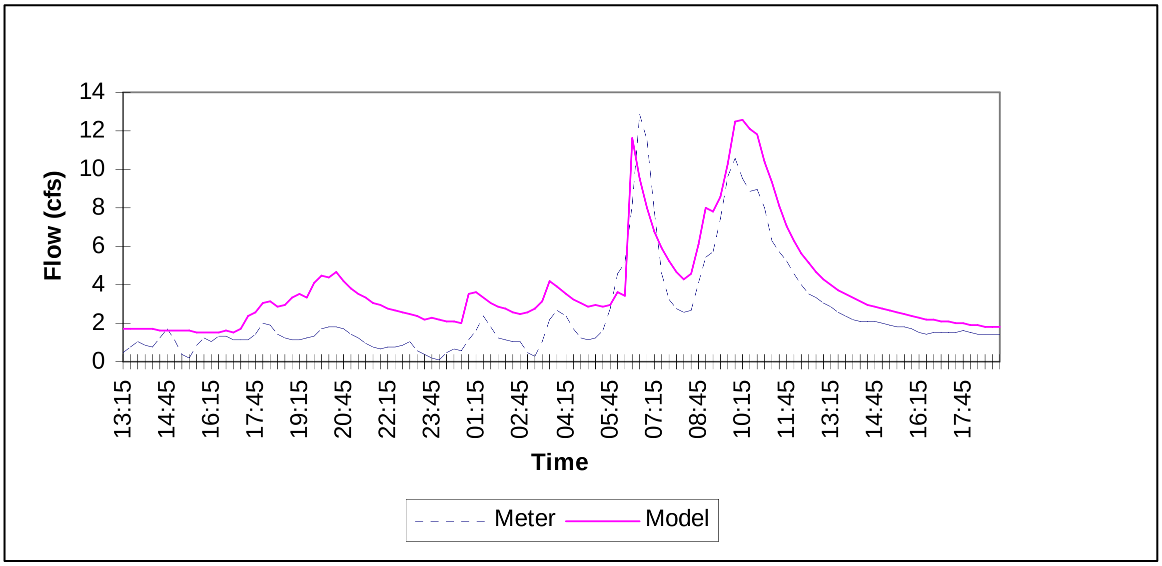
rainfall data. If the results are suitably close, the model is considered to be validated." From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.

To help determine if the validation results are "suitably close," the visual comparisons noted above will be supplemented by statistical procedures, where the goal for comparison between model and flow data for total runoff volume and peak flow over a range of storms will be as follows:

- To get a significant core of meter events with valid data in the +/-35% difference range. In meeting this objective, the expectation is that some comparisons will be significantly lower than the boundaries of this range, i.e., well within +/-20%.
- Get the majority of valid meter events in the +/- 50% difference range.
- Acknowledge that there will be some outliers, even for valid data, because no model can capture potentially atypical responses of the system.
- A primary focus for confirming a good comparison between model and flow data will be to avoid any consistent bias high or low in the percent difference comparisons.

It is important to recognize that review and assessment of any comparison between model results and measured data (whether calibration or validation) presupposes valid data.

Note that the percent difference comparison goals presented above are appropriate for validation; if subsequent calibration is agreed to as necessary, then the percent difference ranges associated with comparison goals for calibration may be narrower. In general, however, the specific number chosen for percent difference comparisons is not the determinant in assessing successful model calibration or validation. Most modelers and some regulatory reviewers recognize that these statistical procedures are relevant measures, but need to be used with some care. For example, the following meter to model comparison from a midwestern LTCP effort would be considered "suitably close" by most observers, and so meet the Guidance standard for validation:



However, the percent volume difference for this example is +52 percent. Clearly, then, whether the comparison range is chosen as +/-20%, +/-35%, or +/-40%, the final decision on validation success will be based on a number of measures, including but not limited to percent difference comparisons. Some comparisons with percent differences of 50% may be considered successful validations based on subjective goodness-of-fit measures. Proper application of these judgment-based measures, and integration with statistical comparisons, requires a thorough understanding of the data, the model, and the system being analyzed.

Summarizing the above, the following sequence will be used as validation criteria for the flow monitored CSO Service Areas:

- Peak flow timing and the general hydrograph shape are similar. This goodness-of-fit criterion will be the primary measure of success.
- Model runoff volumes will be compared to actual flow monitored runoff volumes. The model is validated if the modeled runoff volumes and monitored runoff volumes are within +/- 35 percent for a significant core number of valid events.
- Model runoff peak flow rates will be compared to actual flow monitored runoff peak flow rates. The model is verified if the largest peak flow rate from the model and monitor are within +/- 35 percent for a significant core number of valid events.

2.2.5. Step 5 - Update Calibration of Model as Needed

After the model validation is complete, the results will be reviewed to identify those Phase 2 flow monitors where a refinement of the current calibration may be merited. The flow monitors identified during this step will fall into two categories: (1) flow monitors where the validation results do not meet the guidelines outlined in Step 4, and (2) flow monitors specifically sited in the lower North District or Scajaquada District areas to provide more detailed flow information than the Phase 1 monitoring program did, where further refinement of the calibration could facilitate the development of additional alternatives for these areas. For the flow monitors identified during this step, the calibration will be refined using the same storm events used for the model validation. The model calibration will be refined to try to meet the following calibration targets at these meters:

- Total Flow Volume: -20% to +20%
- Peak Flow Rate: -15% to +25%
- Peak Flow Depth: -0.33’ to +0.33’ (+1.67’ if surcharged)

Following the calibration refinement, any remaining wet-weather events (beyond the two validation events used in Step 4) monitored during the Phase 2 program will be reviewed for the purpose of identifying additional validation events. Presuming such events were captured, and adequate data exists, the validation effort in Step 4 will be repeated for the model areas where calibration was refined.

Appendix 4-3: Model Validation Report

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Model Validation Report

June 2010

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Appendices

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1. Introduction

1.1. Project Background

A System-Wide Long Term Control Plan for CSO Abatement was prepared by the Buffalo Sewer Authority (BSA) and submitted to the New York State Department of Environmental Conservation (NYSDEC) in 2004. As part of developing and calibrating a planning-level collection system model to support development of the LTCP, BSA conducted a data collection program. The BSA flow monitoring and rainfall monitoring was conducted from May 4, 2000 through July 21, 2000. A total of 85 flow monitors were installed throughout the BSA service area. Also, 21 rain gauges were utilized during this same period.

Data from this program was used to calibrate a planning-level model to support BSA's LTCP development process. The data collection, model calibration, and model application followed the incremental and iterative approach outlined in the CSO Guidance:

> "*Another option is to use a simpler CSS model for the whole system and selectively apply a more complex sewer model to portions of the system to answer specific design questions*." From "CSO Guidance for Monitoring and Modeling," Section 4.1.2.

BSA developed and used a planning-level CSS model for the whole system as part of developing the LTCP, and will selectively apply a more complex model (supported as appropriate by additional local calibration) to portions of the system to answer future advanced planning and design questions.

Following review of BSA's submitted LTCP, the NYSDEC and the United States Environmental Protection Agency (USEPA) requested additional collection system model validation for the purpose of developing a Phase 2 LTCP. BSA agreed to this request, and consensus was reached on the model refinement approach based on discussions between the NYSDEC, USEPA and the BSA team. The agreed-upon approach was formalized in the approved "Collection System Model Refinement Workplan," April 2008.

This report summarizes the process and presents the results of BSA's implementation of the model refinement approach documented in the April 2008 Workplan (Appendix A).

1.2. Model Refinement Approach

The agreed-upon model refinement approach implemented the following sequential steps, with each step presented in an individual section of this report:

- Section 2: Update the model structure to incorporate physical collection system improvements implemented since the model was originally developed in 2001.
- Section 3: Perform additional model validation, using new data from a Phase 2 flow monitoring program, and assess the validation using agreed-upon criteria.
- Section 4: Based on the validation results, determine if any individual flow monitoring locations warrant additional model refinement, and if so, perform additional local calibration followed by a second round of independent model validation.
- Section 5: Draw conclusions on overall strength of the collection system model for application to the Phase 2 LTCP development.

2. Model Update

Prior to performing the model validation simulations, it was necessary to incorporate those changes to the system that have occurred since the model was developed in 2001. Updates to the model were implemented in two different stages: in the Fall of 2008, and in the Fall of 2009.

All of the system changes implemented by BSA were a part of the Authority's Nine Minimum Control program, and/or recommendations from the original LTCP. Further, all of these changes had the net effect of reducing stormwater contribution to the combined sewer system, increasing in-line storage, increasing the capture of wet-weather flow, and/or reducing wet-weather overflows.

2.1. 2008 Model Updates

The following system changes were incorporated into the model during the Fall of 2008 (Figure 2-1):

- Removed the orifice plates for the Sewer Patrol Points (SPPs) shown in Table 2-1. These system changes were incorporated by BSA as part of a program to increase the capture of wet-weather flow in the collection system:

Table 2-1. Summary of SPPs with Orifice Plates Removed for the 2008 Model Update.

SPP	Original Orifice Plate Opening Area (ft^2)	Diameter of Underflow Pipe (in.)	Cross Sectional Area of Underflow Pipe (ft^2)
3	0.31	12	0.785
4	0.632	12	0.785
5	0.595	12	0.785
7	0.785	12	0.785
8	0.229	12	0.785
10	0.785	30	4.909
11	0.349	8	0.349
107A	0.614	24	3.142
132	N/A	12	0.785
195	0.393	12	0.785
213	1.131	18	1.767

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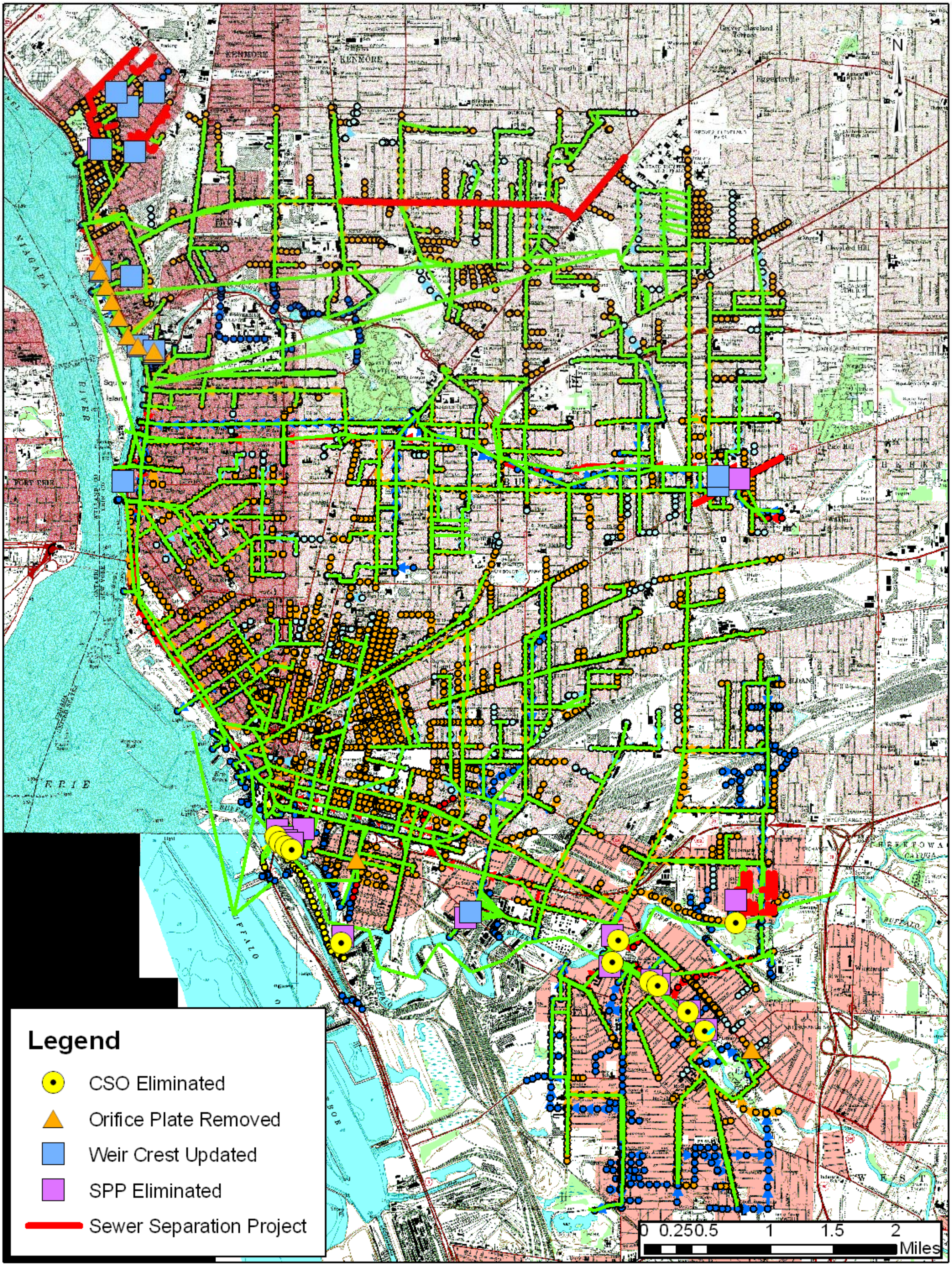

Figure 2-1. System Changes Incorporated During the 2008 Model Update

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- Updated the weir crest elevations for the SPPs shown in Table 2-2. These system changes were incorporated by BSA as part of a program to increase in-line storage and capture of wet-weather flow in the collection system. The italicized SPPs are not explicitly represented in the model:

Table 2-2. Summary of Weir Crest Elevation Changes for the 2008 Model Update.

SPP	Original Weir Crest Elevation (USGS)	Updated Weir Crest Elevation (USGS)	Change (ft)
4	570.49	571.2	0.71
11	574.05	574.38	0.33
22	*N/A*	*575.42*	*N/A*
89	573.94	575.68	1.74
156A	*N/A*	*629.41*	*N/A*
156B	*N/A*	*631.07*	*N/A*
185	585.1	585.6	0.5
187	580.23	581.53	1.3
188	589.2	590.37	1.17
189	586.45	587.83	1.38
190	N/A	588.99	N/A
191	579.96	581.59	1.63
195	574.05	575.85	1.8
213	574.58	575.08	0.5

- Eliminated the SPPs and CSOs shown in Table 2-3. These changes were implemented by BSA as part of system optimization and overflow reduction. The italicized SPPs and CSOs were not explicitly represented in the model:

Table 2-3. Summary of Closed SPPs and Closed CSOs for the 2008 Model Update.

Closed SPP	Closed CSO	Location of Closed SPP
93	*None*	*Smith Street South of South Park Avenue*
108	*41*	*Geary Street and North Legion Drive*
110	*43*	*Hammerschmidt Avenue and North Legion Drive*
111	*45*	*Riverview Place and North Legion Drive*
116	*30*	*Bailey Avenue and McKinley Avenue*
139	21	Illinois Street and South Park Avenue
140	*20*	*Indiana Street and South Park Avenue*
141	*19*	*Washington Street and South Park Avenue*
142	*18*	*Main Street North of South Park Avenue*
143	*None*	*Main Street and South Park Avenue*
192	None	Near Crowley Avenue and Tonawanda Street

207	*36*	*North Legion Drive Between Kingston Place and Peremont Place*
325	*24*	*Ohio Street and Louisiana Street*
328	*65*	*South of Melvin Place*
341B	None	Genesee Street East of Kerns Avenue
344	*34*	*Barnard Street South of Casimir Street*

- Incorporated the following street separation projects. These projects were recommended in the LTCP and carried out as fast-track improvement projects. For the model representation, the street separation was represented by first delineating the impacted street area along with a surrounding buffer area that was assumed to drain to the street. The existing modeled subcatchments were then adjusted by assuming the removed street areas were 100% impervious and the surrounding buffer areas were 30% impervious. The estimated street area included in these projects was 37.6 acres. Taking into account the adjacent buffer areas, the area impacted by these projects was approximately 70.4 acres.

  - Baxter Street
  - Belmont Street
  - Chadduck Avenue
  - Fenton Street
  - Geary Street
  - Genesee Street
  - Hertel Avenue Reconstruction
  - Hertel Avenue (Starin Avenue to Main Street)
  - Kaisertown (south of Clinton Street)
  - Laird Avenue
  - Laird Avenue & Isabelle Street
  - Main Street
  - Ontario Street (Henrietta Avenue to Newfield Street)
  - Peremont Place
  - Roesch Avenue (Skillen Street to Seabrook Street)
  - Ross Avenue
  - Seward Street, Willett Street, & Holly Street
  - Skillen Street (Roesch Avenue & Vulcan Street)
  - Tonawanda Street
  - Vulcan Street
  - Wyandotte Avenue (Argus Avenue & Elgas Street)

2.2. 2009 Model Updates

The following system changes were incorporated into the model during the Fall of 2009 (Figure 2-2):

- Updated the weir crest elevations for the SPPs shown in Table 2-4, for the same reasons noted above:

Table 2-4. Summary of Weir Crest Elevation Changes for the 2009 Model Update.

SPP	Original Weir Crest Elevation (USGS)	Updated Weir Crest Elevation (USGS)	Change (ft)
68	580.55	581.25	0.7
69	580.45	581.75	1.3
74	576.3	576.8	0.5
75	576.45	576.95	0.5
77	576.7	577.2	0.5
78	577.3	577.8	0.5
79	N/A	576.75	N/A
80	575.95	576.45	0.5
81	575.7	576.2	0.5
82	575.95	576.45	0.5
84	N/A	575.92	N/A
85	575.68	576.18	0.5
87	575.45	575.95	0.5
88	575.35	575.85	0.5
90	574.35	574.85	0.5
91	575.59	575.81	0.22
92	575.2	575.7	0.5
94	575.31	576.45	1.14
107	586.35	588.35	2
135A	573.1	573.53	0.43
314	581.22	584.48	3.26

- Incorporated the CSO35 sewer separation project, for the same reasons noted above. The estimated street area impacted by this project was 7.5 acres. Taking into account the adjacent buffer areas, the area impacted by this project was approximately 15.6 acres.

2.3. Additional Updates to Baseline Model

In addition to the system changes listed above, there were also several other changes that have been made to the system since the completion of the 2009 Phase 2 flow monitoring program used to validate the model. Since these changes were not in place at the time of

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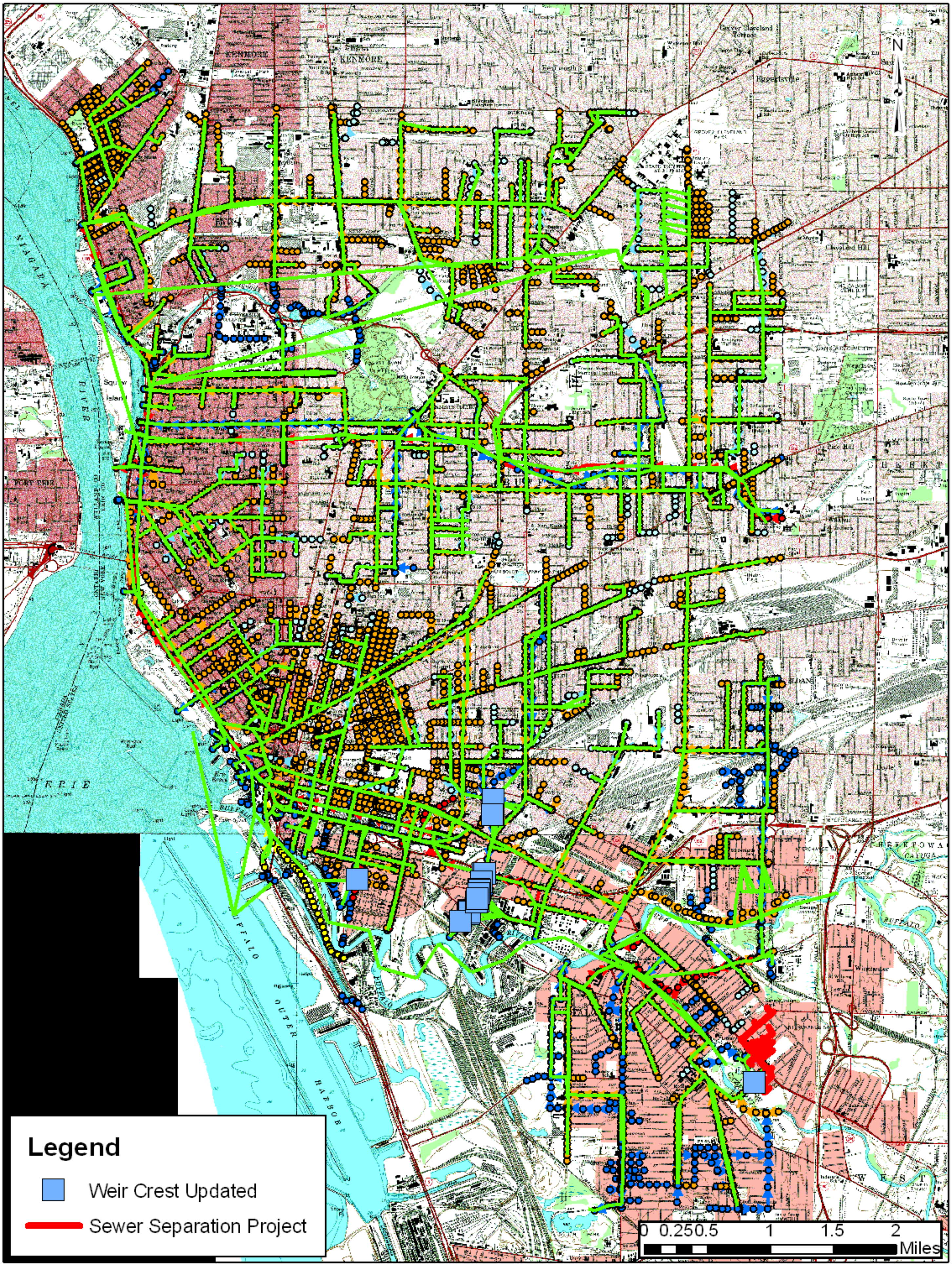

Figure 2-2. System Changes Incorporated During the 2009 Model Update

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the flow monitoring program, they were not incorporated into the validation model. However, they were incorporated into the baseline model that will be used for analysis going forward. These changes are as follows (Figure 2-3):

- Updated the weir crest elevations for the SPPs shown in Table 2-5:

Table 2-5. Summary of Additional Weir Crest Elevation Changes for the Baseline Model.

SPP	Original Weir Crest Elevation (USGS)	Updated Weir Crest Elevation (USGS)	Change (ft)
107A	589.65	590.65	1
121	575.18	575.93	0.75
128	574.13	575.03	0.9
129	N/A	573.35	N/A
131	569.68	570.06	0.38
132	572.45	575.55	3.1
138	N/A	575.2	N/A
145	N/A	573.5	N/A
149A	592.58	593.98	1.4
149B	593.2	593.98	0.78
150	596.03	596.53	0.5
151	605.51	608.01	2.5
197A	594.7	595.87	1.17
197B	594.09	596.49	2.4
197C	593.43	595.5	2.07
198B	594.2	595.6	1.4
199A	607.45	608.75	1.3
199B	604.16	606.46	2.3
199C	606.3	606.8	0.5
248	604.95	607.25	2.3
249	622.78	623.78	1
277	595.85	596.85	1
317	583.45	585.45	2

- Incorporated the Mumford Street sewer improvements. This project consisted of replacing the 24” underflow pipe from SPP121 to the interceptor with a new 48” pipe.

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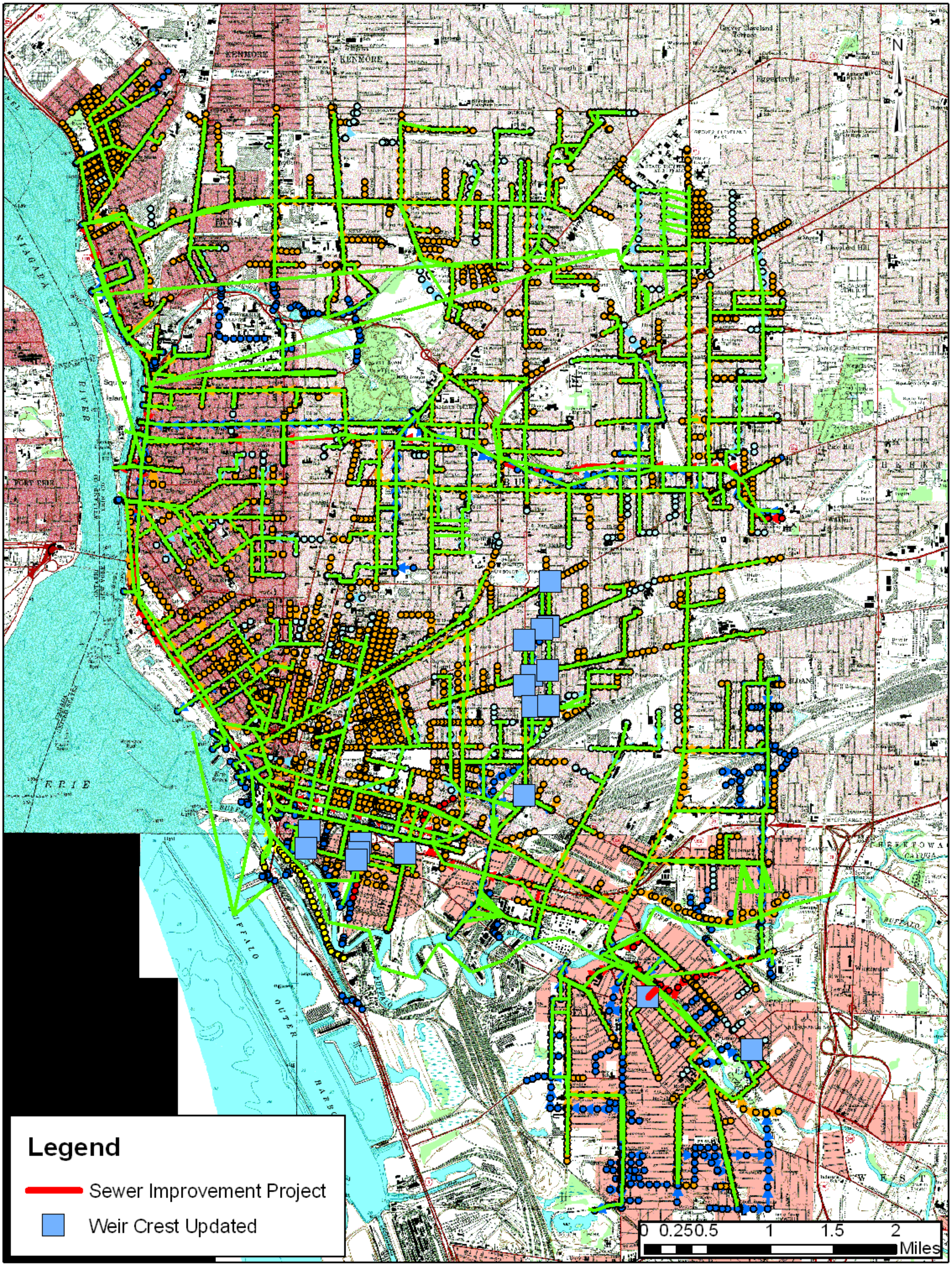

Figure 2-3. System Changes Incorporated During the 2009 Model Update to the Baseline Model

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3. Initial Model Validation

After the model was updated to represent the current system configuration, the original calibration of the model was further validated using the 2009 Phase 2 monitoring data. Data obtained during the 2009 program was reviewed to identify wet-weather validation events. The selected validation events were simulated using the updated model, and the results were compared with the observed data. The success of the validation was then assessed using a series of qualitative and quantitative criteria (as outlined in the approved 2008 Workplan).

3.1. Data Collection Program

The validation of the model was done using data obtained through the 2009 Phase 2 monitoring program performed by ADS. The monitoring program consisted of twelve rain gauge locations (Figure 3-1) and twenty-three flow monitor locations (Figure 3-2), and ran from April 22, 2009 to September 20, 2009. Fourteen of the flow monitor locations recorded both flow and depth data, while only depth data was recorded at nine overflow locations. Detailed information about the monitoring program can be found in ADS's Buffalo flow monitoring report (attached as Appendix B). In addition, overflow activation data obtained at twelve staff gauge locations (Figure 3-3) by the BSA field crew was also utilized during the model validation process.

3.2. Selection of Validation Events

A review of the available flow data resulted in the identification of eight potential candidate validation events, or periods. Because of the large number of available events, it was decided that the model would be validated using four event periods instead of the initially-proposed two event periods. The remaining four event periods were held back as independent datasets for use with additional validation cycles as needed. The four selected validation event periods were chosen to cover a range of conditions in terms of storm volume, storm peak intensity, storm duration, and the presence of back-to-back events. The selected event periods, along with some summary event statistics, are presented in Table 3-1.

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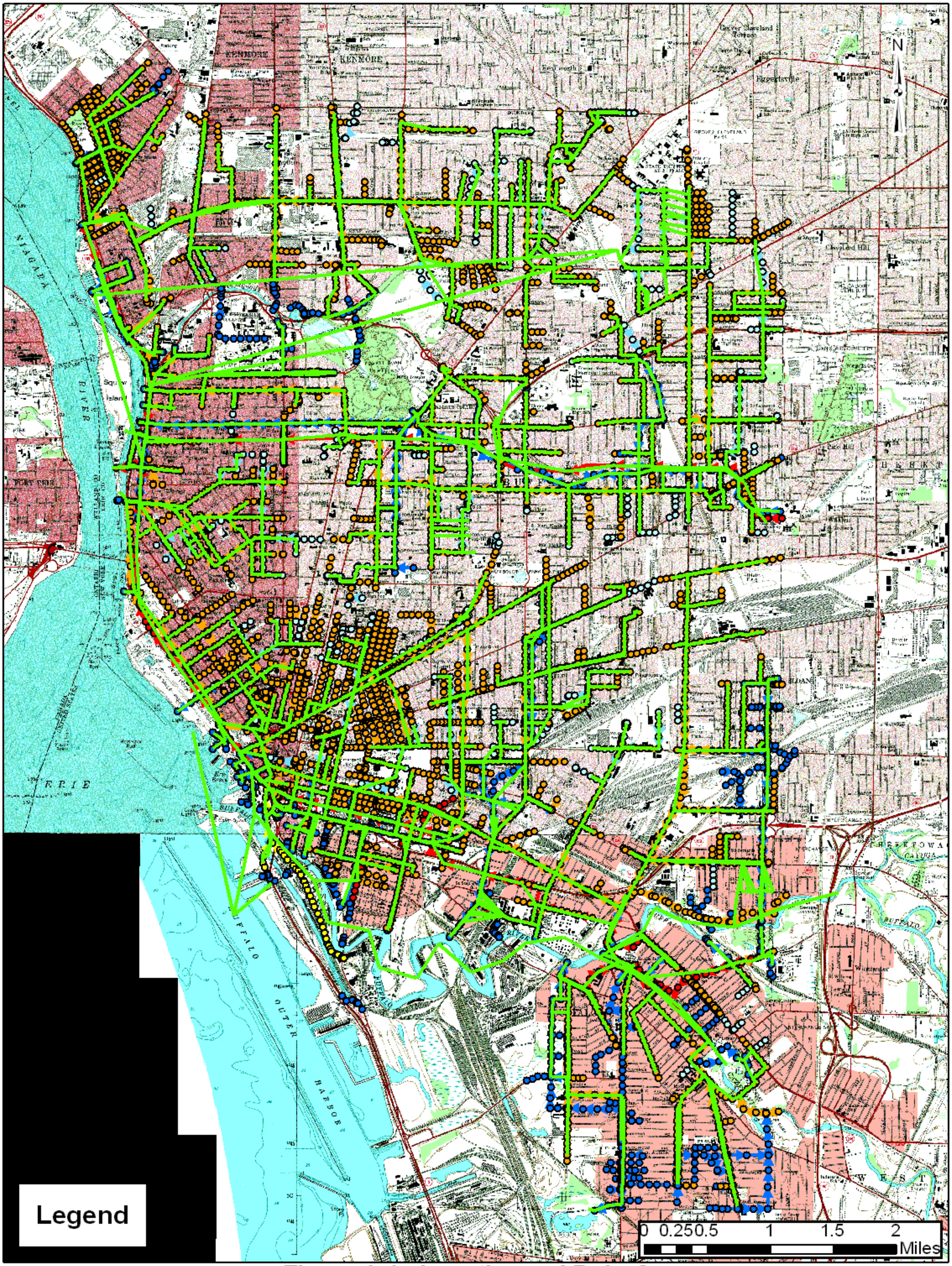

Figure 3-1. Locations of Rain Gauges

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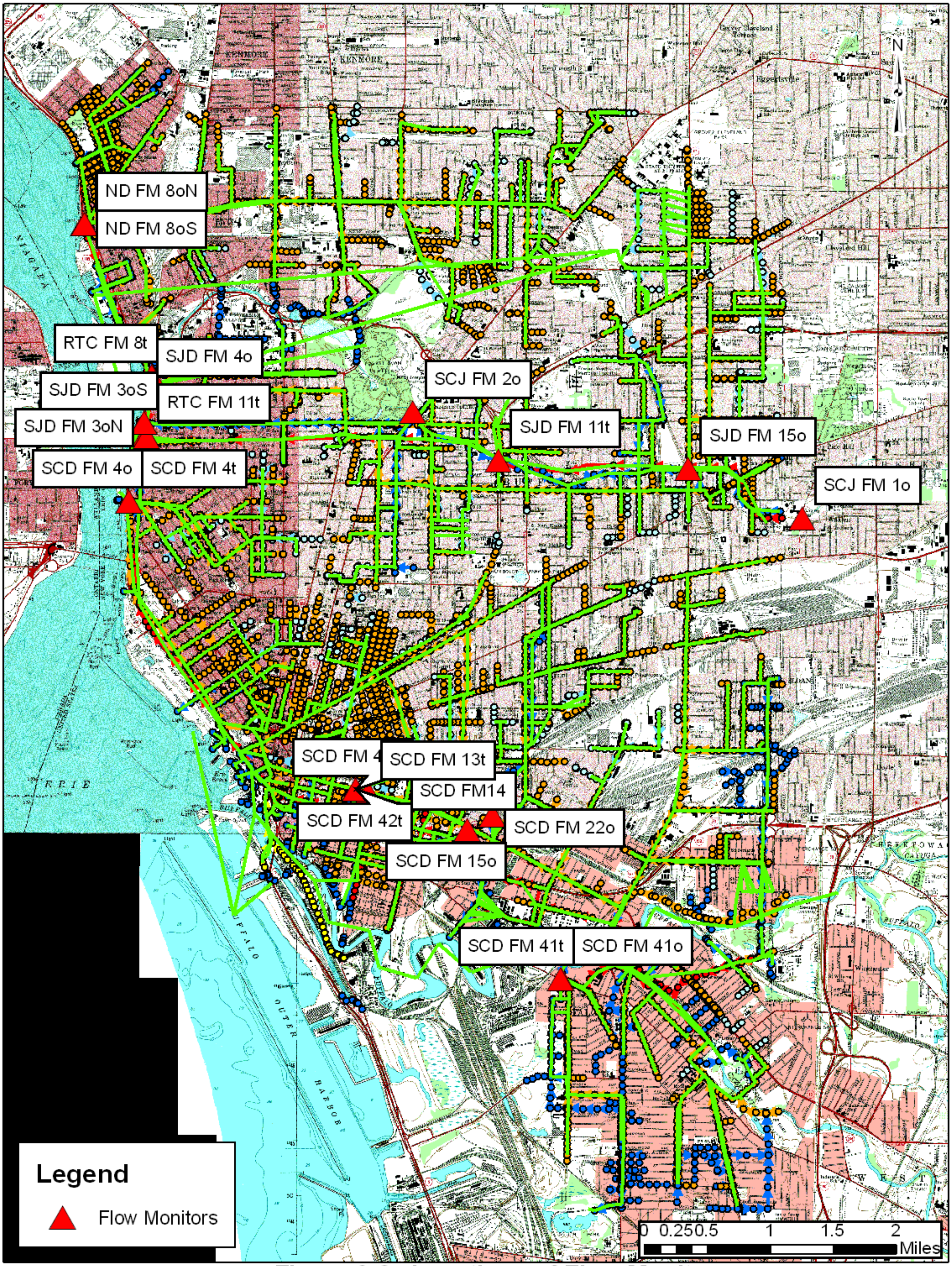

Figure 3-2. Locations of Flow Monitors

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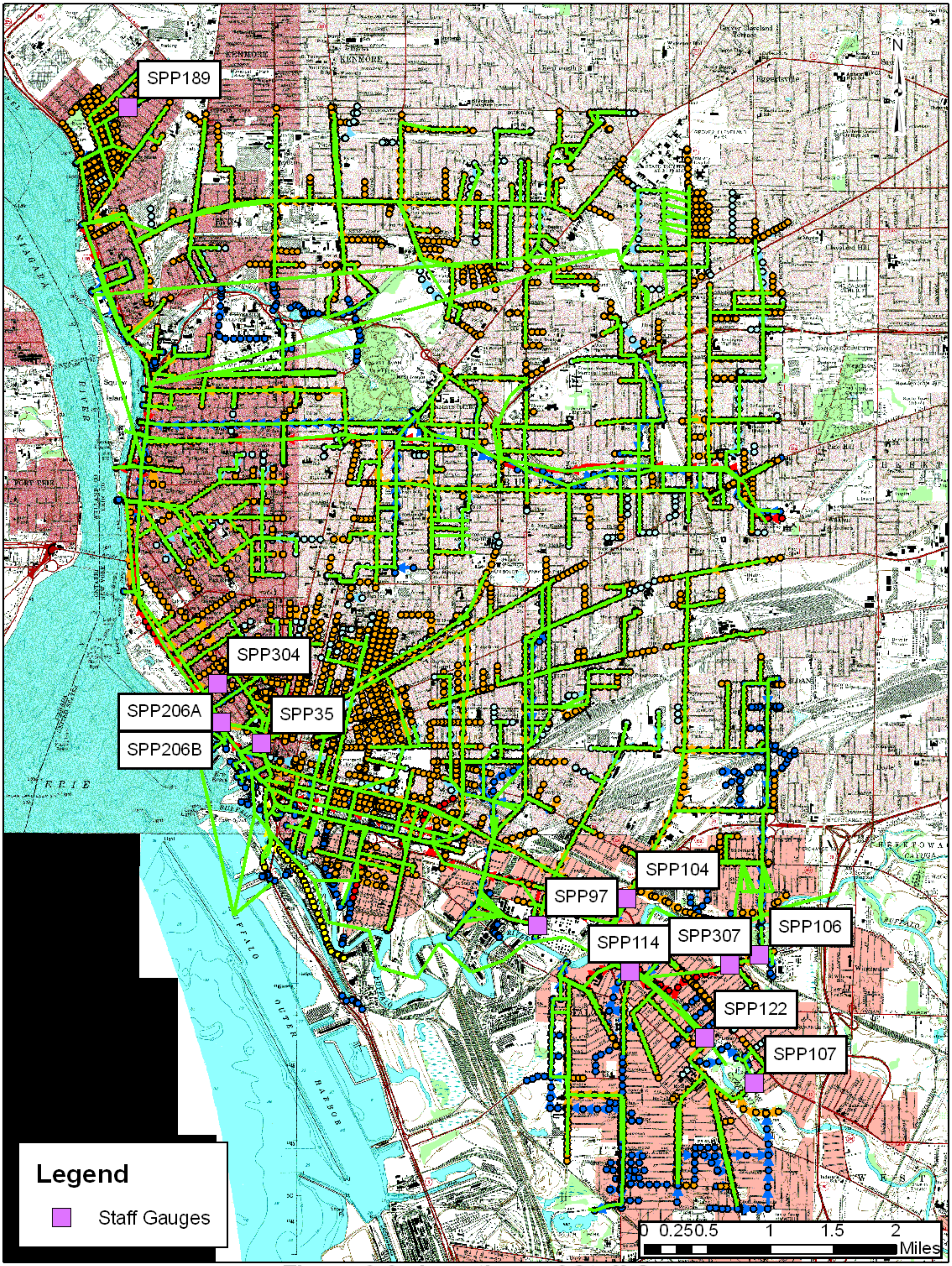

Figure 3-3. Locations of Staff Gauges

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Table 3-1. Summary of Validation Event Periods.

Validation Event	Average Rainfall (in.)	Average Duration (hrs)
May 6-9	0.45	13
June 17-20	0.74	25
July 17-20	0.92	7
July 21-28	2.90	NA(1)

(1) Extended event - includes three rainfall cells in a one-week period.

3.3. Validation Assessment Criteria

As documented in the agreed-upon 2008 Workplan, the following criteria were established to assess the adequacy of the model:

- The primary measure was the "goodness of fit" criterion. This refers to how well the model matches the general monitored hydrograph shape, as well as how well it matches the peak flow timing. This is a qualitative criterion.
- Quantitative comparisons were made between the modeled and observed flow volumes, and also between the modeled and monitored peak flow rates.
  - For the validation to be considered successful, a significant core of the meter events should have the observed and modeled values within +/- 35% of each other.
  - For the validation to be considered successful, a majority of the events should have the observed and modeled values within +/- 50% of each other.
  - With a successfully validated model, it was also expected that for many of the meter events, the % difference would be even lower than the +/- 35% range (i.e., well within +/- 20%).
  - The quantitative comparisons were also evaluated for possible biases. A well-calibrated model should have limited bias either high or low for the percent difference comparisons. If there is a bias, it is preferable that it be a high bias (i.e., the modeled values consistently higher than the observed values).
  - In assessing the quantitative comparisons, it was recognized that there would likely be some meter events that were outliers, since no model can capture potentially atypical responses of the system or account for potential flow metering equipment issues.

Finally, it was recognized that as with any model calibration or validation process, review and assessment of any comparison between model results and measured data presupposes valid data.

3.4. Baseflow Adjustment

The simulated baseflow in the BSA model is a user-defined boundary condition. The baseflow in the current BSA model was defined based on data obtained during the 2000 monitoring program. A review of the flow data obtained from the 2009 revealed that the observed baseflow has dropped during the period between 2000 and 2009. A review of the historical average daily flow rates at the WWTP for 2000-2009 (Figure 3-4) further confirmed this observation. Figure 3-4 shows that the total base dry weather sanitary flow has dropped by ~20 MGD over that 9-year period. Of this drop, a review of available data showed that approximately 2 MGD of the decrease came from the closing of various SIUs (Significant Industrial Users). Other potential contributing factors are increased water conservation, decreased water consumption, decreased population, and closings of smaller businesses and industries.

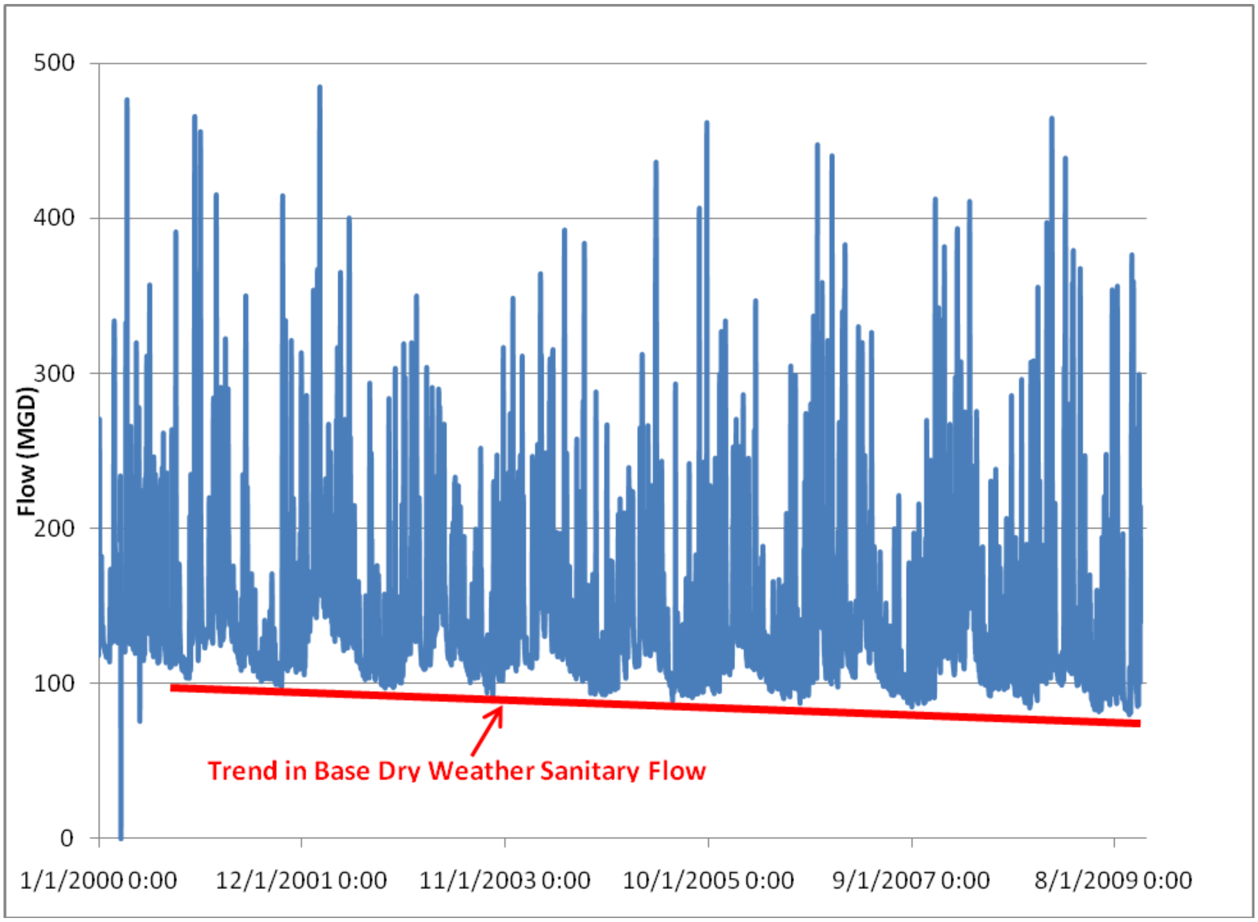

Figure 3-4. Daily Average Flow Rates at the WWTP for 2000-2009

To be able to properly validate the model, it was necessary to account for this drop in boundary condition baseflow. This is a standard step in validating or applying collection system models, given that it is not unusual for baseflows to vary over multi-year periods. Two different approaches are available:

- Post-process the model results by comparing the average modeled 2000 baseflow with the average observed 2009 baseflow, and adjusting the modeled results by the calculated difference.
- Redefine the baseflow boundary conditions in the model to match the observed 2009 baseflow.

The first approach was selected for the purpose of model validation because (1) it is more efficient for the limited number of comparisons required during a validation effort, while producing effectively the same validation comparisons, and (2) while a version of the second approach is likely to be incorporated in the upcoming refined alternative analyses, the desired baseflow conditions for those analyses are yet to be determined (BSA will establish appropriate baseflow conditions based on standard industry practice for projecting future conditions and document their approach in the revised Long-Term Control Plan). Figure 3-5 shows a graphical example of the adjustment process at one location.

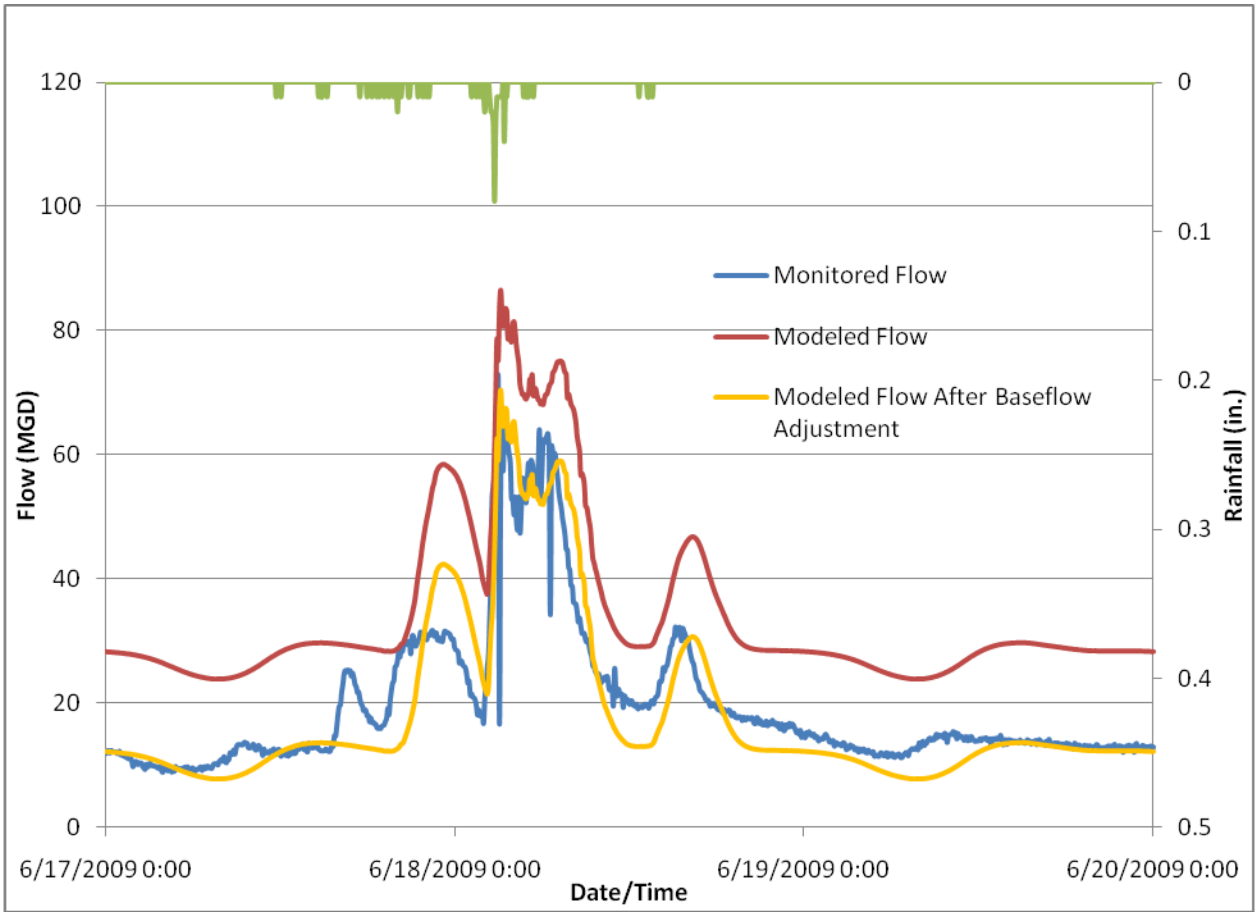

Figure 3-5. Example of Baseflow Adjustment for RTC FM 8t Location

3.5. Validation Results

3.5.1. Comparison Plots

Comparison plots of modeled versus observed flow and depth data were generated for each flow monitor location for each validation event period. While the depth comparison plots were reviewed qualitatively as part of the process, the review of the flow comparison plots was more critical to assessment of the model validation. This is because the flow comparison plots were the means by which it was determined whether the model results successfully met the “goodness-of-fit” criterion, the primary criterion for the model validation. An example of a flow comparison plot is shown on Figure 3-6. The complete set of flow comparison plots for the validation simulations can be found in Appendix C for the fourteen meter locations with observed flow data available. The modeled flow plots represent the modeled flow after accounting for the baseflow adjustments described above. For some of the meters, the dry weather diurnal pattern of the modeled flows is more pronounced than the dry weather diurnal pattern of the monitored flows. This is a result of the baseflow adjustment process. The baseflow adjustment consisted of reducing the modeled flow rates by a constant amount in order to account for the 2009 monitored baseflows in the validation comparison, since as noted previously the sanitary flows have decreased from 2000 to 2009. Since sanitary flows fluctuate diurnally relative to average flow, the reduced 2009 monitored flows will generate a lower magnitude variation (a “flattening” of the overall diurnal pattern) relative to the higher 2000 monitored flows. This “flattening” is not captured by the baseflow adjustment process used here, but is not critical to the validation comparison. A review of the plots shows that for a vast majority of the meter events, the “goodness-of-fit” criterion was clearly met. Given the agreed-upon acceptance of some outliers, the limited number of less-than-ideal goodness of fit comparisons is not an issue.

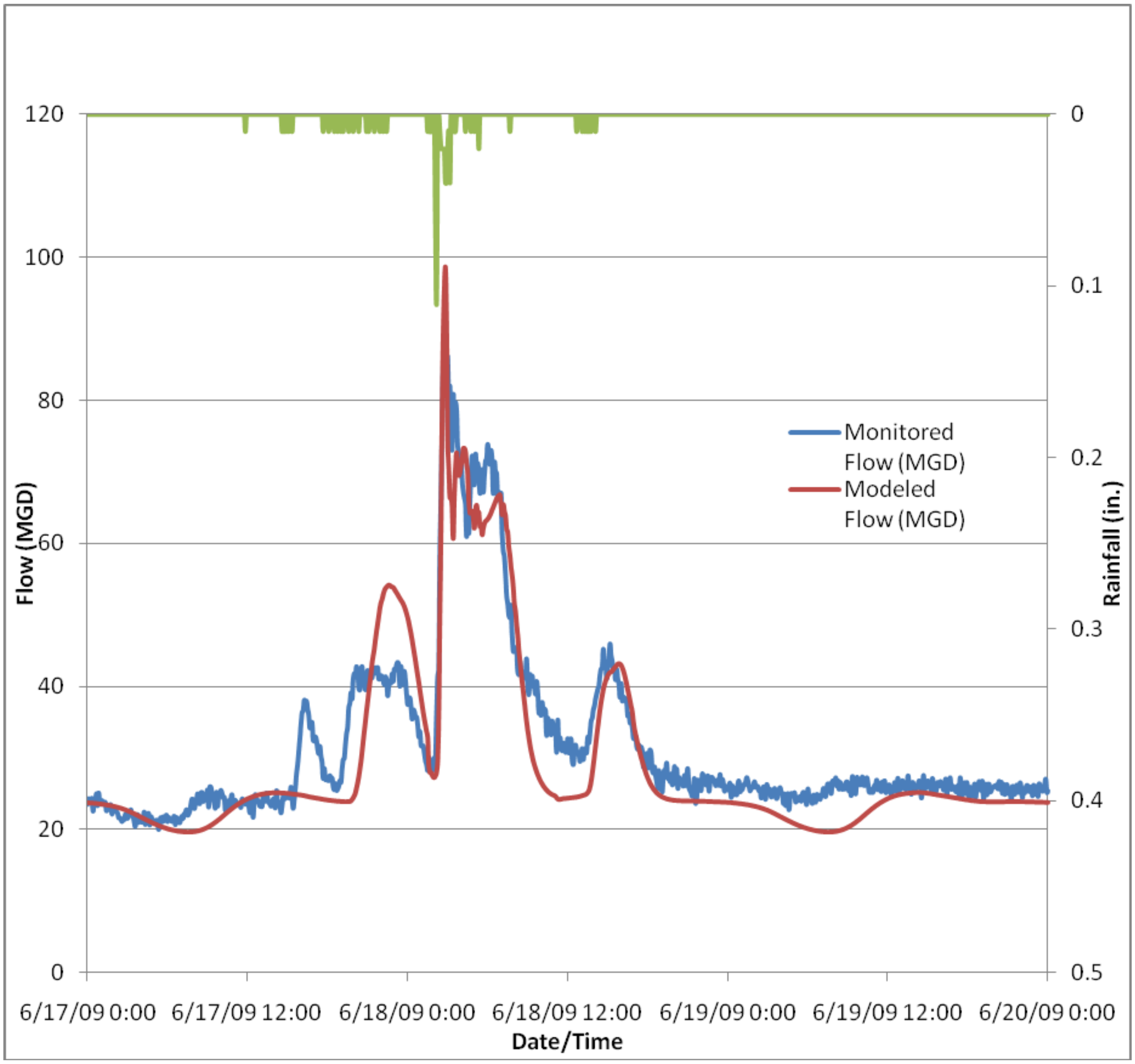

Figure 3-6. Example Flow Comparison Plot for the NDFM 9t Location

3.5.2. Histograms

In order to enable an assessment of the quantitative validation criteria, histograms showing the proportion of meter events falling within different ranges of modeled versus observed percent differences were developed, for both the peak flow rate and flow volume comparisons. The histogram for the peak flow rate comparisons is shown on Figure 3-7.

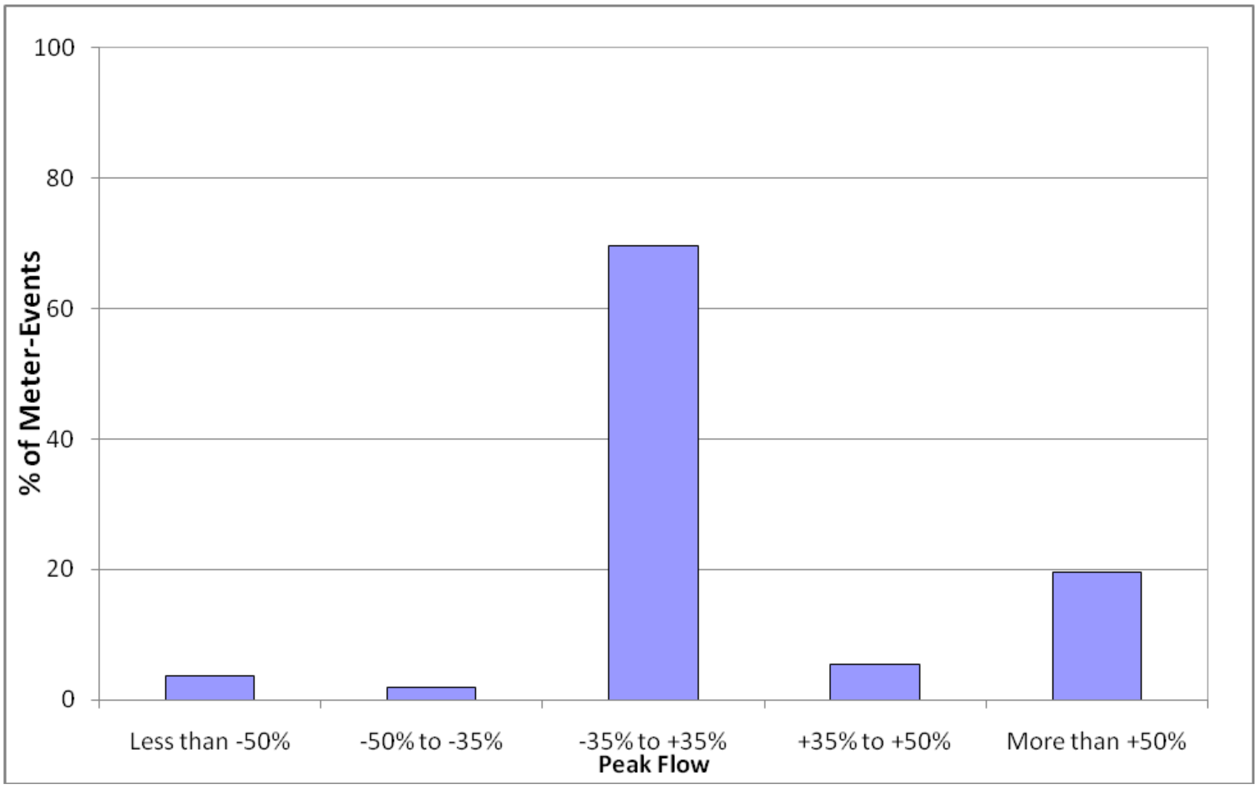

Figure 3-7. Modeled vs. Observed Validation Event Peak Flow Rate Histogram

A review of Figure 3-7 yields the following findings with respect to the defined quantitative model validation criteria:

- At 70%, a significant core of the meter events falls within the +/- 35% range.
- At 77%, a majority of the meter events falls within the +/- 50% range.
- At 52%, a substantial number of the meter events fall within a tighter +/- 20% range (not shown on the figure, but embedded in the central +/- 35% range).
- There is a slight bias in the results, but it is to the high side, which is acceptable.

The above results show that, in terms of the peak flow rate criteria, the model was successfully validated.

The histogram for the flow volume comparisons is shown on Figure 3-8.

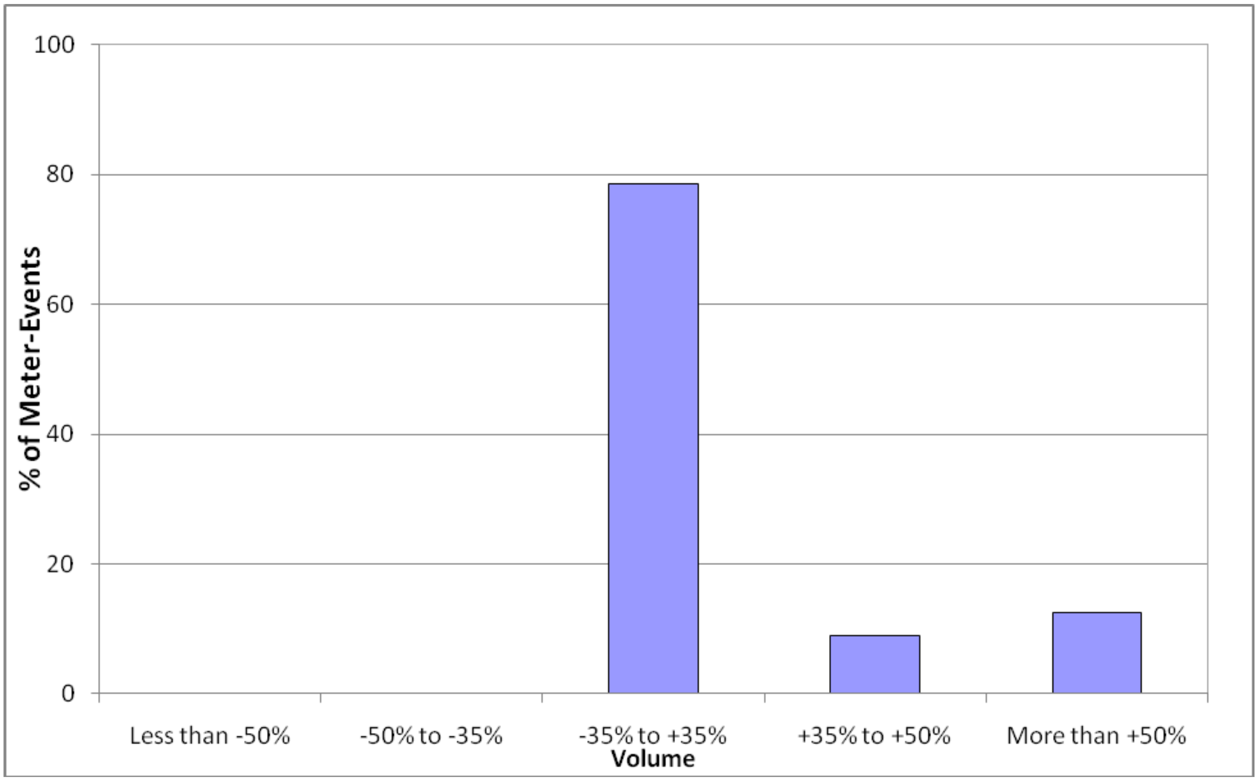

Figure 3-8. Modeled vs. Observed Validation Event Flow Volume Histogram

A review of Figure 3-8 yields the following findings with respect to the defined quantitative model validation criteria:

- At 79%, a significant core of the meter events falls within the +/- 35% range.
- At 88%, a majority of the meter events falls within the +/- 50% range.
- At 71%, a substantial number of the meter events fall within a tighter +/- 20% range (not shown on the figure, but embedded in the central +/- 35% range).
- There is a slight bias in the results, but it is to the high side, which is acceptable.

The above results show that, in terms of the flow volume criteria, the model was successfully validated.

3.5.3. 45-Degree Plots

To assist with the evaluation of the quantitative validation criteria, 45-degree plots were also generated for both peak flow rate (Figure 3-9) and flow volume (Figure 3-10). Each point on these graphs represents a comparison of modeled conditions to observed conditions at an individual meter for an individual validation event. An exact match will fall directly on the "ideal" 45-degree line. In addition, lines were added to the plots to denote the bounds of the +/- 35% and +/- 50% ranges specified in the validation criteria. A review of these plots confirms the findings of the histogram reviews, that the model was successfully validated with respect to meeting the quantitative peak flow rate and flow volume criteria. The plots also show that a majority of the meter events that lie outside of the +/- 50% bounds belong to three meter locations: SCJFM 1o, SCJFM 2o, and SCDFM 4o.

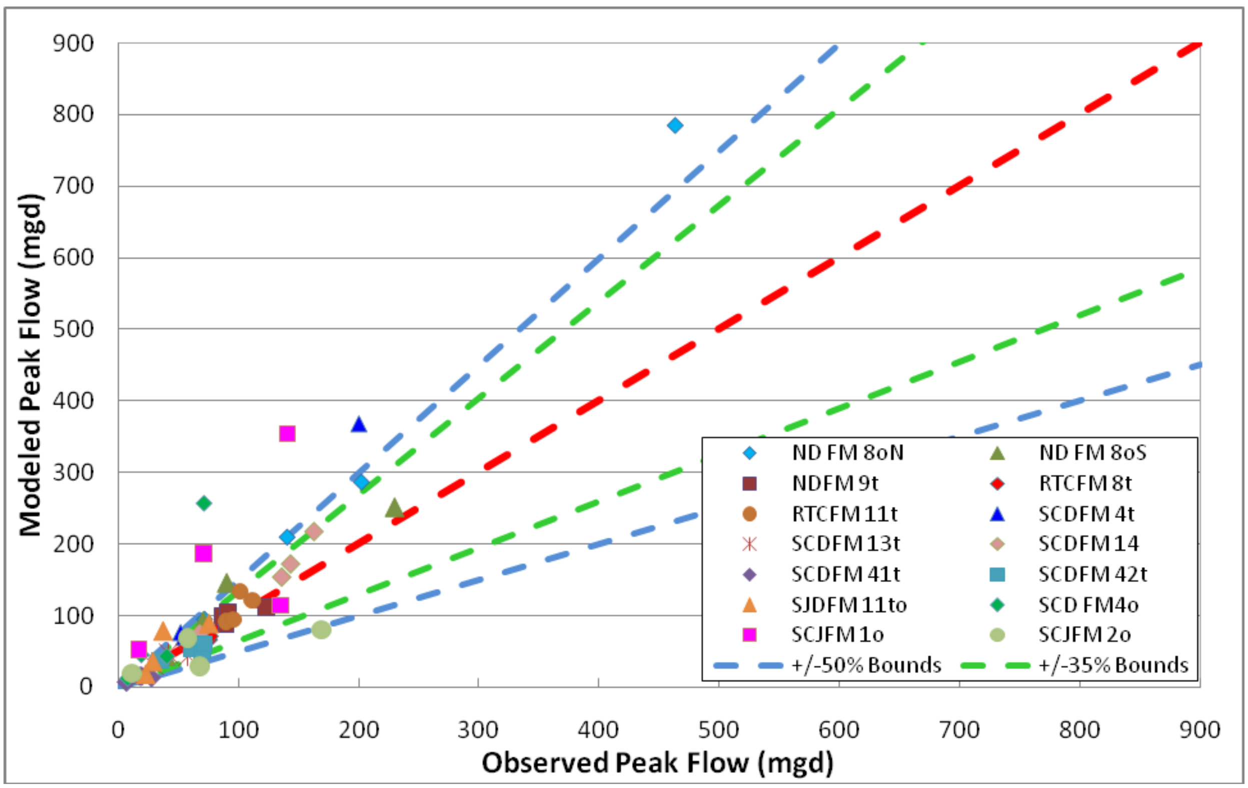

Figure 3-9. Modeled vs. Observed Validation Event Peak Flow Rate

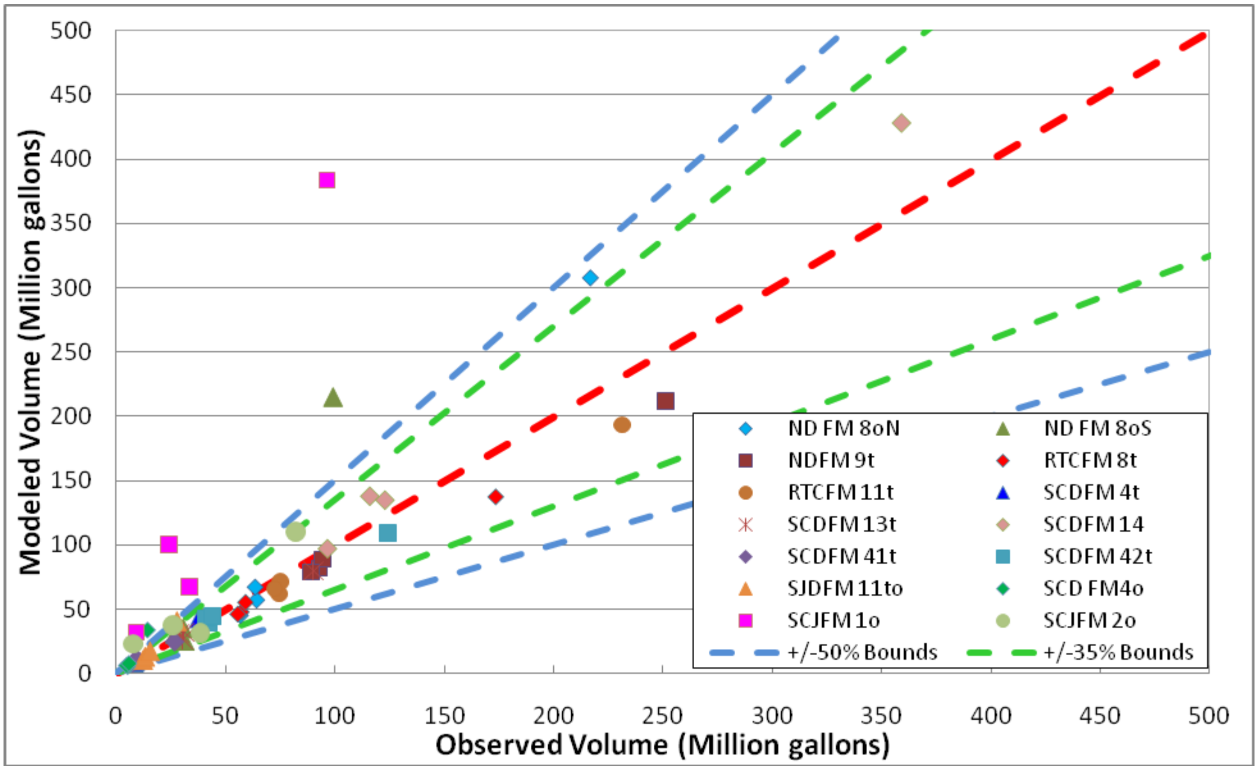

Figure 3-10. Modeled vs. Observed Validation Event Flow Volume

3.5.4. Comparison Tables

Tables 3-2 through 3-9 show quantitative comparisons of the modeled versus monitored peak flow rates and flow volumes for each of the four validation periods. These numerical comparisons are identically the same information as presented in the graphical comparisons (histograms and 45-degree plots) in Sections 3.5.2 and 3.5.3 above.

Table 3-2. Peak Flow Comparisons for the May 6-9 Validation Event.

Flow Meter	Monitored Peak Flow (MGD)	Modeled Peak Flow (MGD)	Difference (MGD)	Percent Difference (%)
ND FM 8oN	71.4	94.2	22.8	31.9%
ND FM 8oS	40.1	42.7	2.6	6.6%
ND FM 9t	89.5	88.1	-1.4	-1.6%
RTC FM 8t	76.3	66.3	-9.9	-13.0%
RTC FM 11t	89.6	91.4	1.8	2.0%
SCD FM 4o	7.5	12.5	5.0	66.8%
SCD FM 4t	16.2	15.5	-0.7	-4.2%
SCD FM 13t	29.2	30.7	1.5	5.1%
SCD FM 14	67.6	74.9	7.3	10.9%

SCD FM 41t	6.5	7.6	1.1	17.3%
SCD FM 42t	35.0	37.5	2.6	7.4%
SCJ FM 1o	17.4	52.7	35.3	202.8%
SCJ FM 2o	11.1	19.5	8.4	76.0%
SJD FM 11to	22.6	17.5	-5.0	-22.3%

Table 3-3. Flow Volume Comparisons for the May 6-9 Validation Event.

Flow Meter	Monitored Flow Volume (MG)	Modeled Flow Volume (MG)	Difference (MG)	Percent Difference (%)
ND FM 8oN	56.9	44.8	-12.1	-21.2%
ND FM 8oS	31.3	25.5	-5.8	-18.4%
ND FM 9t	92.8	81.9	-10.9	-11.7%
RTC FM 8t	57.3	47.7	-9.5	-16.6%
RTC FM 11t	74.3	61.7	-12.6	-17.0%
SCD FM 4o	5.2	5.8	0.6	11.3%
SCD FM 4t	8.9	7.1	-1.8	-20.5%
SCD FM 13t	30.5	26.8	-3.7	-12.2%
SCD FM 14	96.8	96.6	-0.2	-0.2%
SCD FM 41t	7.4	8.1	0.7	9.9%
SCD FM 42t	42.3	38.8	-3.5	-8.4%
SCJ FM 1o	33.4	67.3	34.0	101.8%
SCJ FM 2o	7.6	22.9	15.3	201.8%
SJD FM 11to	12.1	10.8	-1.3	-10.6%

Table 3-4. Peak Flow Comparisons for the June 17-20 Validation Event.

Flow Meter	Monitored Peak Flow (MGD)	Modeled Peak Flow (MGD)	Difference (MGD)	Percent Difference (%)
ND FM 8oN	140.2	209.1	68.9	49.1%
ND FM 8oS	70.8	91.9	21.1	29.8%
ND FM 9t	86.2	98.5	12.3	14.3%
RTC FM 8t	72.5	70.5	-2.0	-2.8%
RTC FM 11t	101.6	134.0	32.4	31.9%
SCD FM 4o	18.8	45.1	26.3	139.8%
SCD FM 4t	19.3	15.8	-3.5	-17.9%
SCD FM 13t	41.6	46.4	4.9	11.7%
SCD FM 14	135.6	153.8	18.2	13.4%

SCD FM 41t	19.3	15.8	-3.5	-17.9%
SCD FM 42t	60.9	52.8	-8.1	-13.3%
SCJ FM 1o	134.8	114.5	-20.4	-15.1%
SCJ FM 2o	67.6	29.3	-38.3	-56.7%
SJD FM 11to	28.6	35.2	6.6	23.3%

Table 3-5. Flow Volume Comparisons for the June 17-20 Validation Event.

Flow Meter	Monitored Flow Volume (MG)	Modeled Flow Volume (MG)	Difference (MG)	Percent Difference (%)
ND FM 8oN	64.3	56.8	-7.5	-11.7%
ND FM 8oS	26.8	30.9	4.0	15.0%
ND FM 9t	94.5	88.6	-5.9	-6.3%
RTC FM 8t	59.2	55.3	-4.0	-6.7%
RTC FM 11t	75.0	71.5	-3.5	-4.6%
SCD FM 4o	4.7	6.8	2.1	43.3%
SCD FM 4t	9.4	8.5	-1.0	-10.2%
SCD FM 13t	28.9	30.8	1.9	6.6%
SCD FM 14	116.2	137.5	21.3	18.4%
SCD FM 41t	9.1	10.0	0.8	8.8%
SCD FM 42t	41.1	43.1	2.0	4.9%
SCJ FM 1o	33.4	67.3	34.0	101.8%
SCJ FM 2o	38.5	31.4	-7.1	-18.5%
SJD FM 11to	13.0	13.3	0.3	2.3%

Table 3-6. Peak Flow Comparisons for the July 17-20 Validation Event.

Flow Meter	Monitored Peak Flow (MGD)	Modeled Peak Flow (MGD)	Difference (MGD)	Percent Difference (%)
ND FM 8oN	202.0	286.1	84.0	41.6%
ND FM 8oS	90.5	145.8	55.3	61.1%
ND FM 9t	91.1	103.9	12.8	14.1%
RTC FM 8t	64.3	56.7	-7.6	-11.8%
RTC FM 11t	95.8	94.2	-1.5	-1.6%
SCD FM 4o	40.0	43.1	3.1	7.6%
SCD FM 4t	51.7	75.7	24.0	46.5%
SCD FM 13t	58.0	43.0	-15.0	-25.9%
SCD FM 14	143.0	172.3	29.4	20.5%

SCD FM 41t	19.3	15.8	-3.5	-17.9%
SCD FM 42t	60.9	52.8	-8.1	-13.3%
SCJ FM 1o	70.8	186.8	116.1	164.0%
SCJ FM 2o	57.8	68.3	10.6	18.3%
SJD FM 11to	75.6	88.8	13.2	17.5%

Table 3-7. Flow Volume Comparisons for the July 17-20 Validation Event.

Flow Meter	Monitored Flow Volume (MG)	Modeled Flow Volume (MG)	Difference (MG)	Percent Difference (%)
ND FM 8oN	63.6	66.8	3.2	5.0%
ND FM 8oS	30.6	35.2	4.7	15.3%
ND FM 9t	89.2	78.9	-10.4	-11.6%
RTC FM 8t	55.7	46.0	-9.6	-17.3%
RTC FM 11t	72.5	65.8	-6.7	-9.3%
SCD FM 4o	5.8	8.2	2.4	42.2%
SCD FM 4t	9.7	10.5	0.7	7.5%
SCD FM 13t	31.0	31.9	0.9	3.1%
SCD FM 14	123.1	134.5	11.4	9.2%
SCD FM 41t	9.9	9.8	-0.1	-1.0%
SCD FM 42t	44.0	44.3	0.3	0.7%
SCJ FM 1o	24.1	100.1	76.0	315.9%
SCJ FM 2o	25.9	37.7	11.8	45.4%
SJD FM 11to	15.3	17.5	2.3	14.8%

Table 3-8. Peak Flow Comparisons for the July 21-28 Validation Event.

Flow Meter	Monitored Peak Flow (MGD)	Modeled Peak Flow (MGD)	Difference (MGD)	Percent Difference (%)
ND FM 8oN	463.0	785.0	322.1	69.6%
ND FM 8oS	230.4	251.6	21.2	9.2%
ND FM 9t	123.1	111.3	-11.8	-9.6%
RTC FM 8t	76.8	71.3	-5.5	-7.2%
RTC FM 11t	111.7	121.5	9.8	8.8%
SCD FM 4o	70.9	257.0	186.1	262.3%
SCD FM 4t	200.2	368.3	168.1	84.0%
SCD FM 13t	64.7	64.3	-0.4	-0.6%
SCD FM 14	162.4	217.7	55.3	34.1%

SCD FM 41t	27.5	14.0	-13.5	-49.1%
SCD FM 42t	71.4	60.7	-10.7	-15.0%
SCJ FM 1o	140.6	354.4	213.8	152.0%
SCJ FM 2o	168.9	79.9	-89.0	-52.7%
SJD FM 11to	37.1	78.6	41.5	111.6%

Table 3-9. Flow Volume Comparisons for the July 21-28 Validation Event.

Flow Meter	Monitored Flow Volume (MG)	Modeled Flow Volume (MG)	Difference (MG)	Percent Difference (%)
ND FM 8oN	216.6	307.7	91.1	42.1%
ND FM 8oS	99.1	214.8	115.8	116.9%
ND FM 9t	251.4	211.7	-39.7	-15.8%
RTC FM 8t	173.7	137.7	-36.0	-20.7%
RTC FM 11t	231.3	193.2	-38.1	-16.5%
SCD FM 4o	14.1	34.2	20.1	142.8%
SCD FM 4t	37.4	41.5	4.2	11.1%
SCD FM 13t	90.1	79.9	-10.3	-11.4%
SCD FM 14	359.4	428.0	68.7	19.1%
SCD FM 41t	26.6	24.3	-2.3	-8.6%
SCD FM 42t	124.1	109.3	-14.8	-11.9%
SCJ FM 1o	96.4	383.6	287.2	297.8%
SCJ FM 2o	82.2	110.4	28.2	34.4%
SJD FM 11to	27.6	40.8	13.2	47.9%

3.5.5. Staff Gauge Location Activations

The BSA field crew recorded overflow activations for the twelve staff gauge locations shown on Figure 3-3 for six events occurring during the four selected validation event periods (three of the inspection events fell during the week-long fourth validation event period). These inspection events are summarized in Table 3-2.

Table 3-10. Summary of Staff Gauge Inspection Events.

Event	Average Rainfall (in.)	Average Duration (hrs)	General Type
May 7	0.45	13	Smaller
June 16-17	0.74	25	Smaller
July 17-18	0.92	7	Larger
July 21	0.39	8	Smaller

July 23	1.58	22	Larger
July 25-26	0.93	7	Larger

As a supplemental step in the model validation process, the number of observed overflow activations was compared to the number of modeled overflow activations for the six inspection events for each of the twelve staff gauge locations. The results of these comparisons are summarized on Figure 3-11 and Figure 3-12.

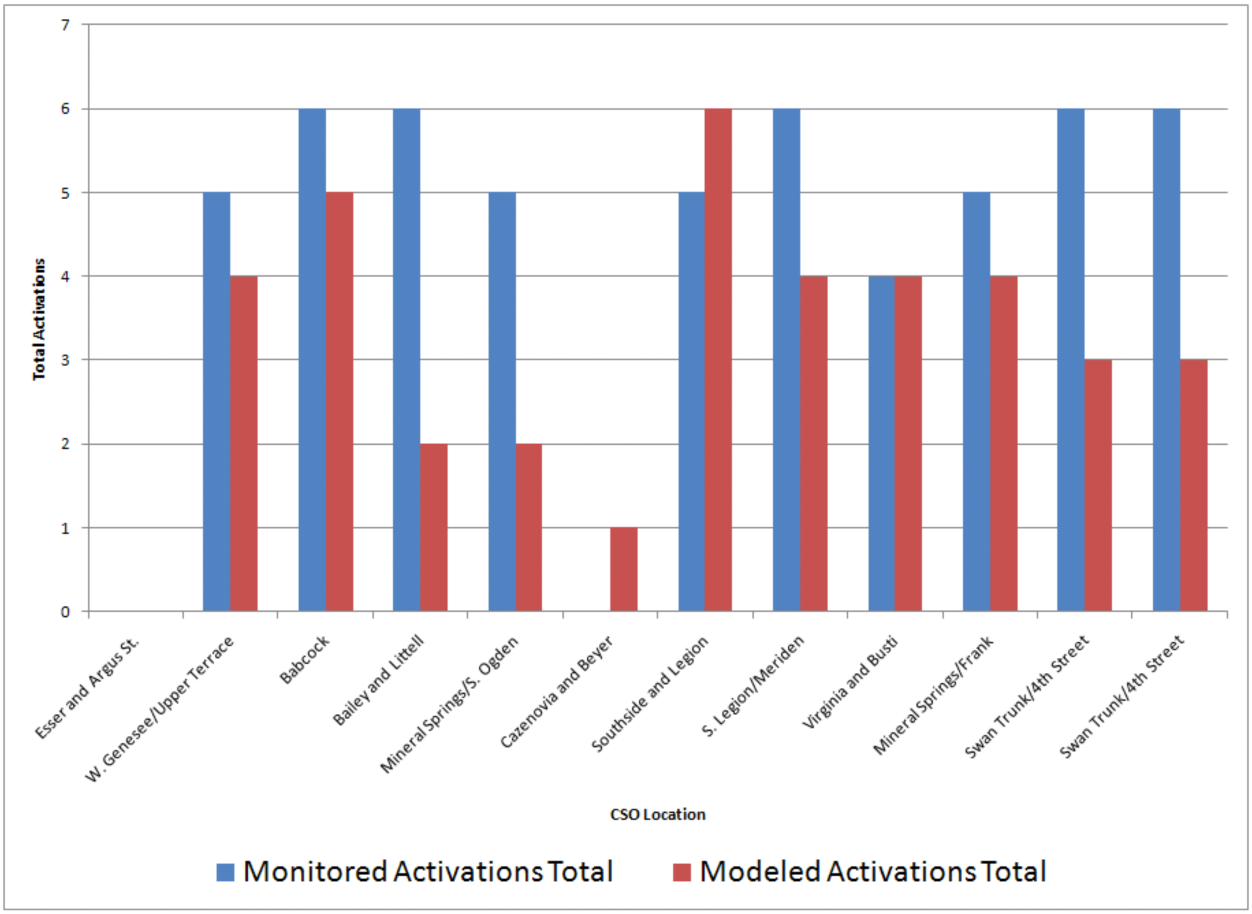

Figure 3-11. Comparison of Observed vs. Modeled Staff Gauge Overflow Activations (All Events)

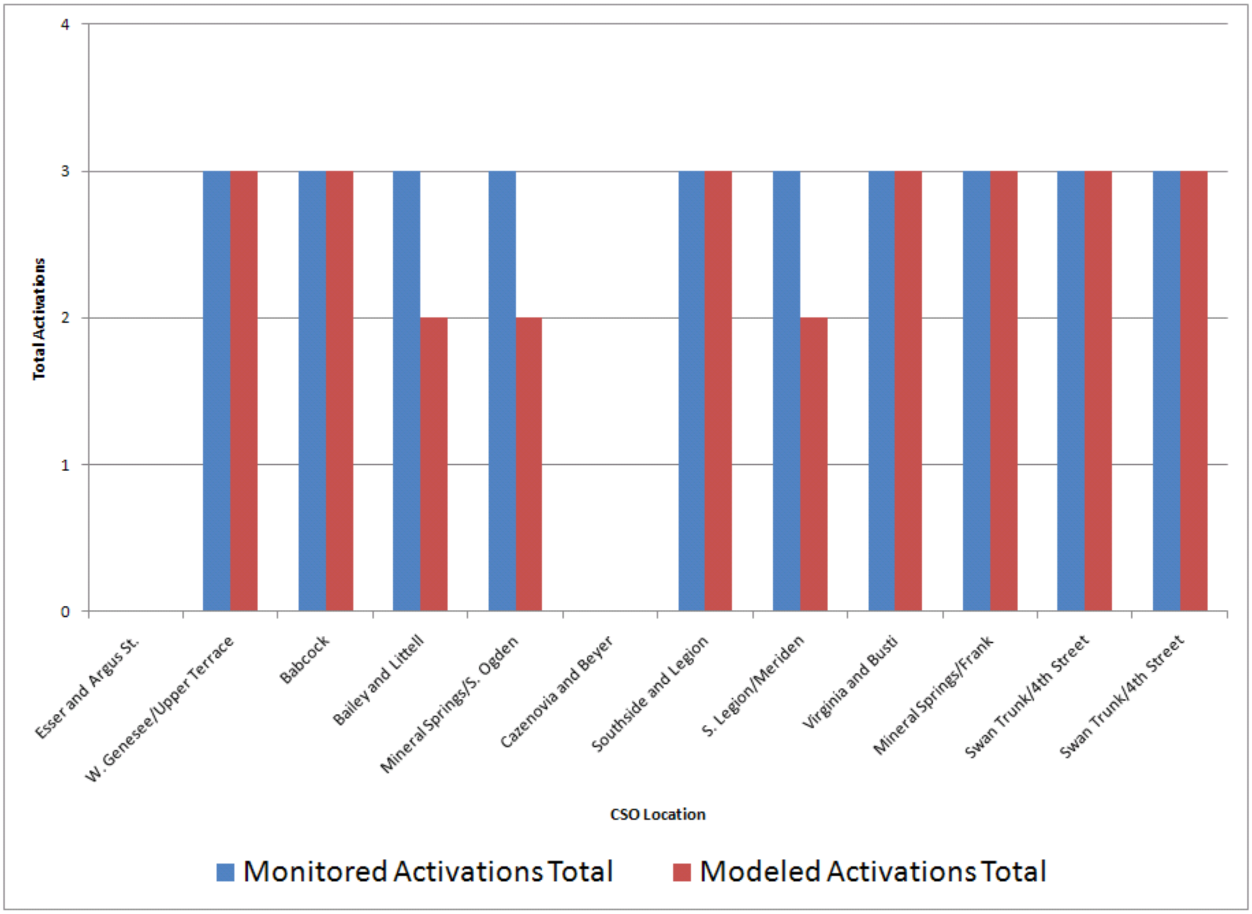

Figure 3-12. Comparison of Observed vs. Modeled Staff Gauge Overflow Activations (Larger Events Only)

The figures show a good match between observed and modeled overflow activations, particularly for the larger events. The better performance with the larger events is expected, since the smaller events are more likely to be closer in size to the overflow's threshold event (i.e., the smallest event that will trigger an overflow at a location). Threshold events typically result in a poorer activation comparison because (1) they are more difficult to read in the field due to the crudeness of staff gauge technology, and (2) they can result in a predicted "just under" or "just over" overflow condition within the model.

3.6. Summary of Findings

Based on the above findings, the following conclusions can be made from the validation of the BSA model:

- The model validation results show a successful validation of BSA's model on a system-wide basis:

  - The flow comparison plots show a strong visual match between the modeled and observed hydrographs, satisfying the "goodness-of-fit" criterion.
  - 70% to 80% of comparisons fall within the +/- 35% range for both peak flow rate and flow volume.
  - There is a strong match on activation counts at staff gauge locations, especially for larger events.
  - The results satisfy all of the specified validation criteria.
- For a few select locations (SCJFM 1o, SCJFM 2o, and SCDFM 4o), additional refinement of the model calibration could further improve the performance of the model.

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4. Model Refinement and Additional Validation

As a result of the model validation, it was decided that the calibration of three meters would be refined: SCJFM 1o, SCJFM 2o, and SCDFM 4o. This additional refinement was not considered necessary for the model's immediate planning-level purpose, but pursued at BSA's discretion as a worthwhile improvement within the context of their overall modeling program. The calibration refinement was done using the four event periods used during the model validation process. Two of the four events that were previously set aside as independent datasets were then used to validate the refined calibrations at these locations.

4.1. Locations for Calibration Refinement

The locations of the three locations where the calibration was refined are shown on Figure 4-1:

SCJFM 1o: This was a stream meter location, located in Scajaquada Creek upstream of where it enters the Scajaquada Drain. This location only had a limited data set available during the original monitoring program. The Scajaquada Creek watershed tributary to this location is shown on Figure 4-2.

SCJFM 2o: This meter was located in the Scajaquada Drain downstream of SPP170A, just upstream of where Scajaquada Creek re-emerges from the Scajaquada Drain. This location wasn't monitored during the original 2000 monitoring program.

SCDFM 4o: This meter was located in an 84" diameter pipe in the Albany Street area. This location wasn't monitored during the original 2000 monitoring program.

4.2. Calibration Refinement and Results

For the calibration refinement, the original four validation events were used. During the refinement, the following changes were made in order to improve the calibration:

- For SCDFM 4o, the following hydrologic parameters of the contributing subcatchments were adjusted during the calibration refinement:
  - The % impervious values were reduced.
  - The subcatchment basin widths were reduced.
  - The Horton's minimum infiltration rate for the pervious areas was increased.

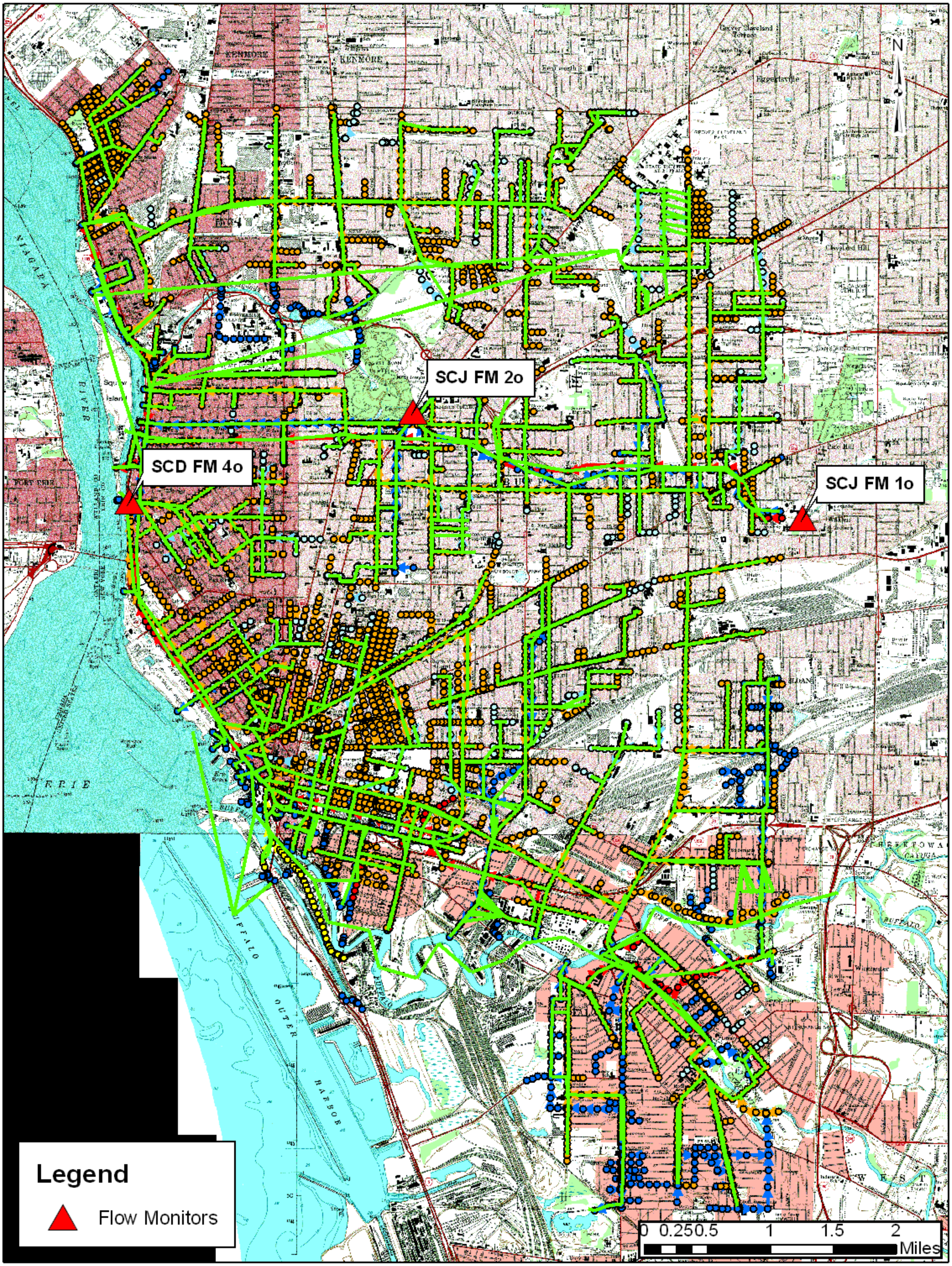

Figure 4-1. Locations of Flow Monitors Where Calibration Refined

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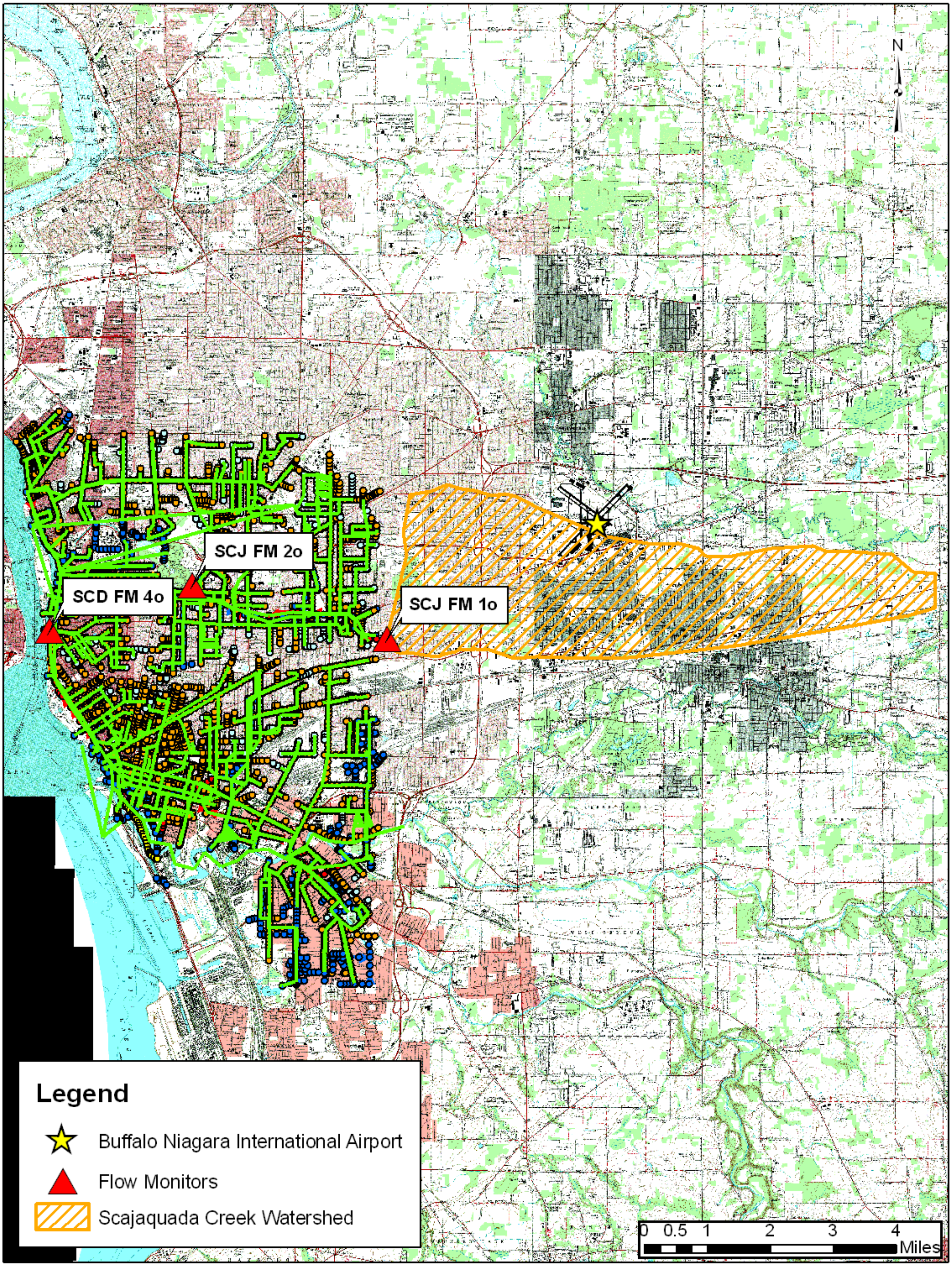

Figure 4-2. Extent of Scajaquada Creek Watershed

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- For SCJFM 1o, the following hydrologic parameters of the lumped subcatchment representing the upstream Scajaquada Creek watershed were adjusted during the calibration refinement:
  - The % impervious value was reduced.
  - The impervious area depression storage was increased.
  - The pervious area depression storage was increased.
  - The impervious area overland Manning's n value was increased.
  - The pervious area overland Manning's n value was reduced.
  - The Horton's maximum infiltration rate for the pervious area was increased.
  - The Horton's minimum infiltration rate for the pervious area was reduced.
  - The Horton's infiltration decay constant was increased.
- To improve the calibration at SCJFM 2o, the hydraulic representation of SPP170A was updated in order to better match how it functions in the field.

The resulting flow comparison plots for these meters for the calibration events can be found in Appendix D. Figure 4-3 and Figure 4-4 show the 45-degree peak flow rate and flow volume plots for these calibration events, and include both the original meter event points (before calibration refinement) and refined meter event points (after calibration refinement). Therefore, these plots show the improvement in the comparisons achieved through the calibration refinements. The meter event points for the refined calibration fall within the desired ranges, with a limited number of acceptable outliers. The instances where the points fall out of the desired ranges were investigated further and found to be likely due to differences in rainfall distributions across the service area. An example of this is shown in Figure 4-5. When using the rainfall data obtained from the monitoring program network for the Scajaquada Creek watershed upstream of SCJFM 1o, the calibration results showed the model substantially underpredicting the monitored flow rates for the 6/17/2009 event. However, the rain gauge used was located on the extreme western edge of the Scajaquada Creek watershed. A review of the National Climate Data Center (NCDC) website showed that for this event, hourly data was available for this event from a weather station located at the Buffalo Niagara International Airport. As can be seen in Figure 4-2, the airport is more centrally located within the Scajaquada Creek watershed than any of the rain gauges within the monitoring program's network. When the hourly rainfall data from the airport station was applied to the Scajaquada Creek watershed within the model for the event, the calibration results at SCJFM 1o improved substantially, as can be seen in Figure 4-5. Overall, the comparison results show substantial improvement over the results from the initial validation cycle.

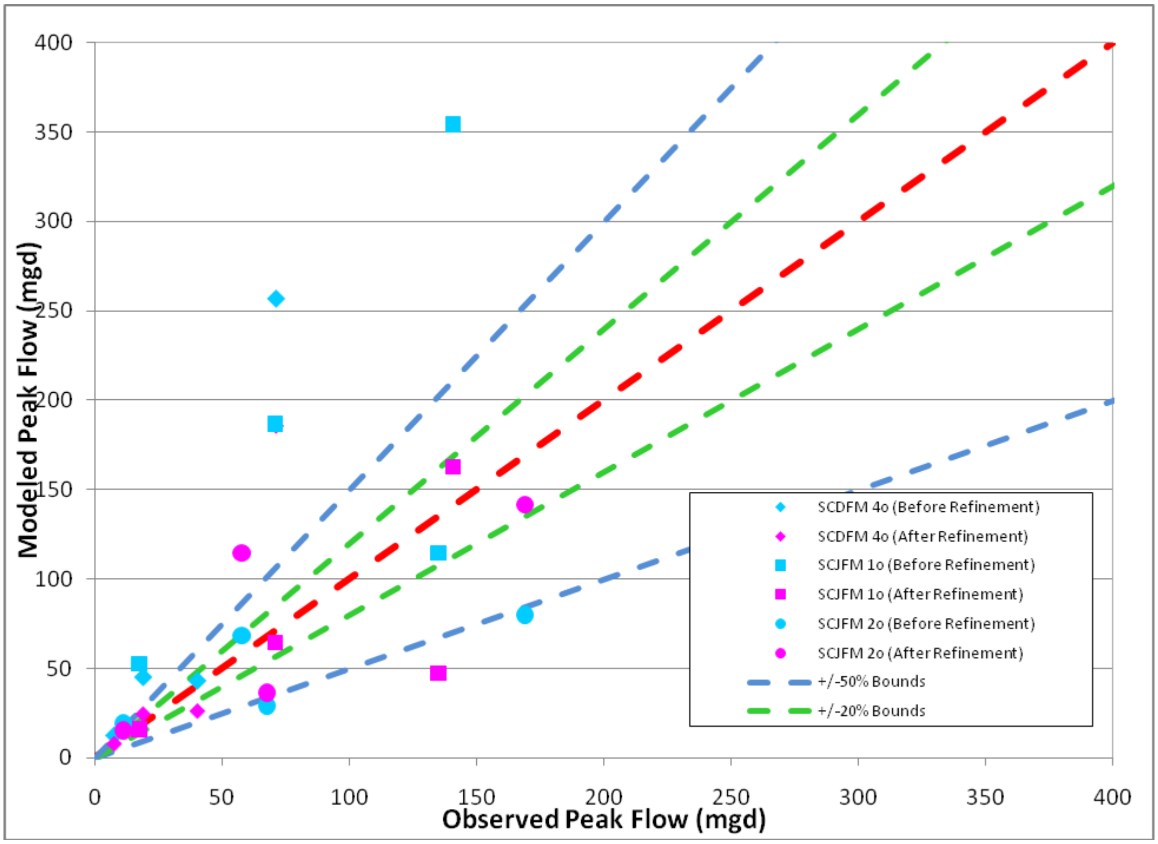

Figure 4-3. Modeled vs. Observed Calibration Event Peak Flow Rate for the Refined Calibration Locations

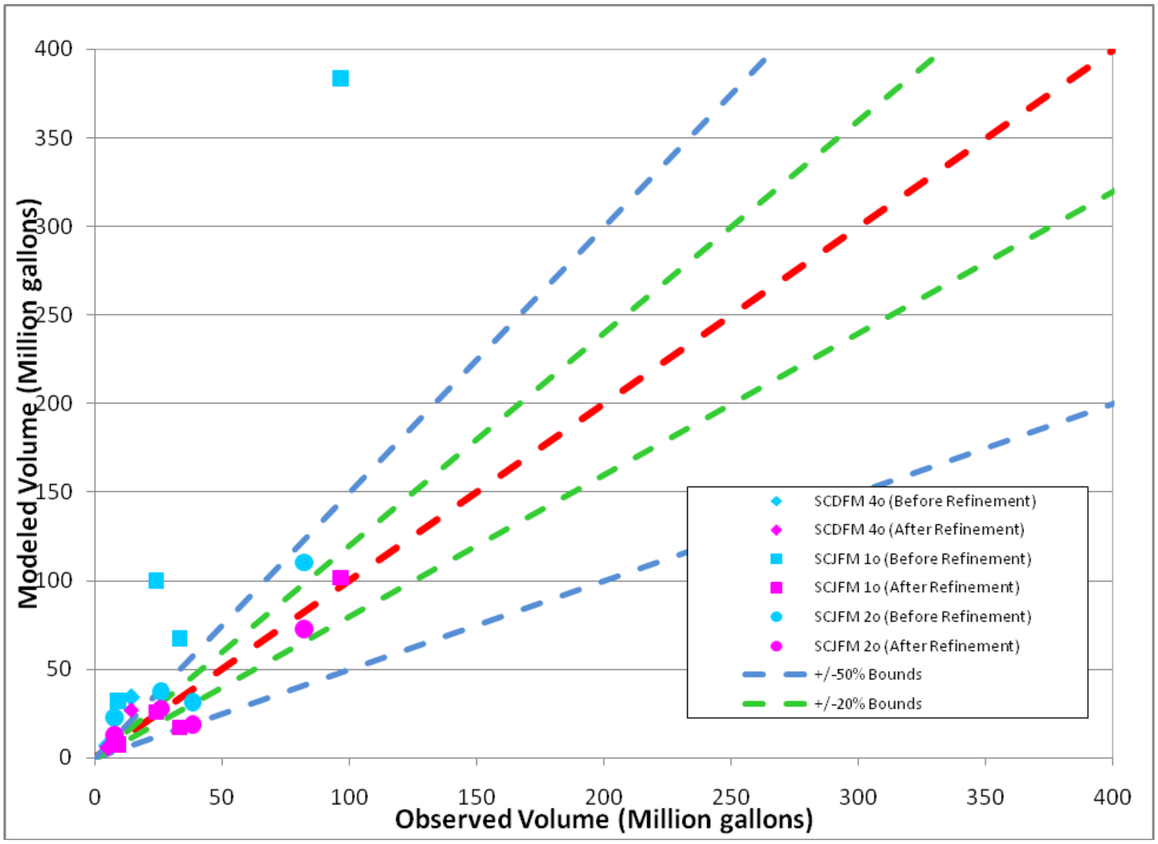

Figure 4-4. Modeled vs. Observed Calibration Event Flow Volume for the Refined Calibration Locations

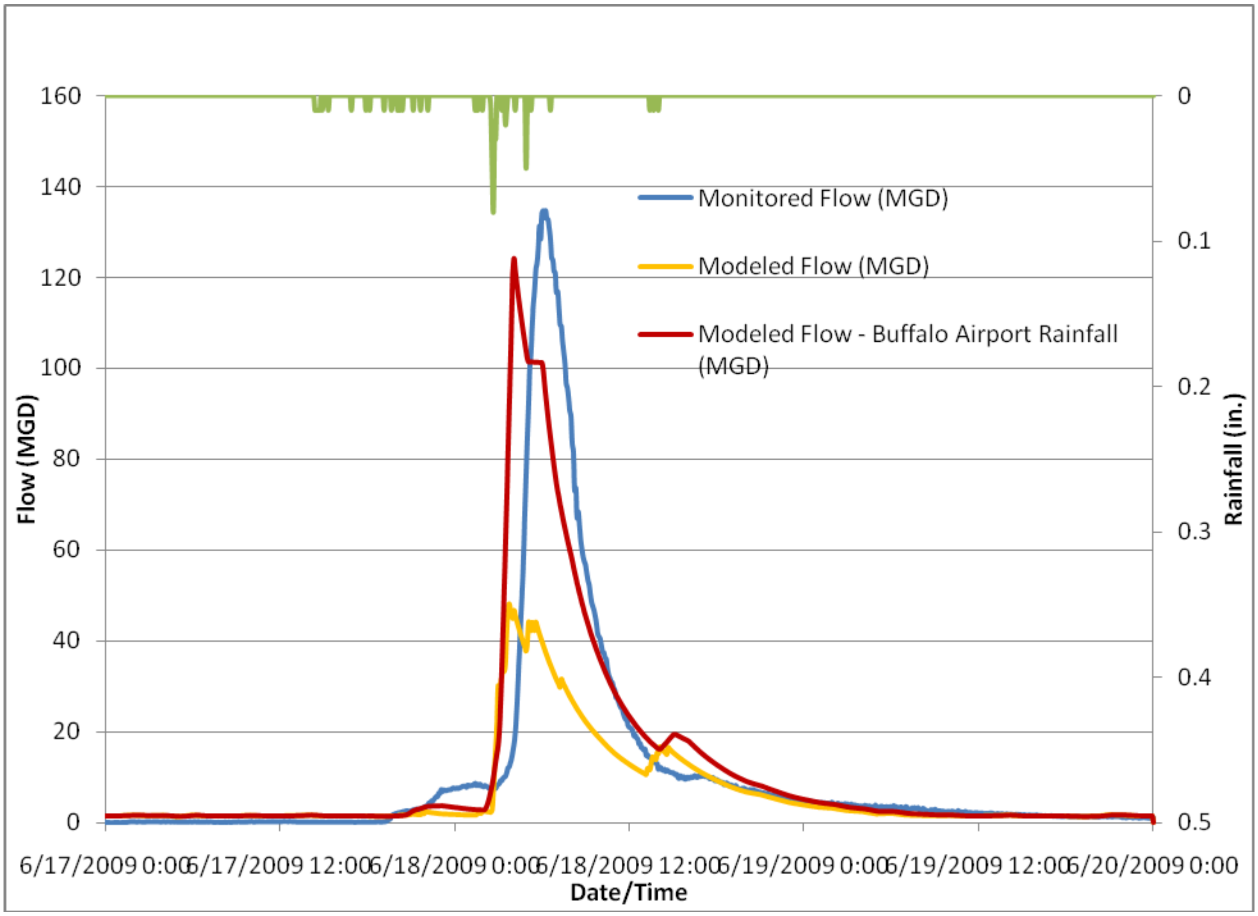

Figure 4-5. Impact of Using Hourly Rainfall Data from the Buffalo Niagara International Airport on the SCJFM 1o Calibration Results

4.3. Validation of Calibration Refinement Locations

After the calibration of these three locations was refined, the meter locations were validated using two of the event periods initially set aside as independent datasets (Table 4-1).

Table 4-1. Summary of Validation Event Periods for Refined Calibration Meters.

Validation Event	Average Rainfall (in.)	Average Duration (hrs)
May 27-June 4	1.03	NA(1)
August 26-September 2	0.72	NA(2)

(1) Extended event - includes four rainfall cells in a one-week period.

(2) Extended event - includes three rainfall cells in a one-week period.

The resulting flow comparison plots for these meters for the calibration events can be found in Appendix E. Figure 4-6 and Figure 4-7 show the 45-degree peak flow rate and flow volume plots for these calibration events. With only two validation events, the number of points on the 45-degree plots is limited. Once again, the meter event points fall within the desired ranges, with a limited number of acceptable outliers. The instances where the points fall out of the desired ranges were investigated further and found to be likely due to differences in rainfall distributions across the service area. Based on these findings, the refined calibrations for these locations were successfully validated.

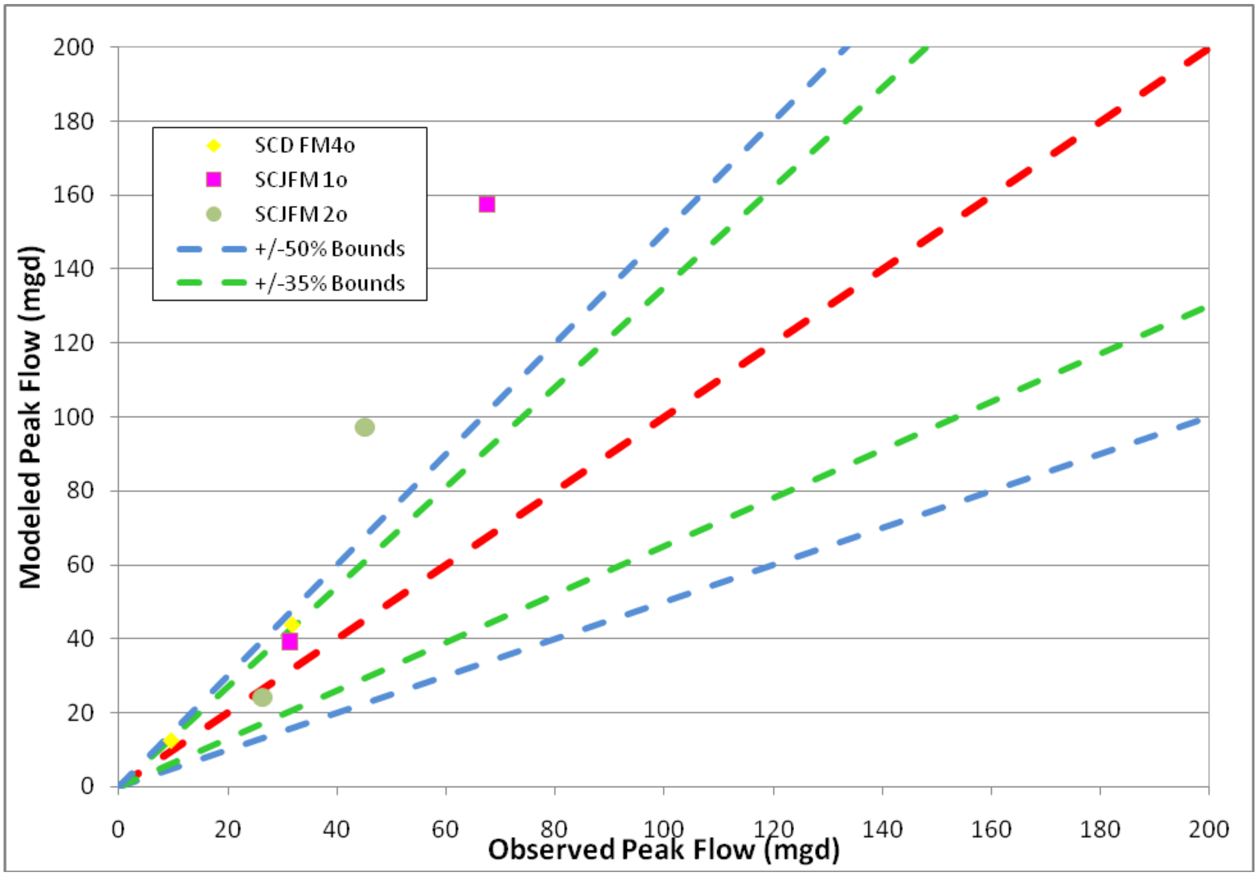

Figure 4-6. Modeled vs. Observed Validation Event Peak Flow Rate for the Refined Calibration Locations

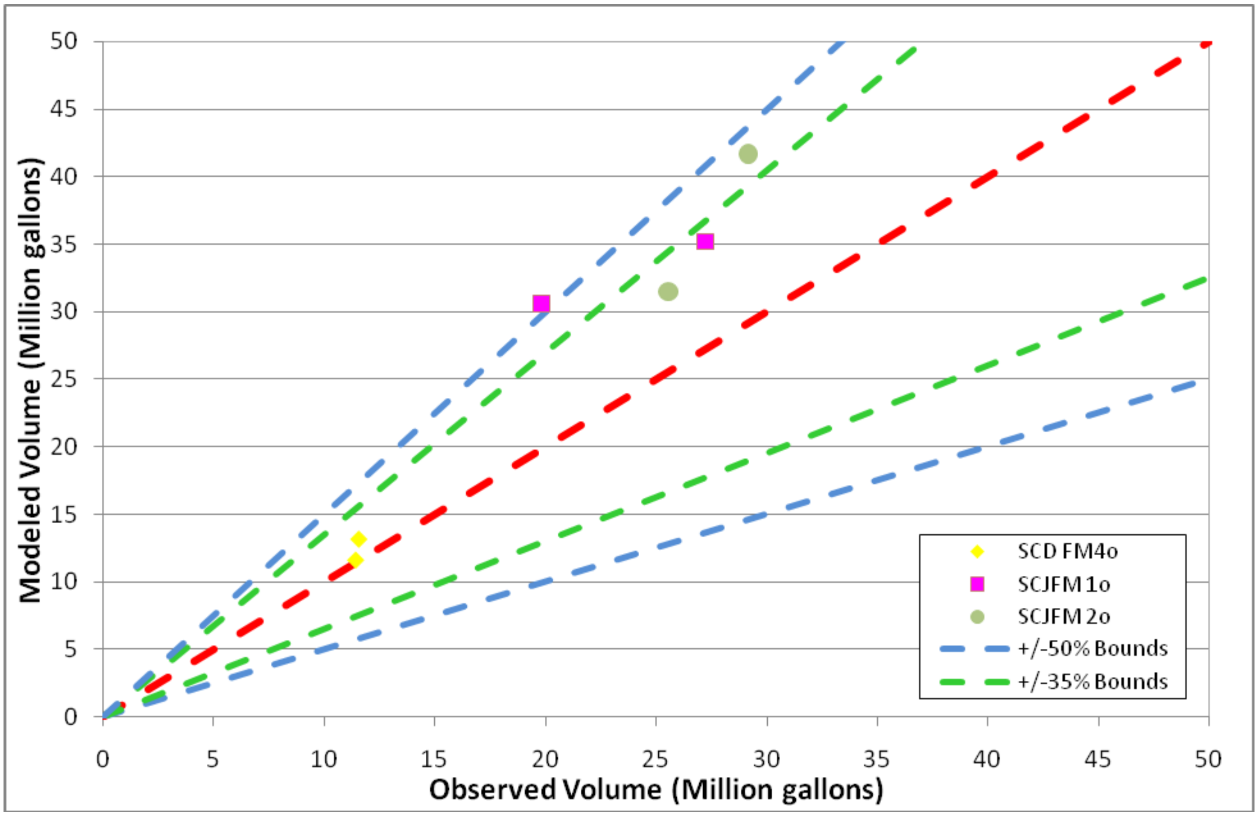

Figure 4-7. Modeled vs. Observed Validation Event Flow Volume for the Refined Calibration Locations

5. Summary and Conclusions

The purpose of model calibration and validation, according to the CSO Guidance, is described in the following excerpts (emphasis added):

> *"Model calibration and validation are used to "fine-tune" a model to better match the observed conditions and demonstrate the credibility of the simulation results. An uncalibrated model may be acceptable for screening purposes, but without supporting evidence the uncalibrated results may not be accurate. To use model simulation results for evaluating control alternatives, the model must be reliable."* From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.
>
> *"Validation is important because it assesses whether the model retains its generality; that is, a model that has been adjusted extensively to match a particular storm might lose its ability to predict the effects of other storms."* From "CSO Guidance for Monitoring and Modeling," Section 7.4.2.

Summarizing this guidance, a collection system model should be appropriately credible, reliable, and retain generality (i.e., be repeatable across multiple events). The validation and calibration refinement results presented in this report clearly demonstrate that BSA's collection system model possesses all three of these characteristics:

- The first cycle of validation tested BSA's 8-year old model (with system updates) against a completely independent 2009 dataset using 4 wet-weather events. This validation resulted in:
  - Strong visual match between modeled hydrographs and monitored hydrographs
  - 70% to 80% of meter to model comparisons fall in the +/-35% difference range for both volume and peak flow
  - Strong match on activation counts at staff gauge locations, especially for larger events

  These results satisfy all agreed-upon validation criteria, and demonstrate successful validation on a system-wide basis with exceptional comparisons at 11 of 14 locations.

- Discretionary calibration refinement was performed at 3 locations, with successful independent validation, producing an even stronger model.

Given these results, BSA is fully confident that their current model is a strong planning-level tool, developed appropriately during the original LTCP effort, and suitable for the Phase 2 LTCP alternatives analysis.

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Appendix 4-4: Receiving Water Quality Sampling Program Summary Report (Jan 2011)

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Buffalo Sewer Authority
65 Niagara Square • 1038 City Hall • Buffalo, NY 14202

Phase 2
CSO Long-Term Control Plan

Receiving Water Quality Sampling Program

Summary Report

November 2010
Revised January 2011

Report Prepared By:

Malcolm Pirnie, Inc.

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Suite 600
Buffalo, New York 14202
716-667-0900

1777-114

MALCOLM PIRNIE

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Contents

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Attachments

1. Introduction

This report presents a summary of the receiving water quality program conducted during Phase 2 of the Buffalo Sewer Authority's (BSA) Combined Sewer Overflow Long-Term Control Plan (CSO LTCP) program. The Phase 2 water quality sampling program was conducted between July 2008 and October 2009 by Malcolm Pirnie in collaboration with Buffalo State College and support by LimnoTech. The primary purposes of this report are as follows:

- Summarize the primary components of the Phase 2 Receiving Water Quality Sampling Program Workplan (*Workplan*; Section 2).
- Summarize the discrete sampling event and continuous monitoring program activities (Section 3).
- Present the program results, including analytical results from discrete sampling events, and data collected from the continuous monitoring program component (Section 4).
- Document quality assurance/quality control procedures and results (Section 5).

This report includes an assessment of the analytical results and data collected during the sampling program. The interpretation of results is not included in this report, which is included primarily in the Water Quality Model Development and Calibration Report prepared by LimnoTech.

1.1. Background

The Phase 2 receiving water quality monitoring program was conducted in response to comments received from the New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA) following their review of BSA's System-Wide Long Term Control Plan for CSO Abatement report, submitted in 2004. The LTCP was developed based on evaluation of BSA's collection and conveyance system, and water quality-based assessments, conducted from 2000 through 2004. NYSDEC and USEPA suggested the need for additional receiving water quality modeling of waterways potentially affected by combined sewer overflows (CSOs). Specifically, modeling of the Niagara River, the Buffalo River and Scajaquada Creek was requested to evaluate concerns regarding bacteria in all three waterways, biochemical oxygen demand (BOD_5) and effects on dissolved oxygen (DO) in the Buffalo River and Scajaquada Creek, and dissolved oxygen impacts in the Black Rock Canal.

The Phase 2 receiving water quality monitoring program was conducted to support the additional receiving water quality modeling work requested by the NYSDEC and the USEPA. The water quality data collected under this Plan will be used together with the receiving stream and CSO discharge water quality data collected under the initial LTCP project for calibration and validation of the receiving water quality models, as defined in the Water Quality Modeling Plan prepared by LimnoTech in April 2008, in order to examine the impacts of CSOs on the water bodies.

1.2. Report Content

This report contains the following information:

- Summary and description of the sampling program components, including the discrete wet and dry-weather sampling events.
- Results for sampling and monitoring efforts.
- Quality assurance/quality control (QA/QC) review

2. Overview of the Phase 2 Receiving Water Quality Monitoring Program

2.1. Workplan Components

Full details of the Phase 2 receiving water quality sampling program, methodology, and rationale are provided in the *Phase 2 CSO LTCP Receiving Water Quality Sampling Program Workplan* (Attachment A) prepared by Malcolm Pirnie on behalf of the BSA in April 2008, and subsequently approved by the USEPA. The *Workplan* outlined the following components of the program:

- Water quality sampling locations.
- Frequency and duration of water quality sampling.
- Determination for which storm events should be targeted.
- Water quality parameters to be analyzed.
- Data storage protocols to be followed.

The Phase 2 program initiated in 2008 with two dry weather samples collected in 2008. However, due to unfavorable weather conditions, no wet weather sampling events were conducted in 2008. With USEPA and NYSDEC concurrence, the wet weather sampling was extended to 2009 with two discrete wet weather sampling events conducted in the fall of 2009. The program was comprised of the following major receiving water sampling components:

- ***Discrete dry and wet weather sampling events:***
  - Comprised of manual surface sampling at locations along five transects in the Niagara River, and specific locations at the mouth of the Buffalo River, and in the Black Rock Canal and Scajaquada Creek (24 total discrete sampling locations). The actual sampling locations are shown on Figure 2-1.
  - Two discrete dry weather (July 16 and September 3, 2008), and two discrete wet weather (initiating on September 26 and October 23, 2009) sampling events, were conducted during the Phase 2 program.
  - Dry weather events included collecting one sample at each location during each event, while wet weather events were comprised of a time series of sampling during each event following the initiation of wet weather conditions and confirmed overflow activation in the BSA's system.

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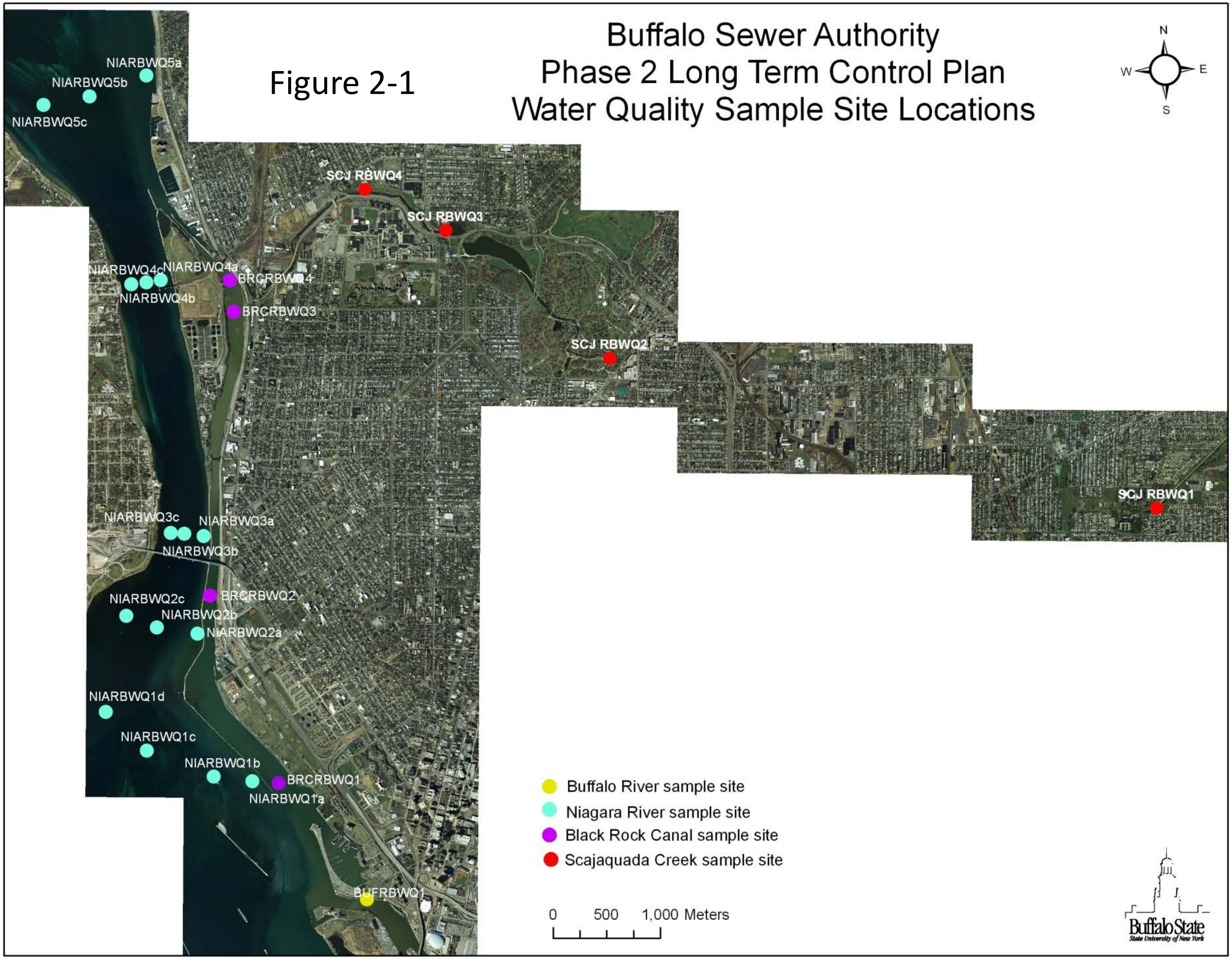
Figure 2-1
Buffalo Sewer Authority
Phase 2 Long Term Control Plan
Water Quality Sample Site Locations
N
W
E
S
NIARBWQ5a
NIARBWQ5b
NIARBWQ5c
SCJ RBWQ4
SCJ RBWQ3
NIARBWQ4c
NIARBWQ4a
BRCRBWQ4
NIARBWQ4b
BRCRBWQ3
SCJ RBWQ2
SCJ RBWQ1
NIARBWQ3c
NIARBWQ3a
NIARBWQ3b
BRCRBWQ2
NIARBWQ2c
NIARBWQ2b
NIARBWQ2a
NIARBWQ1d
NIARBWQ1c
NIARBWQ1b
BRCRBWQ1
NIARBWQ1a
BUFRBWQ1
Buffalo River sample site
Niagara River sample site
Black Rock Canal sample site
Scajaquada Creek sample site
0
500
1,000 Meters
Buffalo State
State University of New York

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- The samples collected during the discrete events were analyzed at contract laboratories for fecal coliform bacteria (all locations), and total and soluble five-day biological oxygen demand (BOD_5, all locations except Niagara River transects). Dissolved oxygen, temperature, and conductivity were measured at the four Scajaquada Creek sampling locations using multi-parameter field probes for each discrete event. Turbidity and pH were recorded for the Black Rock and Buffalo River sites.
- Sampling at the Buffalo River and Black Rock Canal locations also included discrete depth profiling, with grab samples collected, and multi-probe analyses conducted, at a minimum of three separate depths (surface, bottom, and thermocline if present, otherwise at midpoint of total depth).

■ ***In-situ sediment oxygen demand (SOD) sampling/analysis:***

- In-situ SOD was measured during dry weather conditions at four selected locations in Scajaquada Creek and the Black Rock Canal (two in each). For each of the two receiving waters, SOD sampling was conducted at a downstream and upstream location. SOD sampling/analysis was conducted on July 20, 2008 at the two Scajaquada Creek locations and on October 10, 2008 at the Black Rock Canal locations. A summary of the SOD sampling locations for each receiving water is as follows:
  - **Black Rock Canal**
    - Downstream SOD - Black Rock Canal at Scajaquada Creek Mouth: Located approximately 20 feet downstream of the mouth of Scajaquada Creek and approximately 150 feet from the East bank (42^o 55' 44.783" N, 78^o 53' 59.572" W).
    - Upstream SOD - Black Rock Canal at Peace Bridge: Located approximately 50 feet downstream of the Peace Bridge and approximately 30 feet from the West bank (42^o 54' 24.174" N, 78^o 54' 05.924" W).
  - **Scajaquada Creek**
    - Downstream SOD - Located approximately six feet from the Northwest bank and approximately 60 feet Southwest of West Avenue (approximately 35 feet Southwest of the downstream edge of the West Ave. bridge) (42^o 55' 48.46" N, 78o 53' 45.48" W).
    - Upstream SOD - Located in Delaware Park approximately 100 feet upstream of the stream tunnel entrance and approximately eight feet out from the North bank (42^o 55' 51.61" N, 78^o 52' 02.07" W).
- In-situ SOD was measured in bottom sediments at each location using a hemispherical stainless steel chamber (respirometer) to isolate a known volume of water over a specific area of streambed. Water was gently mixed within the chamber using a sealed, recirculating pump system. The change in dissolved oxygen concentrations within the chamber over time was monitored with a YSI dissolved oxygen/temperature probe fitted into the chamber. SOD incubations ran for approximately two hours and depended on the time necessary to obtain an accurate rate of dissolved oxygen depletion. For each instrument, a dark bottle

was filled with river water and incubated in the river simultaneously with the chamber to provide a correction for algal respiration and biochemical oxygen demand (BOD) within the water column. SOD was determined by subtracting the rate of change of dissolved oxygen within the dark bottle from the rate of change in the chamber. The resulting value was then corrected to a temperature of 20° C. Duplicate chambers were deployed at each location, resulting in two calculated SOD values for each location. The final SOD value report for each location is the average of the duplicate results. The SOD sampling/analysis component was managed by LimnoTech. A complete summary of SOD sampling and analysis procedures are included in the technical memorandum included in Attachment H.

- ***Continuous water quality monitoring:***
  - Continuous sampling included deployment of three YSI continuous recording datasondes to collect continuous, incremental water quality data at two locations (two in the Black Rock Canal, and one at the mouth of the Buffalo River). The continuous monitoring locations are shown on Figure 2-2.
  - The YSI units were installed at a depth of approximately two feet below the surface at each location.
  - Continuous water quality data were collected by each YSI unit during the navigable boating seasons of both 2008 and 2009 for the following specific time periods:
    - July 9 through October 30, 2008.
    - April 24 through October 29, 2009.
  - The following parameters were sampled continuously at 15-minute increments by each YSI unit during each monitoring season:
    - Temperature
    - Specific conductance
    - Dissolved oxygen
    - pH
    - Turbidity
- ***Water stage and velocity monitoring:***
  - Hydraulic monitoring instruments (water level sensors and horizontal acoustic Doppler current profilers (HADCP)) were installed at upstream and downstream locations on Scajaquada Creek to record water levels and water velocities during the period of July through October 2008. There were upstream and downstream monitoring locations established for each type of instrument for a total of four locations. These data were collected to support calibration of the hydrodynamic model of the Creek. A summary of the locations for each type of monitor is as follows:
    - **Water Level**
      - <u>Downstream level gauge</u> - Scajaquada Creek at Grant Street Dam: Located approximately two feet from the North bank sheet piling and approximately three feet upstream of Grant St. dam (45^{o} 56' 16.460" N, 78^{o} 53'07.515" W).

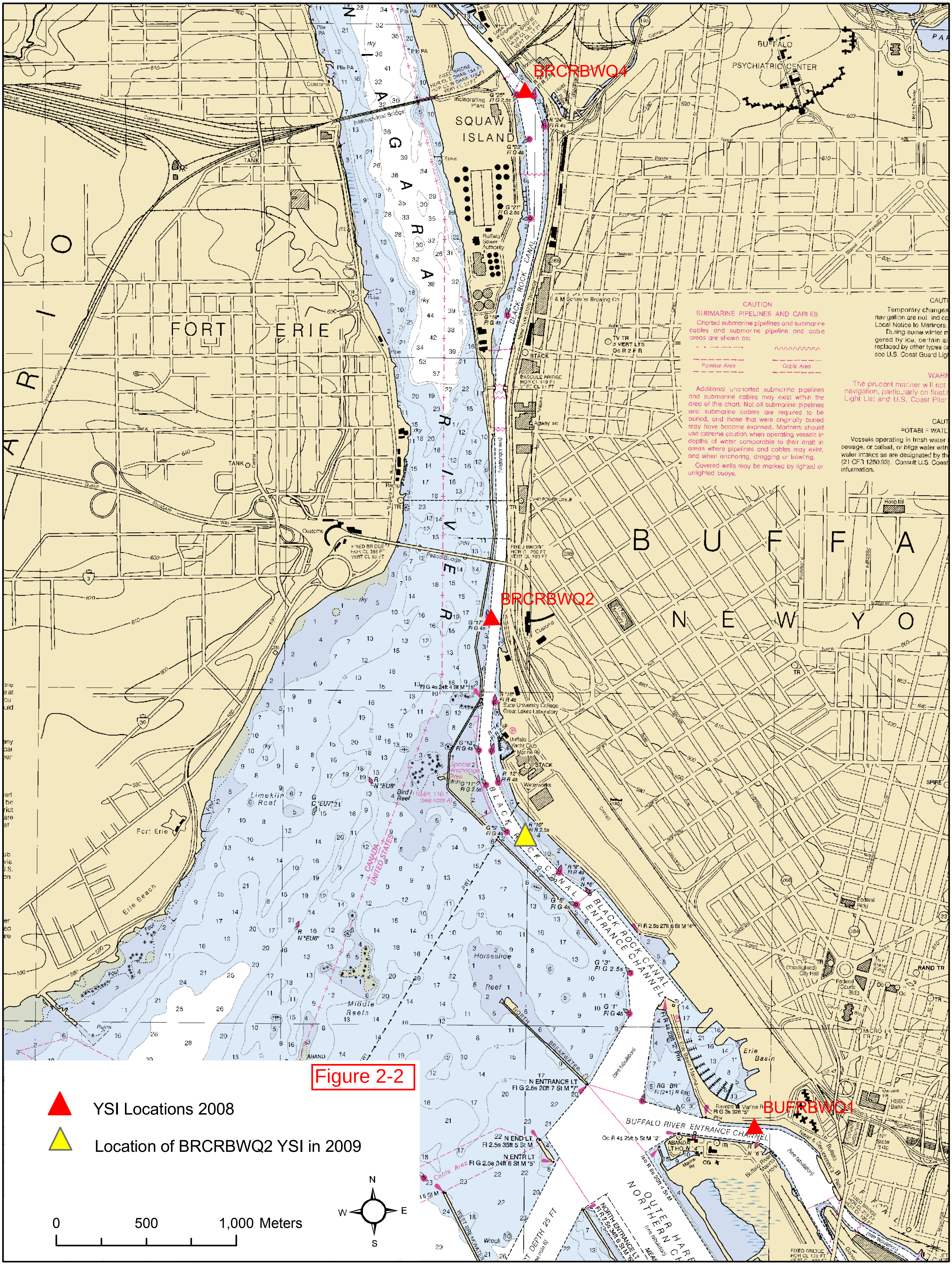
BRCRBWQ4
BRCRBWQ2
BUFRBWQ1
YSI Locations 2008
Location of BRCRBWQ2 YSI in 2009
0
500
1,000 Meters
N
E
S
W
FORT ERIE
SQUAW ISLAND
NIAGARA RIVER
BLACK ROCK CANAL
BUFFA
NEW YO
Erie Basin
BUFFALO RIVER ENTRANCE CHANNEL
BLACK ROCK CANAL ENTRANCE CHANNEL
NORTH BREAKWATER
Horseshoe Reef
Middle Reefs
Limekiln Reef
CANADA
UNITED STATES
BUFFALO PSYCHIATRIC CENTER
CAUTION
SUBMARINE PIPELINES AND CABLES

Figure 2-2

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- Upstream level gauge - Scajaquada Creek at Delaware Park: Located at Delaware Park, approximately 510 feet East of Delaware Avenue on the North end of the concrete channel wall that is at the South side of the stream tunnel entrance and at the East end of the broad-crested weir/lane between Scajaquada Creek and Hoyt Lake (42^{o} 55’ 51.818” N, 78^{o} 52’ 03.494” W).

- **Water velocity**
  - Downstream HADCP - Scajaquada Creek at Grant Street: Located at the South bank on the concrete channel wall approximately 10 feet upstream of the West-bound Scajaquada Expressway Grant St. exit ramp bridge (42^{o} 56’ 14.924” N, 78^{o} 53’ 13.815” W) and 465 feet downstream of the Grant Street Dam.
  - Upstream HADCP - Scajaquada Creek at Pine Ridge Road: Located on the concrete channel wall of the North bank, approximately 330 feet upstream of Pine Ridge Road (42^{o} 54’ 42.742” N, 78^{o} 47’ 41.960” W).

  The Scajaquada Creek hydraulic monitoring effort was managed by LimnoTech with support from Buffalo State.

- ***Rainfall monitoring***
  - A total of 12 tipping-style rain gauges were deployed to individual locations throughout the City. The gauges continually measured rainfall during both the 2008 and 2009 sampling seasons. The gauges were maintained by the subcontractor also responsible for CSO activation monitoring as part of the additional hydraulic modeling/calibration efforts being conducted on the BSA collection and conveyance system concurrent to the Phase 2 water quality program. Operation of both the CSO activation monitors and the rain gauges were integrated into a “remote monitoring” system that included wireless transmission of continuous monitoring data to a central data processing/storage system. These near real-time data were available to water quality sampling team members during all phases of the sampling effort to assist in decisions on sample initiation or stand-down. The rain gauge locations are shown on Figure 2-3.

The Buffalo State Great Lakes Center Aquatic Field Station served as the staging point for all sampling activities conducted during the Phase 2 program. Discrete event and continuous sampling activities were conducted by Buffalo State personnel, with Malcolm Pirnie providing oversight.

Sampling program details, including a tabular list and map of proposed sampling locations, parameters sampled, and mobilization, sampling, and field documentation procedures, are included in the *Workplan* (Attachment A). All Phase 2 sampling and monitoring activities were conducted in accordance with the procedures set forth in the *Workplan.* Any variance between actual sampling activities conducted in the field and those included in the *Workplan* are summarized in Section 5.0.

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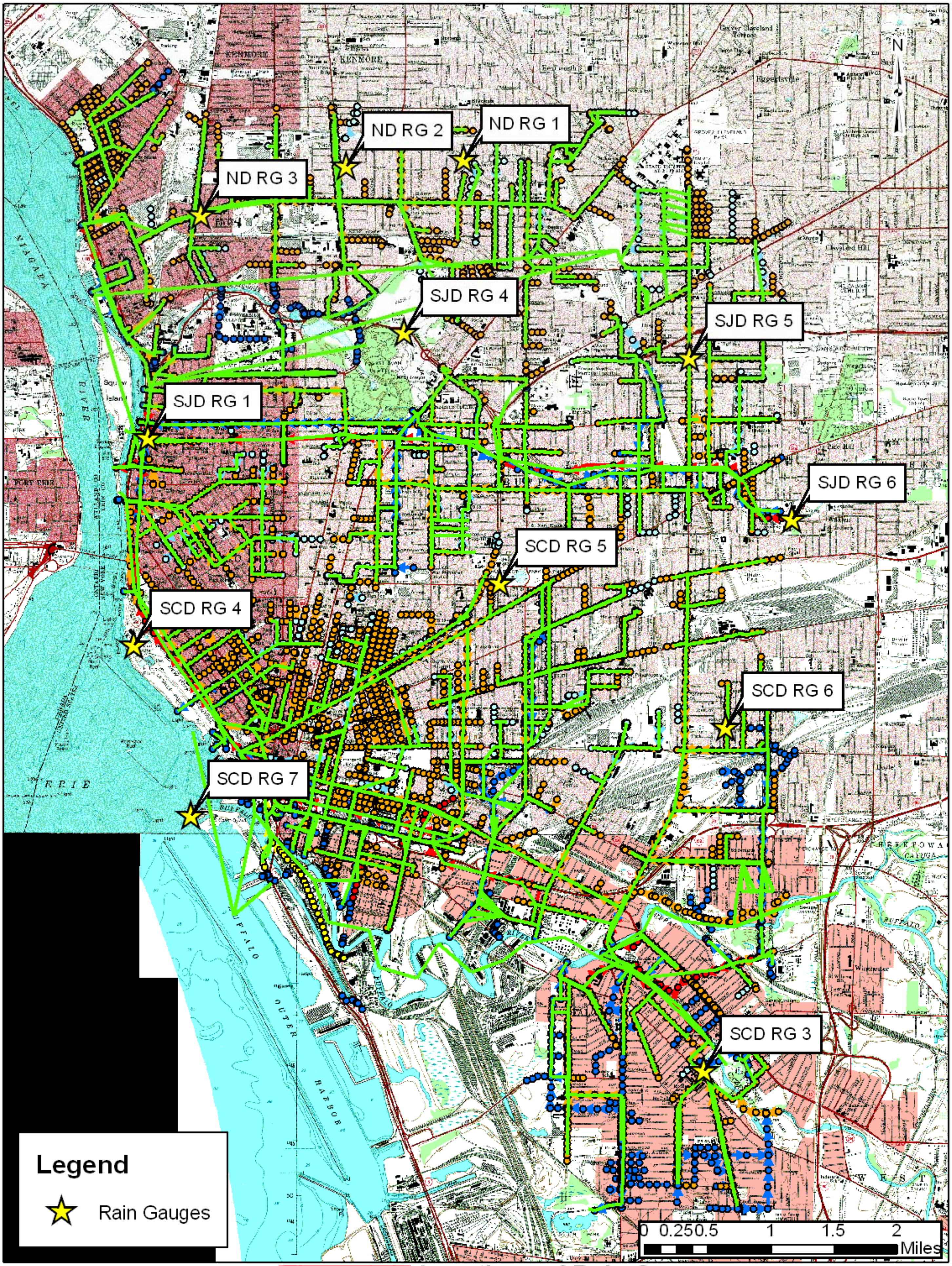

Figure 2-3 **Locations of Rain Gauges**

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3. Sampling Program Summary

This subsection contains a description of the two discrete dry weather and two wet weather sampling events conducted as part of the Phase 2 program. In accordance with procedures set forth in the *Workplan*, weather conditions were tracked continually throughout the 2008 and 2009 sampling seasons to identify optimal dry and wet weather sampling events that best met the criteria in the *Workplan*. Malcolm Pirnie maintained weather condition summaries during both sampling seasons, which are included as Attachment B.

3.1. Dry Weather Event 1 – July 16, 2008

The first Phase 2 dry-weather sampling event was held on July 16, 2008. All sampling crews mobilized at the Great Lakes Field Station and subsequently deployed to their sampling locations. All receiving water body locations were sampled in accordance with the *Workplan*. The weather was partly cloudy and mild with low winds.

3.2. Dry Weather Event 2 – September 3, 2008

The second Phase 2 dry-weather sampling event was held on September 3, 2008. All sampling crews mobilized at the Great Lakes Field Station and subsequently deployed to their sampling locations. All receiving water body locations were sampled in accordance with the *Workplan*. The weather was partly cloudy and mild with low winds.

3.3. Wet Weather Event 1 – September 26 – 28, 2009

The first wet weather water quality sampling event was initiated in response to the rainfall event occurring in the City of Buffalo on September 26, 2009. Sampling crews mobilized to the Buffalo State Field Station at approximately 12:00 AM on September 26 in response to significant rainfall predicted by the National Weather Service (NWS). Contract laboratories were put on alert for impending sampling activity. Consistent precipitation commenced at approximately 3:30 PM on September 26. Sampling crews deployed to their respective sampling locations following confirmation of overflow at the four selected remote overflow activation monitors (SJDFM11, SJDFM4, SCDFM15, NDFM8N) which generally occurred at approximately 12:00 AM on September 27.

The timeline of sample collection at the back end of the sampling event was modified relative to the proposed timeline in the Workplan because a second significant wet weather event hit the project area prior to completion of sampling activities. Specifically, the subsequent event hit the area at approximately 8:15 AM on September 28, and lasted until approximately 9:00 AM on September 29. The event was characterized with severe thunderstorms, high-intensity rainfall, high wind velocities, and lakeshore flooding potential. In response to the event, the Buffalo National Weather Service issued the following formal public warnings/advisories for the follow-up system:

- Severe Thunderstorm Warning
- Lakeshore Flood Warning
- Severe Thunderstorm Watch
- Severe Weather Statement
- Wind Advisory
- Hazardous Weather Outlook

Because of the severity of the subsequent weather system, and the formal warnings and advisories, a decision was made by sampling team members to temporarily suspend sampling activities to allow for the subsequent system to pass through the study area and safe boating conditions to be restored. The decision included collection of remaining samples following passage of the subsequent event. Prior to the temporary suspension of sampling activities, the following samples were collected:

- t:24 and t:48 samples at the Scajaquada Creek locations.
- t:24 samples at the Niagara River, Buffalo River, and Black Rock Canal locations.

Following re-start of sampling activities, an additional set of samples were collected at the Scajaquada Creek sites (t:80).

3.3.1. Antecedent Weather Conditions

Table 3-1 provides a summary of the total rainfall volume as recorded by the rain gauges in the study area during the 72 hours preceding the commencement of rainfall on September 26, 2009. No measureable rainfall was recorded at the gauges in the 72-hour period prior to the sampling event.

Table 3-1
Wet Weather Event 1: September 26 – 28, 2009
Antecedent Rainfall Data for September 24-26, 2009

Rain Gauge Identification No:	72-Hour Antecedent Rainfall Volume (in.)
ND RG 1	0
ND RG 2	0
ND RG 3	0
SJD RG 1	0
SJD RG 4	0
SJD RG 5	0
SJD RG 6	0
SCD RG 3	0
SCD RG 4	0
SCD RG 5	0
SCD RG 6	0
SCD RG 7	0

3.3.2. Event Rainfall Data

Table 3-2 provides a summary of the rainfall characteristics for the wet weather event of September 26 through 28, 2009, as recorded by the study area rain gauges deployed as part of the Phase 2 collection/conveyance system hydraulic model validation that was conducted concurrent with the water quality program. An average volume of 1.29 inches of precipitation was recorded over an average duration of 13 hours 45 minutes during the storm event.

Table 3-2
Wet Weather Event 1: September 26 – 28, 2009
Event Rainfall Data

Rain Gauge No:	Recorded Event Start	Duration (hh:mm)	Total Volume (in.)
ND RG 1	9/26/2009 3:30 PM	14:15	1.00
ND RG 2	9/26/2009 3:30 PM	14:00	1.08
ND RG 3	9/26/2009 3:30 PM	14:00	1.11
SCD RG 3	9/26/2009 4:00 PM	13:45	1.59
SCD RG 4	9/26/2009 3:30 PM	11:30	1.05
SCD RG 5	9/26/2009 3:30 PM	14:00	1.33
SCD RG 6	9/26/2009 3:30 PM	14:00	1.76
SCD RG 7	9/26/2009 3:30 PM	12:00	1.41
SJD RG 1	9/26/2009 3:30 PM	14:15	1.39
SJD RG 4	9/26/2009 3:30 PM	14:45	1.15
SJD RG 5	9/26/2009 3:45 PM	14:45	1.20
SJD RG 6	9/26/2009 3:45 PM	13:45	1.35
Average		**13:45**	**1.29**

3.4. Wet Weather Event 2 – October 23 – 25, 2009

The second wet weather water quality sampling event was initiated in response to the rainfall event occurring in the City of Buffalo on October 23, 2009. Sampling crews mobilized to the Buffalo State Field Station at approximately 12:00 AM on October 24 in response to significant rainfall predicted by the National Weather Service (NWS). Contract laboratories were put on alert for impending sampling activity. Consistent precipitation commenced at approximately 9:00 PM on October 23. Sampling crews deployed to their respective sampling locations following confirmation of overflow at the four selected remote overflow activation monitors (SJDFM11, SJDFM4, SCDFM15, NDFM8N) which generally occurred at approximately 12:00 AM on October 24. Samples at each time increment were collected from each sampling location in accordance with the *Workplan.*

3.4.1. Antecedent Weather Conditions

Table 3-3 provides a summary of the total rainfall volume as recorded by the rain gauges in the study area during the 72 hours preceding the commencement of rainfall on October 23, 2009. Total rainfall recorded at each of the gauges in the 72-hour period prior to the sampling event were below the 0.1 inch threshold as identified in the *Workplan*.

Table 3-3
Wet Weather Event 2: October 23 – 25, 2009
Antecedent Rainfall Data for October 21-23, 2009

Rain Gauge Identification No:	72-Hour Antecedent Rainfall Volume (in.)
ND RG 1	0.03
ND RG 2	0.03
ND RG 3	0.04
SJD RG 1	0.04
SJD RG 4	0.04
SJD RG 5	0.06
SJD RG 6	0.05
SCD RG 3	0.08
SCD RG 4	0.05
SCD RG 5	0.03
SCD RG 6	0.07
SCD RG 7	0.01

3.4.2. Event Rainfall Data

Table 3-4 provides a summary of the rainfall characteristics for the wet weather event of October 23 through 25, 2009, as recorded by the study area rain gauges deployed as part of the Phase 2 collection/conveyance system hydraulic model validation that was conducted concurrent with the water quality program. An average volume of 1.48 inches of precipitation was recorded over an average duration of 21 hours 35 minutes during the storm event.

Table 3-4
Wet Weather Event 2: October 23 - 25, 2009
Event Rainfall Data

Rain Gauge No:	Recorded Event Start	Duration (hh:mm)	Total Volume (in.)
ND RG 1	10/23/2009 6:45 AM	21:30	1.62
ND RG 2	10/23/2009 6:45 AM	21:30	1.73
ND RG 3	10/23/2009 6:45 AM	21:30	1.89
SCD RG 3	10/23/2009 6:15 AM	22:00	0.87
SCD RG 4	10/23/2009 6:30 AM	21:30	1.52
SCD RG 5	10/23/2009 6:30 AM	21:30	1.46
SCD RG 6	10/23/2009 6:15 AM	22:00	0.98
SCD RG 7	10/23/2009 6:30 AM	21:45	1.49
SJD RG 1	10/23/2009 6:45 AM	21:45	1.77
SJD RG 4	10/23/2009 6:30 AM	21:45	1.72
SJD RG 5	10/23/2009 6:45 AM	21:15	1.56
SJD RG 6	10/23/2009 6:30 AM	21:30	1.13
Average		**21:35**	**1.48**

4. Program Results

The following materials associated with the discrete sampling events are included in the following attachments:

- Attachment C - The analytical result reports as obtained from contract laboratories for the discrete sampling events.
- Attachment D - A tabular summary of the BOD_5, and fecal coliform results for each discrete sampling event.
- Attachment E - Temperature, dissolved oxygen, and specific conductance data for each discrete sampling event (including depth profile data at applicable sampling locations).
- Attachment F - The chain of custody forms completed during the discrete sampling events in accordance with Section 2.9 of the *Workplan* (Attachment A).

The data collected during the continuous monitoring component is included in Attachment G. A summary of procedures and results from the sediment oxygen demand sampling/ analysis, and the hydraulic monitoring conducted from July through October 2008, are included in Attachment H (two technical memoranda from LimnoTech).

All data generated were tabulated and reviewed by Malcolm Pirnie and Buffalo State upon receipt to identify gaps and/or obvious discrepancies. A QA/QC review of notable variances in the data collected relative to the Workplan, as conducted by Malcolm Pirnie and Buffalo State, is provided in Section 5.0 of this report. Further review of the data, trends, and interpretation was provided by LimnoTech during the water quality model setup, Calibration, and validation efforts.

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5. Quality Assurance/Quality Control (QA/QC) Review

This section summarizes the QA/QC measures implemented by both the contract analytical laboratories and the sampling team for the Phase 2 effort.

5.1. Laboratory QA/QC Measures

Quality control sample analyses that were performed during this project to document the acceptability of the data included:

- **Equipment Blanks** - An equipment blank (rinsate blank) was collected for each type of sampling device used during sample collection at the field station and staging area immediately prior to initiation of a dry- or wet-weather sampling event. This was conducted by the Buffalo State College Sampling Coordinator and Team Leaders assembled for a sampling event. Laboratory analyte-free water was used to prepare an equipment blank by placing the laboratory water into one of each type of sampling device (decontaminated grab sampler, and bucket etc.) and one set of sampling bottles per type of sampling device was filled. These samples were then submitted for analysis to the laboratory with the other samples.
- **Method Blanks** - The laboratories prepared and analyzed at least one laboratory reagent blank (method blank) for each set of 20 samples received and whenever samples were processed (extracted, digested etc.) or other appropriate QA/QC as documented in lab QAPP and SOPs.
- **Matrix Spikes -** The laboratories prepared and analyzed at least one laboratory matrix spike for each set of 20 samples received and whenever samples were processed (extracted, digested etc.) or other appropriate QA/QC as documented in lab QAPP and SOPs. Matrix spikes were prepared by injecting a known quantity of a surrogate compound into a blank sample.
- **Duplicate Samples** - For both dry and wet weather sampling events, at least one duplicate sample was collected by each sampling team. The locations at which these duplicates were collected were determined by the Buffalo State College Sampling Coordinator. The duplicates were used to assess the precision of the data collected.

All quality control sample analytical results as provided by the contract laboratories are included in the analytical reports for each event in accordance with data acceptance criteria (Attachment C). A tabular summary of pertinent QA/QC sample results for each sampling event are summarized in tabular form in Attachment K. A summary of results for each type of QA/QC sample noted above is as follows:

- **Equipment Blanks –** The purpose of the equipment blanks was to determine the error and “overall cleanliness” associated with the sampling equipment used for the project. As shown in Attachments C and K, most equipment blank results came back as “non detect” or below applicable detection limits. Above detection limit counts/concentrations of parameters were observed in equipment blanks for wet weather events #1 and #2 for fecal coliform samples only as follows:

Wet Weather Event #1	Count (cfu/100 mL)
Equipment Blank #1	50
Equipment Blank #2	120
Wet Weather Event #2	
Equipment Blank #1	10

- **Method Blanks –** The purpose of the method blanks were to determine the error associated with the handling, processing, and analysis of samples by the contract laboratories. As shown in Attachments C and K, all method blank samples analyzed for the project produced results of “non detect”.
- **Matrix Spikes –** Surrogate recovery in matrix spike samples was utilized as a measure of accuracy of the data, defined as the absolute certainty about a true value. As shown in Attachments C and K, a range of method blank/matrix spike percent recovery values (74 to 143%) were determined by the contract laboratories, but were generally near 100%. All recoveries were within percent recovery limits.
- **Duplicate Samples –** Agreement between duplicates was analyzed via determination of the relative percent difference (RPD) between duplicate sample results. The definition of RPD is as follows:

$$RPD = \frac{|C1 - C2|}{mean\ (C1, C2)}$$

RPD is due to real random error associated with sample collection, handling, and analysis. As shown in Attachment K, results of the duplicates for this study are mixed. Most RPD values are below 50%, with a few outliers being identified. RPD outliers (greater than 50%) were observed in duplicate samples for wet weather events #1 and #2 for fecal coliform samples only as follows:

Wet Weather Event #1	RPD
SCJRBWQ01	199%
SCJRBWQ02	107%
SCJRBWQ04	53%
NIARBWQ5C	72%
Wet Weather Event #2	**RPD**
BUFRBWQ01	60%
BRCRBWQ01	93%
NIARBWQ3A	100%

Generally, the RPD values for the fecal coliform duplicates were higher than those for the BOD duplicates, which is likely indicative to the variability in processing, analysis, and quantification of fecal coliform samples.

5.2. Team QA/QC Measures Implemented

Team-oriented quality assurance procedures were applied during the Phase 2 sampling program in accordance with the *Workplan*. These procedures are presented below.

5.2.1. Field Documentation

Consistent field documentation was a priority for the sampling program team. Sampling event summary sheets were completed during each sampling event by each sampling team in accordance with the *Workplan*. Completed summary sheets for each sampling event are included in Attachment I. Each team was also equipped with a field book to record any additional observations during sampling.

5.2.2. Team Training

Team training provides an important quality assurance mechanism for a water quality sampling program of this magnitude. A formal training workshop session was held before each sampling season to ensure that field personnel were comfortable with the sampling procedures. The workshop was conducted by the Buffalo State College and MPI sampling coordinators. All members of the sampling teams participated in the workshop. The primary source document for the training session was the *Workplan*, all elements of which were included in the session.

5.3. Variance from the Workplan Components

The purpose of this section is to summarize components of the Phase 2 sampling program that were conducted in variance from the *Workplan*. A summary of these components is as follows:

- **<u>Wet weather sampling event #1 holding time exceedances:</u>**
  - Following completion of wet weather sampling event #1, the laboratory contracted to analyze the BOD_5 samples collected during the event (Test America, Inc.) informed MPI that holding times were exceeded on a specific group of samples (58 samples in total) due to laboratory error. Test America further specified that all samples were submitted for analysis with sufficient time for them to conduct to analyses, and that the exceedances were due to circumstances under their control. A listing of BOD_5 samples that exceeded holding times, as well as formal correspondence from Test America regarding the exceedances, is included as Attachment J. The average holding time exceedance is 3 hours, 50 minutes with a minimum of 5 minutes and a maximum of 9 hours, 16 minutes. All other samples collected during the Phase 2 effort were analyzed within holding time guidelines. Data for the BOD_5 samples that exceeded holding times was included in the dataset used by LimnoTech for receiving water quality model calibration and validation efforts.

- **<u>Niagara River transect NIARBWQ01 changes:</u>**
  - A decision was made by the project team to add a fourth discrete sampling location (NIARBWQ01d) to the NIARBWQ01 transect. This decision was made to further define upstream boundary conditions across the width of the mouth of the Niagara River in support of receiving water quality model development using the data from the sampling program.
  - The location of the discrete samples comprising Niagara River transect NIARBWQ01 were modified relative to the locations originally included in the *Workplan*. The change in sampling location was primarily due to unsafe navigable conditions in the portion of the River as confirmed during site reconnaissance conducted at the beginning portion of the sampling effort. Several reefs, sand bars, and shallow water conditions were encountered by sampling team personnel at the transect location as originally proposed in the *Workplan*. Also, the original sampling locations were located further out into Lake Erie, an area which is relatively more difficult to navigate during storm conditions experienced during wet weather sampling events. In response, the transect was shifted from a predominant northeast-to-southwest alignment (as shown on Figure 2-1 in the *Workplan* – Attachment A), to a more east-to-west alignment closer to interface between Lake Erie and the Niagara River (as shown on Figure 2-1 of this report).

- **<u>Niagara River transect NIARBWQ05 changes:</u>**

  - Transect NIARBWQ1 was modified slightly relative to the locations originally included in the *Workplan*. NIARBWQ1 is the northern most transect and is located 985 yards south of Strawberry Island. Bathymetric charts and work done in Phase 1 of the LTCP showed that a large sand bar extends 400-500 yards out from the head of Strawberry Island and flow begins to split around the island at approximately 765 yards upstream of the island. This flow split clearly was visible during the site location reconnaissance done for the Phase 2 work. During this site location reconnaissance it was decided to locate transect NIARBWQ01 upstream of where the flow begins to split into two channels but the reconnaissance team also was careful to locate the transect downstream of Cornelius Creek (CSO 055). It was not possible to place a transect north (downstream) of CSO 054 due to the proximity of Strawberry Island and the divergence of flow around the island. However, CSO 054 has not activated during either wet weather sampling event and in consultation with LimnoTech, it was determined that the sampling location change would not adversely impact the Niagara River model calibration and validation results.

- **<u>Black Rock Canal dissolved oxygen (DO) concentration data inconsistencies:</u>**

  - Inconsistencies were observed between discrete surface water DO sample results as collected during wet weather events, and long-term, continuous DO data collected by YSI continuous recording datasondes. These discrepancies were discovered during the receiving model calibration conducted by LimnoTech, and documented in Section 5.2.1. of their Water Quality Model Development and Calibration Report. In general, the continuous DO data was observed to be approximately 2 mg/L lower than the DO concentrations measured for samples collected at similar depths and similar times. LimnoTech and Malcolm Pirnie initiated dialogue with Dr. Kim Irvine of Buffalo State College (responsible for management of the discrete and continuous sampling) regarding the discrepancy. Dr. Irvine stated "that the stationary site DO data are more reflective of true conditions in the Black Rock canal than the DO profiles collected during the storm events. Dissolved oxygen data discrepancies exist between the 2009 long-term hydrolab and wet weather data taken at the surface. This discrepancy is on the order of 2 mg/L, with higher DO values associated with the wet weather events" (Buffalo State, 2010).

    Based on these findings and recommendations, continuous DO data collected by the YSI continuous recording datasondes were favored by LimnoTech over event data as a basis for calibration. Specifically, dissolved oxygen simulations under wet weather conditions were primarily calibrated to the long-term surface, continuous measurements rather than the discrete measurements. However, the discrete wet weather event DO data is still useable. Therefore, LimnoTech utilized the discrete wet weather event DO data to assess the degree of stratification in the water column in the canal. The discrete data adequately served as a secondary calibration target for the wet weather events.

Attachment A

BSA CSO LTCP - Phase 2 Receiving Water Quality Sampling Workplan

MALCOLM PIRNIE

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Buffalo Sewer Authority

PHASE 2 LONG TERM CONTROL PLAN

Receiving Water Quality Sampling Program Workplan

April 2008

INDEPENDENT ENVIRONMENTAL ENGINEERS, SCIENTISTS AND CONSULTANTS

MALCOLM PIRNIE

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Receiving Water Quality Sampling Work Plan

Buffalo Sewer Authority
Phase 2 Long-Term Control Plan

Prepared by:
Malcolm Pirnie, Inc.

April 2008

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1. Introduction

1.1. Project Background

The New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA) have reviewed the Buffalo Sewer Authority (BSA) *System-Wide Long Term Control Plan for CSO Abatement* submitted in 2004 and have suggested the need for additional receiving water quality modeling of waterways potentially affected by combined sewer overflows (CSOs). Specifically, modeling of the Niagara River, the Buffalo River and Scajaquada Creek was requested to evaluate concerns regarding bacteria in all three waterways and biochemical oxygen demand (BOD) and effects on dissolved oxygen (DO) in the Buffalo River and Scajaquada Creek. The existing Buffalo River model was developed to simulate BOD and DO in the lower Buffalo River. This model will be extended upstream to approximately the Buffalo City boundary. Subsequent discussions with USEPA and NYSDEC have identified concerns regarding dissolved oxygen impacts in the Black Rock Canal.

This Receiving Water Quality Sampling Work Plan (Plan) defines the sampling activities to be performed in support of the Receiving Water Quality Modeling Work requested by the NYSDEC and the USEPA.

1.2. Scope of This Plan

This Plan describes the locations and methodologies that will be used by the BSA to gather water quality data for the receiving water bodies. Water quality data is required for the receiving water bodies during dry weather and during storm events. The water quality data collected under this Plan will be used together with the receiving stream and CSO discharge water quality data collected under the initial LTCP project for calibration and validation of the receiving water quality models, as defined in the Water Quality Modeling Plan, in order to examine the impacts of CSOs on the water bodies.

The discussion in this Plan includes:

- The water quality sampling locations.
- The frequency and duration of water quality sampling.
- The determination for which storm events should be targeted.
- The water quality parameters to be analyzed.
- Data storage protocols to be followed.

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2. Receiving Water Quality Sampling Program

The Great Lakes Center Aquatic Field Station (Buffalo State College) has performed many receiving water sampling projects. Buffalo State College will be contracted to assemble sampling teams to perform the water quality sampling work under this Plan.

2.1. Receiving Water Data Needs

Discrete samples of receiving water will be collected for laboratory analyses at seven transects along the Niagara River and Black Rock Canal. In addition, samples will be collected at the mouth of the Buffalo River and in Scajaquada Creek. The expected data needs for development of the receiving water quality models are summarized below.

2.1.1. Niagara River

Development of the Niagara River model will require collection of the following bacteria data (surface samples):

- Fecal coliform

Data collected in the Niagara River should include two dry-weather and two wet-weather events.

2.1.2. Buffalo River

To validate the Buffalo River model's predicted loads during Niagara River calibration events, water quality data will be collected at one location near the mouth of the Buffalo River, where it interfaces with the Niagara River.

- The following data will be collected (depth discrete profiling for 3 depths - at top, bottom and thermocline):
  - BOD (Total and Soluble)
  - Fecal coliform (Surface sample only)
  - DO
  - Temperature
  - Conductivity

Data collected near the mouth of the Buffalo River should include two dry-weather and two wet-weather events.

2.1.3. Scajaquada Creek

Development of the Scajaquada Creek model will require collection of the following data:

- Water quality data from four locations in Scajaquada Creek. The following data will be collected during two dry-weather and two wet-weather events:
- Surface samples
  - BOD (Total and Soluble)
  - Fecal coliform
  - DO
  - Temperature
  - Conductivity

Additionally, Sediment Oxygen Demand (SOD) data at 2 locations in Scajaquada Creek will be collected under dry weather conditions. SOD will be measured in situ at locations representative of typical bottom conditions in the channel. SOD chambers will be secured to the bottom and dissolved oxygen degradation within the chambers will be used to calculate an estimate of SOD that provides an important coefficient for calibration of the dissolved oxygen water quality model.

Also, stage and current data from the downstream end of Scajaquada Creek, near the confluence with Black Rock Canal, to provide downstream boundary conditions for hydrodynamic model calibration will be collected. This will be accomplished through deployment of a side-looking acoustic Doppler current profiler (ADCP) or equivalent device for two months.

Stage data at two intermediate locations in the Creek (for the same duration as the ADCP data) will also be required to support hydrodynamic model calibration. The locations will be investigated and determined based on field conditions.

2.1.4. Black Rock Canal

Development of the Black Rock Canal model will require collection of the following data:

- Water quality data from four locations in the Black Rock Canal. The following data will be collected during two dry-weather and two wet-weather events (depth discrete profiling for 3 depths - at top, bottom and thermocline):
  - BOD (Total and Soluble)
  - Fecal coliform (Surface sample only)
  - DO
  - Temperature
  - Conductivity

Additionally, Sediment Oxygen Demand data at 2 locations in the Black Rock Canal will be collected under dry weather conditions using the same technique as listed above for Scajaquada Creek.

Also, deployment of two continuous recording datasondes will be used to collect continuous data at two locations for a two-month period. The locations will be investigated and determined based on field conditions.

2.2. Water Quality Sampling Locations

The dry and wet weather water quality sampling locations are listed in Table 2-1 and shown on Figures 2-1, 2-2 and 2-3. The figures are intended to present the general locations for this document. The sampling locations listed in Table 2-1 will be field investigated and may change based on field conditions. Final sampling locations will be identified and photographs, along with the GPS-obtained coordinates, will be taken prior to implementation of the sampling program.

2.2.1. Niagara River

Development of the Niagara River model will require collection of bacteria data from several transects. These transects consist of three stations aligned across the river (total of 15 stations) channel as shown on Figure 2-1 and listed below:

1. NIA RBWQ1 (3 stations) – Located downstream of the Buffalo River adjacent to the City of Buffalo water intake.
2. NIA RBWQ2 (3 stations) – Located near the mouth of the Niagara River
3. NIA RBWQ3 (3 stations) – Located near the Peace Bridge
4. NIA RBWQ4 (3 stations) – Located near the International Bridge
5. NIA RBWQ5 (3 stations) – Located upstream of Strawberry Island

The sampling at these locations will be performed from boats. It is likely that early monitoring will indicate that CSO impacts and Buffalo River flows do not extend across the entire Niagara River channel. If this is the case, BSA will consider reducing the number of stations at each transect to focus on water quality conditions nearest the east bank.

2.2.2. Buffalo River

It will be necessary to collect water quality data near the mouth of the Buffalo River, where it interfaces with the Niagara River, in order to validate the Buffalo River model's predicted loads during Niagara River calibration events. The existing Buffalo River model was developed to simulate BOD and DO in the lower Buffalo River. This model will be extended upstream to approximately the Buffalo City boundary. For this purpose, sampling location BUF RBWQ1 was chosen as shown on Figure 2-3 (near previous data location SCD RBWQ 5). The sampling at this location will be performed from a boat.

Buffalo Sewer Authority
Phase 2 LTCP

Table 2-1 Water Quality Sampling Locations

Sample Point ID	Sample Point Location	Number of Stations	Samples per Station per circuit			Sampling Schedule: Hours after Storm Commencement
			Fecal Coliform	BOD	TSS	
Niagara River						
NIA RBWQ 1	Downstream of the Buffalo River adjacent to City of Buffalo water intake	3	1	0	0	0, 4, 8, 16, 24, 48
NIA RBWQ 2	Near the mouth of the Niagara River	3	1	0	0	0, 4, 8, 16, 24, 48
NIA RBWQ 3	Near the Peace Bridge	3	1	0	0	0, 4, 8, 16, 24, 48
NIA RBWQ 4	Near the International Bridge	3	1	0	0	0, 4, 8, 16, 24, 48
NIA RBWQ 5	Upstream of Strawberry Island	3	1	0	0	0, 4, 8, 16, 24, 48
Buffalo River						
BUF RBWQ 1	Mouth of the Erie Basin Marina	1	1	3	3	0, 2, 4, 6, 12, 18, 24, 48
Scajaquada Creek						
SCJ RBWQ 1	Upstream end of the Scajaquada Drain tunnel	1	1	1	1	0, 2, 4, 6, 12, 18, 24, 48
SCJ RBWQ 2	Downstream end of the Scajaquada Drain tunnel	1	1	1	1	0, 2, 4, 6, 12, 18, 24, 48
SCJ RBWQ 3	Downstream of the lake at Forest Lawn Cemetery	1	1	1	1	0, 2, 4, 6, 12, 18, 24, 48
SCJ RBWQ 4	Halfway between the lake and the downstream end of the creek U/S of Grant St. Dam (near previous data location SJD RBWQ 2)	1	1	1	1	0, 2, 4, 6, 12, 18, 24, 48
Black Rock Canal						
BRC RBWQ 1	Upstream end of the breakwater	1	1	3	3	0, 2, 4, 6, 12, 18, 24, 48
BRC RBWQ 2	Between the USGS gage at Anderson (gage No. 04216060) and the Bird Island Wastewater Treatment Plant	1	1	3	3	0, 2, 4, 6, 12, 18, 24, 48
BRC RBWQ 3	At the confluence of Scajaquada Creek	1	1	3	3	0, 2, 4, 6, 12, 18, 24, 48
BRC RBWQ 4	Between the International Bridge and the canal locks	1	1	3	3	0, 2, 4, 6, 12, 18, 24, 48

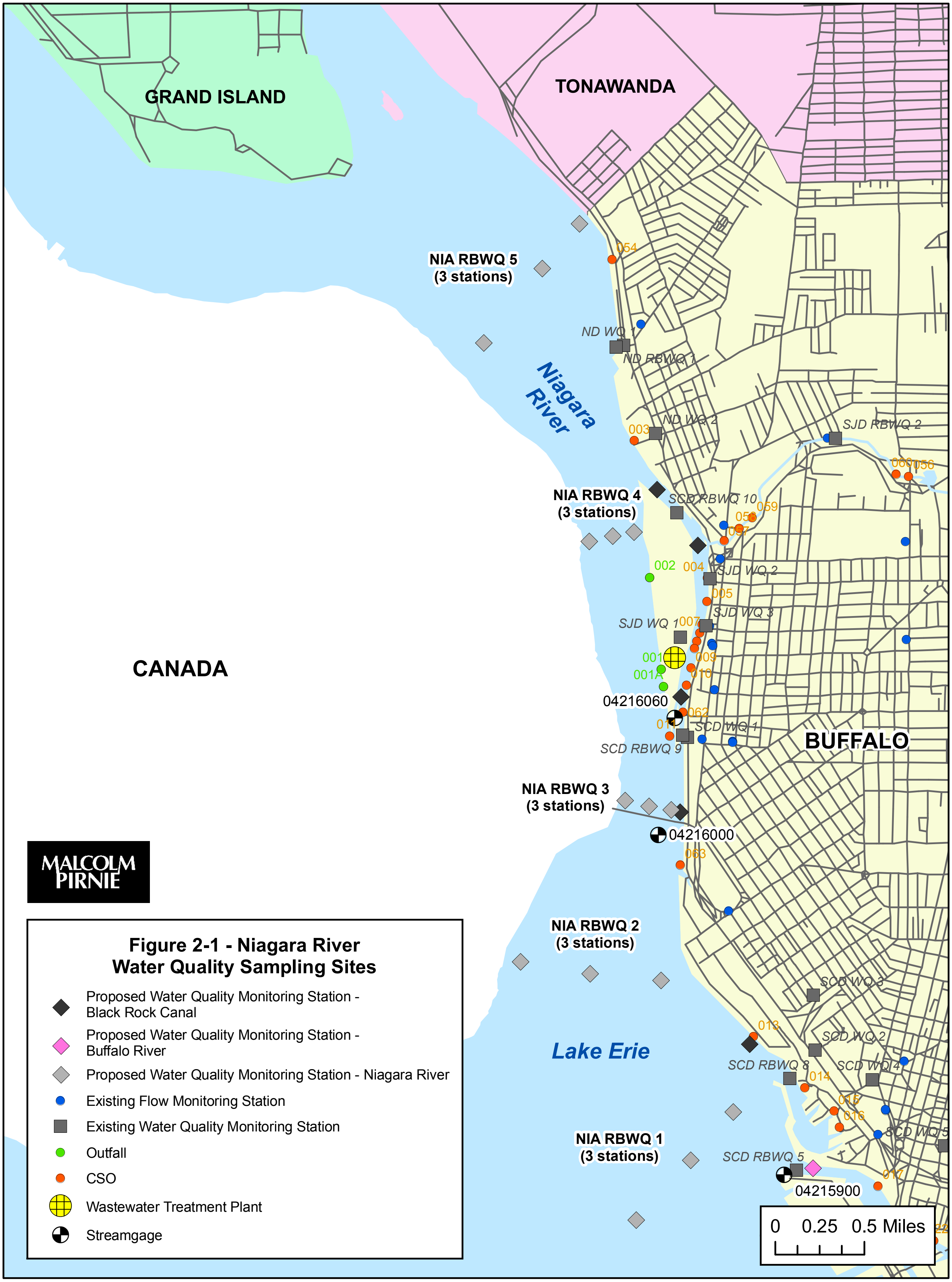

Figure 2-1 - Niagara River Water Quality Sampling Sites

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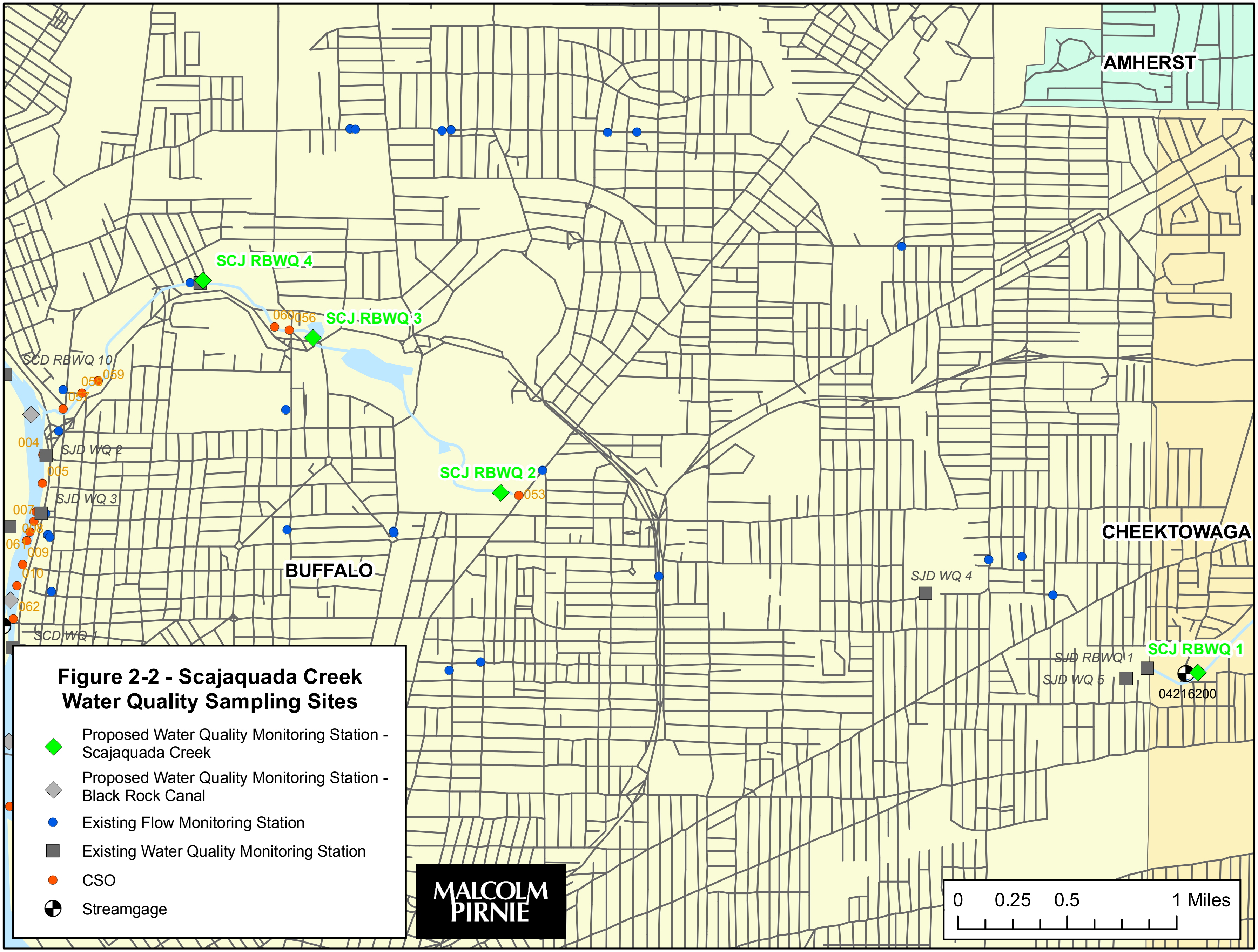

Figure 2-2 - Scajaquada Creek Water Quality Sampling Sites

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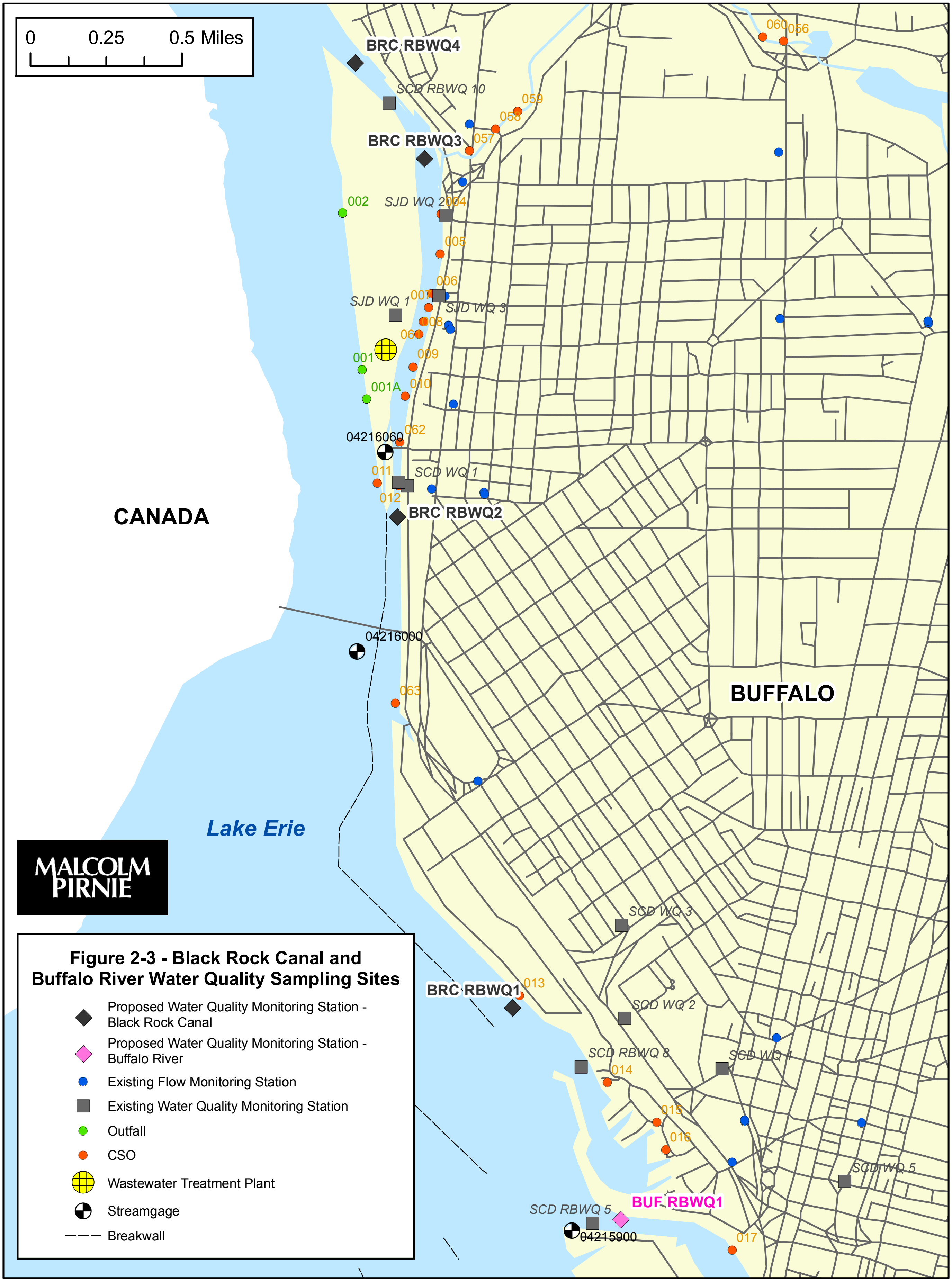

Figure 2-3 - Black Rock Canal and Buffalo River Water Quality Sampling Sites

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2.2.3. Scajaquada Creek

Water quality data will be required for model calibration and validation from four locations (total of 4 stations) in Scajaquada Creek:

1. SCJ RBWQ1 – Located upstream of the upstream end of the Scajaquada Drain tunnel.
2. SCJ RBWQ2 – Located downstream of the downstream end of the Scajaquada Drain tunnel.
3. SCJ RBWQ3 – Located downstream of the lake at Forest Lawn Cemetery.
4. SCJ RBWQ4 – Located halfway between the lake and the downstream end of the creek, upstream of the Grant Street Dam (near previous data location SJD RBWQ 2).

The approximate locations of these stations are shown on Figure 2-2. The sampling at these locations will be performed from land, with the exception of SCJ RBWQ5, which may be accessed by boat.

Collection of sediment oxygen demand data in the Scajaquada Creek will be performed at two locations.

2.2.4. Black Rock Canal

The Black Rock Canal model will require collection of data at four locations (total of 4 stations) within the canal.

1. BRC RWBQ1 – Located near the upstream end of the breakwater.
2. BRC RWBQ2 – Located between the USGS gauge at Anderson (No. 04216060) and the Bird Island Wastewater Treatment Plant.
3. BRC RWBQ3 – Located at the confluence of Scajaquada Creek.
4. BRC RWBQ4 – Located between the International Bridge and the canal locks.

The approximate locations of these stations are shown on Figure 2-3. The sampling at these locations will be performed from a boat. In addition, continuous recording data sondes will be installed at 2 locations for control data to support model calibration.

Collection of sediment oxygen demand data in the Scajaquada Creek will be performed at two locations.

2.3. Program Organization and Communications During Sampling Events

The sampling period will coincide with the recreational season and begin in June 2008 and last until sufficient samples are collected (through September 2008, if necessary). Two dry-weather events will be sampled at all receiving water body locations during the sampling effort. Two wet-weather events will be sampled at all designated receiving water body locations.

A Sampling Coordinator (from Malcolm Pirnie staff) will be designated for the sampling program. The Sampling Coordinator will be present in the field during all sampling events. Buffalo State College has been contracted to assemble sampling teams to be deployed during dry and wet weather events. Sampling will be performed at the locations using dedicated teams made up of two to three field personnel. Each sampling team will be responsible for specific sampling locations grouped within close proximity to each other.

Based on the proximity of the sampling locations, it is estimated that there will be five to six sampling teams required. Each sampling team will be led by Buffalo State College personnel.

The Great Lakes Center Aquatic Field Station (Buffalo State College) located at 9 Porter Avenue, Buffalo, New York will be used as the field station and staging area for the dry and wet weather sampling events. The Buffalo State College Sampling Coordinator and Malcolm Pirnie Sampling Coordinator will coordinate the sampling effort from this location. The staging area will also be used for organization, preservation and packaging of samples prior to delivery to the laboratories.

The Buffalo State College Sampling Coordinator is responsible for communication with all field sampling teams throughout the sampling events.

2.4. Sampling Equipment Specifications

The water quality sampling program will use the following equipment:

- Boat samples for the parameters to be analyzed in the lab will be collected by a team of 2 to 3 field personnel. Boat samples will be collected with sampling bottles provided by the laboratories. The boat sampling methodologies have been used successfully by team member Dr. Kim Irvine on past Buffalo River studies.
- For water body sampling from bridge access points, stainless steel buckets or swing-type grab samplers will be used for sample collection for the parameters to be analyzed in the lab as appropriate. Where required, ropes or poles will be used to lower buckets into the flow.
- A multi-parameter field probe will be used to collect field parameters during sample collection at all sampling locations. Multi-parameter probe measurements should be taken directly in the stream.
- For sites where multi-depth sampling is required the multi-parameter probe should be lowered and a reading should be taken at every meter. If a thermocline is observed, the mid depth sample should be taken at that depth. The deep sample should be taken

at a depth between 0.3 and 1.0 meter from the bottom to avoid collecting excessive sediment.

- A GPS locator will be used by each team to ensure consistent sampling locations for dry and wet weather events.
- Sampling Event Summary Sheets (see Attachment 1) and pens will be required for each sampling team to record details of sample collection activities.
- Nitrile surgical gloves (disposable) will be worn by sampling personnel at all times during sampling.
- Decontamination supplies will be required for equipment decontamination between sampling events.
- Continuous monitoring using portable continuous recording data sondes.
- Stage and current data from the downstream end of Scajaquada Creek through short-term deployment of a side-looking acoustic Doppler current profiler (ADCP) or equivalent device.

2.5. Surface Water Sampling Procedures

Surface water samples will be collected using the direct grab sampling technique outlined in Section 9.10.4 and 9.11.4 of the *New York State Department of Environmental Conservation (NYSDEC) Standard Operating Procedure: Collection of Ambient Water Quality Samples* (SOP) (NYSDEC, 2002) included as Attachment 2 to this document. New, sterile, nitrile powder-free surgical gloves will be worn by sampling personnel at all times during sampling. Sampling gloves will be changed between sampling locations. Samples will be collected in the following order using the procedures outlined below:

1. BOD (total and soluble)
2. Fecal coliform
3. In-situ field measurements (dissolved oxygen, temperature and conductivity)

<u>Procedure:</u>

- Face upstream and into the flow of the River.
- Orient the capped sample container with the opening toward the flow and in front of the sampler.
- Lower the capped sample container to a depth of approximately 6 to 10 inches below the water surface.
- Uncap the container underwater. Avoid touching the inside of the sample bottle and cap.
- Allow the container to fill with water and re-cap the container underwater when it is full.

- Remove the capped sample container from the water, label in accordance with Section 2.7, and place in a cooler with ice. Note sample time in the Sampling Event Summary Sheet. Repeat the sampling process with the remaining containers.
- When laboratory sample collection is complete, lower the multi-parameter field probe to the sampling depth. These activities can be done simultaneously should sufficient personnel be available.
- Allow meter readings to stabilize, then record field parameter measurements on the Sampling Event Summary Sheet.

If the exterior of a sample bottle becomes grossly contaminated during sample collection due to highly turbid surface water, the exterior of the bottles will be rinsed with deionized water before placing the sample container in the cooler.

Fecal coliform samples must be delivered to the laboratory within approximately five hours of sample collection to meet the six hour holding time for these analyses.

For sites where multi-depth sampling is required, samples will be collected with a Van Doren type bottle or Kemmerer sampler. Those samplers should be field cleaned and rinsed between sites to minimize the possibility of cross contamination. The sampling bottle should be lowered to the depth determined by the multi-parameter probe taking care not to lower the bottle diagonally and using measurements marked on the sample line. The bottle should be lowered to the appropriate depth and then lifted up and down to exchange the water in the bottle with the surrounding water several times. When the bottle is positioned at the correct depth the appropriate messenger should be dropped to release the bottle and cap the sample. The collected sample should be immediately transferred to the appropriate containers for lab analysis.

2.6. Sample Collection Methodology

The sampling methodology is similar for all the sampling locations including the list of parameters for which samples will be analyzed. Access to each site may differ. The sections below detail sampling frequencies, durations, and methodologies for both dry- and wet-weather sampling. Necessary containers for each sampling event, with labels and with preservatives, will be coordinated by Malcolm Pirnie through the selected analytical laboratories. The designated field station and staging area will be used for required preservation and packaging of samples after the sampling events.

2.6.1. Dry-Weather Receiving Water Sampling

The goal of the dry weather sampling is to collect two samples during two separate events with sufficient antecedent conditions as described in Section 3. The sampling period will begin in June 2008 and last through September 2008 to cover the river recreational season. For each dry weather event, analytical samples will be collected at each sampling position for a total of 62 samples per event.

2.6.1.1. Dry-Weather Laboratory Analysis Sample Collection

Laboratory analyses for the samples will be performed for fecal coliform and BOD (total and soluble). Immediately upon collection, all the samples will be sealed, labeled and packed in coolers with ice, ready for transport to the laboratory. These samples will be taken to the field station and staging area at the completion of the sampling event for transport with the other samples collected. Malcolm Pirnie will coordinate transportation of samples with the laboratories.

2.6.1.2. Dry-Weather Field Measurements

All sampling locations will be verified using a hand-held GPS unit. The field measurements that will be performed at each sampling position are: dissolved oxygen, temperature and conductivity. These measurements will be conducted using a multi-parameter field probe as described in Section 2.4.

Field parameters will be logged on field data sheets so that the project team is aware of the ambient conditions under which the water quality samples were collected.

2.6.2. Wet-Weather Receiving Water Sampling

The wet-weather sampling will be performed for two qualified (as described in Section 3) storm events during the same period as the dry-weather sampling. Up to eight circuits of sampling will be performed at each of the same locations as the dry-weather sampling events. The goal is to collect samples over a 48-hour period starting at the commencement of a storm event and finishing after the rain has ended and stormwater runoff has subsided. The individual grab samples analyzed at the receiving water sampling locations provide a record of the time-variation of parameters within a wet-weather event. The approximate sample collection schedule is as follows:

Buffalo River, Black Rock Canal and Scajaquada Creek (Total of 9 stations)

- Circuit 1 – storm event start (T0)
- Circuits 2 - 4 – two-hour intervals since the storm start (T2 through T6)
- Circuits 5 - 7 – six-hour intervals (T12 through T24)
- Circuit 8 – 24-hour interval (T48)

Niagara River (Total of 15 stations)

- Circuit 1 – storm event start (T0)
- Circuits 2 - 3 – four-hour intervals since the storm start (T4 through T8)
- Circuits 4 - 5 – eight-hour intervals (T16 through T24)
- Circuit 6 – 24-hour interval (T48)

Up to a total of 932 discrete grab samples (47 samples per circuit x 8 circuits x 2 sampling events + 15 samples per circuit x 6 circuits x 2) will be taken during the receiving water wet-weather monitoring period.

2.6.2.1. Wet-Weather Laboratory Analysis Sample Collection

Laboratory analyses for the samples will be performed for fecal coliform and BOD (total and soluble). Immediately upon sample collection at each location, the samples will be sealed, labeled and packed in coolers with ice. Samples will periodically be taken to the field station and staging area for transport with the other samples collected by the other sampling teams. Malcolm Pirnie will coordinate transportation of samples with the laboratories.

Samples for fecal coliform will be delivered to the laboratory within 5 hours of the samples being collected, due to the six-hour test holding time for fecal coliform.

The exact schedule will be determined during the sampling event based on the discussions between the Sampling Coordinator and Team Leaders. All 48 hours of sampling may not be required based on the duration of the rainfall event.

2.6.2.2. Wet-Weather Field Measurements

All sampling locations will be verified using a hand-held GPS unit. The field measurements that will be performed at each sampling position are: dissolved oxygen, temperature and conductivity. These measurements will be conducted using a multi-parameter field probe as described in Section 2.4.

Field parameters will be logged on field data sheets so that the project team is aware of the ambient conditions under which the water quality samples were collected. In addition to laboratory analyses and field parameters, rainfall data will also be compiled following each sampling event and maintained in the project database.

2.7. Field Documentation During Sampling

Sampling Event Summary Sheets will be completed during each sampling event by each sampling team. These will include entry spaces for:

- Sample Location (and depth if necessary)
- Time
- Date
- Initials of Recorder
- Weather Conditions
- Flow Conditions

- Ambient Temperature
- Water Quality Readings:
  - DO
  - conductivity
  - temperature
- Physical Observations:
  - presence of grease
  - presence and type of floatables
  - presence of atypical smells
- A comment area will be used for any additional observations deemed relevant by the sampling team.

These sheets will be completed by each field team and submitted to the Buffalo State College Sampling Coordinator immediately upon completion of the sampling event.

Each sampling team will also be equipped with a field book to record any additional comments and observations at the time that the samples are taken.

A database will be maintained with the field measurements and laboratory testing results for each dry and wet weather sampling event.

2.8. Sample Labeling

All sample containers must be labeled in indelible ink on waterproof labels with:

- Date
- Time of sampling
- Sample number
- Sample location and depth / location identification number
- Team Leaders name and organization

All containers for submission of samples to the laboratory must be labeled with the above plus parameter type and preservative. Sample bottle labels must be filled out by the sampling team members to the extent possible prior to the sampling event. Labels should be wrapped with clear tape after being completely filled out.

2.9. Sample Shipping and Chain-of-Custody

This guideline presents a method for chain-of-custody procedures to track sample shipments, to minimize loss or misidentification of samples, and to ensure that unauthorized persons do not tamper with collected samples.

1. Fill out the Chain-of-Custody form completely with all relevant information (the white original goes with the samples and should be placed in a "Ziploc" plastic bag and taped inside the sample cooler lid; the yellow copy should be retained by the sampler).
2. Mark liquid volume levels on sample bottles with grease pencil.
3. Place about 3 inches of inert cushioning material such as Styrofoam peanuts or bubble pack in bottom of cooler. Place bottles in cooler with VOA vials (in a "Ziploc" bag) in the center of the cooler.
4. Cover pack bottles, especially VOA vials, with ice in plastic bags. Pack cooler with blue ice in "Ziploc" plastic bags and additional cushioning material.
5. Tape drain shut and wrap cooler completely with strapping tape to secure lid.
6. Place lab address on top of cooler. To protect the shipping coolers against tampering during shipment, the cooler lid will be taped to the cooler body. A chain-of-custody seal will be placed over the tape. A broken seal will indicate that the contents may have been tampered with.
7. For out-of-town laboratory shipments, specify that the contents are "Fragile" and place "This Side Up" labels on all four sides of the cooler. "This Side Up" labels are yellow labels with a black arrow with the arrow head pointing toward the cooler lid. "This Side Up" labels should not be affixed to the cooler lid or the cooler bottom.

2.10. Equipment Decontamination

Between sampling events (between the two wet-weather events and two dry-weather events), equipment will be decontaminated by Buffalo State College by autoclaving at the field station and staging area or following the sampling equipment decontamination protocol. All liquid waste generated from decontamination must be collected and disposed of appropriately by Buffalo State College.

No decontamination of grab sample bottles is required since all grab sample bottles used in the field during each event must be provided by the laboratory that will analyze the samples.

During dry and wet weather sampling events, each sampling location requiring any additional sampling equipment will have a clean sterile field sampling device dedicated to that location.

2.11. Submission of Samples to Laboratories

The laboratories to be used for water quality analysis will be specified by Malcolm Pirnie. All laboratories specified will be NYS ELAP certified laboratories. The following key points regarding sample submission will be addressed by all parties:

- All samples will be submitted to the laboratories in laboratory provided bottles. For discrete samples collected at all sampling locations, the Chain-of-Custodies will be completed immediately upon collection of the samples by Buffalo State College.
- All coliform samples must arrive at the laboratory for analysis within 5 hours of the sample collection time, with regard to the 6 hour holding time. All other samples must be submitted for analysis within 12 hours of collection.
- All samples must be packed in coolers with ice after collection.
- Malcolm Pirnie is responsible for coordinating pick-up or delivery of all samples with the laboratories. Malcolm Pirnie will work with the laboratories to make appropriate arrangements to receive or take custody of the samples out-of-hours as required by the date and time of occurrence of the storm events. The field teams are responsible for transporting all samples to the field station and staging area, and submitting all samples in appropriate containers with appropriate labeling and Chains-of-Custody to the Buffalo State College Sampling Coordinator immediately after the event.
- Malcolm Pirnie is responsible for system-wide record keeping and for directing the laboratories in sample analysis.
- Sample results will be forwarded by the laboratories to Malcolm Pirnie in a format specified by Malcolm Pirnie.

Section 2.9 contains the Standard Procedure for Sample Shipping that will be followed by Malcolm Pirnie and Buffalo State College.

2.12. Equipment Calibration and Maintenance Protocols

All equipment will be programmed to the clocks of cellular telephones of the field personnel. As part of the pre-sampling staging before a dry or wet weather sampling event, all multi-parameter field probes carried into the field by sampling crews will be checked for calibration following manufacturer’s recommendations.

2.13. Health and Safety

Each Buffalo State College sampling team member is solely and completely responsible for conditions of the work sites, including safety of all persons (including employees) and property during performance of the services described in this Plan. Buffalo State College is responsible for developing appropriate Health and Safety Plans for all work involved in project services. Safety and Health provisions shall conform to the U.S. Department of Labor Occupational Safety and Health Act, any equivalent state law, and all other applicable federal, state, county and local laws, ordinances, codes, and regulations.

Buffalo State College shall be solely and completely responsible for ensuring its employees and subcontractors engaged in project activities receive appropriate training prior to the individual’s commencement of work on the project.

Health and Safety plans for this project shall be available at all times at all Project Site(s) performed by Buffalo State College members. Buffalo State College shall ensure that its subcontractor(s) completely comply with the requirements of this Section.

Buffalo State College shall be responsible for conformance with all Federal and New York State Departments of Transportation requirements for work in streets and in traffic controls. Buffalo State College shall coordinate its activities with the local law and traffic enforcement agencies and with agencies responsible for overseeing the waterways.

This work will be coordinated with Marty Boryszak, BSA Health and Safety Officer.

3. Determination of When to Sample

3.1. Dry-Weather Sampling

Dry-weather events will be sampled at all receiving water body locations identified in Table 2-1. Dry-weather sampling will tentatively occur on the third consecutive dry day after installation of all flow meters and sampling equipment and again on the third consecutive dry day occurring at least three weeks after the first dry-weather sampling event. Dry-weather sampling events will generally occur during business hours, Monday through Friday. The initiation and termination of dry-weather sampling will be determined by Malcolm Pirnie who will notify Buffalo State College to mobilize 24 hours in advance of sampling. Malcolm Pirnie will specify the time at which dry-weather sampling is to commence. Buffalo State College will initiate sampling at the time specified, provided that a rain event does not occur between notification to mobilize and the sampling event commencement. Should rain occur during the sampling, Malcolm Pirnie will decide on whether the event should be aborted or completed.

3.2. Wet-Weather Sampling

Two wet-weather events will be sampled at all receiving water body locations identified in Table 2-1. The goal for the sampled storms will be to meet the following targets, though minor deviations may be required to meet the sampling schedule:

- Be a community-wide storm event. The decision on whether or not an event is "community-wide" will be an ongoing judgment by the Malcolm Pirnie Sampling Coordinator during the sampling event.
- Have a rainfall depth of at least 0.5 inches +/-50% (0.25 to 0.75 inches).
- Have a minimum predicted duration of 6 hours +/- 50% (3 to 9 hours).

There must be a minimum of 72 hours of antecedent dry weather prior to a storm event for the event to be sampled. Interpretation of situations during an initiated event, such as intermittent overflows due to intermittent rainfall, etc., and any subsequent decisions on continuing the sampling event, are the responsibility of the Malcolm Pirnie Sampling Coordinator. The weather conditions will be tracked throughout the monitoring period to identify the appropriate times to mobilize crews for the wet-weather events. Due to the variability of weather patterns, there is the potential for sampling crews to be mobilized and then have to head back due to lack of rain.

In order to initiate a wet-weather sampling, the procedure described below in Section 3.3 will be followed.

3.3. Procedures for Initiation of Wet-Weather Sampling

3.3.1. General

The Malcolm Pirnie Sampling Coordinator will designate a qualified person to review real-time weather information and forecasts through two websites: will review real-time weather information and forecasts through two websites: Channel 4's Weather Watch school network (www.aws.com/wivb/), and the National Weather Center for Buffalo (www.wbuf.noaa.gov) to determine if a significant storm is forecast for the City of Buffalo within the next 48 hours and to monitor actual weather patterns. Another source is the metro radar loop of Intellicast (http://www.intellicast.com/National/Radar/Metro). The Channel 4 web site provides real-time data for Doppler radar, temperature, wind speed and direction. The National Weather Center web site contains forecasts for the next three to five days and predicted hydrologic information, e.g., likely rainfall intensities. The National Weather Center web site is updated four times daily at approximately 5:00 A.M., 10:00 A.M., 4:00 P.M. and 10:00 P.M. The forecasting sites will be checked seven days a week at 8:00 A.M., 11:00 A.M. and 5:00 P.M.

The sampling period will begin in June 2008 and last through September 2008 or until two qualifying events are completed, whichever comes first. In addition, during the first three weeks of the sampling period, wet-weather events will only be sampled if storms are initiated on weekdays between 6:00 A.M. on Mondays and 5:00 P.M. on Fridays. Sampling will not be initiated for rain occurring between 5:00 P.M. on Friday and 6:00 A.M. on Monday. Wet-weather sampling teams will therefore be on stand-by at all times except the period between 5:00 P.M. on Friday and 6:00 A.M. on Monday. Should at least one storm event have been captured by the end of the first four weeks, this will continue. If no storm events have been captured, teams will then be on standby to sample 24 hours a day, 7 days a week. If one storm is captured in the first four weeks but after another two weeks (six weeks of sampling in total) a second storm event has not been captured, teams may then be on standby to sample 24 hours a day, 7 days a week.

3.3.2. Stage 1: Preparation

If an appropriate storm is forecast, the Malcolm Pirnie Sampling Coordinator will notify Buffalo State College 12 to 24 hours in advance of the storm's estimated arrival time.

Buffalo State College will then contact their sampling teams to be on standby to assemble for wet-weather sampling.

3.3.3. Stage 2: Assembly of Teams

The Malcolm Pirnie Sampling Coordinator will continue to track the storm and when the storm is predicted to hit Buffalo within two to four hours, the Buffalo State College Sampling Coordinator will immediately contact the Team Leaders and inform them that a sampling event will be initiated.

The Buffalo State College Sampling Coordinator will contact all the Team Leaders who will contact their wet-weather sampling teams and instruct them to assemble at the designated field station and staging area as soon as possible prior to the storms predicted arrival. The Buffalo State College Sampling Coordinator will also go to the wet-weather staging area two hours prior to the storm.

3.3.4. Stage 3: Initiation of Sampling

Once the wet-weather sampling teams have assembled at their designated field station and staging areas at least two hours prior to the storms predicted arrival, the field teams will mobilize and sample preparation will be initiated.

The Sampling Coordinator will then monitor the weather both visually and on-line using the field station's real-time weather network link, and as soon as rainfall starts, the Buffalo State College Sampling Coordinator will record the time and inform the Team Leaders that the event has started. At this stage, all the sampling teams will proceed to collect samples throughout the duration of the storm for up to 8 circuits (6 in the Niagara River) at each sampling location.

The exact schedule will be determined during the sampling event based on the discussions between the Sampling Coordinator and Team Leaders.

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4. Laboratory Analysis

4.1. Designated Laboratories

The laboratories to which samples will be submitted for analysis by Buffalo State College have not yet been selected. However, it is anticipated that multiple labs may be required due to the large quantity of sample analysis required. The work will be coordinated with Gary Aures, BSA Laboratory Director.

4.2. Analytical Methods

Table 4-1 details the parameters that will be sampled for and the analytical methods. Once the laboratories have been selected, the same filter type and manufacturer will be specified following a discussion with the laboratories. Laboratory SOPs will be reviewed and checked for consistency. Each lab should provide sufficient range of sample dilutions to accommodate for a potential range of fecal coliform counts from 10 to 1,000,000.

Table 4-1.
Laboratory Analysis Details

Parameter	Method	Holding Time
Fecal Coliform	Membrane Filtration – Standard Method 9222D	6 hours
Total BOD	Standard Method 5210 B	24 hours
Soluble BOD	Use 0.45 micron filter and then follow Standard Methods	24 hours
TSS	SM 2540D	24 hours

Notes: Estimated/anticipated detection limits only – to be confirmed by discussion with selected laboratories.

4.3. Laboratory Quality Assurance/Quality Control (QA/QC)

Quality control sample analyses that will be performed during this project to document the acceptability of the data will include:

- Equipment Blanks
- Method Blanks
- Field Blanks
- Duplicate Samples

- An equipment blank (rinsate blank) will be collected for each type of sampling device used during sample collection at the field station and staging area immediately prior to initiation of a dry- or wet-weather sampling event. This will be conducted by the Buffalo State College Sampling Coordinator and Team Leaders assembled for a sampling event. Laboratory analyte-free water will be used to prepare an equipment blank by placing the laboratory water into one of each type of sampling device (decontaminated grab sampler, and bucket etc.) and filling one set of sampling bottles per type of sampling device and submitting them for analysis to the laboratory with the other samples.
- The laboratories will prepare and analyze one laboratory reagent blank (method blank) for each set of 20 samples received and whenever samples are processed (extracted, digested etc.) or other appropriate QA/QC as documented in LAB QAPP and SOPs.
- For each wet-weather sampling event, one duplicate sample will be collected for every 10 samples collected in the field by each field team during the event. The sampling teams must ensure they take extra sets of laboratory sample bottles into the field for collection of these duplicate samples during each event.
- For dry-weather sampling events, one duplicate dry-weather sample will be collected by each of the five sampling teams for a total of five duplicate samples. The locations at which these duplicates will be collected will be determined by the Buffalo State College Sampling Coordinator who will inform the Team Leaders prior to the dry-weather sampling event.

All quality control sample analytical results will be reported on standard forms in conjunction with data acceptance criteria. The selected laboratories will submit a detailed Quality Assurance Project Plan for review by Malcolm Pirnie prior to initiation of the sampling program.

5. Team Quality Assurance Procedures

The Great Lakes Center Aquatic Field Station (Buffalo State College) has performed many receiving water sampling projects. Several quality assurance procedures will be applied to team activities. These procedures are presented below.

5.1. Field Maintenance Activities and Documentation

Consistent field maintenance activity and documentation is a priority for the team. Prior to the implementation of the sampling program, the following activities will be carried out and documented:

- A site report will be prepared for each sampling location by Buffalo State College. Each site report will include a map showing the physical location and access if it is a river sampling location and GPS-obtained coordinates. Visual observations of any hydraulic characteristics along with any safety concerns will also be included on the report. A photograph will also be obtained showing the location of each site and submitted to Malcolm Pirnie in electronic format. A template for the site report will be provided by Malcolm Pirnie.
- All sampling teams will be equipped with a field book by the Team Leader and Sampling Event Summary Sheets from Malcolm Pirnie to document comments and observations at the time the samples are taken.

5.2. Team Training

Team training provides an important quality assurance mechanism for a water quality sampling program of this magnitude. A formal training workshop will be held to ensure that field personnel are comfortable with the sampling procedures. The workshop will be conducted by the Buffalo State College Sampling Coordinator. All members of the sampling teams will participate in the workshop. Training topics will include:

- Health and Safety
- Sampling Protocols
- Coordination

5.3. QA/QC Plans

Prior to the start of any field data collection activities, a task specific field sampling and analysis plan shall be prepared and reviewed by all sampling team members. The sampling plan will include task specific field QA/QC procedure, including but not limited to field equipment cleaning and decontamination protocols, sample handling procedures, chain of custody procedures and documentation, information of sample hold times, procedures for collection of QA/QC blanks including some proportion of field blanks and duplicate or co-located samples as required for laboratory QA/QC.

6. Data Submission and Reporting

6.1. Format for Submission of Data to Sampling Coordinator

Malcolm Pirnie will coordinate with the analytical laboratories to ensure proper data transfer. Templates will be provided to the laboratories before the first sampling event to facilitate the transfer. The data will be provided to Malcolm Pirnie as Excel spreadsheets and will include QA/QC results.

6.2. Data Storage

Malcolm Pirnie is responsible for final storage of system-wide water quality data, made up of the transmittals from the analytical laboratories. Buffalo State College is responsible for transmitting copies of all installation reports, maintenance reports, and sampling field logs and summary sheets to Malcolm Pirnie for inclusion in the project master files.

The turnaround time for the data will be specified with the laboratories that are selected to conduct the laboratory analyses.

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7. Program Management

7.1. Responsibilities of the Project Team (Project Organization)

Buffalo State College is responsible for:

- Providing staff and all equipment for field sampling teams.
- Acquiring all sampling equipment, including grab samplers, 500 ml grab sampling bottles, buckets, boats, field books etc.
- Provision of hand held DO, pH and temperature probes for in system sampling activities.
- Obtaining pre-labeled sample bottles, with preservatives, and shipping materials from laboratories.
- Providing a Sampling Coordinator to coordinate sampling activities from the staging area.
- Sample collection and transport to the wet-weather staging area.
- Sample preservation.
- Equipment decontamination between sampling events.
- Proper labeling of all samples.
- Record keeping for the sampling event and sample submission.
- Maintenance and calibration of equipment.
- Downloading data from 1 Acoustic Doppler current profiler (ADCP) or equivalent device.
- Downloading data from 2 stage and current data devices in Scajaquada Creek.
- Providing equipment, installing, maintaining and downloading the data for 2 Continuous sampling recording data sonde units.

Malcolm Pirnie is responsible for:

- Acoustic Doppler current profiler (ADCP) or equivalent device
- Coordinating pickup or delivery of samples with the laboratories.
- Compilation and storage of system-wide water quality analytical data.
- Production of the Water Quality Data Summary Report.
- Storage of data provided by Buffalo State College and others.

- Notification to Buffalo State College Sampling Coordinator should problems arise, field equipment malfunction or other issues arise that may effect the water quality sampling effort.

7.2. Variation from the Plan

During implementation of this Plan, should the location of any sampling point require relocation due to unanticipated conditions in the field, the Malcolm Pirnie Sampling Coordinator must be notified as soon as practical. All sampling locations must be agreed to by Malcolm Pirnie prior to sample collection.

Should any other modifications to this Plan be required through unanticipated field conditions or other events, the Malcolm Pirnie Sampling Coordinator must be notified immediately.

Wet-weather water quality sampling in a system as complex as Buffalo's is an iterative process. If water quality data obtained from one or more completed sampling events suggest a benefit from changing any sampling protocol defined in this Plan, BSA may choose to make such a change. Similarly, should physical constraints to sampling or constraints in laboratory capabilities for dealing with such a large quantity of samplers be encountered, this Plan may be modified. Any such change will be documented, with justification, in an Addendum to this Plan.

Changes from the protocol described herein will be pre-approved to the extent possible with the USEPA and NYSDEC.

Receiving Water Quality Sampling Work Plan

Buffalo Sewer Authority
Phase 2 Long-Term Control Plan

ATTACHMENT 1

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Buffalo Sewer Authority - Phase 2 LTCP

Attachment 1 - Sampling Event Summary Sheet

Initials:
Project:
Sampling Team:
Date:
Weather:
Temperature:

Page ___ of ____

Sampling Location	Time	Field Parameter	Measurement	Physical Observations	Comments
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	
		DO		Grease	
		temperature		Floatables	
		conductivity		Odors	

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Receiving Water Quality Sampling Work Plan

Buffalo Sewer Authority
Phase 2 Long-Term Control Plan

ATTACHMENT 2

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New York State Department of Environmental Conservation

Division of Water

Standard Operating Procedure: Collection Of Ambient Water Quality Samples

Date: August 8, 2002

Prepared by: ________________________________ **Date:**______________

Reviewed by: ________________________________ **Date:**______________

Approved by:________________________________ **Date:**______________

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Table of Contents

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1. Scope and Applicability

1.1 This practice covers the collection of representative ambient flowing water column samples for the purpose of chemical and physical analysis in the assessment of water quality. It includes samples collected from streams and rivers of various depths and velocities using depth-integrating samplers, point samplers and both compositing and non-compositing techniques.

1.2 This document does not cover guidelines for planning water quality activities, the design of monitoring programs, sample handling and preservation, data assessment or quality assurance of samples or field measurements.

1.3 This SOP is to be followed unless project objectives or physical conditions make it inappropriate. In such a case, the exact procedures followed, or deviations from the SOP must be documented in the field logbook, and a copy of the log entry submitted to the Division of Water Quality Assurance Officer for possible incorporation into future updates to this SOP.

2. Summary of Method

2.1 Water quality may vary throughout the cross section of a stream due to a number of factors such as groundwater influence, point and non-point discharges, tributary inflows and variations in velocity and channel characteristics. Therefore, a composite sample collected from a cross section of the stream's width and depth is recommended for parameters that are amenable to compositing.

2.2 The collection of water column samples at multiple depths is accomplished through the use of specially designed water collection equipment such as teflon-coated *Kemmerer Water Sampler*, Polypropylene *Polypro Water Sampler* and flow-orienting depth integrating suspended-sediment samplers. The water column samples collected across the stream's depth and width are then composited in a sample splitting churn.

2.3 Collection of water column samples for parameters that by their nature can not be composited and require special handling are achieved using water collection equipment tailored for specific needs.

3. Definitions

3.1 Composite sample: A sample that is made up of smaller samples that are collected from across sections of a stream's width and depth.

3.2 Depth-integrating suspended sampler: A depth-integrating suspended sampler is designed to accumulate a water/suspended sediment sample from a stream vertical at such a rate that the velocity in the nozzle is nearly identical to that of the stream.

3.3 Dip: One complete cycle of the depth-integrating suspended sampler from the water surface to the bottom and back again that fills the sample bottle with the ambient waters.

3.4 Grab sample: A single sample taken directly in the stream.

3.5 Quality Assurance Project Plan (QAPP): A document that describes project-specific information such as the necessary quality assurance, quality control, and other technical activities that are implemented to ensure that the results of the work performed satisfies acceptance criteria.

3.6 Stream depth: The stream depth is the vertical height of the water column from the existing water surface level to the channel bottom.

3.7 Stream width: The stream width is the horizontal distance along a line from shore to shore.

3.8 Transect line: A line determined by two points on opposite streambanks, is useful as the location reference for the measurement of ambient flowing water column samples, and allows for determination of chemical and physical conditions existing at a point within a stream.

3.9 Trip: A unit that refers to the number of times the depth-integrating suspended sampler and sample bottle is brought above the water surface and the sampled ambient waters are emptied into a churn.

3.10 Water column: The vertical location at which the sampler is lowered and raised below the surface water level.

4. Health and Safety Warnings

4.1 This standard does not address all safety concerns associated with conducting field sampling and the handling of chemical reagents. The reader is referred to the Division of Water's Health and Safety SOP and to follow the appropriate health and safety practices covered therein.

4.2 Safety is more important than the task. If for any reason conditions at the monitoring site are considered unsafe, suspend sampling and leave the site.

4.3 When sampling from a boat, the field team should follow general boating safety procedures.

5. Cautions

5.1 Always work with at least one partner when collecting ambient water quality samples.

5.2 Never wade in swift or high water. Use a walking stick to steady yourself and to test for deep water and muck.

5.3 Know what is upstream of a sampling site before entering the stream. An unexpected dam release could leave a sample collector stranded and in trouble in the stream.

5.4 Wear and maintain assigned personal protective equipment.

5.5 Never eat and drink when collecting and handling samples.

5.6 Always wash hands before and after collecting and handling samples.

5.7 Cover all personal open cuts and abrasions before sampling.

5.8 Protect sampling equipment from blows against rocks, bridge rails and any other objects in the stream or stream bank. *Extra care must be used with teflon samplers because the material is brittle and easily damaged.*

5.9 Wear proper field clothing to prevent hypothermia, heat exhaustion, sunstroke, drowning, or other dangers.

5.10 Be fully aware of all lines of communication that address emergency and safety situations.

5.11 Use caution when working from a bridge or boat.

6. Interferences

6.1 Sample integrity is critical in obtaining meaningful data from water quality samples. Introduction of contaminants into the sample from sampling equipment, sample preparation, sample handling, location of sampling site and improper collection methods can affect the integrity of the sample.

6.2 Following proper collection and handling procedures will ensure a representative (well-mixed) sample is collected.

6.3 Following proper storage, cleaning and handling of all sampling equipment will minimize and possibly eliminate the introduction of contaminants to the sample. Refer to the Division of Water's SOP#101-02 Sample Handling, Transport and Custody and SOP#103-02 Equipment Cleaning.

6.4 A representative stream sample must contain similar proportions of sediment particles that are present in the water column of the stream. Stirring up bottom sediments while collecting water samples may introduce more suspended sediments than is normally found in the stream and must be avoided.

7. Personnel Qualifications

7.1 All staff responsible for collecting water quality samples shall be familiar with the procedures outlined in this standard, the Quality Assurance Plan for the sampling project and the DOW Health and Safety SOP prior to conducting water quality sampling.

8. Equipment and Supplies

8.1 The equipment needed for the collection of ambient water quality samples includes, but is not limited to the following:

8.1.1 Point samplers (Teflon-coated Kemmerer Water Sampler or Polypropylene PolyproWater Sampler 1400 mL size)

8.1.2 Depth-integrating suspended sediment sampler (Flow-orienting US DH –76 or US DH- 81 Adapter)

8.1.3 Sample suspension apparatus (crane)

8.1.4 Wading rods

8.1.5 Sample collection bottles (1 quart and glass)

8.1.6 Nozzles

8.1.7 Line and messengers

8.1.8 Rope

8.1.9 Sample splitting churn

8.1.10 Stainless steel pail

8.1.11 Whirl-Pak sampling bags and poles

8.1.12 Sterile bacteriological bottles (Bac-T bottles)

8.1.13 Teflon or Polyethylene dippers

8.1.14 Maps

8.1.15 Personal protective equipment

8.1.16 Field sheets/log book

8.1.17 Stakes and flagging tape

8.1.18 Camera

8.1.19 Global Positioning System (GPS)

8.1.20 Approved QAPP

8.1.21 Portable multi-parameter meter (pH, dissolved oxygen. conductivity and temperature)

9. Procedures

9.1 The following procedures should allow for the collection of representative samples from the majority of flowing waters (rivers and streams) encountered.

9.2 There must be a Quality Assurance Project Plan (QAPP) approved by the Division of Water's Quality Assurance Officer before collecting any water samples for chemical analysis.

9.3 Sampling personnel should wear new, clean gloves. If gloves become contaminated, they must be replaced.

9.4 During the sample collection and transfer process, one person is responsible for handling the samples and sample bottles ("clean hands") and another person is responsible for all activities that do not involve direct contact with the samples ("dirty hands"). Refer to EPA Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels.

9.5 Sample Collection – General

9.5.1 Determine the appropriate sampling method and device based upon stream type and parameters to be analyzed.The selection of a sampling method is based on minimizing any loss or introduction of the parameter being analyzed and ensuring that the water sample is representative of the chemical, biological and physical characteristics of the stream being studied.

9.5.2 Determine what special collection requirements are needed to maintain integrity of the parameter to be analyzed. For example, a water sample cannot be aerated when collecting for volatile halogenated organics analysis. Check with the analytical laboratory, Standard Methods or Table 1 of this document for verification of parameter specific information.

9.5.3 Determine compatibility of sampling device construction materials with parameters to be analyzed. As an example, when collecting samples for organic analysis, do not use plastic sampling devices.. Check with the analytical laboratory, Standard Methods or Table 1 of this document for verification of appropriate material types for specific parameters.

9.5.4 Determine the quantity/ volume of sample that needs to be collected based on the parameters to be analyzed and quality controls samples that need to be collected. If sample will be partitioned into sub-samples using a sample splitting churn an additional (2) liters of sample is required to allow for proper mixing. Refer to SOP # 101-02 Sample Handling, Transport and Chain-of-Custody for sub-sampling requirements.

9.5.5 Assess the sites physical characteristics such as stream velocity, depth, width, sources of inflows and accessibility.

9.6 Sample Collection – Preparation

9.6.1 Assemble the necessary sampling equipment and set up a clean work space away from automobile and boat emissions.

9.6.2 Prior to sampling, regardless of the method of collection, all sampling equipment employed should be free from contaminants. Refer to SOP#103-02 Equipment Cleaning.

9.6.3 The first water sample collected at a sampling site is used to rinse the samplers and sample splitting churns.

9.6.4 When doing depth-integrating suspended sediment sampling, glass bottle containers should be site-dedicated. If possible, the sampling nozzles should also be site-dedicated. If not, clean the nozzles according to SOP#103-02 Equipment Cleaning.

9.6.5 Point samplers should be rinsed with distilled/deionized water after sample collection is completed and allowed to dry in the "open" position.

9.6.6 The sample splitting churn should be rinsed thoroughly with distilled/deionized water after sample collection is completed. To keep the churn from drying out during short-term storage, add a liter or so of distilled/deionized water.

9.7 Sample Collection – Method Options

9.7.1 Point Samplers

9.7.1.1 Point samplers allow for a water sample to be collected at a discrete point. It is recommended for use where there is limited variation/ stratification in the composition of the stream, the velocity is less than 2 ft/s and for larger, deeper waters (greater than 4 ft.). The Oswego River at Minetto, Upper Hudson River at Waterford or the Buffalo River in Buffalo would be appropriate sampling sites.

9.7.1.2 Point samplers are available in various configurations of shape, closing mechanism, and construction materials. They generally consist of a hollow tube/ cylinder with stoppers at both ends and a weighted base. The sampler is lowered to the desired depth by a rope with a weighted messenger attached. The stoppers are tripped closed with the messenger sealing the bottle contents from any further contact with the stream water.

9.7.1.3 Common point samplers used in ambient water quality sampling are Kemmerer bottle, Van Dorn bottle, and Polypro sampler.

9.7.2 Depth-Integrating Suspended Sediment Samplers

9.7.2.1 A depth-integrating suspended sampler is designed to accumulate a water/suspended sediment sample from a stream vertical at such a rate that the velocity in the nozzle is nearly identical to that of the stream. This results in the collection of a sample that has a water/suspended sediment ratio similar to that of the stream.

9.7.2.2 Since many pollutants adhere to suspended sediment particles in the stream, a representative water column stream sample must contain a representative proportion of sediment particles.

9.7.2.3 This sampling method allows the collection of a water sample to be collected continuously through a vertical column of the stream depth.

9.7.2.4 There are many types of depth-integrating suspended samplers that vary by construction material, weight and manner in which they are lowered or raised through the water column. They may be used in all flowing waters and are designed so the nozzle is facing into the flow and collecting the sample into a collection container.

9.7.3 Special Water Column Samplers

9.7.3.1 When there is incompatibilities between the compositing sample collection techniques and the nature of some stream parameters, an alternative collection method can be tailored to meet the stream parameters. Alternative collection methods include the use of dissolved oxygen samplers, teflon or polyethylene dippers, whirl-pak sampling bags, Bac-T Bottles, poles and stainless steel buckets.

9.8 Sample Collection - Field Parameters

Field parameter measurements are taken directly from the water column to be sampled. All field measurements are recorded on field sheets with the appropriate units.

9.8.1 Dissolved Oxygen (D.O) – Use a multi-parameter probe or an appropriate D.O. meter. Make sure that the equipment has been appropriately calibrated following the manufacturer's specifications. Be sure to record the appropriate units.

9.8.2 Conductivity – Use a multi-parameter probe or an appropriate conductivity meter. Make sure that the equipment has been appropriately calibrated following the manufacturer's specifications. Be sure to record appropriate units.

9.8.3 pH – Use a multi-parameter probe or an appropriate pH meter. When calibrating the meter, select two pH buffers that reflect the expected pH of the stream. Make sure that the equipment has been appropriately calibrated following the manufacturer's specifications.

9.8.4 Water Temperature – Use a multi-parameter probe or mercury-filled thermometer. If using a thermometer, insert the thermometer to the immersion line in a bucket of sample water that has been placed in the shade. Allow the mercury column to stabilize (~ 2 min.), and record the temperature from the immersed thermometer. Be sure to record appropriate units.

9.8.5 Barometric Pressure - Record the barometric pressure for the sampling date from a barometer, local airport or weather station report. Be sure to record appropriate units.

9.9 Sample Collection – Methodology Parameters

9.9.1 Transect

The number and location of sampling transects is a matter of judgement based on stream uniformity of flow (discharge) and field parameters (such as pH, water temperature, and dissolved oxygen). At a minimum, three transects should be collected across the stream width. All transects should be equally spaced. In general, uniform streams require less transects while streams showing wider variations between flow and field parameters require more transects.

9.9.2 Depth

Depth is only a factor when point samplers are used. The number of discrete depths to be sampled in the water column is contingent on the homogeneity of the stream. A general rule is the more homogeneous the stream is the fewer discrete depth samples are needed. At a minimum, three depths (top, middle and bottom) are required at each sampling interval.

9.9.3 Stream Accessibility

Sampling may be conducted from a bridge, boat, or directly from a stream. The latter is the preferred way of sampling because the sample will not be subjected to significant chemical changes (contamination) during the sample collection process. When accessibility to a stream is hindered because of flow rates and water depths, sampling from a bridge or boat is recommended. All sampling methods have inherent dangers, and safeguards should be taken to minimize the risk of falls, slips, drownings, capsizing and so forth.

9.9.3.1 Avoid disturbing the bottom sediment.

9.9.3.2 Avoid sampling along the riverbank, in stagnant water, or from an eddy.

9.9.3.3 Avoid sampling near piers or other man-made obstructions.

9.9.3.4 Avoid banging equipment into structures or the sides of the boat.

9.9.3.5 Avoid sampling near or from power sources such as power lines and boat motors.

9.9.3.6 Avoid contaminating the sample by having one person sample the water and another person run the boat.

9.10 Sample Collection – Sampling Procedures

9.10.1 Sampling from a bridge with a depth-integrating suspended sediment sampler

9.10.1.1 Assemble the sampling crane with the depth-integrating suspended sediment sampler attached to the cable.

9.10.1.2 Secure a collection bottle or bag (designated for the specific site) to the sampler.

9.10.1.3 Choose an appropriate nozzle for the sampler and insert it into the sampler. Small nozzles are appropriate for high stream velocities while large nozzles are recommended for slower moving streams.

9.10.1.4 Select the first transect in the portion of the stream that appears to have the highest flowing volume of water.

9.10.1.5 Lower the sampler until it breaks the water surface.

9.10.1.6 Record start time and set the depth gauge on the crane to zero.

9.10.1.7 Lower the sampler to the bottom of the stream and read and record the depth displayed on the gauge. Track the depth on subsequent descents to prevent the sampler from disturbing the bottom sediments.

9.10.1.8 Raise the sampler to the water surface, keeping it just below the water surface level, and then lower sampler towards the streambed.

9.10.1.8.1 One complete cycle from the water surface to the stream bed and back to the water surface is referred to as a "dip."

9.10.1.8.2 Repeat dips until the collection bottle is about 75% full. When the collection bottle is filled beyond 75% full, it will act as a sediment trap.

9.10.1.8.3 Keep track of the number of dips or cycles on a field sheet.

9.10.1.8.4 The number of dips is dependent on the stream depth and the speed with which the collection bottle fills.

9.10.1.9 Raise the sampler above the water surface level when the collection bottle reaches about 75% full and empty the collected water into a sample splitting churn.

NOTE: The first water collected is used to rinse the sample splitting churn and determine the rate of descent/ascent and the number of dips. A uniform rate of descent/ascent should be maintained while raising and lowering the sampler through the water column. The transit rate is a function of the type of collection bottle or bag, size of sampler nozzle, and the desired sample volume.

9.10.1.9.1 Each time the sampler and collection bottle is brought up and emptied into the sample splitting churn is referred to as a "trip."

9.10.1.9.2 Each transect must have the same number of trips made up of the same number of dips.

9.10.1.9.3 The number of trips collected at each transect is a function of the volume of water and the number of transects.

9.10.1.9.4 A representative sample is ensured when more transects and fewer trips and dips are taken.

9.10.1.10 Move sampling crane to the next transect and continue the sample collection, using the same number of trips and dips and the same rate established at the first transect.

9.10.1.11 After collecting the sample into a sample bottle, record the number of transects, trips, and dips, sampling end time, ending gage height, and any deviations from standard sampling procedures on field sheets and in a logbook.

NOTE: The number of transects, trip and dips should remain consistent for subsequent samples collected at the site and under similar stream flow conditions.

9.10.2 Sampling directly from a stream (i.e., stream wading) with a depth-integrating suspended sediment sampler

9.10.2.1 Assemble the rod and nozzle head and secure the collection bottle, designated for the site, into the nozzle head.

9.10.2.2 Enter the stream downstream from where sample will be collected.

9.10.2.3 Select the first transect in the portion of the stream that appears to have the highest flowing volume of water.

9.10.2.4 Record start time and orient sampler with nozzle facing upstream and into the flow while standing downstream of sampler.

9.10.2.5 Lower sampler through the water column to the bottom of the stream without disturbing the bottom sediment. Bed material may enter through the nozzle, resulting in erroneous data.

9.10.2.6 Raise sampler to the water surface level. A uniform rate of descent/ascent should be maintained while raising and lowering the sampler through the water column.

9.10.2.6.1 One complete cycle from the water surface level to the stream bottom and back again is referred to as a "dip."

9.10.2.6.2 Repeat dips until the sample bottle is about 75% full and keep track of the number of dips on a field sheet. Do not fill the sample bottle more than 75%, as it will act as a sediment trap.

9.10.2.6.3 Each time the sampler and sample bottle is brought up and emptied into the churn is considered a "trip." A trip is made up of the same number of dips along each transect.

9.10.2.6.4 The number of trips to be collected at each transect is determined by the volume of water that is required and the number of transects.

9.10.2.6.5 The number of dips per trip depends upon the stream depth and the speed with which the sample bottle fills.

9.10.2.6.6 It is generally preferred to have more transects and fewer trips to ensure a representative sample.

9.10.2.7 Move to the next transect and continue the sample collection using the same number of trips and dips as was established at the first transect.

9.10.2.8 After collecting the sample, record the number of transects, trips, and dips, sampling end time, and any deviations from standard sampling procedures on field sheets or in a logbook.

NOTE: The number of transects, trip and dips should remain consistent for subsequent samples collected at the site and under similar stream flow conditions.

9.10.3 Sampling with a point sampler

9.10.3.1 Set sampler to the open position by following the manufacturer's instructions for setting the end caps. This is done by either pulling the trip head into the trip plate or by holding the top and bottom stoppers and giving a short, hard pull to the bottom stopper.

9.10.3.2 Lower the sampler to a desired depth while holding the messenger and feeding the sampler cord through the sampler.

9.10.3.3 Release the messenger or trip the mechanism used to close both of the end caps/stoppers.

9.10.3.4 Raise the sampler and pour water from the drain valve or one of the sampler ends into the sample splitting churn.

9.10.3.5 Rinse the sampler and sample splitting churn with the first collected water.

9.10.3.6 Repeat steps 9.10.3.1-9.10.3.4 at desired depths and verticals across the stream for actual sample collection.

9.10.3.6.1 Take sample from the deepest depth first then move up the water column to the middle section, and finally, to the top section.

9.10.3.7 After sampling is completed, rinse point sampler with distilled/deionized water, let dry in the "opened" position and store the sampler in the "closed" position.

9.10.4 Direct Grab

9.10.4.1 Enter the stream downstream from where the sample will be collected.

9.10.4.2 Select the area of the stream having the greatest flow.

9.10.4.3 Face upstream and into the flow.

9.10.4.4 Orient sample container with the opening towards the flow and in front of you.

9.10.4.5 Invert sample container.

9.10.4.6 Lower container into water six (6) to ten (10) inches below the water surface.

9.10.4.7 Uncap the container underwater to avoid introducing surface scum into the bottle.

9.10.4.8 Tilt the container at a 45-degree angle and hold the container steady

9.10.4.9 Allow the container to fill with water.

9.10.4.10 Cap the container underwater when container is full.

9.11 Sample Collection – Special Samples

9.11.1 Collection Methodology

A single grab sample taken directly in the stream is the most efficient way of collecting water column samples when the nature of the parameter to be analyzed is not amenable to compositing collection techniques (ie., depth-integrating suspended sediment sampler). To ensure that the most representative sample is collected, select the area of the stream having the greatest flow and avoid agitation or aeration to the sample. If a direct sample cannot be collected, the sample collection equipment must be constructed of an inert material or material compatible with the parameter being analyzed (Table 1). Ropes or extension poles can be used to lower collection equipment into the water column. Detailed procedures for the most commonly collected parameters requiring non-compositing techniques are listed below.

9.11.2 Phenolic Compounds

9.11.2.1 Direct Grab

9.11.2.1.1 Select the area of the stream having the greatest flow.

9.11.2.1.2 Continue by following procedures (9.10.4.1-9.10.4.10) for a direct grab sample.

9.11.2.1.3 Collect a grab water sample directly into a glass sample container.

9.11.2.1.4 Do not composite sample.

9.11.2.2 Alternative Method – steel bucket or swing sampler

9.11.2.2.1 Use a stainless steel bucket or a swing sampler with glass bottle attached.

9.11.2.2.2 Rinse stainless steel bucket /glass container with water from the site to be sampled before collecting the sample.

9.11.2.2.3 Select area of the stream with the greatest flow.

9.11.2.2.4 Collect a grab water sample with stainless steel bucket or swing sampler. Try to minimize agitating the sample.

9.11.2.2.5 Fill the phenol bottle directly.

9.11.2.2.6 Do not composite sample.

9.11.3 Volatile Halogenated Organics (VHOs)

9.11.3.1 Direct Grab

9.11.3.1.1 Select the area of the stream having the greatest flow.

9.11.3.1.2 Continue by following procedures (9.10.4.1-9.10.4.10) for a direct grab sample.

9.11.3.1.3 Hold the vial at a 45-degree angle and slowly submerge and uncap the vial.

9.11.3.1.4 Hold the vial in place for 15 - 20 seconds to ensure the transfer of a non-turbulent flow of sample down the inside of the vial.

9.11.3.1.5 Fill the vials completely and secure the cap while the vial is still submerged to avoid aeration.

9.11.3.1.6 Remove the sample vial from the water.

9.11.3.1.7 Turn the vial upside down and tap the side lightly to check for air bubbles. If the vial contains any air bubbles, the sample vial must be uncapped and topped off with more sample.

9.11.3.2 Alternative Method 1 – dissolved oxygen bucket

9.11.3.2.1 Use a dissolved oxygen (D.O.) sampling bucket outfitted with pre-cleaned Tygon tubing.

9.11.3.2.2 Select the area of the stream having the greatest flow.

9.11.3.2.3 Place two (2) clean, uncapped biochemical oxygen demand (BOD) bottles into D.O. sampling bucket.

9.11.3.2.4 Close the D.O. bucket lid making sure the Tygon tubing is inserted into the BOD bottles.

9.11.3.2.5 Lower the sampling bucket one (1) foot below the water surface.

9.11.3.2.6 When all the air has escaped from the exhaust vent, gently raise the D.O. sampling bucket. Be sure not to agitate the water that has been collected in the bucket.

9.11.3.2.7 Slowly remove the lid of the D.O. sampling bucket and cap the BOD bottles under the water surface of the bucket.

9.11.3.2.8 Submerge, uncap and fill pre-cleaned, 40-mL vials with the collected water. This is accomplished by slanting the vials at a 45 degree angle and letting the sample flow down the inside of the vial.

9.11.3.2.9 Secure the vial caps underneath the water surface of the bucket, making sure the Teflon side of the septum comes in contact with the sample creating a hermetic seal.

9.11.3.2.10 Turn the vial upside down and tap the side lightly to check for air bubbles. If the vial contains any air bubbles, the sample vial must be uncapped and topped off with more sample.

9.11.3.3 Alternative Method 2 – stainless steel or glass container

9.11.3.3.1 Select the area of the stream having the greatest flow.

9.11.3.3.2 Use a clean sample container made of either stainless steel or glass.

9.11.3.3.3 Lower the sample container into the stream using a rope or a swing sampler extension pole.

9.11.3.3.4 Raise the sampler making sure not to agitate the water that has been collected.

9.11.3.3.5 Submerge, uncap, and fill pre-cleaned 40-mL vials. This is accomplished by slanting the vials at a 45-degree angle and allowing the sample to flow slowing down the inside of the vial.

9.11.3.3.6 Secure the vial caps underneath the water surface of the container, making sure the Teflon side of the septum comes in contact with the sample creating a hermetic seal.

9.11.3.3.7 Turn the vial upside down and tap the side lightly to check for air bubbles. If the vial contains any air bubbles, the sample vial must be uncapped and topped off with more sample.

9.11.4 Bacteriological Samples

Bacteriological samples are collected directly into a special bacteriological container obtained from the analytical laboratory. Extra care needs to be taken to ensure that the sample container and cap and the sample itself is not contaminated during the collection process.

9.11.4.1 Direct Grab

9.11.4.1.1 Select the area of the stream having the greatest flow.

9.11.4.1.2 Continue by following procedures (9.10.4.1-9.10.4.10) for a direct grab sample.

9.11.4.1.3 Remove the cap from the sterile container taking care not to touch the inside of the container.

9.11.4.1.4 Place the cap in a clean, poly bag or by wrapping the cap in clean aluminum foil to prevent contamination.

9.11.4.1.5 Grasp the container at the base with one hand and plunge the mouth of the container into the water facing the current direction.

9.11.4.1.6 Avoid introducing surface scum by sampling at a depth 6-12 inches below the water surface.

9.11.4.1.7 Fill the container and secure the container's cap.

9.11.4.2 Alternative Method – Whirl-Pak sampling bags

9.11.4.2.1 Select the area of the stream having the greatest flow.

9.11.4.2.2 Attach a sterile sample container to a rope or a swing sampler extension pole. If using Whirl-Pak sampling bags, use Whirl-Pak sampling pole or line.

9.11.4.2.3 Remove the cap from the sterile container taking care not to touch the inside.

9.11.4.2.4 Place the cap in a clean, poly bag or by wrapping the cap in clean aluminum foil to prevent contamination.

9.11.4.2.5 Lower the container into the stream about 6-12 inches below the water surface.

9.11.4.2.6 Fill the container.

9.11.4.2.7 Raise the container and secure the cap.

10. Sample Handling, Transport, and Chain-of-Custody

Samples must be handled in accordance with the NYSDEC DOW SOP# 101-02 for Sample Handling, Transport, and Chain-of-Custody.

11. Data and Records Management

11.1 Each instrument has a logbook assigned to it. The logbook serves as record of calibration checks, repair work, routine maintenance and cleaning performed on the instrument. Dates, times, comments, and names of individuals performing the work are to be noted in the logbooks. The recording of the calibration data, maintenance, and repair work is necessary to counter challenges to the quality, integrity and acceptability of the field data.

11.2 All pertinent information regarding the field sampling process must be recorded on field sheets or in a field logbook. Sampling information to be recorded should be sufficient to reconstruct the sampling event without relying on the sample collector's memory. At a minimum, the field person should record an unique sampling site identifier (name or number), a description of the sampling site, sample collector's name, type of samples collected, type of analyses requested, date and time of sample collection, weather conditions, and field observations and measurements.

12. Quality Assurance/Quality Control

12.1 The samples that are collected for analyses must accurately represent the stream being sampled and be unaffected by the collection procedures. The objective of this quality assurance methodology is to establish and maintain standards that will ensure the integrity of the water samples collected.

12.1.1 Prior to use, check all equipment to ensure good operating condition and cleanliness.

12.1.2 Follow manufacturer's specifications in carrying out routine maintenance on sampling equipment.

12.1.3 To the extent possible and practical, backup equipment should be available.

12.1.4 All sampling equipment (buckets, churn, sampler, etc.) should be cleaned and rinsed with a distilled (de-ionized) water wash before and after each sampling event. Refer to SOP#102-03 Equipment Cleaning.

12.1.5 At each sampling site, equipment should be rinsed with ambient water before a sample is collected and rinsed with distilled water after sampling is completed.

12.1.6 Whenever the sampling site has known or suspected contamination problems, sampling equipment should be washed with a phosphate free detergent, then scrubbed with water, and finally rinsed with distilled water.

12.1.7 A record of equipment cleaning should be maintained.

12.1.8 Whenever possible, use site-dedicated sample collection equipment.

12.1.9 Sampling should progress from the sites with the best water quality to the poorest.

12.1.10 The sample equipment must be appropriate for the samples being analyzed.

12.1.11 All instruments used in the field must be calibrated following manufacturers' instructions. Frequency for calibrating instruments should be based on either the manufacturer' recommendations or as outlined below, whichever is the more stringent.

12.1.11.1 Initially, instruments shall be calibrated before and after each day of fieldwork. After it has been demonstrated that the instrument can hold a calibration, the frequency may be adjusted. At a minimum, instruments should be calibrated at least once during each week of sampling. All calibrations are recorded in a instrument logbook.

12.1.12 Sampling equipment should be replaced when the equipment is damaged or exposed to highly contaminated waters, or when routine equipment cleaning is impaired.

12.1.13 All sampling equipment should be stored and maintained in a "clean" manner.

13. References

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Table 1 – SAMPLING HANDLING SPECIFICATIONS – Water Column				
Parameter	**Collection Method**	**Sample Processing**	**Sample Container**	**Filling**
Alkalinity	Depth Integrated	Composite	Plastic Glass	DO NOT AERATE
Ammonia	Depth Integrated	Composite	Plastic Glass	
Chloride	Depth Integrated	Composite	Plastic Glass	
Coliform-Total & Fecal	Grab - direct into Sterile container	none	sterile	
Conductance	Direct Field measurement			
Dissolved Oxygen	Direct Field Measurement			DO NOT AERATE
Fluoride	Depth Integrated	Composite	Plastic only	
Hardness	Depth Integrated	Composite	Plastic Glass	
Kjeldahl Nitrogen	Depth Integrated	Composite	Plastic Glass	
Metals, Total Recoverable	Depth Integrated	Composite	Plastic Glass	
Metals, Dissolved	Depth Integrated	Composite Filtered	Plastic Glass	
Mercury, Total	Depth Integrated	Composite	Plastic Glass	
Nitrate-Nitrite	Depth Integrated	Composite	Plastic Glass	
Nitrate	Depth Integrated	Composite	Plastic Glass	
Nitrite-NO_2	Depth Integrated	Composite	Plastic Glass	

Table 1 – SAMPLING HANDLING SPECIFICATIONS – Water Column (cont.)

Parameter	Collection Method	Sample Processing	Sample Container	Filling
Oil and Grease	Grab	Do Not Composite	Glass only	DO NOT AERATE
Orthophosphate	Depth Integrated	Composite Filtered	Plastic Glass	
pH	Direct Field Measurement			
Phenolic Compounds	Grab - Steel Bucket	Do Not Composite	Glass only	
Phosphorous, Total	Depth Integrated	Composite	Plastic Glass	
Solids: Total	Depth Integrated	Composite	Plastic Glass	
Solids: Total Dissolved	Depth Integrated	Composite	Plastic Glass	
Solids Total Suspended	Depth Integrated	Composite	Plastic Glass	
Solids Total Volatile	Depth Integrated	Composite	Plastic Glass	
Sulfate	Depth Integrated	Composite	Plastic Glass	
Toxicity Testing Sample	Depth Integrated	Composite	2 L Plastic	
Turbidity	Depth Integrated	Composite	Plastic Glass	
Volatile Halogenated Organics	Direct Grab or D.O. Sample Bucket	Do Not Composite	Glass, Teflon lined septa	DO NOT AERATE

Appendix 4-5: Water Quality Modeling Work Plan for Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek (May 2008)

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Water Quality Modeling Work Plan For Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek

Prepared On Behalf Of
The Buffalo Sewer Authority

May 30, 2008

LimnoTech
Water | Environment | Scientists | Engineers

Ann Arbor, Michigan
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1. INTRODUCTION

This work plan describes development of water quality models of the Niagara River, the Buffalo River, Black Rock Canal, and Scajaquada Creek, to address recent comments from the New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA) on the *System-Wide Long Term Control Plan for CSO Abatement* prepared by Malcolm Pirnie, Inc., on behalf of the Buffalo Sewer Authority (Malcolm Pirnie, 2004a, b). LimnoTech prepared this work plan on behalf of the Buffalo Sewer Authority (BSA), under subcontract to Malcolm Pirnie.

1.1 BACKGROUND

The government agencies involved in reviewing the Long Term Control Plan (LTCP) have suggested the need for the Buffalo Sewer Authority (BSA) to conduct receiving water quality modeling of waterways potentially affected by combined sewer overflows (CSOs). Specifically, modeling of the Niagara River, the Buffalo River, and Scajaquada Creek was requested in a letter to BSA (Palumbo, 2007) to evaluate specific concerns regarding bacteria, biochemical oxygen demand (BOD), and effects on dissolved oxygen (DO) in these waterways. Subsequent discussions with government agencies have identified concerns regarding dissolved oxygen impacts in Black Rock Canal. BSA, in conjunction with the University of Buffalo, conducted previous water quality modeling to evaluate dissolved oxygen conditions in the Buffalo River. The modeling work described in this work plan will build on the previous Buffalo River modeling and will develop new models for other receiving waters to enhance BSA's understanding of the impacts of CSOs on these receiving waters. These models will be used in the future to evaluate the benefits of proposed CSO control projects.

1.2 OBJECTIVES

The overarching objectives for development of receiving water quality models for the Buffalo waterways are to improve the understanding of the impacts of CSOs on receiving water quality and to support decision-making regarding CSO control alternatives. Discussions with the NYSDEC and USEPA have defined a set of questions to be answered by the receiving water quality models described in this work plan.

1.2.1 General Questions Applicable to All Models

Several questions have been formulated that describe general water quality model needs for all of the models. These include the following:

- What is the relative contribution of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters during and following a CSO event relative to other watershed sources, such as direct runoff, other tributary sources, and sources in the watershed above the city?

- What are the effects of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters in the hypothetical absence of other contributions or potential reductions of other contributions?

- What effect will proposed Phase 1 CSO control projects have on receiving water quality, relative to current conditions?

The water quality models developed under this work plan will allow evaluation of the impacts of BSA's CSOs on water quality in the absence of other sources and under varying upstream loads and other sources. The models will allow evaluation of attainment of existing water quality standards, where appropriate. The models will also support use attainability analysis (UAA) but, because of the nature of UAAs, may not be sufficient by themselves. In addition to the general questions listed above, several waterway-specific questions have been identified, as described below.

1.2.2 Waterway Specific Questions

In addition to the general questions listed above, the following waterway-specific questions have been identified:

Niagara River

- What is the spatial and temporal distribution of bacteria in the Niagara River following an overflow event?

- What are the impacts of Scajaquada Creek and Black Rock Canal CSOs on Niagara River water quality, with respect to bacteria?

- How will CSO discharges and flows from the Buffalo River move in the Niagara River; under what conditions will these flows "hug" the eastern bank?

- What effect will proposed Phase 1 CSO control projects have on water quality in the Niagara River, relative to current conditions?

Buffalo River

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in the Buffalo River? How will SOD and the resulting DO in the Buffalo River change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in the Buffalo River?

- What is the effect of CSOs on water quality in the Buffalo River, specifically with respect to bacteria? How will this change with CSO controls?

- How is BOD and bacteria loading to the Inner Harbor affected by Buffalo River CSOs?

Scajaquada Creek

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in Scajaquada Creek? How will SOD and the resulting DO in Scajaquada Creek change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in Scajaquada Creek?

- What controls are necessary for the Scajaquada Creek CSO discharges in order to meet standards in that part the system designated as Class B with regard to designated uses?

- What will the bacteria loads to the Black Rock Canal and Niagara River be from Scajaquada Creek during various storm events with and without CSO controls?

Black Rock Canal

- What is the impact of BSA's CSO discharges to dissolved oxygen concentrations in Black Rock Canal?

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in Black Rock Canal? How will SOD and the resulting DO in Black Rock Canal change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in Black Rock Canal?

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2. DESCRIPTION OF WATER QUALITY MODELS

Four water quality models will be developed to meet the objectives and answer the questions outlined in section 1.2 of this work plan. Each of the models is described below. The relative locations and spatial extents of the models are depicted on Figure 1.

2.1 BUFFALO RIVER MODEL

The existing Buffalo River model developed at the University at Buffalo by Drs. Atkinson and DePinto (now with LimnoTech) will be modified to meet the objectives identified in section 1.2. A description of the model and information on planned calibration of the modified model are presented below.

2.1.1 Model Description

The existing Buffalo River model was developed to simulate BOD and DO in the lower Buffalo River, where dredging has significantly deepened the river. The model, as it presently exists, does not extend upstream past the confluence of Cazenovia Creek with the Buffalo River. In order to capture all CSOs on the Buffalo River within the model, and to provide the capability to examine water quality impacts from individual CSOs on the Buffalo River, the Buffalo River model will be extended upstream along the Buffalo River and Cazenovia Creek branches to approximately the Buffalo municipal boundary (see Figure 2).

The existing Buffalo River model is a two-dimensional, laterally averaged model because the lower Buffalo River has been deepened by dredging. It is not expected that the upstream reaches of the model will need to be two-dimensional; therefore some modification to link the upstream one-dimensional reaches to the existing two-dimensional model will be necessary.

In addition to extending the spatial domain of the model, it will be modified to allow estimation of the relative contribution of particulate BOD deposition to long term changes in sediment oxygen demand. The model will be used to simulate bacteria fate and transport, as well as BOD/DO dynamics, therefore additional modification of the model will be conducted to incorporate this function.

2.1.2 Boundary Conditions

As described above, the Buffalo River model will extend from the Buffalo City boundary on the upstream ends of the Buffalo River and Cazenovia Creek, downstream to the inner harbor. The boundary conditions for the model are described below:

- Flows at the upstream boundary will be based on the measured flows at USGS gages on the Buffalo River (USGS gage No. 04214500) and Cazenovia Creek (USGS gage No. 04215500).

- Downstream hydraulic boundary conditions will be specified using data collected at the USGS gage near the river mouth (USGS gage No. 04215900).

- Water quality at the upstream boundary will be specified using existing data from water quality monitoring stations on the Buffalo River (station No. SCD RBWQ 1) and Cazenovia Creek (station No. SCD RBWQ 6). Existing data will be used for model calibration and validation.

- The lower Buffalo River is subject to flow reversal under certain conditions; if necessary, water quality at the downstream boundary will be specified using existing or new data from the water quality monitoring station at the mouth of the Buffalo River (station No. SCD RBWQ 5).

CSO loads to the Buffalo River model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model.

2.1.3 Calibration & Validation

The Buffalo River model has already been calibrated and validated for dissolved oxygen using an extensive data set; however expansion of the model domain will require supplemental validation of model hydraulics. In addition, the model will require calibration and validation for bacteria fate and transport simulation. It is expected that existing data from previous monitoring efforts will be used for this. The data to be used for supplemental calibration and validation of the Buffalo River model is described in Section 3.1.

2.2 SCAJAQUADA CREEK MODEL

A model of Scajaquada Creek will be developed to facilitate understanding of CSO impacts on DO and bacteria conditions in the Creek, as well as to simulate BOD/DO and bacteria loading to Black Rock Canal. Description of the Scajaquada Creek model and its calibration are provided below.

2.2.1 Model Description

The Scajaquada Creek model will be developed as a one-dimensional hydrodynamic and water quality (BOD/DO dynamics and bacteria fate and transport) model to simulate water quality response in the Creek to CSO loading and to compute pollutant loading time series to Black Rock Canal during CSO events. The Scajaquada Creek model will also be designed and applied to estimate the relative contribution of particulate BOD deposition to long term changes in sediment oxygen demand in the Creek.

The U.S. Geological Survey (USGS) Full Equations Model (FEQ) will be used to model hydrodynamics in Scajaquada Creek. The creek geometry data needed to develop this model will be obtained from existing sources such as FEMA Flood Insurance Studies. The hydrodynamic model will include the Grant Street dam and will simulate the backwater effects from Black Rock Canal below the dam. The Scajaquada Creek water quality model will be a time-variable, one-dimensional model, developed using the USEPA-supported Water Quality Analysis Simulation Program (WASP). The model domain will extend from the upstream end of the Scajaquada Drain tunnel, down to the confluence with Black Rock Canal (see Figure 3). The Scajaquada Creek model will be capable of computing pollutant loading time series to Black Rock Canal during overflow events and it will have the ability to evaluate water quality response to varying CSO and upstream pollutant loads. The model will take into account the dynamic nature of Scajaquada Creek and Drain.

2.2.2 Boundary Conditions

The Scajaquada Creek model will extend from the upstream end of the Scajaquada Drain tunnel to Black Rock Canal on the downstream end. Boundary conditions for the Scajaquada Creek model will be specified as follows:

- Upstream hydraulic boundary conditions will be specified using data collected specifically for this purpose. The data collection required for this is described in Section 3.2. Downstream hydraulic boundary conditions will be determined by the calibrated Niagara River model, which will include Black Rock Canal, into which Scajaquada Creek flows.

- Water quality at the upstream boundary will be specified using new data collected for this project. Water quality data collected at the downstream model boundary will be used as a boundary condition during periods of flow reversal. These data will include BOD/DO and bacteria measurements for both dry weather and wet weather conditions.

CSO loads to the Scajaquada Creek model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model.

2.2.3 Calibration & Validation

The hydrodynamic model will require calibration and the data to be used for calibration and validation of the Scajaquada Creek model is described in Section 3.2.

The Scajaquada Creek water quality model will be calibrated and validated for BOD, dissolved oxygen, and bacteria, which will require the collection of new data. The

Scajaquada Creek model will be calibrated to one dry-weather event and one wet-weather event. One dry-weather and one wet-weather event will be used for validation. It is assumed that collection of new water quality, hydraulic, and sediment oxygen demand data to support calibration and validation of the Scajaquada Creek model will be coordinated with other data collection activities and is not included in this scope of work.

2.3 NIAGARA RIVER MODEL

The Niagara River Model will be designed to simulate bacteria fate and transport and to provide hydrodynamic simulation output for subsequent use in the Black Rock Canal model, described in section 2.4 of this work plan. Further details are provided below.

2.3.1 Model Description

The Niagara River model, which will include the inner harbor and Black Rock Canal, will be developed using the USEPA Environmental Fluid Dynamics Code (EFDC). The Niagara River model will be time-variable, two-dimensional, and vertically averaged.

The hydrodynamic model domain of the Niagara River model will extend from Lake Erie to Niagara Falls, as shown on Figure 4. The model domain of the Niagara River water quality model will be smaller than the domain of the hydrodynamic model. As shown on Figure 4, the upstream boundary of the water quality model will coincide with the hydrodynamic boundary, but the downstream boundary of the water quality model will only extend to the southern end of Grand Island. It is expected that the water quality model will be calibrated to a transect even with the northern Buffalo municipal boundary, because of uncertainty with respect to loads downstream of that point. Therefore, the model will not include inputs from Tonawanda and Ellicott Creeks.

The model grid will be designed to allow simulation of hydrodynamic circulation in and around the Inner Harbor and Black Rock Canal, to capture gradients in bacteria in the transition of classification zones of the river, and to simulate flow from the mouth of Scajaquada Creek into Black Rock Canal. The model will also be designed with sufficient detail to accurately simulate hydrodynamic conditions in Black Rock Canal, given operation records for the lock during model simulation period.

2.3.2 Boundary Conditions

Boundary conditions for the Niagara River model will be specified as follows:

- Stage and flow at the upstream boundary will be specified using available stage, flow, and/or velocity data from the U.S. Army Corps of Engineers or other agencies.

- Downstream hydraulic boundary conditions will be specified using existing measurements of flow at Niagara Falls.

- Water quality at the upstream boundary of the water quality model will be specified using new data collected for this project. These data will include bacteria measurements for both dry weather and wet weather conditions. Approximate monitoring locations are depicted on Figure 4.

CSO loads to the Niagara River model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model. Tributary flows and pollutant loads from the Buffalo River and Scajaquada Creek will be generated using the Buffalo River and Scajaquada Creek models.

2.3.3 Calibration & Validation

It is expected that the hydrodynamic model of the Niagara River will be calibrated using available stage, flow, or velocity data from the U.S. Army Corps of Engineers or other agencies. Calibration and validation of the Niagara River hydrodynamic model will not rely on dry-weather vs. wet-weather conditions because the size of the river makes it generally unresponsive to short-term weather events.

The bacteria fate and transport component of the Niagara River model will be calibrated to one dry weather event and one wet weather event. One dry-weather and one wet-weather event will be used for validation.

2.4 BLACK ROCK CANAL MODEL

A separate dissolved oxygen model of the Inner Harbor and Black Rock Canal will be developed to run independently of the Niagara River EFDC model, to focus specifically on the regions of interest for dissolved oxygen. This will be computationally more efficient than modeling dissolved oxygen throughout the entire Niagara River. Bacteria fate and transport in the Black Rock Canal will be addressed using the Niagara River EFDC model.

2.4.1 Model Description

Hydrodynamics in the Black Rock Canal will be modeled as part of the Niagara River hydrodynamic EFDC model, discussed in section 2.3. The Black Rock Canal water quality model will be a two-dimensional, laterally-averaged model designed to simulate BOD/DO dynamics in the canal. The spatial domain of the Black Rock

Canal water quality model will extend from the southern end of the Black Rock Canal breakwater to a point near the northern end of Squaw Island as shown on Figure 5.

2.4.2 Boundary Conditions

Boundary conditions for the Black Rock Canal model will be specified as follows:

- Water quality at the upstream model boundary will be specified using new data collected for this project. These data will include DO and BOD data collected during both dry-weather and wet-weather conditions.
- Water quality at the downstream boundary will be specified using water quality data collected at the lock near the northern end of Squaw Island. These downstream data will include event-based BOD/DO measurements.

CSO loads to the Black Rock Canal model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model. Tributary flows and pollutant loads from Scajaquada Creek will be generated using the Scajaquada Creek model.

2.4.3 Calibration & Validation

Hydrodynamic calibration and validation of the Niagara River model will be relied upon for simulation of hydrodynamic conditions in Black Rock Canal. The Black Rock Canal dissolved oxygen model will be calibrated using BOD/DO data collected during the same data collection events as Scajaquada Creek. Potential data collection locations are depicted in Figure 5. Sediment oxygen demand data will be collected during dry weather conditions.

3. DATA NEEDS

Existing data will be used, to the extent practicable, in developing the models described in this work plan. However, review of the available data indicates that existing data alone will not be sufficient for calibration and validation of all the models. The expected data needs for model development are summarized below.

3.1 BUFFALO RIVER MODEL

It is expected that very little new data will be required to support the Buffalo River model, for several reasons. First, the existing model has been thoroughly calibrated for BOD/DO dynamics, so only validation in the upstream reaches of the model will be required for BOD/DO. Second, the dry-weather and wet-weather bacteria data collected during past planning efforts appear to be sufficient for calibration and validation of the bacteria fate and transport model. The data collected from the 2000 water quality monitoring program will be used for this purpose. It is expected that the May 4, 2000 dry weather event and the June 9-11, 2000 wet weather event will be used for calibration, and the September 7, 2000 dry weather event and the August 23-25, 2000 wet weather event will be used for validation.

Collection of new sediment oxygen demand (SOD) data is not planned for the Buffalo River. SOD data have been collected from the lower Buffalo River in the past by the New York Department of Environmental Conservation (NYDEC) and have been used in previous modeling efforts by the University of Buffalo. In the model reaches upstream of the Cazenovia Creek confluence, Cazenovia Creek and the Buffalo River are relatively shallow and DO conditions are likely dominated by reaeration and temperature, so SOD data will not be collected there.

Existing data will, however, be supplemented in the Buffalo River as follows:

- Bacteria data will be collected near the mouth of the Buffalo River, where it interfaces with the Niagara, in order to validate the Buffalo River model's predicted loads during Niagara River calibration events. For this purpose, bacteria data will be collected from the mouth of the Buffalo River, roughly collocated at the water quality monitoring location used in past monitoring activities by BSA (SCD RBWQ 5). Bacteria data will be collected at this location during each dry-weather and wet-weather event.

- Validation and, if necessary, calibration, of model hydraulics in the upper reaches of the Buffalo River and Cazenovia Creek will require collection of new flow, stage, and/or velocity data in these reaches. This will involve short-term (one month minimum) deployment of continuous reading equipment such as side-looking acoustic Doppler current profiler (ADCP) or acoustic Doppler velocimeter for velocity measurement and down-looking radar for stage measurement. It is expected that upstream boundary flows will be specified using existing USGS gages on these systems, so the focus of hydraulic data collection will be on intermediate locations in the system to serve as calibration points. The specific equipment to be deployed and locations of deployment will depend on field conditions in the Buffalo River and Cazenovia Creek systems and will be determined after an initial reconnaissance inspection of the system. Data from these continuous reading instruments will be supplemented and/or verified as necessary using manual stage/discharge measurements.

At this time, no other new data are required from the Buffalo River.

3.2 SCAJAQUADA CREEK MODEL

Development of the Scajaquada Creek model will require collection of the following new data:

- Hydrodynamic calibration of the Scajaquada Creek model will require collection of flow, stage, and/or velocity data at various locations in the Scajaquada Creek system. This will involve short-term (one month minimum) deployment of continuous reading equipment such as side-looking acoustic Doppler current profiler (ADCP) or acoustic Doppler velocimeter for velocity measurement and down-looking radar for stage measurement. It is expected that data will be collected at the upstream end of the Scajaquada Creek tunnel to characterize upstream boundary flows, as well as at intermediate locations in the system to serve as calibration points. The specific equipment to be deployed and locations of deployment will depend on field conditions in the Scajaquada Creek system and will be determined after an initial reconnaissance inspection of the system. Data from these continuous reading instruments will be supplemented and/or verified as necessary using manual stage/discharge measurements.

- Water quality data will be required for model calibration and validation from four locations in Scajaquada Creek: upstream of the upstream end of the Scajaquada Drain tunnel; downstream of the downstream end of the Scajaquada Drain tunnel; downstream of the lake at Forest Lawn Cemetery; and upstream of the Grant Street dam (near previous data location SJD RBWQ 2). The approximate locations of these stations are shown on Figure 2. Data collected at these stations should include BOD/DO and bacteria data, collected during two dry-weather and two wet-weather events.

- The Scajaquada Creek model will also require collection of sediment oxygen demand data from two locations. The SOD monitoring locations will be determined after initial field inspection.

Channel bathymetry data will be required to accurately model hydraulics in Scajaquada Creek. Through inquiry with the U.S. Army Corps of Engineers' Buffalo District and the New York Department of Environmental Conservation (NYDEC), it is understood that hydraulic modeling of Scajaquada Creek was previously conducted for the Federal Emergency Management Agency (FEMA) flood mapping program and that a new flood study is underway. These flood mapping studies require channel cross-section surveys which will be used for the Scajaquada Creek model in this project.

3.3 NIAGARA RIVER MODEL

Development of the Niagara River model will require collection of new data as described below:

- Calibration and validation of the Niagara River water quality model will require collection of bacteria data from several transects. These transects consist of three stations aligned across the river channel as shown on Figure 4. In some cases, an additional easternmost station will be aligned with the Niagara River transects, but will actually fall within the Black Rock Canal. Data collected at these transects should include bacteria (fecal coliform) data collected during two dry-weather and two wet-weather events.

It is likely that early monitoring will indicate that CSO impacts and Buffalo River flows do not extend across the entire Niagara River channel. If this is the case, it will be possible to reduce the number of stations at each transect to focus on water quality conditions nearest the east bank.

3.4 BLACK ROCK CANAL MODEL

The Black Rock Canal model will require the data collection described below:

- Event-based sampling of BOD/DO data will be required for calibration and validation of the Black Rock Canal model. These data will be collected at four locations within the canal: near the upstream end of the breakwater; near the downstream end of Squaw Island; at the confluence of Scajaquada Creek; and between the International Bridge and the canal locks. Data should be collected at these stations during two dry-weather and two wet-weather events. It should be noted that bacteria will also be sampled in the Black Rock Canal but will be used with the Niagara River EFDC model.

- Continuous dissolved oxygen data should be collected using hydrolabs at two locations in Black Rock Canal: one hydrolab will be deployed at or near the southern end of the Black Rock Canal breakwater (for specification of the upstream boundary condition) and the other will be deployed at an intermediate location in Black Rock Canal to be determined after field inspection (to support model calibration).

- The Black Rock Canal model will also require collection of sediment oxygen demand (SOD) data from two locations. The SOD monitoring locations will be determined after initial field inspection.

At this time, it does not appear necessary to collect any new bathymetric or hydrodynamic data to support development of the Black Rock Canal model.

4. DELIVERABLES

As part of the model development process, the following deliverables will be produced and submitted:

- **Model Calibration Technical Memo:** For each of the water quality models described in this plan, calibration will be conducted using data from one dry weather and one wet weather event. Upon completion of model calibration, a technical memorandum will be prepared to describe the methods and outcome of the calibration and to identify any issues or concerns that may require modification of future data collection activities for model validation. This technical memorandum will include:
    - Tabular summaries of pre- and post-calibration hydrologic and hydraulic inputs.
    - Plots of model output versus field data for each calibration and validation event.
    - Tabular and narrative summaries of degree of calibration achieved.
- **Final Modeling Report:** Upon completion of the water quality modeling activities described in this work plan, a written report will be prepared to document the model development process and outcome. At a minimum, the Final Modeling Report will include document the following aspects of model development for each of the models:
    - Model code/software used
    - Model inputs
    - Boundary conditions
    - Model calibration
    - Model validation

These deliverables will be provided in both hard copy and electronic formats to facilitate distribution and review.

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5. SCHEDULE

Based on the data needs for the modeling effort and the expected schedule for collection of those data, an overall model development schedule of 18 months is expected, in keeping with previous discussions with BSA and regulatory agencies. It is expected that model development will begin after approval of this work plan, on or about June 1. Given this start date, delivery of the final modeling report would be targeted for not later than November 30, 2009.

Model development activities can proceed in parallel with data collection activities, but completion of all model calibration and validation tasks will depend on the timing of wet weather events and therefore cannot be predicted with accuracy.

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FIGURES

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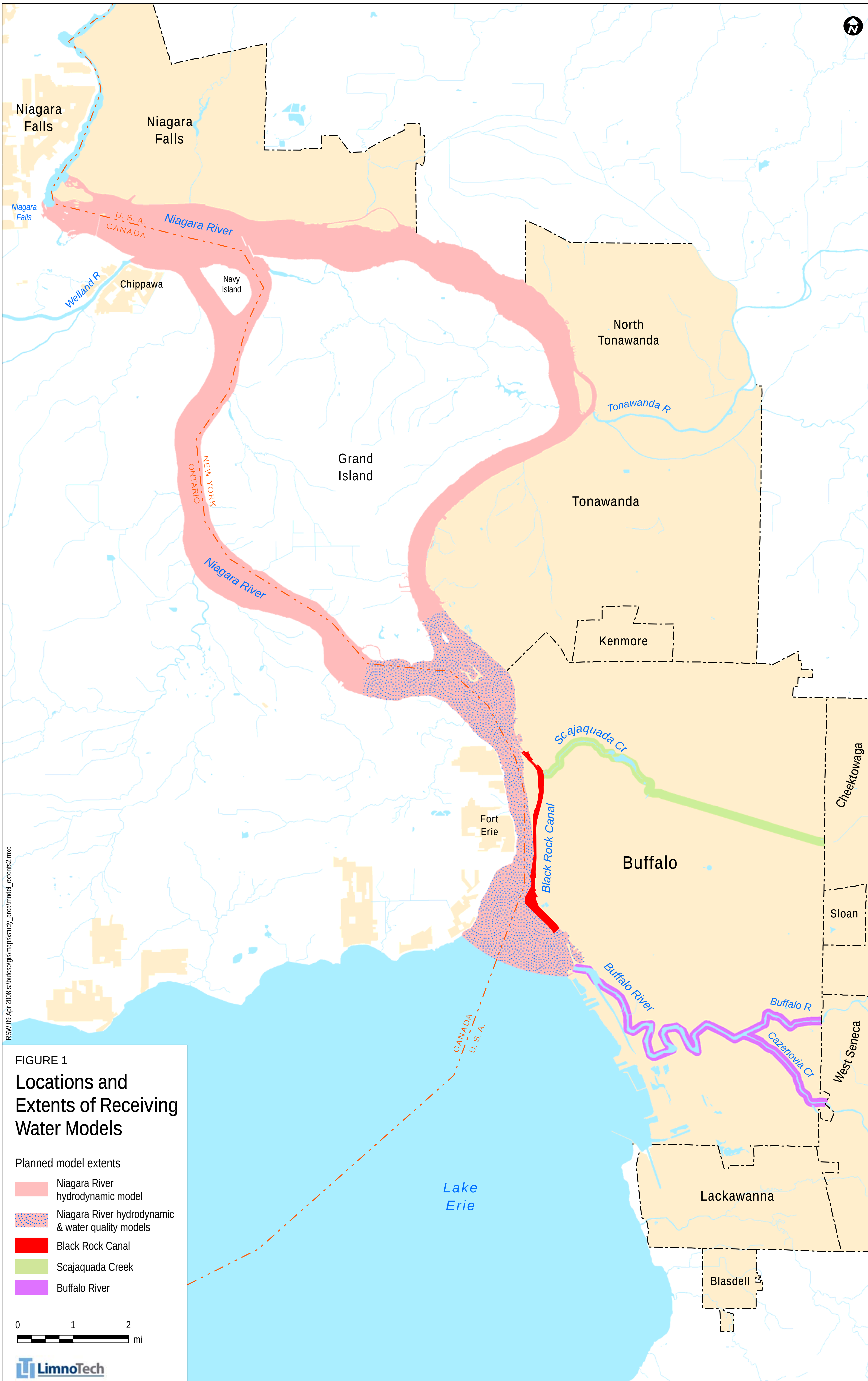

FIGURE 1
Locations and Extents of Receiving Water Models

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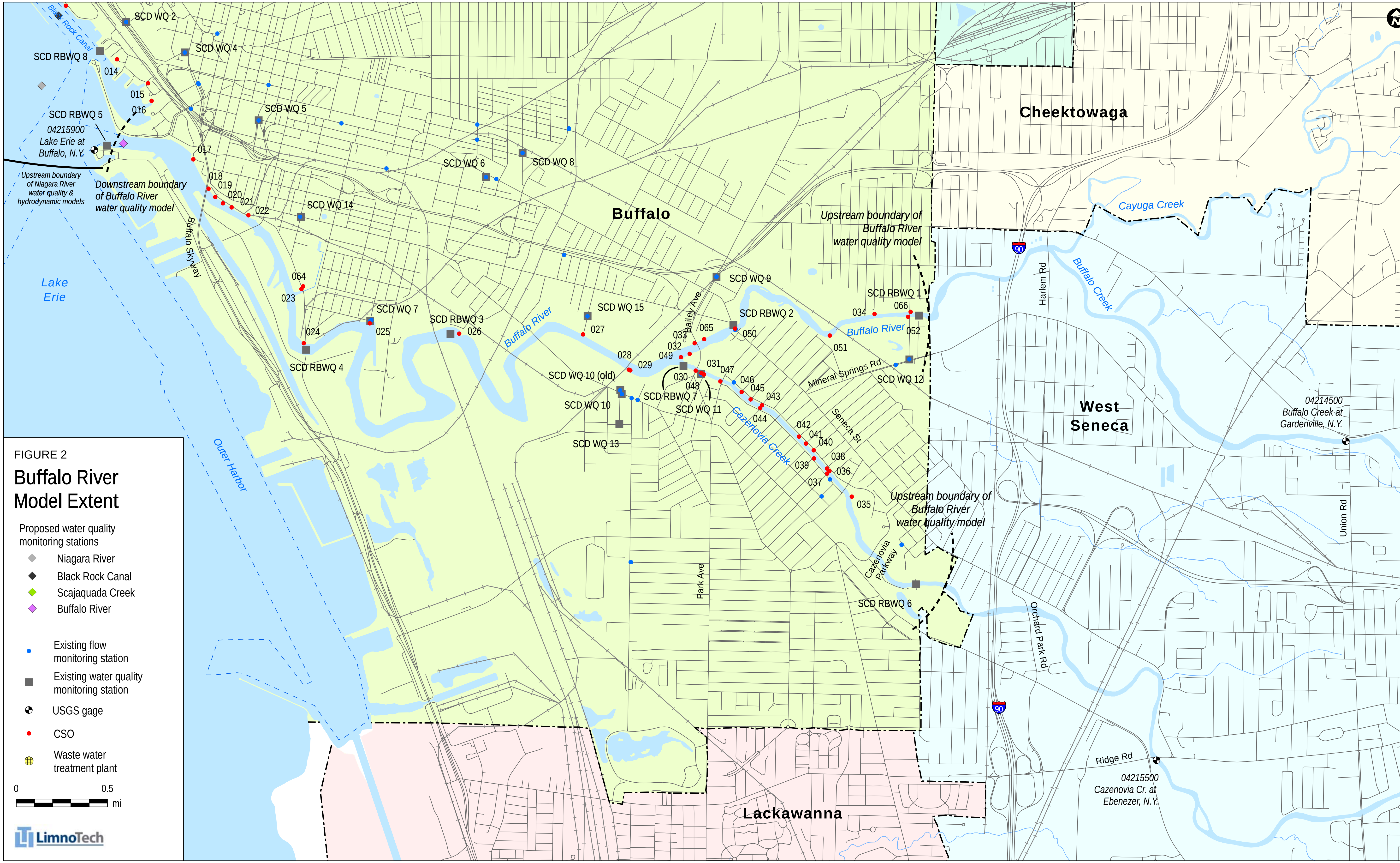

FIGURE 2
Buffalo River Model Extent

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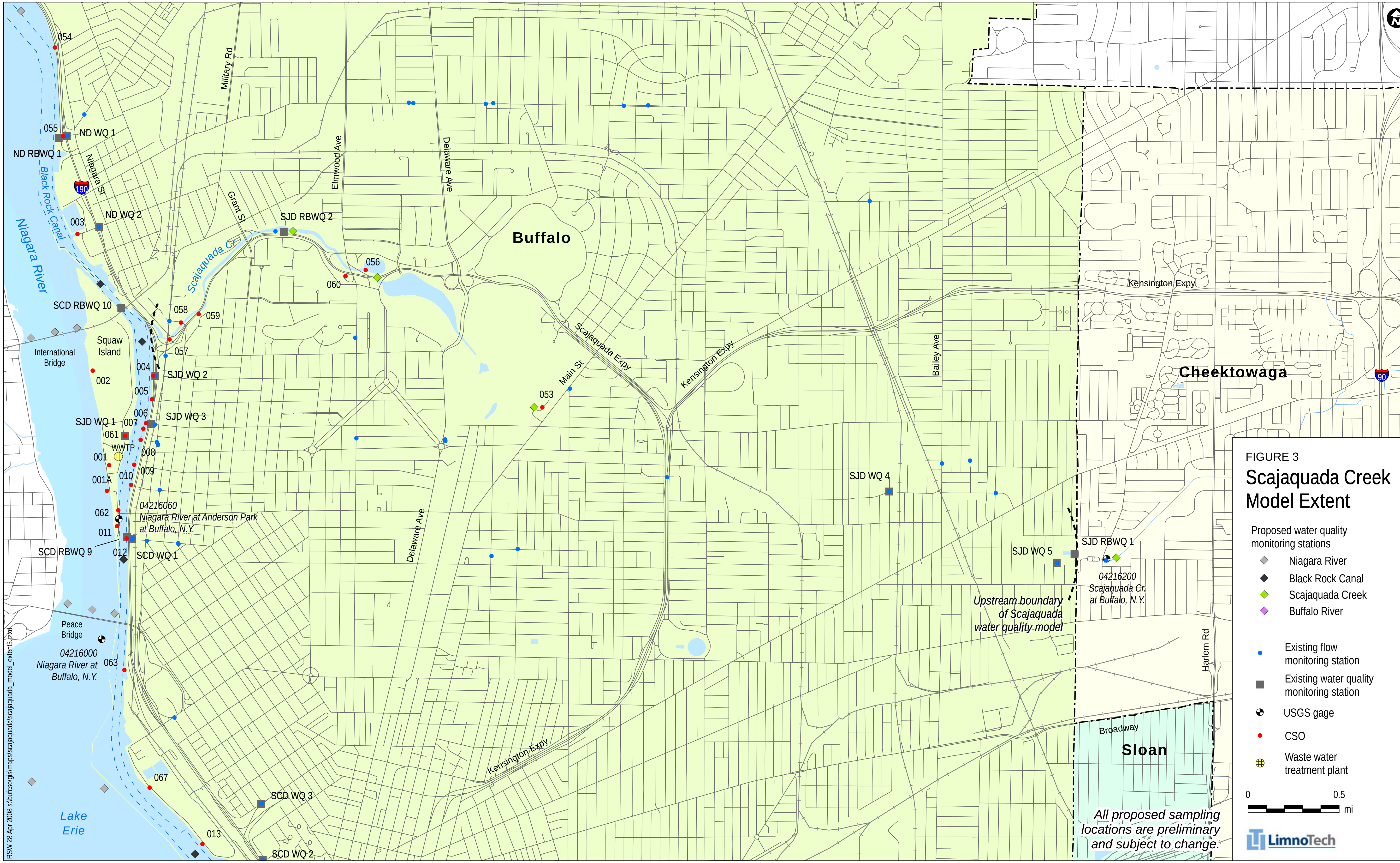

FIGURE 3
Scajaquada Creek Model Extent

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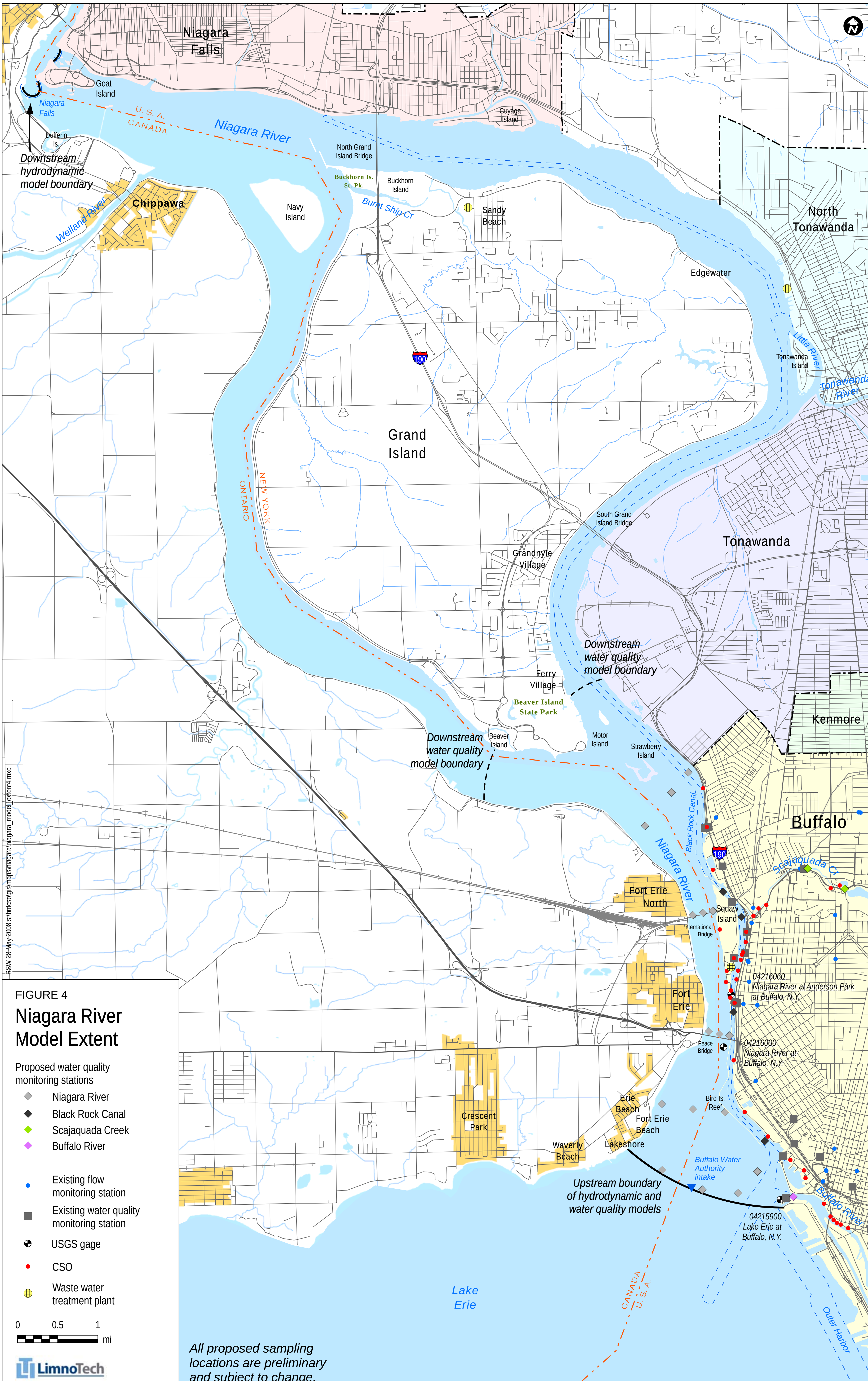

FIGURE 4
Niagara River Model Extent

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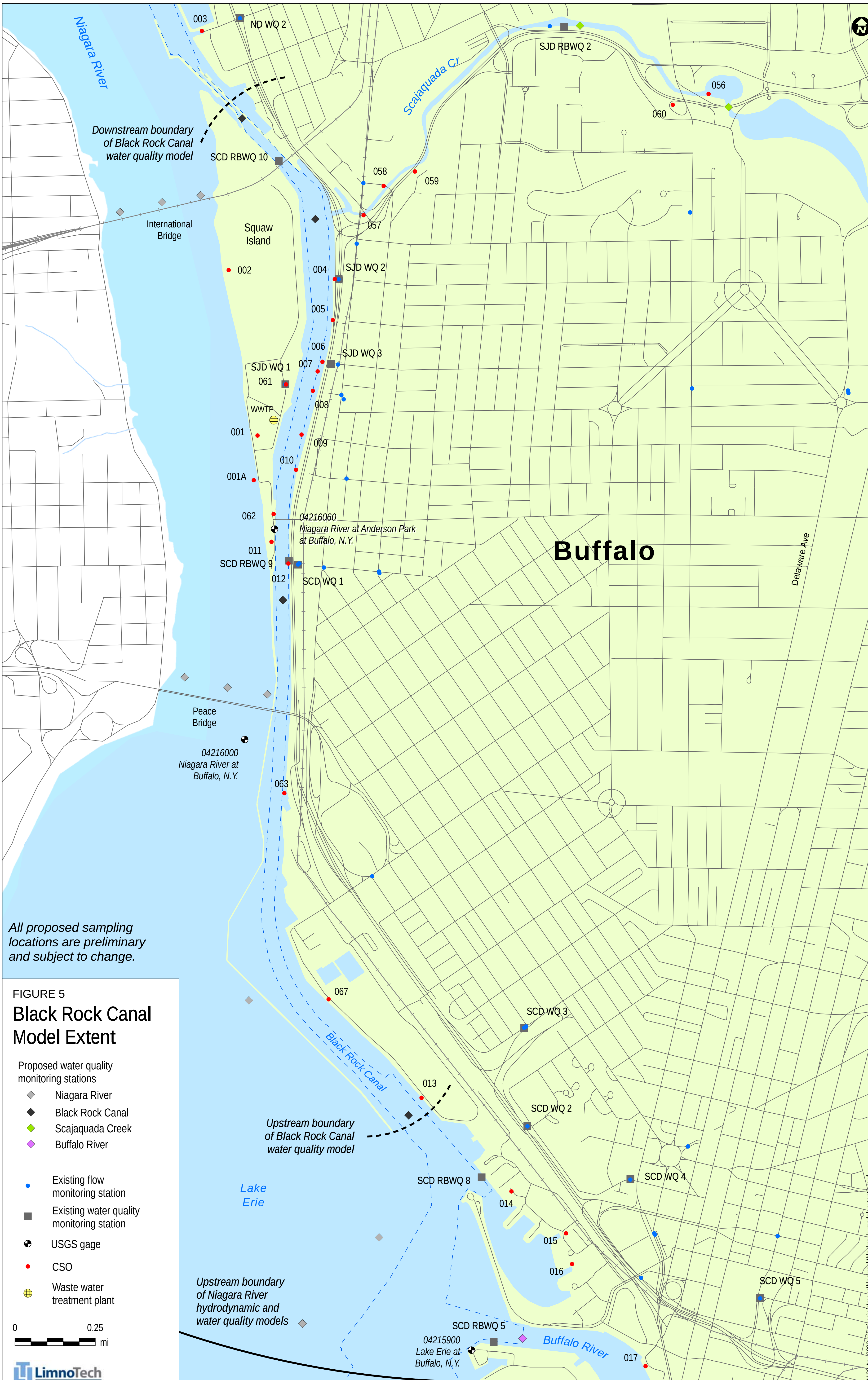

FIGURE 5
Black Rock Canal Model Extent

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Appendix 4-6: Water Quality Model Development and Calibration Report for Buffalo River, Scajaquada Creek, Niagara River, and Black Rock Canal

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Water Quality Model Development and Calibration Report For Buffalo River, Scajaquada Creek, Niagara River, and Black Rock Canal

Prepared On Behalf Of
The Buffalo Sewer Authority

November 23, 2010

LimnoTech
Water | Environment | Scientists | Engineers

Ann Arbor, Michigan
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APPENDICES

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1. INTRODUCTION

This report describes development of water quality models of the Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek, to address recent comments from the New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA) on the *System-Wide Long Term Control Plan for CSO Abatement* prepared by Malcolm Pirnie, Inc., on behalf of the Buffalo Sewer Authority (Malcolm Pirnie, 2004a, b). LimnoTech prepared this report on behalf of the Buffalo Sewer Authority (BSA), under subcontract to Malcolm Pirnie.

1.1 BACKGROUND

The government agencies involved in reviewing the Long Term Control Plan (LTCP) have suggested the need for the Buffalo Sewer Authority (BSA) to conduct receiving water quality modeling of waterways potentially affected by combined sewer overflows (CSOs). Specifically, modeling of the Niagara River, the Buffalo River, and Scajaquada Creek was requested in a letter to BSA (Palumbo, 2007) to evaluate specific concerns regarding bacteria, biochemical oxygen demand (BOD), and effects on dissolved oxygen (DO) in these waterways. Subsequent discussions with government agencies have identified concerns regarding dissolved oxygen impacts in Black Rock Canal. BSA, in conjunction with the University at Buffalo, conducted previous water quality modeling to evaluate dissolved oxygen conditions in the Buffalo River but did not model other receiving waters in the system. Water quality sampling of other receiving waters and CSO discharges was conducted under the previous LTCP effort. The modeling work described in this report builds upon previous work and involved development of new receiving water models to enhance BSA's understanding of the impacts of CSOs on these receiving waters. These models will be used in the future to evaluate the extent to which the existing BSA and CSO discharges impact the receiving waters and the benefits of proposed CSO control projects. See Figure 1-1 on the following page for the locations of BSA's CSO and storm water discharges.

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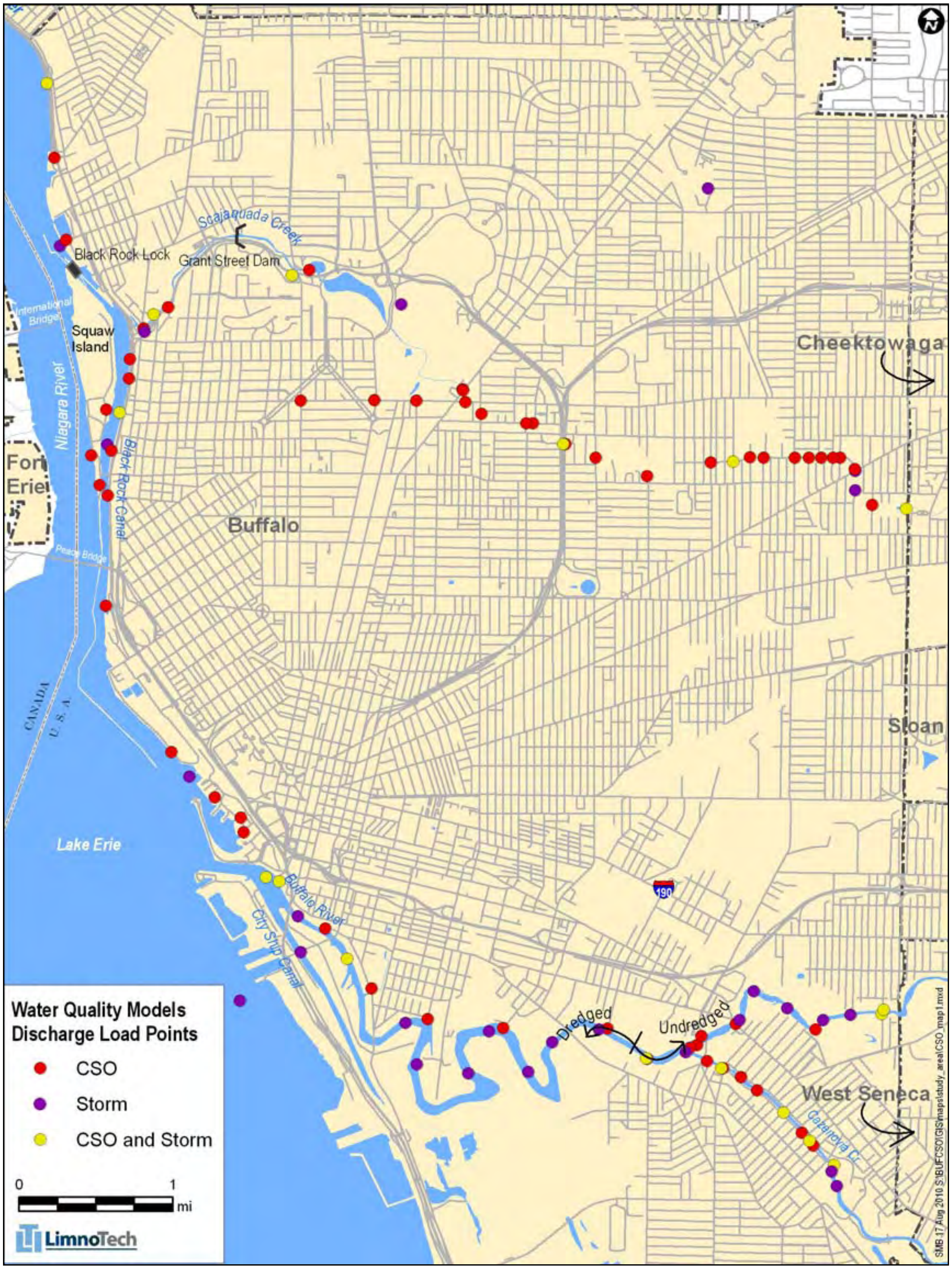

Figure 1-1: BSA's CSO and Storm Discharge Locations

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1.2 OBJECTIVES

The overarching objectives for development of receiving water quality models for the Buffalo waterways were to improve the understanding of the impacts of CSOs on receiving water quality and to support decision-making regarding CSO control alternatives. Discussions with the NYSDEC and USEPA defined a set of questions to be answered by the receiving water quality models described in this report, including the following:

- What is the relative contribution of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters during and following a CSO event relative to other watershed sources, such as direct runoff, other tributary sources, and sources in the watershed above the city?

- What are the effects of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters in the hypothetical absence of other contributions or potential reductions of other contributions?

- What effect will considered CSO control projects have on receiving water quality, relative to current conditions?

The water quality models described in this report will allow evaluation of the impacts of BSA's CSOs on water quality in the absence of other sources and under varying upstream loads and other sources. The models will allow evaluation of attainment of existing water quality standards, where appropriate. The focus of the work described in this report is the development and calibration of the models. Application of the tools to answer the questions stated above will be completed as a future effort concurrent with the CSO control alternative evaluations.

1.3 OVERVIEW OF WATER QUALITY MODELS

Four receiving water quality models were developed to meet the objectives and answer the questions outlined in Section 1.2. The models use CSO loading data generated from BSA's collection system model, as well as other input datasets. Each of the receiving water quality models is described below. The relative locations and spatial extents of the models are depicted on Figure 1-1. A more detailed description of each water body in the system is provided in Appendix B.

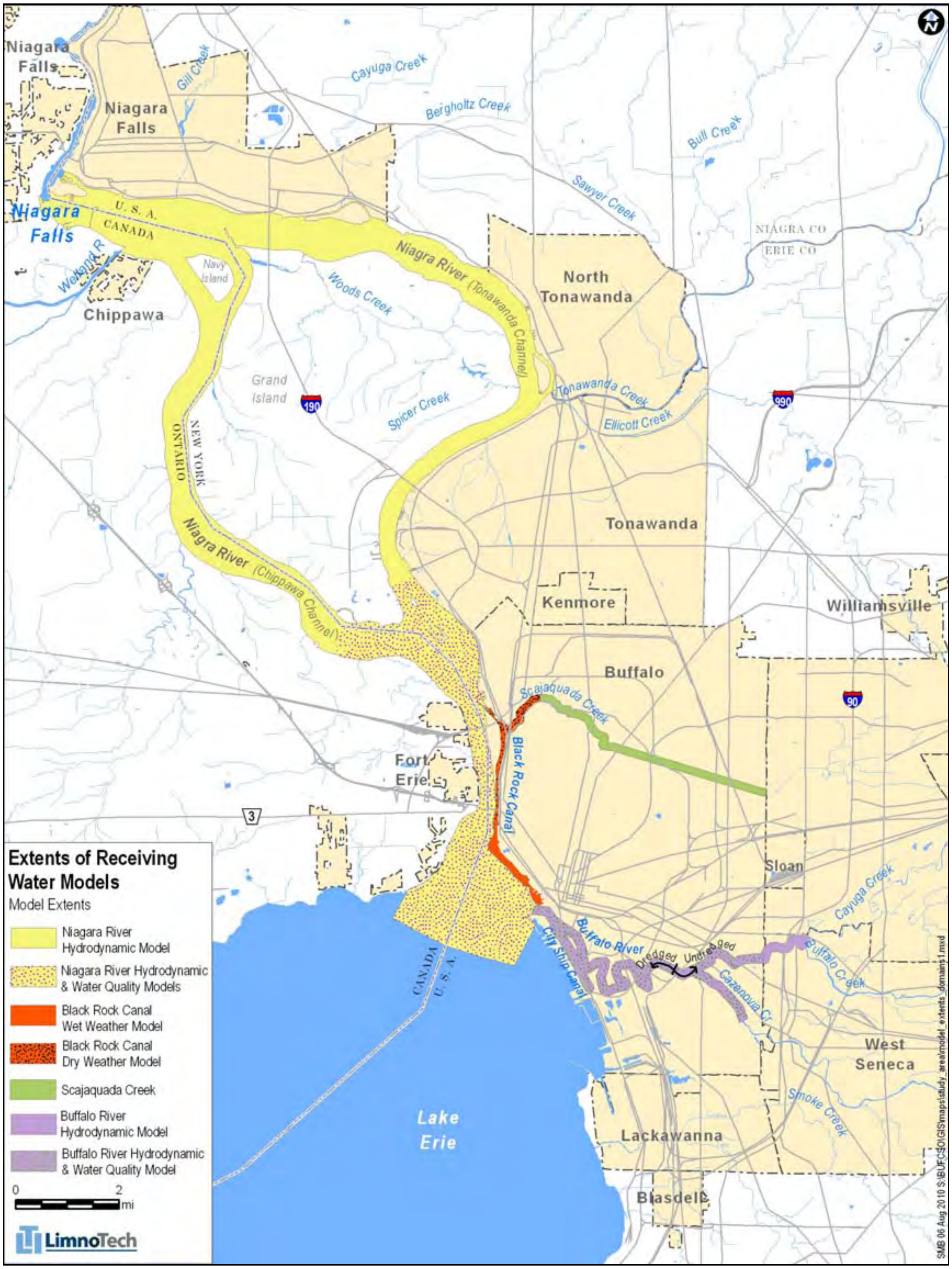

Figure 1-2: Model Locations and Extents

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1.3.1 Buffalo River Model

A model of the Buffalo River was developed to facilitate understanding of CSO impacts on the river. The Buffalo River model is characterized as follows:

- The Buffalo River model was developed using the USEPA-supported Environmental Fluid Dynamics Code (EFDC).

- It is a time-variable and two-dimensional, laterally averaged, model.

- The water quality constituents of concern are DO and bacteria.

- The Buffalo River model domain extends upstream along the Buffalo River and Cazenovia Creek branches to approximately the Buffalo municipal boundary. The model also includes the City Ship Channel, which is a branch of the river that extends in a southeast direction from the mouth of the river.

The Buffalo River model was calibrated to wet weather water quality data collected in 2000 and 1994, as well as hydrodynamic data collected in 2008. It is discussed in detail in Section 3 of this report.

1.3.2 Scajaquada Creek Model

A model of Scajaquada Creek was developed to simulate water quality and loading to Black Rock Canal. A description of the Scajaquada Creek model and its calibration is provided below.

- The Scajaquada Creek model is a one-dimensional hydrodynamic and water quality model.

- Hydrodynamics of the creek are simulated using the U.S. Geological Survey (USGS) Full Equations Model (FEQ).

- Water quality in Scajaquada Creek is simulated using the USEPA-supported Water Quality Analysis Simulation Program (WASP). Bacteria and DO are modeled.

- The model domain extends from the upstream end of the Scajaquada Drain tunnel, down to the Grant Street dam.

The Scajaquada Creek model was calibrated to data collected in 2009, with 2008 data used for validation, and is described in detail in Section 4 of this report.

1.3.3 Niagara River Model

A hydrodynamic and water quality model of the Niagara River was developed to simulate bacteria fate and transport and to provide hydrodynamic simulation output for subsequent use in the Black Rock Canal DO/BOD model, described in Section 1.3.4. Further details are provided below:

- The Niagara River bacteria model was developed using EFDC.
- The model is time-variable, two-dimensional, and vertically averaged.
- The domain of the hydrodynamic model extends from Lake Erie to Niagara Falls. The model domain of the water quality model extends from Lake Erie downstream to the southern end of Grand Island. The model does not include inputs from Tonawanda and Ellicott Creeks.
- The Niagara River model includes the Black Rock Canal to simulate bacteria only.

The Niagara River model was calibrated to 2009, with 2008 data used for validation, data and is described in detail in Section 5 of this report.

1.3.4 Black Rock Canal Model

A separate model of the Black Rock Canal was developed to run independently of the Niagara River EFDC model, to focus specifically on the regions of interest for dissolved oxygen. Bacteria fate and transport in the Black Rock Canal is addressed using the Niagara River EFDC model. The Black Rock Canal model has the following characteristics:

- The Black Rock Canal water quality model is a two-dimensional, laterally averaged, EFDC model designed to simulate BOD/DO dynamics in the canal.
- The spatial domain of the Black Rock Canal water quality model extends from the southern end of the Black Rock Canal breakwater to the Black Rock Lock, near the northern end of Squaw Island. It also includes the lower portion of Scajaquada Creek, below the Grant Street Dam.
- Due to the lock at the northern end of the canal, flow in the canal generally runs in a north to south direction (opposite of the Niagara River) during wet weather events.

The Black Rock Canal model was calibrated to 2009 data, with 2008 data used for validation, and is described in detail in Section 6 of this report.

1.4 WATER QUALITY MODELING WORK PLAN

Each of the water quality models discussed above was developed according to the Water Quality Modeling Work Plan For Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek (LimnoTech, 2008, Updated 2010). For reference, this work plan is included as Appendix A.

2. BUFFALO RIVER MODEL

The Buffalo River model includes a hydrodynamic and water quality model of the river from its origin (confluence of Buffalo and Cayuga Creeks), through the City of Buffalo and down to Lake Erie. Portions of Cazenovia Creek and the City Ship Canal are also included in the model. The primary use of the model is to simulate the impact of combined sewer overflows on the receiving waters. The parameters of concern include fecal coliform bacteria and biochemical oxygen demand (BOD), along with the short and long term impacts of BOD on dissolved oxygen levels in the dredged portions of the Buffalo River. Figure 2-1 depicts the domain of the Buffalo River model.

Figure 2-1: Buffalo River Model Domain

2.1 MODEL DEVELOPMENT

The specific objectives for the Buffalo River model are to allow the following uses (LimnoTech, 2008):

- Assess the relative contribution of BSA CSO discharges to the bacteria and DO in receiving waters during and following a CSO event relative to other watershed sources.

- Assess the effects of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters in the hypothetical absence of other contributions or potential reductions of other contributions.

- Determine the effect considered CSO control projects will have on receiving water quality, relative to current conditions.

- Evaluate the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in the Buffalo River.

- Determine the controls necessary for the Buffalo River CSO discharges in order to meet standards in that part of the system designated as Class B with regard to designated uses.

- Calculate the bacteria loads to the Black Rock Canal and Niagara River from the Buffalo River during various storm events with and without CSO controls.

The model developed and calibrated under this project can be used to meet these objectives. The following sections describe the development and calibration of the model.

2.1.1 Model Selection and Background

The Buffalo River model was developed using a state-of-the-art modeling framework package, the Environmental Fluid Dynamics Code, which includes subroutines for hydrodynamics and water quality. As discussed in Appendix B, previous models of the Buffalo River have been developed; however, these tools were developed using custom computer programs for specific research projects. As described in the modeling work plan (Appendix A), review of the existing Buffalo River models revealed significant limitations in applying the models for this project. Therefore, a new Buffalo River model, using the USEPA-supported Environmental Fluid Dynamics Code (EFDC) was developed. EFDC is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions. It has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic models in the world (USEPA, 2007).

EFDC was selected for the Buffalo River for the following reasons:

- EFDC can readily link a downstream two-dimensional section with upstream one-dimensional reaches;

- EFDC can readily be used to simulate dissolved oxygen and bacteria fate and transport;

- EFDC was also chosen for the Niagara River and Black Rock Canal models, therefore facilitating system-wide simulations and linkages;

- The Matlab application SeaGrid and accompanying GIS processing tools developed by LimnoTech provide for simplified model grid construction and refinement compatible with EFDC; and

- LimnoTech has already developed a model processing and visualization utility for EFDC that will facilitate presentation and evaluation of model results.

In order to provide flexibility and efficiency when simulating the impact of CBOD and fecal coliform loading from a variety of sources, the EFDC water quality sub-model was enhanced by LimnoTech to incorporate two additional state variables for CBOD and fecal coliform, including a unique set of input coefficients for these variables. For the Buffalo River model simulations, the three state variables were used to represent upstream (i.e., above city boundaries), combined sewer overflow (CSO), and separate stormwater sources to the model domain. The EFDC model reports predicted concentrations for each individual state variable, as well as the total constituent concentration. The multi-variable approach effectively provides a “built-in” component analysis for all model cells which will be useful during the model application phase.

The primary objectives of the Buffalo River DO model are to simulate the short and long term impacts of CSOs on dissolved oxygen concentrations. The short term impacts will be assessed directly through model simulations. Longer term impacts will be addressed in subsequent phases of this project by first establishing a relationship between settled organic matter (particulate CBOD) and sediment oxygen demand (SOD) similar to the methods employed by Chapra (1997), DiToro (2001), and others. A decrease in the particulate CBOD load will lead to a reduction in CBOD deposition to the sediments, which will in turn lead to a reduction in the sediment oxygen demand and vice versa. The model will be used to predict the reduction in CBOD deposition under CSO controls, relative to baseline conditions. Then, a combination of site-specific data and/or literature data will be used to define the corresponding reduction in SOD. Finally, the model will be run under the revised SOD condition and impacts on dissolved oxygen levels in the river will be predicted.

2.1.2 Domain and Segmentation

The area of interest for this model is the Buffalo River and Cazenovia Creek within the city limits of Buffalo. The model grids for both the hydrodynamic and water quality portions of the Buffalo River model are shown in Figures 2-2 and 2-3, respectively. Enlarged versions of these maps are provided in Appendix E. The upper and lower boundaries of the Buffalo River model domain were chosen based on available data sets and system features. For both hydrodynamic and water quality simulations, the model’s upstream boundary was set sufficiently upstream of the City of Buffalo’s CSO sources. The upstream boundary for the Cazenovia Creek model branch is located at the water falls in Cazenovia Park. The water fall hydraulically separates all CSO impacted waters in the downstream reach from upstream waters.

The upstream limit of the Buffalo River model branch is positioned at the confluence of Buffalo and Cazenovia Creeks. Hydrodynamic boundary conditions/forcings are applied at this location to allow seiche impacts from Lake Erie to move freely past the city limits without hitting an artificial barrier (e.g., the model domain). This also allows the hydrodynamic boundary conditions to be applied closer to the locations where USGS gages are located on each tributary (Buffalo and Cayuga Creeks). Upstream water quality boundary conditions/forcings for the Buffalo River model branch are applied at the Buffalo city limits to be consistent with water quality sampling station locations.

The downstream model boundary location was set to be consistent for both hydrodynamic and water quality simulations. This location corresponds with the outlet of the Buffalo River to Lake Erie and corresponds with the location of a NOAA operated water level gage.

The model segmentation was chosen to be similar to historical models of the river system. All model segments were of similar length and only included one or two CSO inputs. For most of the model domain each branch is only one cell wide; however, near the mouth of the Buffalo River the model grid widens to three cells wide to accommodate the significant change in the river width in this reach. Each model segment is approximately 500 ft long and there are 133 model segments in the model domain.

The vertical segmentation of the model was set up using the Generalized Vertical Coordinate (GVC) system in EFDC. This coordinate system maintains a fixed number of vertical cells in each segment throughout the simulation period with deeper river sections represented with more vertical layers and shallower reaches with fewer vertical layers. For this study, the maximum number of vertical layers is 10 and the minimum is 3. The thickness of each layer is typically one meter or less. As the water surface changes the layer thickness increases or decreases to maintain the same number of vertical layers within that segment.

Figure 2-2: Buffalo River Hydrodynamic Model Grid

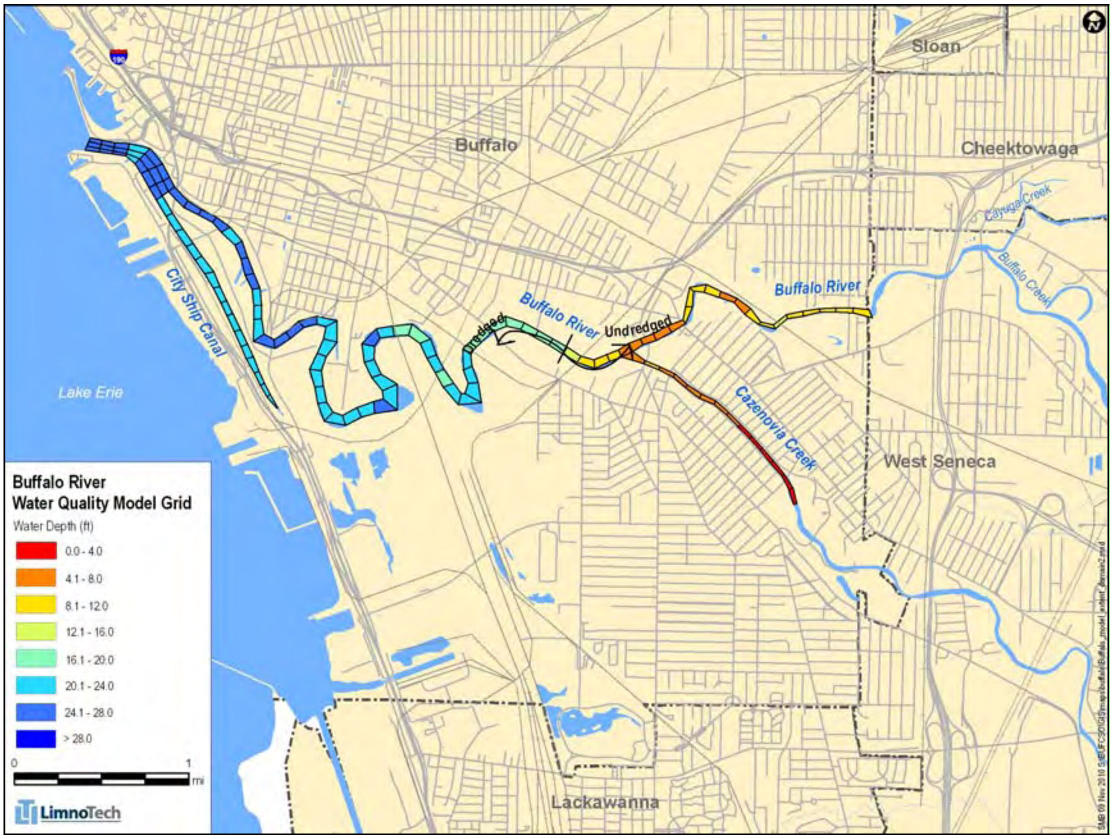

Figure 2-3: Buffalo River Water Quality Model Grid

2.1.3 Model Input Development

This section summarizes the development of model inputs that are required for each model simulation.

2.1.3.a System Data

Bathymetric data for the Buffalo River and Cazenovia Creek were obtained from several sources. The U.S. Army Corps of Engineers (USACE) collected multi-beam sonar data in 2008 that covers the dredged portion of the Buffalo River from the mouth moving upstream to river mile 5.25. From river mile 5.25 through river mile 6.25, single beam sonar bathymetric data collected in 2008 was obtained from MACTEC Engineering. Bathymetry data for the remaining portions of the Buffalo River (river mile 6.25 through 8.50) and Cazenovia Creek were obtained from Flood Insurance Studies (FIS) conducted for the City of Buffalo under the direction of the Federal Emergency Management Agency (FEMA) (NYDEC, 2008). The FIS studies were conducted for the Buffalo River in 1999 and Cazenovia Creek in 2007.

All bathymetric data were converted to a common vertical datum of IGLD85. In areas with a high density of bathymetric data on the lower Buffalo River all data points were averaged within each model segment to calculate an average bottom elevation.

In areas with sparse bathymetric data, the bottom elevation was estimated using available data and adjusted to be consistent with upstream and downstream segments.

Meteorological data obtained from three separate sources were used to define climate boundary conditions for the Buffalo River model. Hourly surface data including rainfall and relative humidity were obtained from the National Climatic Data Center (NCDC) for the Buffalo Niagara International Airport (COOP ID 725280). Air temperature, cloud cover, and barometric pressure data were obtained from the Great Lakes Environmental Research Laboratory (GLERL). Typical year solar radiation data obtained from Capella Energy (Capella Energy, 2010) were applied for the 2008 and 2009. Solar radiation time series for the period of interest were not available at surrounding climate stations and therefore limited the extent of temperature calibration.

2.1.3.b Boundary Conditions

The hydrodynamic model is bounded on the upstream side by flow from Cayuga, Buffalo, and Cazenovia Creeks and on the downstream side by the water surface elevation of Lake Erie at the mouth of the Buffalo River. This section describes the development of the forcing functions for the hydrodynamic and water quality models and each boundary location.

The upstream boundaries of the model domain include the upper Buffalo River at the confluence of Buffalo and Cayuga Creeks and Cazenovia Creek at the water fall in Cazenovia Park (near Cazenovia St.). The flow boundary conditions were based on best available USGS flow data from nearby gages upstream of the point of interest. For the Buffalo River boundary condition, flow data from gages on Cayuga and Buffalo Creeks were multiplied by a scale factor based on the ratio of the drainage area at the gage to the drainage area at the confluence to estimate the flow at the model boundary (Table 2-1). A similar approach was used for Cazenovia Creek. High frequency flow data (15 min) were used for all three tributaries. The only exception was for Cayuga Creek during the June 9, 2000 wet weather event, where a daily flow value was substituted for a gap in the high frequency data at this location.

Table 2-1: USGS Flow Gages and Drainage Area Ratios

Stream	Gage ID	Area at Gage (sq mile)	Area at Confluence (sq mile)	Scale Factor
Buffalo Creek	04214500	142.6	146	1.02
Cayuga Creek	04215000	96.4	128	1.33
Cazenovia Creek	04215500	134.6	137.2	1.02

Upstream water quality boundary conditions for DO and temperature were constructed from high frequency monitoring equipment (continuous Hydrolab measurements) installed at the Buffalo City limits on the Buffalo River and Cazenovia Creek between April and October of 2000 as part of the System-wide LTCP for CSO abatement (Malcolm Pirnie, 2001). The 15-min data were averaged on an hourly basis to minimize the size of the input files. The sensors recorded data in 15-min intervals with several major data gaps (6/14/00 to 6/20/00 and 7/19/00 to 8/2/00). The model pre-processor linearly interpolated between any data gaps to generate a continuous dataset. BOD and fecal coliform boundary conditions were driven by grab sample measurements taken during the same time period.

Downstream hydrodynamic boundary conditions were established based on six-minute water level data 2000 from station 9063020 (NOAA) located at the mouth of the Buffalo River. Downstream water quality boundary conditions were constructed from high frequency (15-min) monitoring equipment (dissolved oxygen and temperature) and grab samples (BOD and fecal coliform) collected in 2000. To reduce the size of the input files the 15-minute data were averaged to hourly values.

2.1.3.c Loads to System

Direct loads to the Buffalo River within the model domain include CSOs and point source discharges.

Wet weather CSO volumes were simulated with the collection system model developed and calibrated in 2000 (under the original LTCP effort) and further refined in 2009. The collection system model relied on a full network of rain gages installed for the 2000 and 2009 monitoring programs to calculate CSO flows for the 2000 data for the Buffalo River and the 2009 data for the remaining receiving stream models. Flow results from the collection system model for all CSO's within the model domain were provided to LimnoTech at 5 minute intervals for two wet weather events in 2000 (June 6 and August 23). Loads of fecal bacteria, BOD, and DO from CSOs were calculated using these flows from the collection system model and event mean concentration (EMC) data collected during the sampling program under the previous LTCP effort (Malcolm Pirnie, 2004a, b). As described in the 2004 LTCP, analytical water quality and flow data collected during the year 2000 were combined to calculated mass pollutant loadings under wet weather conditions. System-wide average EMCs were calculated to be 92,500 #/100mL for fecal coliform bacteria and 24.1 mg/L for BOD (Malcolm Pirnie, 2004b Table 3-1). These system-wide EMCs were used as initial inputs and adjusted as needed during calibration.

Table 2-2 summarizes the inflow sources that were included in the Niagara River model based on outputs from the collection system model. Table 2-3 summarizes the concentrations used to calculate wet weather loads for CSO sources.

Table 2-2: Summary of Inflow Sources in the Buffalo River Model

CSO Source	Receiving Water	River Mile	Total Overflow Volume (MG)	
			Wet Weather Event 1 (6/6/2000)	Wet Weather Event 2 (8/23/2000)
CSO-017	Buffalo River	0.43	12.28	14.64
CSO-021	Buffalo River	0.80	0.07	0.19
CSO-022	Buffalo River	0.90	0.17	0.23
CSO-025	Buffalo River	2.13	0.20	0.22
CSO-026	Buffalo River	3.84	5.50	7.81
CSO-027	Buffalo River	5.07	0.13	0.54
CSO-028	Buffalo River	5.35	2.72	5.27
CSO-029	Buffalo River	5.35	1.58	2.69
CSO-032	Buffalo River	5.82	0.00	0.00
CSO-033	Buffalo River	5.92	2.09	3.98
CSO-034	Buffalo River	7.15	0.00	0.02
CSO-035	Cazenovia Creek	1.18	0.25	0.63
CSO-037	Cazenovia Creek	1.00	1.72	4.06
CSO-039	Cazenovia Creek	0.90	0.00	0.02
CSO-044	Cazenovia Creek	0.52	0.49	1.12
CSO-046	Cazenovia Creek	0.33	0.01	0.06
CSO-047	Cazenovia Creek	0.24	0.68	0.89
CSO-048	Cazenovia Creek	0.14	0.00	0.02
CSO-049	Buffalo River	5.73	0.00	0.00
CSO-050	Buffalo River	6.11	0.31	0.61
CSO-051	Buffalo River	6.87	0.26	0.63
CSO-052	Buffalo River	7.34	0.09	1.27
CSO-064	Buffalo River	1.37	0.31	0.31
CSO-066	Buffalo River	7.34	2.31	2.83

Table 2-3: CSO Pollutant Concentrations for Buffalo River

Parameter	Units	CSOs
CBODU	mg/L	24
Dissolved Oxygen	mg/L	Variable
Fecal Coliform	CFU/100 ml	150,000

Based on discussions with Malcolm Pirnie and review of sewer maps during development of the Buffalo River model, it was determined that there were no major storm water outfalls to the Buffalo River (i.e., major storm water sewers ultimately fed into combined sewers), therefore direct storm water inputs were not included in the Buffalo River model.

The number of point sources that discharge to the Buffalo River has changed over the past decade as businesses have closed or changed operations. According to data obtained electronically from NYSDEC for the 2000 and 2008-2009 time periods, there are only two significant NPDES facilities that discharge directly to the Buffalo River within the model domain. During the 2000 period, PVS Chemical (NY0110043) and Buffalo Color Corp (NY0002470) withdrew water from Lake Erie through the Buffalo River Improvement Corporation (BRIC) intake and discharged into the Buffalo River at river mile five. These two facilities are located close together and their effluent was applied to the same model cell. The primary use of the water is for non-contact cooling water. The discharge monitoring reports (DMR) for the 2000 period recorded average flows of 6.4 MGD for Buffalo Color Corp and 3.81 MGD for PVS chemicals. For modeling purposes, a total discharge of 10 MGD was applied to the model cell at river mile 5. Concentrations of DO, BOD, and bacteria for the discharge were assumed to be the same as Lake Erie.

Review of the 2000 and 2008 to 2009 data indicated that an additional permit holder, Linde, Inc. (NY0085294), formerly known as BOC Gases, currently discharges into the Buffalo River at river mile three. Flow data from 2000 and 2009 show that flows are very low (typically less than 14,000 gallons per day), and therefore this point source was not included in the model.

2.1.3.d Reaction Rates

Reaction rates were initially based on literature from previous Buffalo River models (Atkinson and Blair 1992, Atkinson 2004, Hall 1997, Wight 1995) and best professional judgment, and subsequently modified as needed during the calibration process. For bacteria and CBOD, reaction parameters include first order decay rate and in the case of CBOD settling rate. For dissolved oxygen, reaction rate parameters include CBOD deoxygenation rate, reaeration and sediment oxygen demand.

SOD values ranged from 1.25 to 3.00 g/m2/d, which is within the range of SOD used in previous DO models of the Buffalo River (Wight 1995; Atkinson and Blair 1992). Higher SOD values were used at the head of the navigation channel, which corresponds to the area where the average water velocity in the Buffalo River decreases significantly, thus allowing for sediment deposition. The first order BOD decay rate was set to 0.1/d, which is also similar to previously calibrated values (Wight 1995; Atkinson and Blair 1992). More detail on these parameters is provided in the subsequent model calibration section of this report.

2.2 MODEL CALIBRATION

The Buffalo River model was calibrated using data collected in 1994, 2000, and 2008 by various agencies. As part of earlier Long Term Control Plan efforts in 2000, wet and dry weather data for DO, BOD, and fecal coliform bacteria were collected at the Buffalo River water surface for an extended time period in 2000. Dissolved oxygen vertical profile data were collected by SUNY-Buffalo during June and July 1994. In 2008, LimnoTech collected water level and velocity data for a separate project funded by Honeywell, Inc. Together these datasets were used to calibrate the hydrodynamic (2008), fecal coliform bacteria (2000) and BOD and DO (1994 and 2000) sub models.

Water quality sampling locations in the Buffalo River are depicted in Figure 2-4.

Figure 2-4: Buffalo River Water Quality Sampling Locations

2.2.1 Approach

The model was calibrated by visual comparison of output to observed data. Time periods for calibration of various model components were based available data sets. The hydrodynamic model was calibrated first, followed by the bacteria model, and finally the CBOD and DO models. Table 2-4 presents the pre-calibration and final calibrated model coefficients for the CBOD, DO, and fecal models. All reaction rates used in the model are within ranges found in published literature such as Chapra (1997), USEPA (1987), and USEPA (1985).

Table 2-4: Calibrated model coefficients for the Buffalo River

System	Parameter	Units	Pre-Calibration	Background	CSO	Storm Water
CBOD	Deoxygenation Rate	1/d	0.5	0.1	0.1	0.1
CBOD	Deoxygenation Rate Temp.Corr.Factor		0.041	0.041		
CBOD	Half Sat. Constant	mg/L O_2	1.5	1.5		
CBOD	Settling Velocity	m/d	0.5	0.1	0.5	0.1
Fecal	Decay Rate	1/d	1.0	0.5	0.5	0.5
Fecal	Decay Rate Temp Corr.		1.07	1.07		
Wind	Reaeration Rate (Ka)	1/day	0 - 1	0.2		
SOD	Sediment Oxygen Demand	g/m2/d	1.0 – 5.0	1.25 to 3.0		

2.2.2 Hydrodynamics

The hydrodynamic model was calibrated and validated using continuous water level and velocity measurements collected from October 14, 2008 to November 16, 2008 at three locations (RM 0.7, 2.9, and 5.2) in the dredged portions of the Buffalo River. Figure 2-5 and 2-6 show the water level and velocity at three locations during a seven-day period of the simulation. Appendix F contains additional water level and velocity calibration results for the entire modeling time period. The water level and velocity calibration was obtained by adjusting the roughness of the sediment bed to a value of 0.0018 m (1.8 mm). This roughness height is representative of a fine grained sediment bed and is consistent with the value used for other hydrodynamic models (Environ, et al. 2008) of the system.

As shown in Figure 2-5 the model does an excellent job of simulating water level. However, as shown in Figure 2-6 water velocity is underpredicted in some locations, specifically near the mouth of the Buffalo River (RM 0.7). The magnitude and direction (in or out of the Buffalo River) of the water velocity near the mouth is very similar to observed data. The slight difference in velocity may be due to the lateral averaging that occurs in this model versus the velocity profile measured in the field. The velocity instrument was placed in the center of the channel where velocities are faster than near the edges.

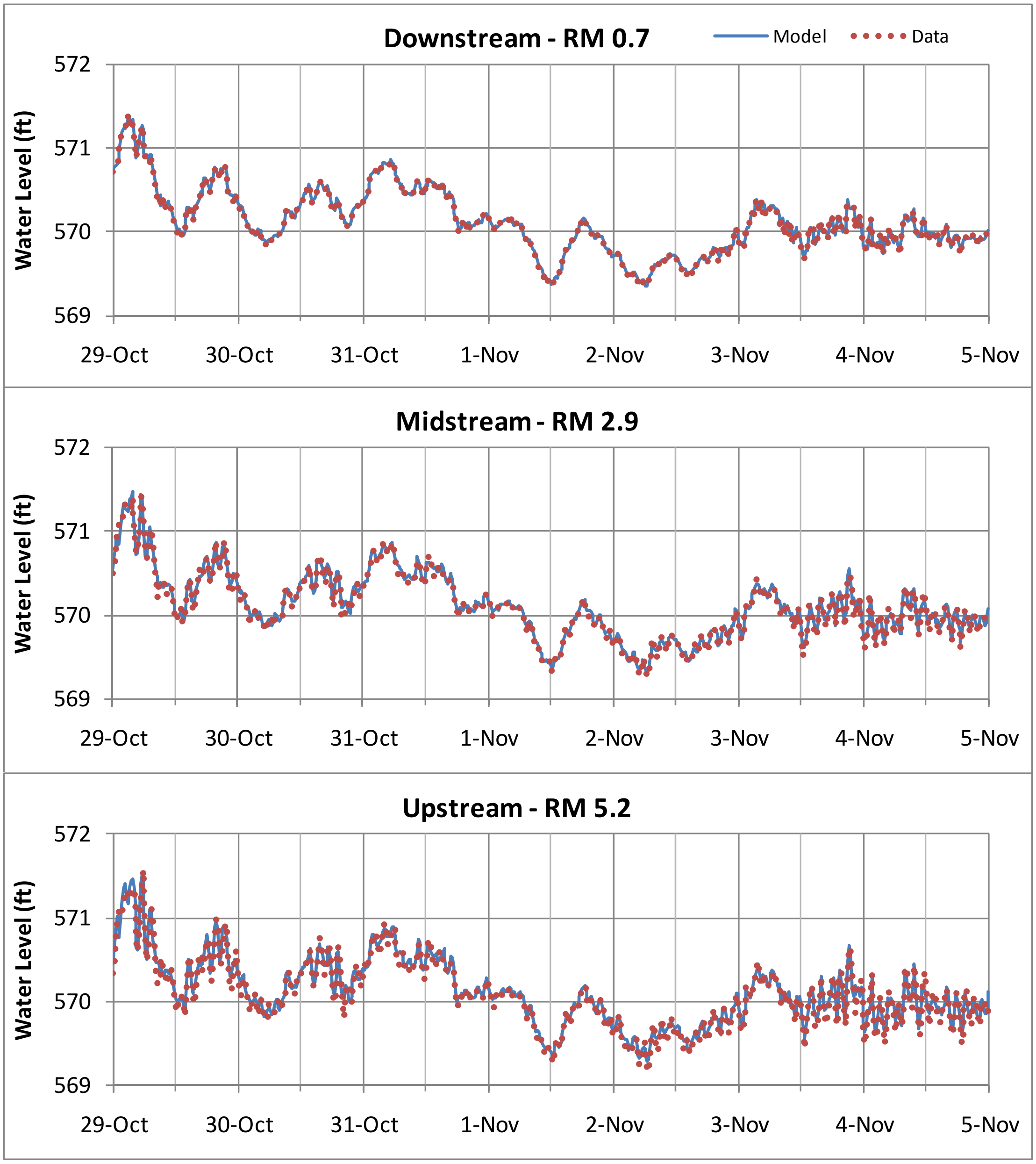

Figure 2-5: Water Level at Three Locations in the Buffalo River from October 29, 2008 to November 5, 2008

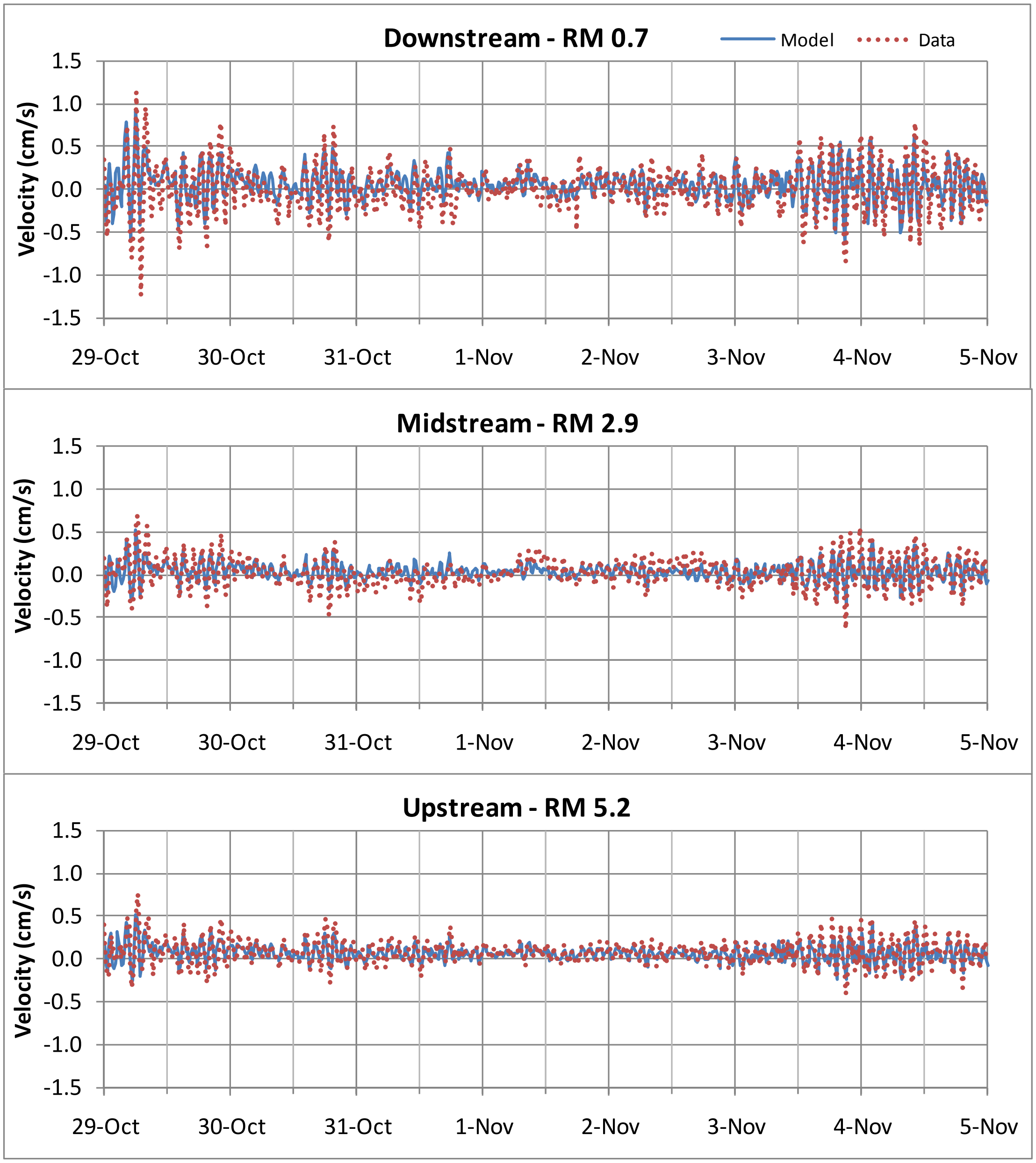

Figure 2-6: Velocity at Three Locations in the Buffalo River from October 29 to November 5, 2008

2.2.3 Dissolved Oxygen

Calibration of dissolved oxygen in the Buffalo River was conducted by comparing model output to both continuous surface concentrations (2000) and profile measurements collected over a range of depths (1994). The continuous data from March through October 2000 were used to calibrate the vertical mixing component, surface reaeration, and BOD decay rates. This time period included both dry weather and wet weather conditions. The 1994 profile data were used to evaluate the prediction of river bottom DO and determine if the specified SOD rates were appropriate.

Temperature data were also compared with model predictions to ensure that any temperature dependent reaction rates were being computed accurately. The daily average model predicted temperature and data were within 1 to 3 °F at all locations and results are shown in Appendix F.

Dissolved oxygen data collected from the Buffalo River in 2000 only included measurements of DO near the surface (via continuous hydrolab instruments). Figures 2-7 and 2-9 show a time series comparison of model predicted dissolved oxygen and sampling results at two locations along the Buffalo River (SCD RBWQ 04 and SCD RBWQ 03) for the entire simulation time period from March 31, 2000 to October 31, 2000. These two locations are within the dredged portion of the river and are representative of model to data DO comparisons. Simulation results at these two locations for two dry weather and two wet weather periods within this range of dates are provided in Appendix F. Figures 2-8 and 2-10 show scatter plots of model to data for DO at these locations. Appendix F contains additional comparisons of model predicted dissolved oxygen and continuous measurements for three additional locations in the Buffalo River system (SCD RBWQ 02, SCD RBWQ 07, and SCD RBWQ 05).

The calibrated model coefficients are shown in Table 2-4 above. The reaeration rate was set to a constant value of 0.2 per day for all reaches of the river. This calibrated value is below what is estimated by the O'Connor and Dobbins (1958) formula of approximately 0.45 per day, but is within the range of acceptable values (0.07 to 0.5 per day) as reported by USEPA (1985) for streams and lakes of similar depth.

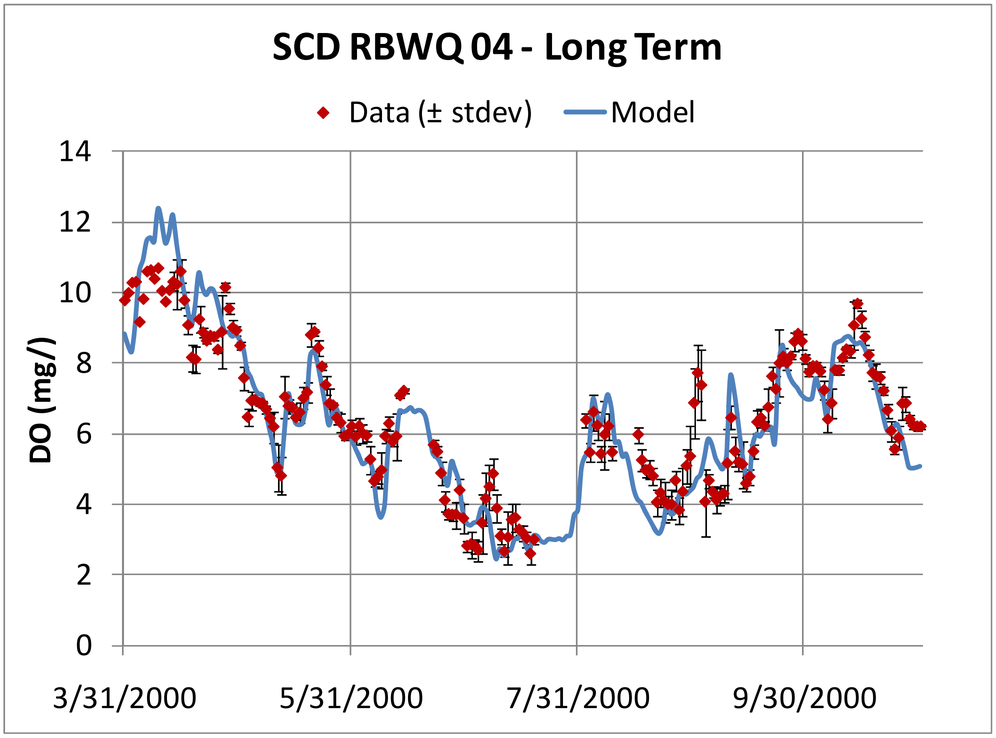

Figure 2-7: Comparison of Daily Average Surface DO at River Mile 3.74 (SCD RBWQ 04) in 2000

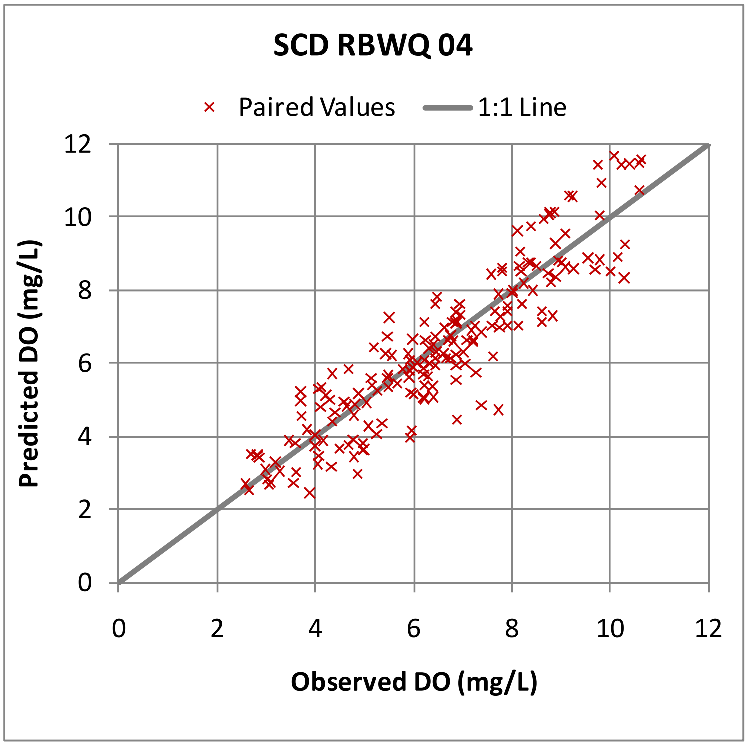

Figure 2-8: Comparison of Observed and Predicted DO at River Mile 3.74 (SCD RBWQ 04) in 2000

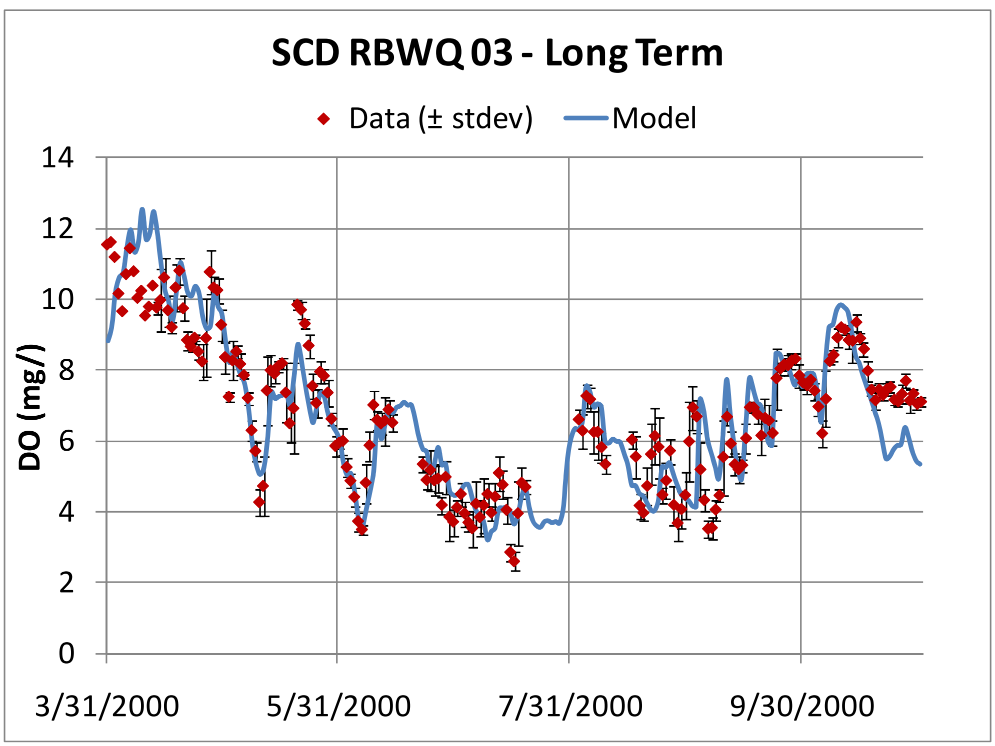

Figure 2-9: Comparison of Daily Average Surface DO at River Mile 1.75 (SCD RBWQ 03) in 2000

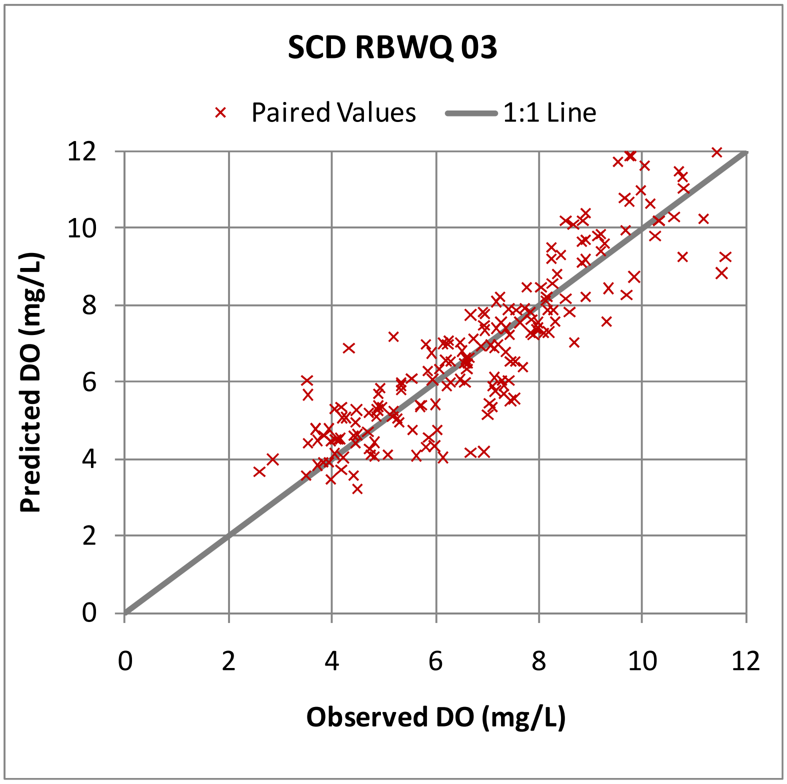

Figure 2-10: Comparison of Observed and Predicted DO at River Mile 1.75 (SCD RBWQ 03) in 2000

Overall, the EFDC model closely matches the observed daily average DO at the surface. During high flow events the upstream DO had a strong influence on downstream DO, while during low flow periods surface DO became depressed. Not shown is the surface DO at the Buffalo City limit (upstream boundary) which averaged between 6 and 8 mg/L between June and September.

The only calibration parameter that includes a spatial component is the sediment oxygen demand, which ranges from 3.0 $g/m^2/d$ near the head of the navigation channel to 1.50 $g/m^2/d$ near Lake Erie.

While the 2000 dataset provided excellent surface DO data at a high temporal resolution, it did not capture the impact of sediment oxygen demand (SOD) on DO concentration in the deeper portions of the dredged channel, nor did it provide any usable CBOD data. All CBOD5 samples collected at the upstream boundaries during dry weather events were non detect (detection limit of 5 mg/L). In addition, high levels of algae are likely to have influenced the surface DO concentration. To provide for a robust calibration, the Buffalo River model was run for a summer period during 1994 when vertical profiles of temperature and DO were available for several locations in the dredged portion of the Buffalo River. Vertical profile data were obtained for June and July of 1994 (Wight 1995). These data were originally collected by NYSDEC as part of the Remedial Action Plan for the Buffalo River. Forcing functions for the simulation were based on 1994 conditions. A constant Lake Erie water level input was used to fill in data gaps from 7/1/94 to 7/6/94. A summary of the upstream and downstream DO, BOD, and temperature boundary conditions used during the simulation are shown in Table 2-5 below.

Table 2-5: Upstream and Downstream Boundary Conditions for the 1994 Simulation

Location	DO (mg/L)	CBOD (mg/L)	Temperature (deg C)
Upstream	6-7	6	15-24
Downstream	8	1	15-24

EFDC was run from 6/7/94 to 7/6/94 and vertical DO profiles measured on 6/22/94 and 7/6/94 were used to calibrate SOD and CBOD reaction rates. These were the only dates when data were available in this time period. During this time period there were no high flow events and as such, DO stratification was strong. Figure 2-11 shows profile plots of the dissolved oxygen model output compared with observed data. The model results represent an hourly average and coincide with the timing of the profile measurements. Additional profile model-data comparisons of temperature are shown in Appendix F.

The EFDC model does an excellent job of capturing the vertical DO profile in the dredged portion of the Buffalo River. Observed DO at the surface can be several mg/L higher than model predictions, but the data were likely collected close to the surface, whereas model results are averaged over the top 3 to 5 ft depending on the depth. The only large deviation from observed values is the near the mouth on July 6, 1994 when 6-minute water level data were not available to drive the boundary condition. A large gap in the water level data in early July likely resulted in the under prediction of DO in the bottom layers near the mouth of the Buffalo River. A synthetic boundary condition could have been used to simulate the boundary condition, but this illustrates how much the seiche activity of Lake Erie mixes the entire water column in the lower Buffalo River.

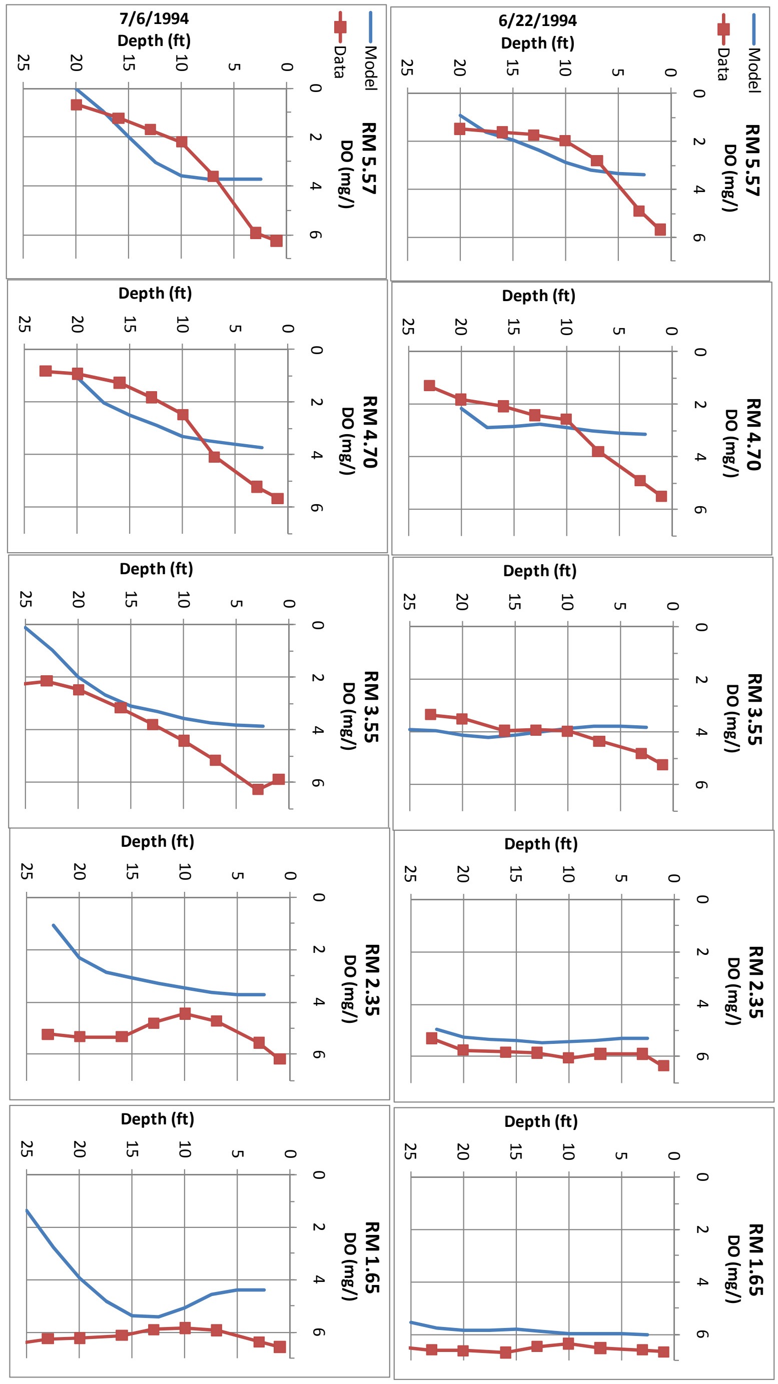

Figure 2-11: Comparison of Model and Data DO Profiles on 6/22 and 7/6 of 1994 at 3 Locations in the Dredged Portion of the Buffalo River

During the initial calibration phases it became apparent that wind forcings/vertical mixing estimated by the model were too great if the wind speed measured at the airport was used directly. The Buffalo/Niagara Airport is located 8.5 miles to the northeast of the Buffalo River and measurements are taken in a wide-open field 10 meters off the ground. As such, surface winds over the Buffalo River are likely to be less that those measured at the airport. To account for differences in site conditions each hourly wind measurement was scaled by a factor of 0.62. This factor was used throughout all model simulations.

2.2.4 Bacteria

The Buffalo River model was calibrated for fecal coliform bacteria under both dry weather and wet weather conditions. Longitudinal plots showing simulated and observed bacteria for two dry weather events (5/4/2000 and 9/7/2000) are provided in Appendix F. The model does a very good job of predicting the relatively low bacteria levels (less than 500 CFU/100 mL) that were measured during the first dry weather period, but it appears that the model slightly underpredicts bacteria during the second period at a few locations. The observed discrepancy between model prediction and data for the second period does not significantly limit the calibration, nor will it limit the utility of the model for wet weather simulation.

In the following two sections, time series comparisons of model-predicted fecal coliform bacteria are compared with sampling results at stations SCD RBWQ 03 and 05 for two wet weather events in 2000. These two stations represent the only two locations where discrete (versus time composited) samples were taken during each storm event. Station #3 is located in the dredged portion of the Buffalo River about half way between the city limits and the mouth. Station #5 is located at the mouth of Lake Erie and while this is a boundary location, the water column is only forced to this boundary when water is flowing into the model domain (from Lake Erie upstream). During a wet weather event, the flow of the Buffalo River is always out of the Buffalo River so model predictions at this location represent simulated (rather than forced) conditions. In addition a direct (one-to-one) comparison of predicted and observed fecal concentrations from all stations during each wet weather event was made.

2.2.4.a Wet Weather Event 1 Calibration

Model to data comparisons for wet weather event 1 (June 9 to June 13, 2000) are shown below. Model predictions are averaged hourly from the same model cell that the data were collected. Observed data are shown with error bars representing double and one half of the measured result. All replicates were averaged. Time series plots are shown in Figures 2-12 and 2-13, and a one-to-one plot is shown in Figure 2-14. The error bars on the model predictions in Figure 2-14 represent the range of model results observed 4 hours before and 4 hours after the collection of the field sample. This allows for some imprecision in the recording of sample collection times as well as the timing of the forcing functions in the model. The plots also include a 1:1 line (grey). Points which fall directly upon the 1:1 line would indicate a perfect fit. The plot also includes lines that bracket a factor of two (dark blue) and an order of magnitude (light blue). The factor of two brackets is intended to encompass uncertainty in analytical results, whereas the factor of ten brackets encompasses all sources of uncertainty in the observed data, including factors such as in-stream variability and sample collection and handling.

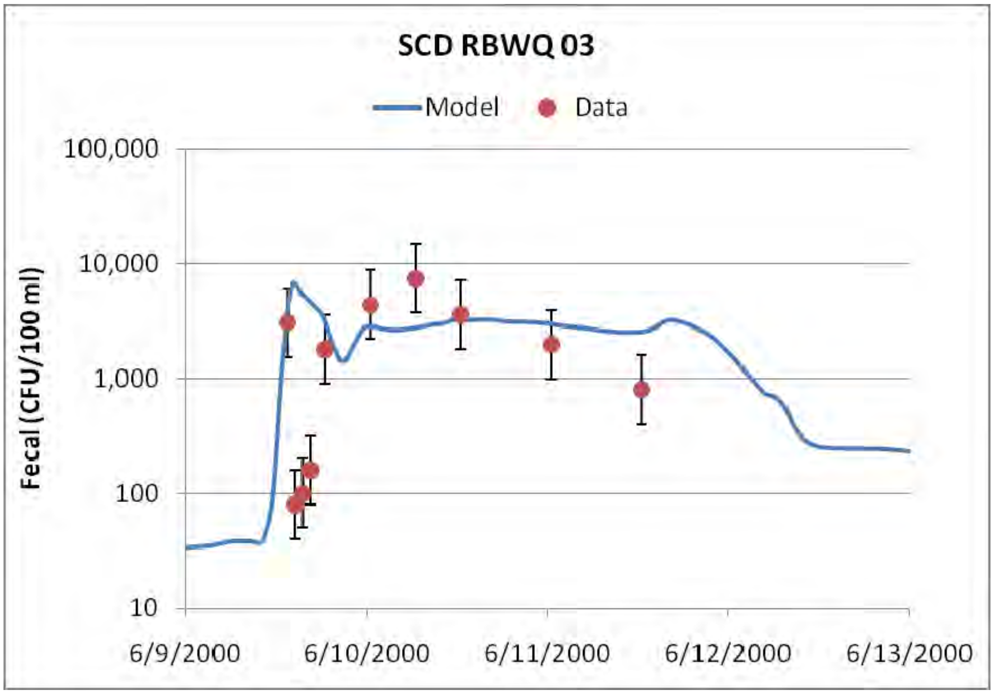

Figure 2-12: Time series plot of fecal bacteria at mile 3.74 (SCD RBWQ 03) on the Buffalo River

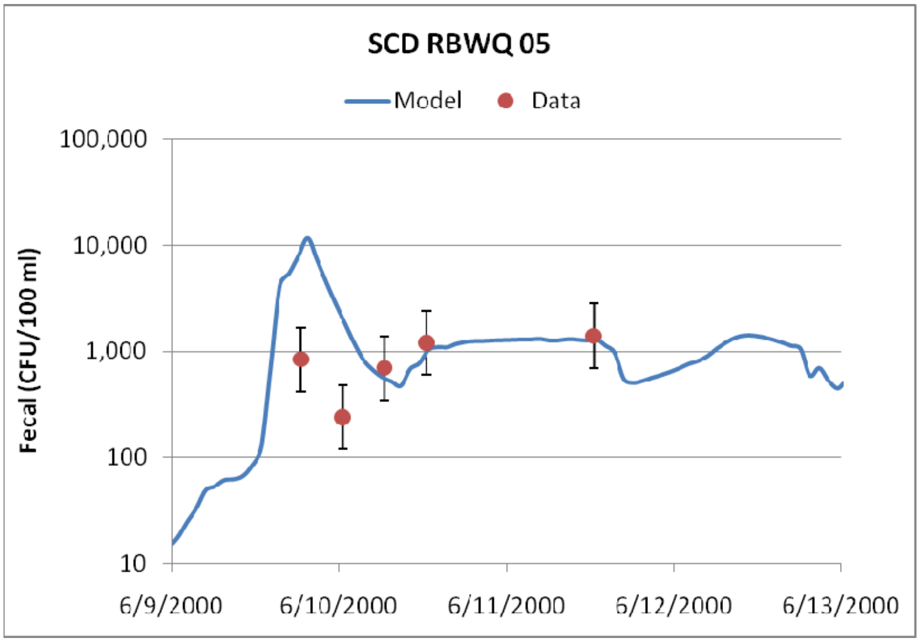

Figure 2-13: Time Series Plot of Fecal Bacteria at the Mouth of the Buffalo River (SCD RBWQ 05)

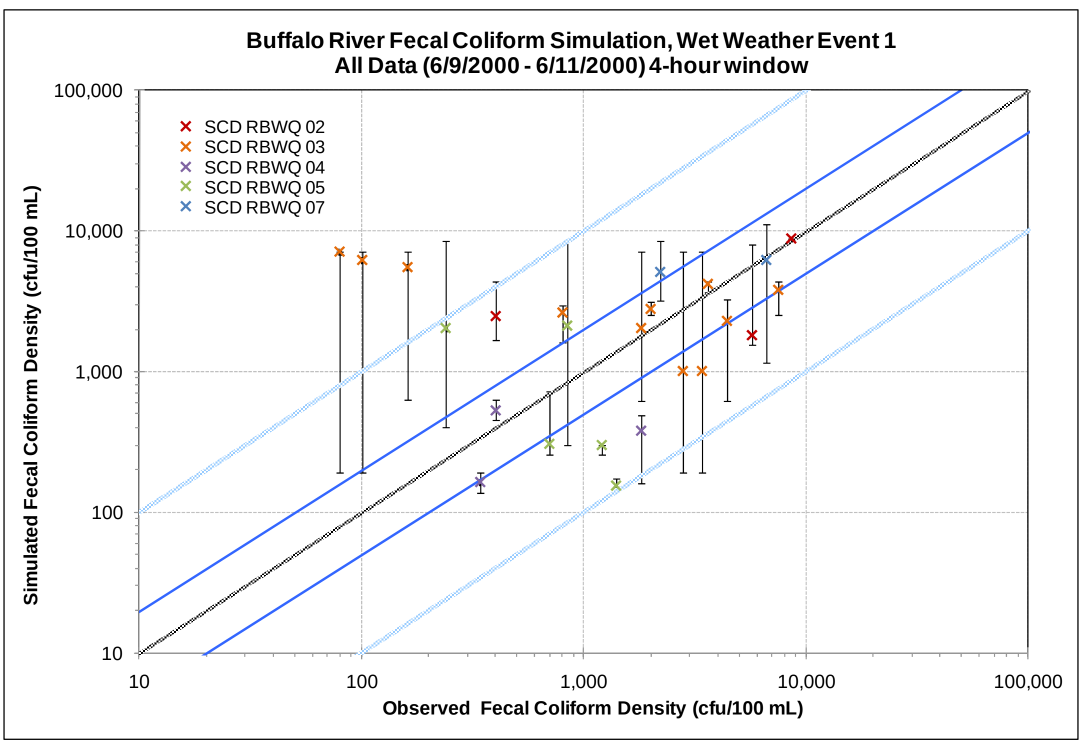

Figure 2-14: One to One Plot of Observed and Predicted Model Results The error bars represent the range of model results within four hours before and after the fecal sample was taken.

2.2.4.b Wet Weather Event 2 Calibration

Model to data comparisons for wet weather event 1 (August 23 to August 27, 2000) are shown below. Model predictions are averaged hourly from the same model cell that the data were collected. Observed data are shown with error bars representing double and one half of the measured result. All replicates were averaged. Time series plots are shown in Figure 2-15 and Figure 2-16, and a one-to-one plot is shown in Figure 2-17. The error bars on the model predictions in Figure 2-13 represent the range of model results observed 4 hours before and 4 hours after the collection of the field sample. The plot also includes 2X (dark blue) and 10X (light blue) confidence interval lines.

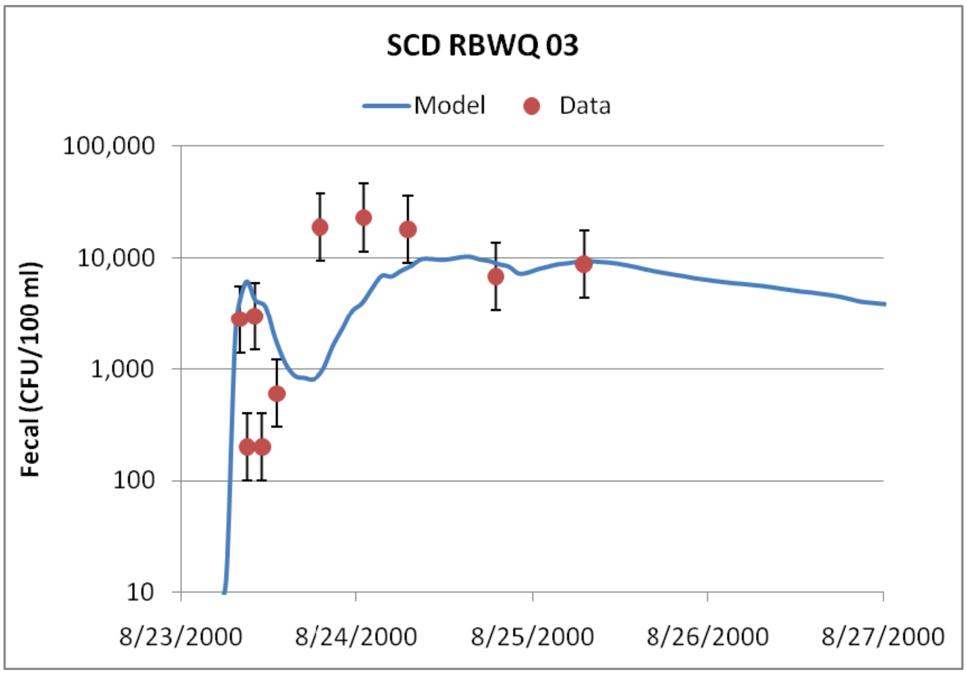

Figure 2-15: Time Series Plot of Fecal Bacteria at Mile 3.74 (SCD RBWQ 03) on the Buffalo River

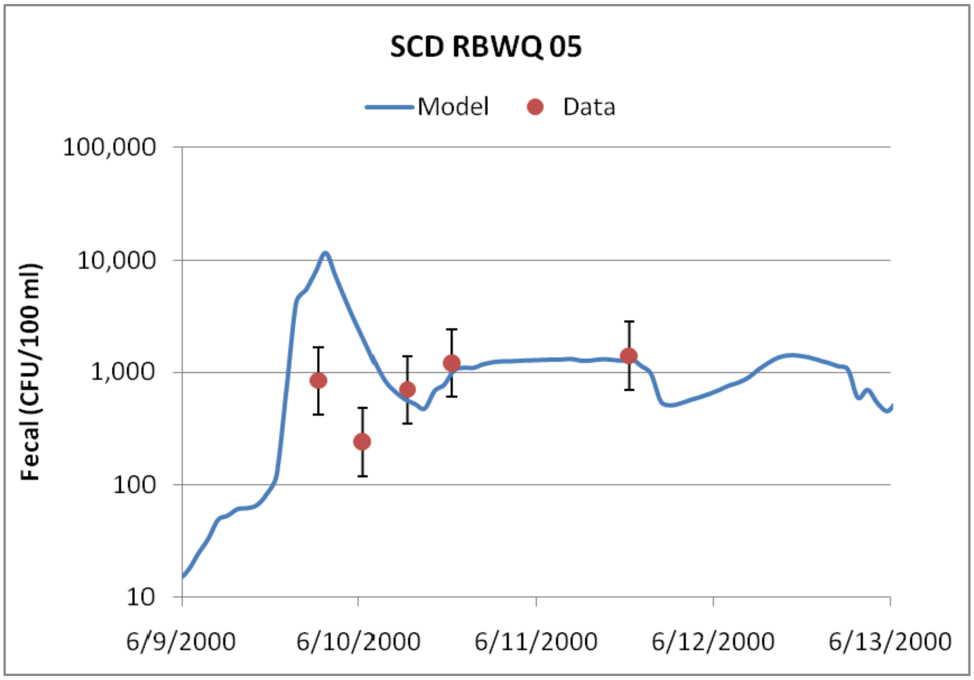

Figure 2-16: Time Series Plot of Fecal Bacteria at the Mouth of the Buffalo River (SCD RBWQ 05)

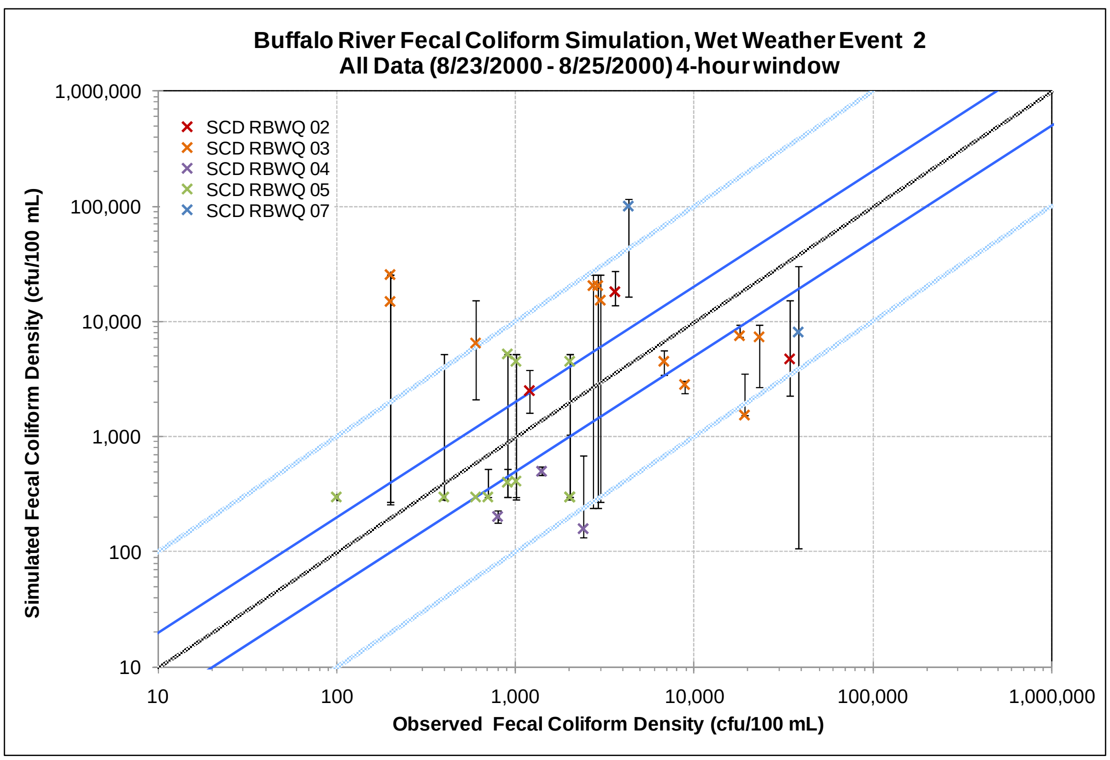

Figure 2-17: One to One Plot of Observed and Predicted Model Results
The error bars represent the range of model results within four hours before and after the fecal sample was take.

Unlike the DO calibration, there are few parameters that can be adjusted that would yield a significant difference in the model predicted fecal coliform concentration. Due to the short lived nature of wet weather events (on the order hours to days) the bacterial decay rate is relatively unimportant when predicting the concentration through a short river reach with a relatively high water velocity. A fecal die off rate of 0.5 per day was chosen as it best fit both sets of data under both dry and wet weather conditions.

What is important to model calibration is having accurate boundary conditions (e.g. flow, upstream fecal concentration) that can successfully simulate the dynamic nature of the Buffalo River during a wet weather event. During model calibration it became evident that the model could predict the peak of fecal concentrations very well, however the timing of the peak could be off by an hour or two depending on the location. For this reason the one-to-one plots illustrate the range of model predictions within a relatively short time period (8 hour window). It should be noted here that, although the one-to-one plots shown in Figures 2-14 and 2-17 show some outliers at low fecal coliform levels below 1,000 cfu/100 mL, the model results are conservative since the predicted values are higher than the measured values in this range.

2.2.5 Calibration Summary

A single modeling framework was developed for the Buffalo River that is capable of simulating DO and bacteria during wet and dry conditions. Calibration of the DO model initially focused on data collected in 2000, but was expanded to include data from 1994 (vertical profiles during the summer) and 2008 (water level and velocity). While model to data comparisons to 2000 DO data are reasonable, the strength of the calibration is shown with model-to-data comparisons from 1994 and 2008. The most sensitive parameters during calibration included the SOD rates as well as the reaeration rate. In addition, the vertical mixing predicted by applying 100% of the wind magnitude measured at the Buffalo Airport seemed unreasonable and was scaled back. Overall the model satisfactorily predicts strong DO stratification during low flow periods, but the stratification is quickly overcome under higher flow conditions.

Bacteria concentrations during wet weather events in the Buffalo River are heavily influenced by the upstream load coming from Buffalo, Cayuga, and Cazenovia Creeks. As such, having accurate boundary conditions is critical to simulating bacteria within the Buffalo River. Overall, the model was able to predict both the initial spike of fecal load following a heavy rain and the gradual decline in concentrations as the upstream boundaries “flushed” the system over the following 24 to 72 hours. The calibration process for the fecal model under wet weather conditions only involved plugging in all of the inputs and assigning them concentrations that were measured as part of the 2000 sampling effort (either upstream boundaries or CSO concentrations). While some of the CSO data showed that fecal concentrations decline through the event, the data was limited to relatively small CSOs and were considered not representative of all CSOs. In addition, the upstream fecal signal quickly overshadowed any instream CSO fecal loads and it became difficult to distinguish the upstream load from the CSO load. While the model can track each source independently, the sampling data were measured fecal as concentrations from all sources.

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3. SCAJAQUADA CREEK MODEL

The domain of the Scajaquada Creek model extends from the City of Buffalo municipal boundary, at the upstream end of the Scajaquada tunnel, to the Grant Street dam. The Delavan Drain, a diversion conduit for flood water, was also included in the model. Figure 3-1 depicts the model domain.

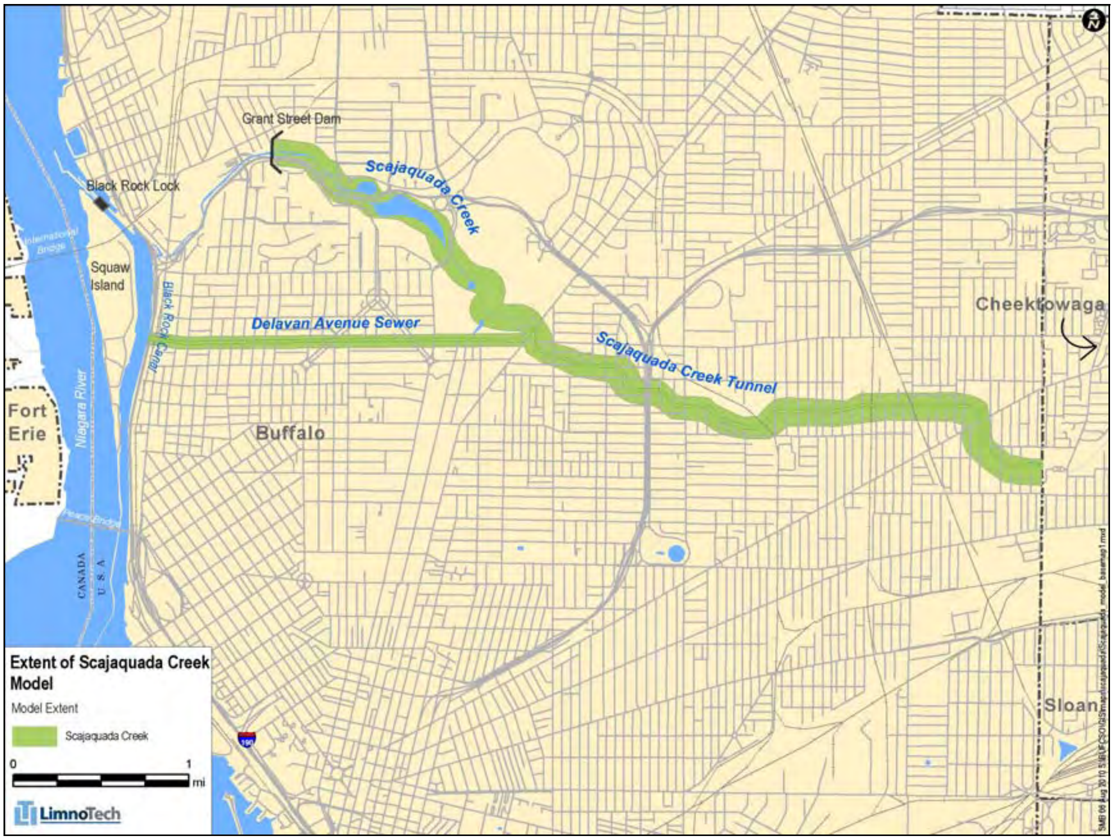


Figure 3-1: Scajaquada Creek Model Domain

The development and calibration of the Scajaquada Creek model are discussed in the following sections.

3.1 MODEL DEVELOPMENT

The specific objectives for the Scajaquada Creek model are to allow the following uses (LimnoTech, 2008):

- Assess the relative contribution of BSA CSO discharges to the bacteria and DO in receiving waters during and following a CSO event relative to other watershed sources.

- Assess the effects of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters in the hypothetical absence of other contributions or potential reductions of other contributions.

- Determine the effect proposed Phase 1 CSO control projects will have on receiving water quality, relative to current conditions.

- Determine the controls necessary for the Scajaquada Creek CSO discharges in order to meet standards in that part the system designated as Class B with regard to designated uses.

- Calculate the bacteria loads to the Black Rock Canal and Niagara River from Scajaquada Creek during various storm events with and without CSO controls.

The model developed and calibrated under this project can be used to meet these objectives. The following sections describe the development and calibration of the model.

3.1.1 Model Selection and Background

Scajaquada Creek is unlike the Buffalo and Niagara Rivers in that it is not influenced hydraulically by seiche effects in Lake Erie, nor does it exhibit the stratification that results from dredging to navigational depths. Further, the combination of its generally channelized geometry with a highly urbanized watershed leads to flashy wet weather response. An open-channel system such as this, where longitudinal advective transport is the dominant mechanism, is often considered to be one-dimensional (1-D) for modeling purposes. While EFDC can be used to simulate 1-D systems, experience has demonstrated that models specifically intended for 1-D systems tend to be more robust, especially where closed conduits are involved as they are in the Scajaquada system.

The USGS FEQ model (Franz and Melching, 1997) was selected for use in developing the 1-D, unsteady hydraulic simulation model for Scajaquada Creek. This decision was based largely on previous success in using this model, along with a water quality model linkage, in simulating urban streams in other parts of the country. FEQ has the needed flexibility to simulate the various diversion structures and closed conduits found in the Scajaquada Creek system, as described in Appendix B of this report.

The FEQ model is linked with EPA's Water Quality Analysis Simulation Program (WASP), (U.S. EPA, 1993) which has been adapted by LimnoTech to facilitate simulation processes that are important in urban wet weather water quality. The fate and transport of bacteria are simulated using first-order decay and settling, the latter being applied to a specified fraction that is associated with solids. The code accommodates up to four distinct bacteria components so that multiple sources (i.e., CSO, upstream nonpoint sources) can be tracked through the system, each with its own decay rate and settling characteristics. Dissolved oxygen is modeled using the mechanisms of first-order degradation via carbonaceous biochemical oxygen demand (CBOD), reaeration and zero-order sediment oxygen demand (SOD). In addition to acting as a first-order sink for DO, the particulate fraction of CBOD is subject to removal by settling. Like bacteria, CBOD from up to four sources can be tracked separately.

3.1.2 Domain and Segmentation

The domain of the model extends from just upstream of the entrance to Scajaquada Drain, at the boundary between the City of Buffalo and Cheektowaga, to the Grant Street Dam on the downstream end. The downstream end was chosen because the dam forms a hydraulic boundary below which seiche effects from Lake Erie, via Black Rock Canal, have been observed. The lower portion of Scajaquada Creek has been included in the Black Rock Canal model as described in Section 5 of this report. The model segmentation is shown in Figure 3-2. An enlarged version of this map is provided in Appendix E.

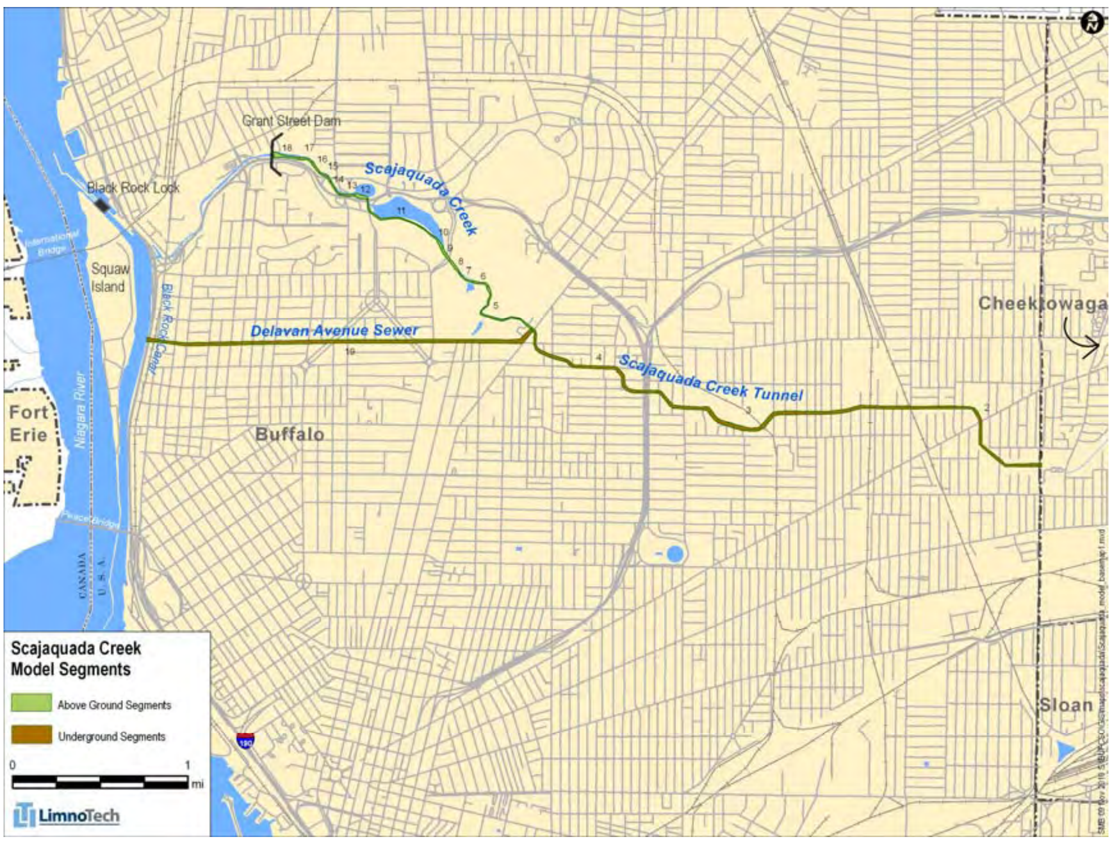


Figure 3-2: Scajaquada Creek Model Domain and Segmentation

Note that while the water quality model does not explicitly include Hoyt Lake, a diversion to the lake is included in the FEQ model. Flows that overtop the pedestrian walkway on the southeastern edge of Hoyt Lake leave the system and can reenter over the downstream weir if the level of Hoyt Lake rises sufficiently. There is anecdotal information stating that overtopping may occur a few times per year; however, specific information regarding the flow conditions that cause overtopping was not available. The FEQ model did not predict overtopping to occur during either wet weather event used for model calibration.

3.1.3 Model Input Development

The following sections describe model inputs for the Scajaquada Creek model.

3.1.3.a System Data

The primary source of physical data describing the Scajaquada Creek system was a previously developed HEC-2 model (FEMA, 2008). This modeling work was originally conducted by U.S. Army Corps of Engineers as part of a FEMA Flood Insurance Study (FIS) for the City of Buffalo, and later updated by various contractors as part of a countywide FIS.

Virtually all of the georeferenced cross sections from the HEC-2 model were incorporated into the FEQ model, which accounted for the open channel portion of the system. The enclosed portion of Scajaquada Drain and the representation of the Delavan Avenue sewer were based on structure data in the collection system model. The diversion around Hoyt Lake was not explicitly modeled in HEC-2; however, record drawings were obtained from BSA and used to model the closed conduits in FEQ.

The Delavan Avenue Sewer originates in the lower (western) end of the Scajaquada tunnel. A control structure allows base flows in Scajaquada to bypass the Delavan Avenue Sewer under dry weather conditions. The representation of the diversion was taken directly from the collection system model provided by Malcolm Pirnie and slightly modified as necessary for use in the FEQ model. In general, dry weather flow heads out of the drain into the creek via a cunette, and wet weather flows are diverted to the sewer via a weir. It was noted during model development that after the Delavan Avenue sewer becomes surcharged, the water level in this branch eventually exceeds the weir elevation and the flow regime changes from a freely overflowing weir to a submerged weir. FEQ does not handle this transition implicitly, however, so the weir equation was replaced with a stage-discharge relationship, calculated separately, that included a Villamotte-type submerged weir relationship where needed. The flow split was not specifically calibrated but it was represented in the model as follows:

- All dry weather flow remains in the Scajaquada Drain until it reaches a depth of 2.5 feet (at a flow of about 20 cfs).

- At flows above 20 cfs, a portion of flow is diverted down Delavan Drain based on a weir calculation. The weir diverts wet weather flows to the Delavan Avenue Sewer, which ranges in diameter from 8.5 feet to 11.0 feet, up to the sewer’s capacity of approximately 700 cfs.

- When wet weather flows exceed 700 cfs, the excess flow continues through Scajaquada Drain and on to the creek.

The HEC-2 model also included data on bridge structures. FEQ has various options for representing head losses from bridges, the most robust being the development of lookup tables based on detailed modeling such as HEC-2. It was intended to apply the HEC-2 model to develop such tables; however, the actual losses through the bridges were insignificant for flow rates up to a 20-year return period. The water quality model is not intended to simulate such large flows, as they would pass through the system too quickly to have discernable effects on the parameters of interest, with respect to compliance. Therefore, bridge effects were not included in the FEQ model.

3.1.3.b Boundary Conditions

The downstream boundary of the FEQ hydrodynamic model was modeled as a simple transverse weir. The upstream condition consisted of specified inflows, which were calculated using a stage-discharge relationship developed with data collected in 2008, described below.

A downstream boundary condition was also required for the Delavan Avenue sewer portion of the FEQ model. This was specified as a constant elevation of 573.8, which was also used as a basis for the backwater profile used to calculate the weir submergence for the flow split described above.

For the water quality model, upstream boundary conditions consisted of specified concentrations for the model state variables. These concentrations were based on sampling data for the various events simulated. Downstream boundary conditions were not required because no mass transfer mechanisms are simulated at these boundaries.

3.1.3.c Loads to System

The only loads to the systems come from wet weather flows, consisting of CSOs and storm water inputs. CSO volumes were simulated with the updated collection system model. The collection system model relied on a full network of rain gages installed for the 2000 and 2009 monitoring programs to calculate CSO flows for the 2000 data for the Buffalo River and the 2009 data for the remaining receiving stream models. Time series of flows from each CSO outfall simulated by the model (15 minute frequency) were used directly in Scajaquada Creek model. Table 3-1 summarizes the inflow sources that were included in the Scajaquada Creek model. The first four entries in Table 3-1 represent groups of individual pipes flowing into Scajaquada Drain, and are grouped according to the model segmentation. The next two represent the two active CSO outfalls within the model domain. The final entry represents composite storm water inflows.

CSO concentrations were based in part on event sampling conducted in 2000, and in part by adjustment during model calibration. Loads of fecal bacteria, BOD, and DO from CSOs were calculated using these flows from the collection system model and event mean concentration (EMC) data collected during the sampling program under the previous LTCP effort (Malcolm Pirnie, 2004a, b). As described in the 2004 LTCP, analytical water quality and flow data collected during the year 2000 were combined to calculated mass pollutant loadings under wet weather conditions. System-wide average EMCs were calculated to be 92,500 #/100mL for fecal coliform bacteria and 24.1 mg/L for BOD (Malcolm Pirnie, 2004b Table 3-1). These system-wide EMCs were used as initial inputs and adjusted as needed during calibration. Table 3-2 summarizes the concentrations used to calculate wet weather loads. Based on experience with similar systems, a general approach has been adopted that allows different concentrations to be specified for the first hour, second hour and all remaining hours of wet weather discharges. A review of the 2000 event sampling results suggested that event mean concentrations (EMCs) would be the most consistent way to express the CSO discharges, so these single values are used for all three of the possible temporal components. For storm water discharges, however, it was determined in calibration that using a reduced concentration for the balance of discharges was useful in reproducing the data.

Table 3-1: Summary of Inflow Sources in Scajaquada Creek Model

Source Type	Name	River Mile	Total Overflow Volume (MG)	
			Wet Weather Event 1 (Sept. 23-25, 2009)	Wet Weather Event 2 (Oct. 24-25, 2009)
CSO	ScajDrain1&2	6.56	0.417	0.000236
	ScajDrain3-15	5.62	68.9	23.5
	ScajDrain16-22	4.04	66.7	20.0
	ScajDrain23	3.06	6.32	1.33
	CSO 056	1.56	0.000269	0.0364
	CSO 060	1.51	1.91	1.92
Storm Water	ScajStorm	2.32	18.5	17.3

Table 3-2: CSO and Storm Water Pollutant Concentrations for Scajaquada Creek

Parameter	Units	CSO			Storm Water		
		1st hour	2nd hour	Balance	1st hour	2nd hour	Balance
CBODU	mg/L	26	26	26	30	30	2
Dissolved Oxygen	mg/L	3.0	3.0	4.0	5.0	5.0	6.0
Fecal Coliform	#/100 mL	200,000	200,000	200,000	150,000	150,000	1,000

3.1.3.d Reaction Rates

Reaction rates were initially based on literature and judgment, and subsequently modified as needed during the calibration process. For bacteria and CBOD, reaction parameters include first order decay rate, particulate fraction and settling velocity. For dissolved oxygen, reaction rate parameters include CBOD exertion, reaeration and sediment oxygen demand. More detail on these parameters is provided in the subsequent model calibration section of this report.

3.2 MODEL CALIBRATION

The Scajaquada Creek model was calibrated to data collected in 2008 and 2009 by various team members. Data collected in 2008 was limited to dry weather conditions, and these were used to calibrate the steady-state behavior of the model. The transient, wet weather response of the model was calibrated using wet weather survey data collected in 2009. Water quality sampling locations in Scajaquada Creek are depicted in Figure 3-3.

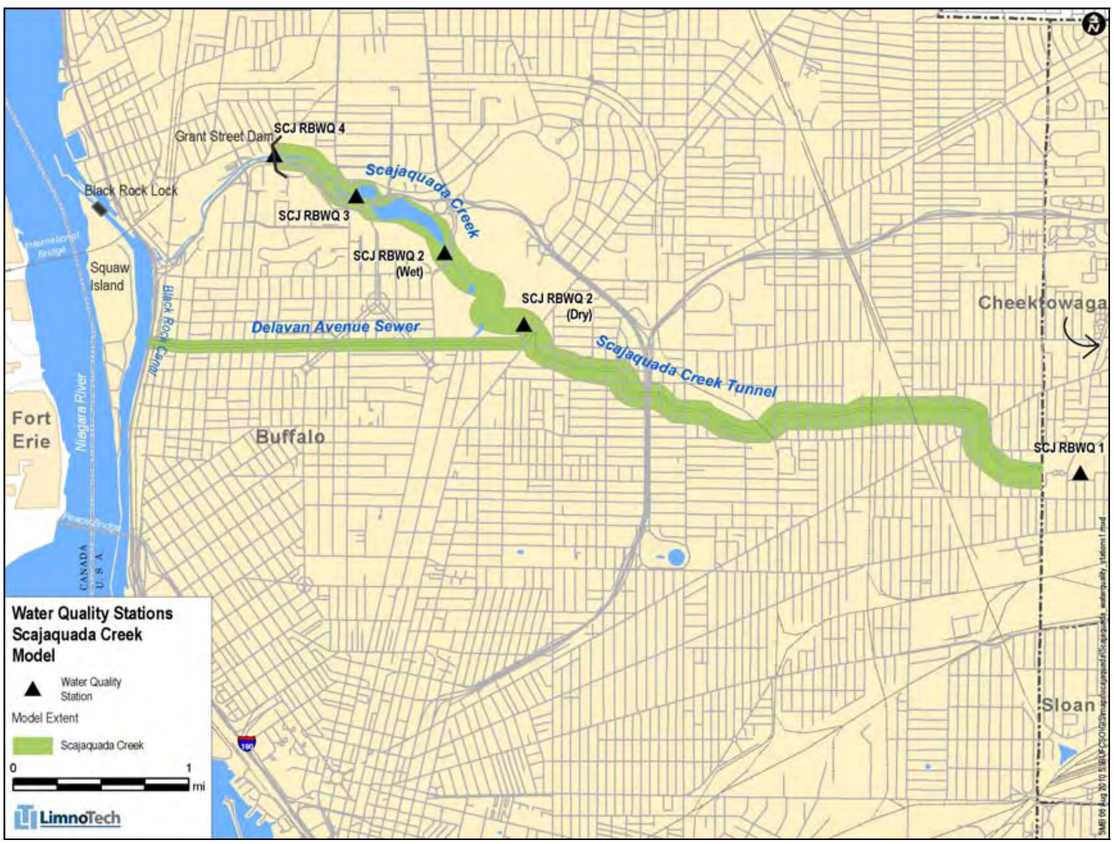


Figure 3-3: Scajaquada Creek Water Quality Sampling Locations

Mobilization for wet weather sampling was made complicated by the requirement of simultaneous event response in the Niagara and Buffalo Rivers, in addition to Scajaquada Creek. Only two successful sampling events took place, and the first of these had the potentially confounding effect of significant additional rainfall less than 48 hours after the beginning of the sampling. Initially, the model was calibrated to this first event, and the second event was used for model confirmation. However, the simulation of the second event was not satisfactory using the initial calibration, so modifications to various parameters were made. Ultimately the calibration presented here reflects a balance between the two events.

3.2.1 Approach

The model was calibrated by visual comparison of output to data. Quantitative measures of fit, such as relative percent or root-mean-square error, were not considered to be appropriate because of the relative sparseness and uncertainty of the grab samples from the wet weather survey. Instead, it was required that the model reflect the changes in water quality associated with the onset wet weather inflows, and the general rate of return to dry weather conditions as wet weather flows recede. In particular, emphasis was placed on neither underestimating bacteria concentration, nor overestimating dissolved oxygen levels. Water quality data were collected at four stations as described in Appendix C of this report. The data collected at SCJ RBWQ1 were used as upstream boundary concentrations for the model, so this point is not included in the model-to-data comparisons that follow.

Both kinetic parameters and the event mean concentrations of pollutants in CSO and storm water discharges were varied during the calibration. The pre-calibration and final calibrated values of the kinetic parameters are given in Table 3-3. All reaction rates used in the model are within ranges found in published literature such as Chapra (1997), USEPA (1987), and USEPA (1985). The event mean discharge concentrations were given previously in Table 3-2. Note that the SOD values in Table 3-3 range from 2.5 to 3.0 g/m^2/day for the open channel sections of the system, but were held to 0.5 to 0.75 g/m^2/day for the enclosed portions. The SOD values for the open channel sections are within the range of the field measurements taken in 2008 and documented in Appendix D.

Table 3-3: Summary of Kinetic Parameters for the Scajaquada Creek WASP Model

Parameter	Units	Pre-Calibration Values	Calibrated Values
	CBOD - CSO Sources		
Deoxygenation Rate	day^{-1}	0.5	0.5
Particulate Fraction	--	0.5	0.5
Settling Velocity	m/day	0.0	4.0
	CBOD - Storm Water Sources		
Deoxygenation Rate	day^{-1}	0.001	0.4
Particulate Fraction	--	0.5	0.25
Settling Velocity	m/day	0.0	1.0
	Fecal Coliform - CSO Sources		
Decay Rate	day^{-1}	1.0	0.5
Particulate Fraction	--	0.75	0.75
Settling Velocity	m/day	0.0	4.0
	Fecal Coliform - Storm Water Sources		
Decay Rate	day^{-1}	1.0	0.5
Particulate Fraction	--	0.5	0.5
Settling Velocity	m/day	0.0	1.0
	Segment Specific Parameters		

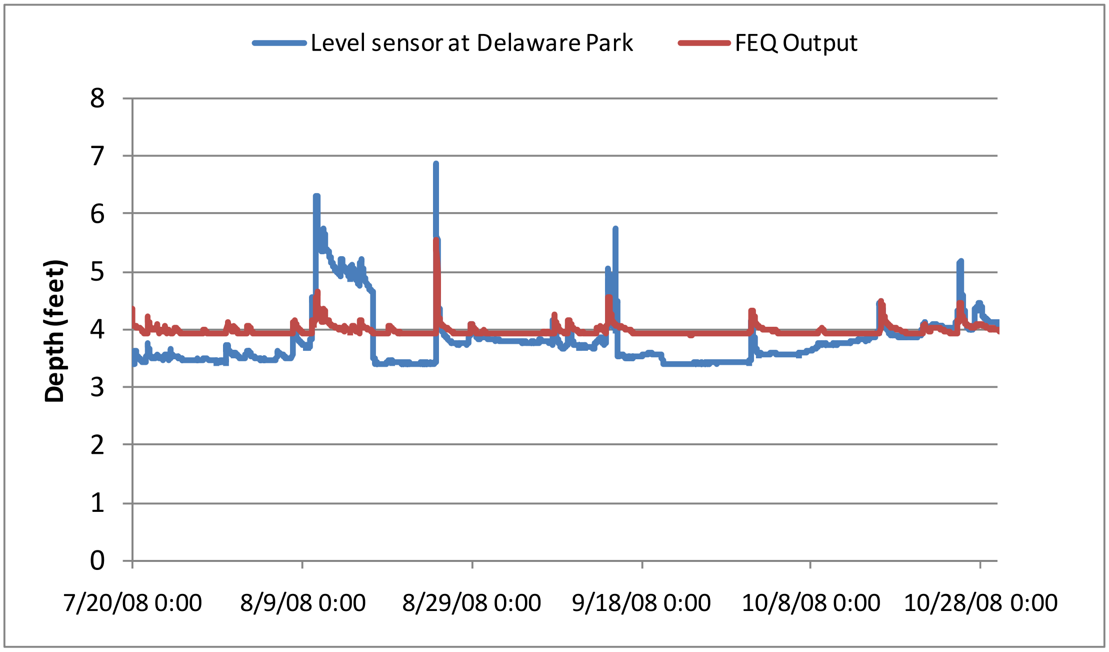
Segment ID	Pre-Calibration SOD ($g/m^2/d$)	Calibrated SOD ($g/m^2/d$)	Segment ID	Pre-Calibration SOD ($g/m^2/d$)	Calibrated SOD ($g/m^2/d$)
1	0.10	0.75	11	0.33	0.75
2	0.10	0.75	12	0.33	3.00
3	0.10	0.75	13	0.33	3.00
4	0.10	0.75	14	0.33	3.00
5	0.33	2.50	15	0.33	3.00
6	0.33	2.50	16	0.33	3.00
7	0.33	2.50	17	0.33	3.00
8	0.33	3.00	18	0.33	3.00
9	0.33	3.00	19	0.33	0.50
10	0.33	3.00			

3.2.2 Hydrodynamics

Development of the Scajaquada Creek hydrodynamic model directly followed the approach outlined in the EPA approved Modeling Work Plan (Appendix A). Because the model does not need to reproduce phenomena such as stratification or lateral mixing, it was felt that the combination of the HEC-2 geometry and inflows from the calibrated collection system model and upstream measurements would adequately represent the hydraulic behavior of the system with respect to advective transport. The ADCP stage and flow data collected at the upstream end of the model domain were used to drive the model's upstream flow boundary condition. The two downstream stage measurement locations were used for comparison with model predictions of water surface (Figure 3-4). This comparison showed relatively good agreement between model and data with a discrepancy of approximately 0.5 feet or less over a channel depth of about four feet.

The occasional underprediction of stage is likely attributable to the temporary collection of debris on the "picket fence" trash rack that tops the Grant Street Dam. For example, there is a step decrease in elevation following a wet weather event on August 16, and also an increasing trend that begins around September 30. These features are not reproduced by the FEQ model because it does not dynamically alter the head loss associated with the inlet structure; such a feature would be impractical to apply in water quality simulations.

Although the model could have been modified to "curve fit" to the data points, the model inputs driving system hydraulics (bed configuration, slope, and channel roughness) were determined from previous modeling performed by the U. S. Army Corps of Engineers and there was basis to significantly alter them. It is unlikely that the discrepancies between simulated and observed depth would significantly impede the utility of the model for its intended purpose.



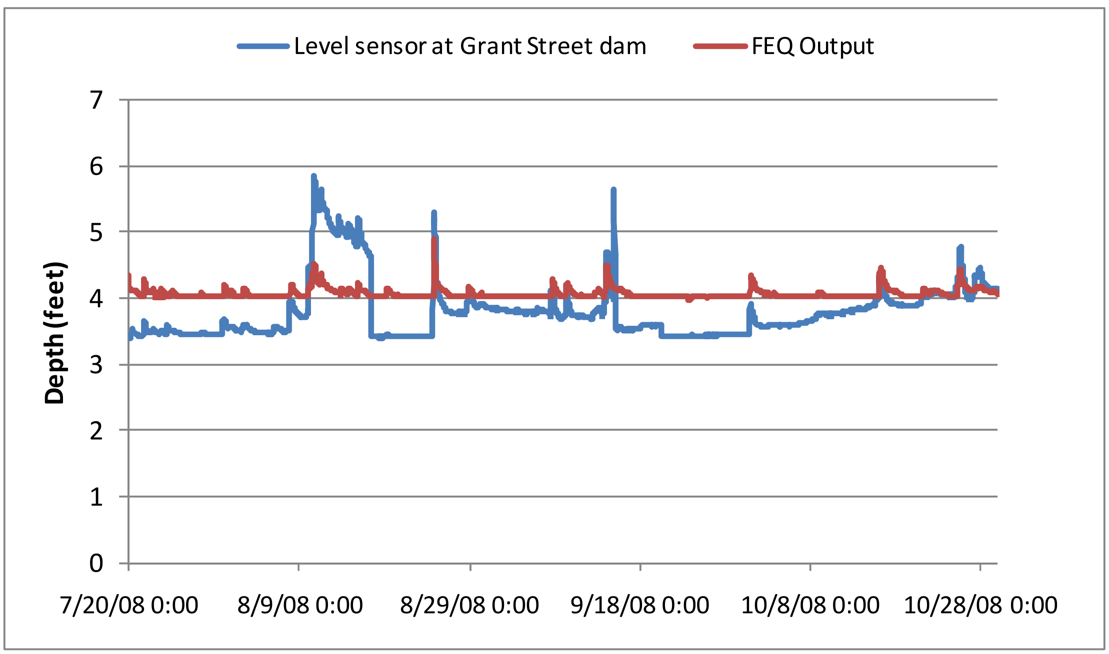


Figure 3-4: Comparison of Observed and Simulated Water Depth at Delaware Park and Grant Street Dam during 2008 Data Collection Period

3.2.3 Dissolved Oxygen

Calibration of the Scajaquada Creek dissolved oxygen model was performed for both dry weather and wet weather conditions. The first dry weather water quality event preceded deployment of the ADCP and stage monitoring equipment, therefore upstream flow was not recorded on Scajaquada Creek during the first dry weather event. As a result, dry weather calibration was only performed for the second dry weather event (September 3, 2008). Results of the dry weather calibration are presented in Appendix G. The results indicated that model is adequately predicting low dissolved oxygen along the length of Scajacquada Creek during dry weather.

The wet weather calibration of dissolved oxygen was performed for both wet weather events in 2009. Time series comparisons of model-predicted dissolved oxygen are compared with the sampling results at stations SCJ RBWQ2, SCJ RBWQ3 and SCJ RBWQ4 in Figure 3-5, Figure 3-6, and Figure 3-7, respectively. These figures present the first wet weather event.

The model reproduces the general trend of DO, in that the initial inflows of storm water and CSO tend to push DO higher, followed by a decrease as oxygen demand is satisfied. The observed decreases in DO at downstream stations RBW3 and RBW4 are somewhat steeper than predicted by the model. This drop in DO corresponds with a transition point between two precipitation events and may be due to the potential "noise" in the data set. If so, the data may not be a realistic representation of "dry weather" DO following a wet weather event. Further evaluation of model results indicate that this depletion of DO is likely due to impacts other than the decay of BOD which has entered the creek during the wet weather event. Model results indicate that when DO is dropping (after 9/27 18:00), the spike in BOD load has already been consumed. This observation is illustrated in Figure G-3.

Parameters, such as sediment oxygen demand (SOD), were adjusted to improve the simulation of the decline of DO; however, in order to parameterize the model to match this DO drop which occurs during the transition point between precipitation events, SOD rates would have to be adjusted beyond a reasonable range. This adjustment would likely have a negative impact on the dry weather calibration shown above. Another factor related to the challenge of calibrating low DO is that the model formulation does not include the simulation of diurnal fluctuations of DO caused by productivity. The model predicts a daily average DO concentration which was compared with single DO measurements collected during various times of the diurnal cycle.

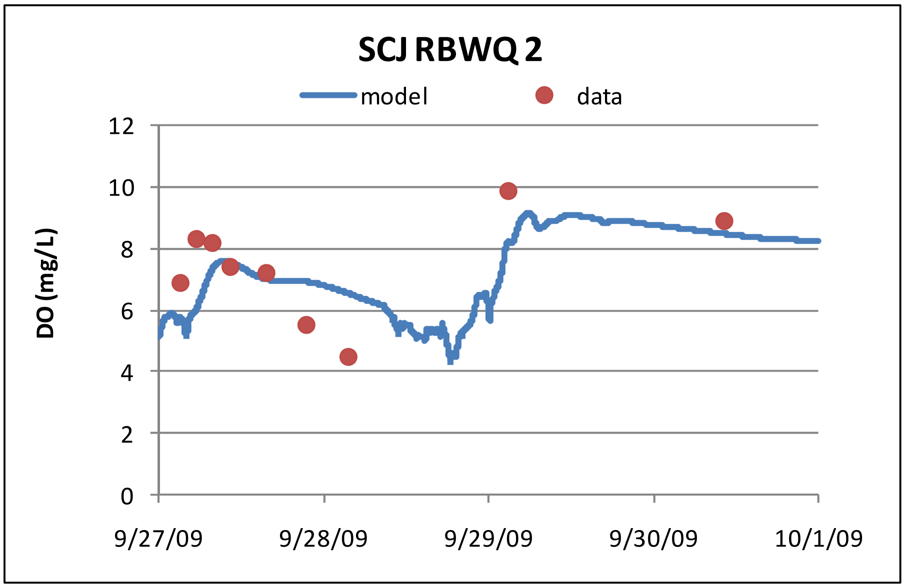


Figure 3-5: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ2 during the September 27, 2009 Event

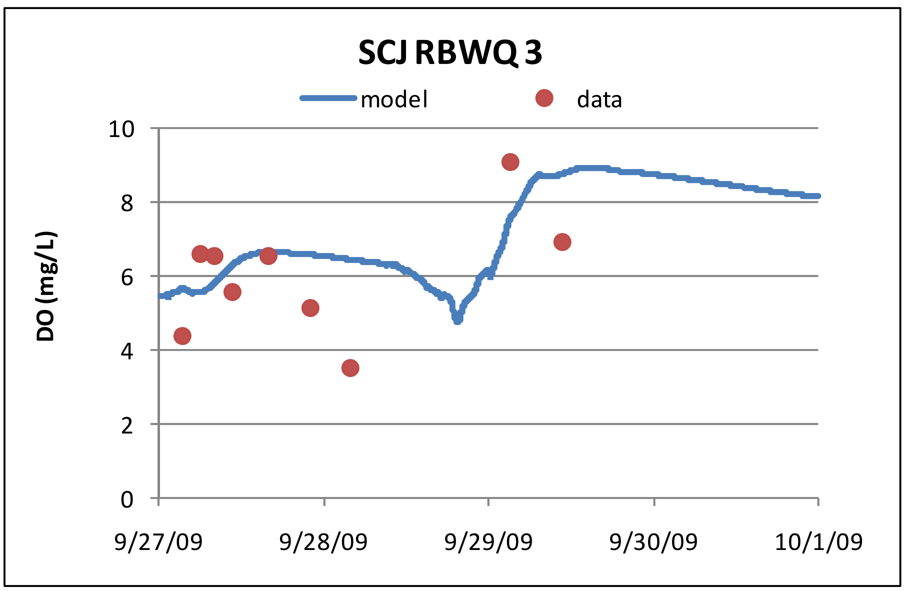


Figure 3-6: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ3 during the September 27, 2009 Event

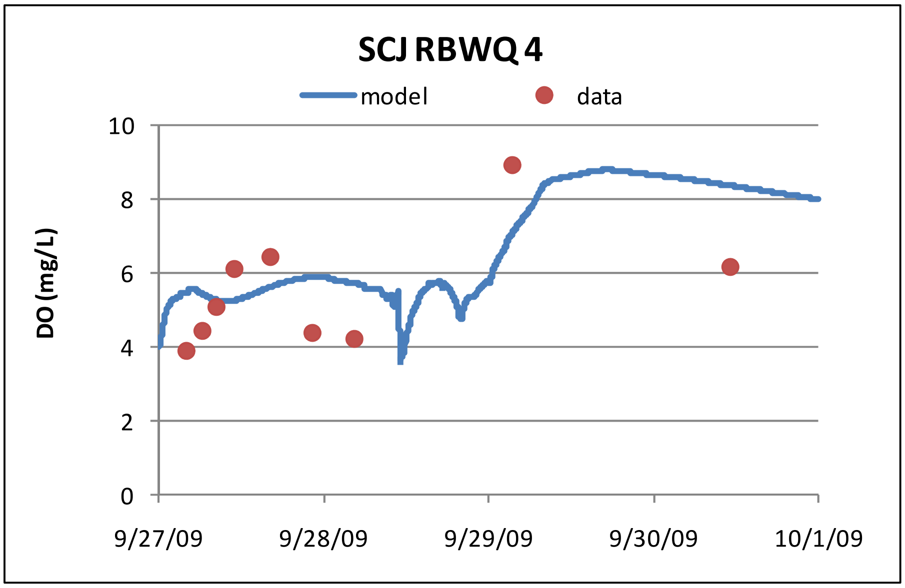


Figure 3-7: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ4 during the September 27, 2009 Event

The next group of figures (Figure 3-8, Figure 3-9, and Figure 3-10) presents DO results for the second wet weather event. Here, the model appears to follow the pattern of DO variation fairly well at station RBWQ2, but the subsequent decrease in DO at downstream stations is exaggerated. This is an example of the balance between events that was mentioned previously: the DO sag could be reduced for this event by changes in kinetic parameters, but then the first event would show over-prediction. Ultimately, the desire is to avoid understating the effects of wet weather flows on DO levels, so the results for the second event are considered acceptable given the various limitations in the model representation.

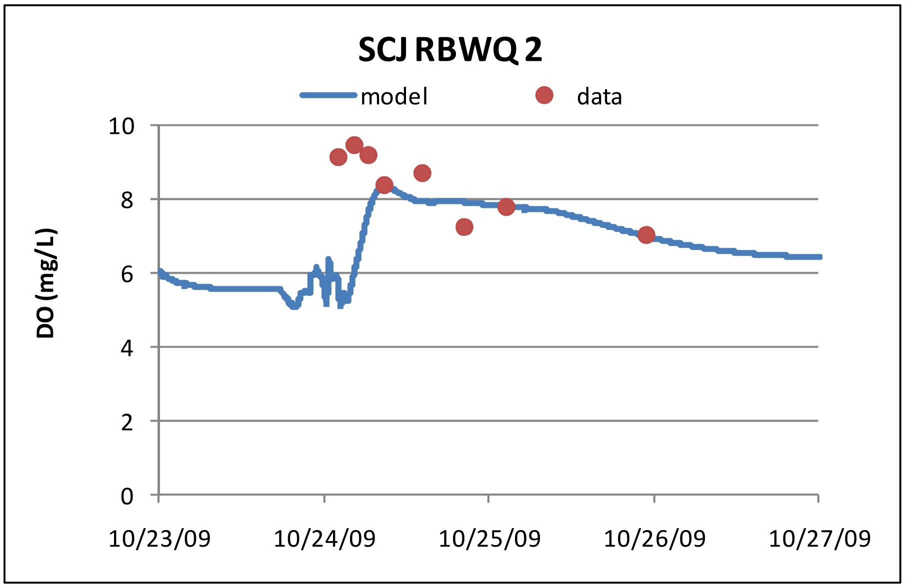


Figure 3-8: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ2 during the October 23, 2009 Event

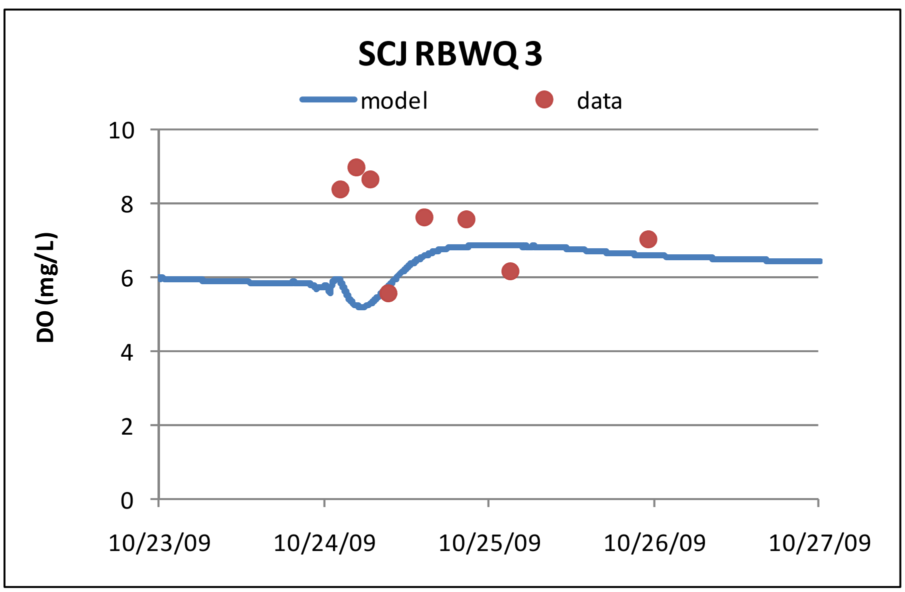


Figure 3-9: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ3 during the October 23, 2009 Event

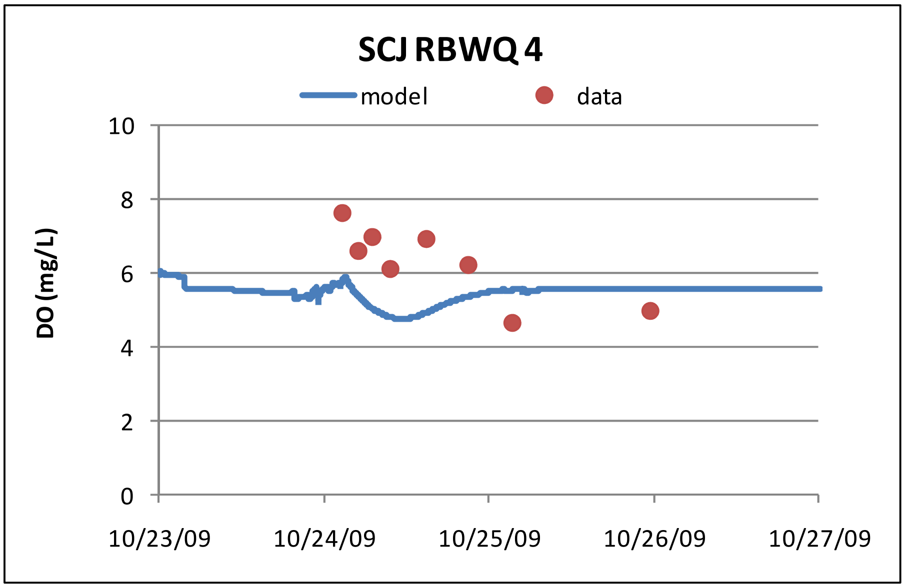


Figure 3-10: Temporal Profile of Observed and Simulated Dissolved Oxygen at Station SCJ RBWQ4 during the October 23, 2009 Event

Scatter plots of model predictions versus data provide an alternate depiction of a model's performance, and these are presented in Figure 3-11 and Figure 3-12 for the first and second wet weather events, respectively. In the first event, the scatter plot indicates that the lower values of DO (less than 5 mg/L) tend to be overpredicted by the model in this event, whereas higher values (greater than 8 mg/L) tend to be underpredicted. The overprediction of low values was discussed previously. The underprediction may be partly a matter of timing, as the scatter plot matches the model output point that is closest in time to the sample datum. As seen in the time series plots, the predicted DO rise appears to lag the sampling somewhat in this event.

For the second event, the scatter plot suggests a general tendency to underpredict DO concentrations. As noted in the discussion of the time series plots, this event appeared to have higher DO concentrations in general, and it was felt that parameter adjustments to match these results more closely would produce a less conservative model overall.

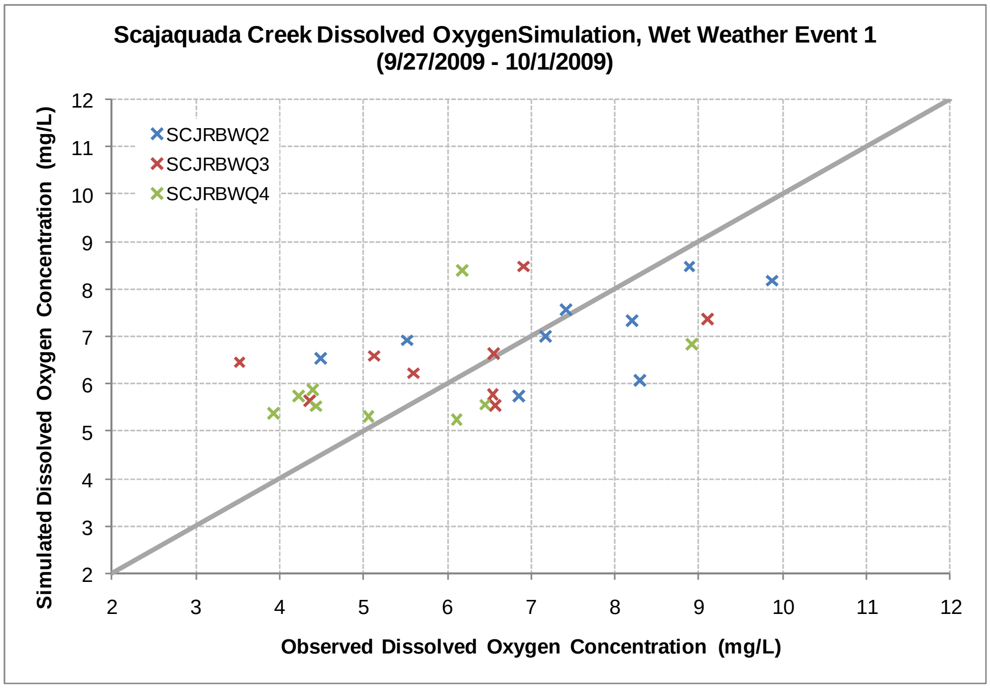


Figure 3-11: Comparison of In-Stream Observed and Simulated Dissolved Oxygen Concentrations during the September 27, 2009 Event at All Locations on Scajaquada Creek

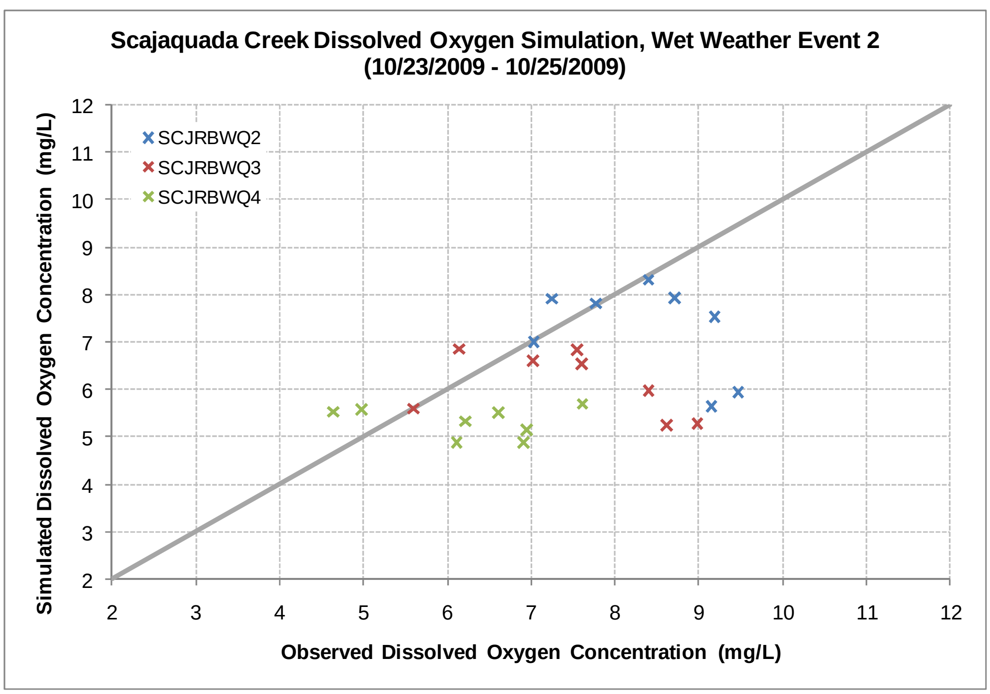


Figure 3-12: Comparison of In-Stream Observed and Simulated Dissolved Oxygen Concentrations during the October 23, 2009 Event at All Locations on Scajaquada Creek

3.2.4 Bacteria

Calibration of the Scajaquada Creek fecal coliform bacteria model was performed for both dry weather and wet weather conditions. The first dry weather water quality event preceded deployment of the ADCP and stage monitoring equipment, therefore upstream flow was not recorded on Scajaquada Creek during the first dry weather event. As a result, dry weather calibration was only performed for the second dry weather event (September 3, 2008).

Dry weather water quality data were reviewed for suitability in calibrating the model for dry weather flow. It was noted that bacteria levels downstream of the Scajaquada Drain Tunnel were considerably higher than upstream; this pattern was also observed in other data sources, such as those supplied by the Buffalo Riverkeeper organization. The increase in bacteria suggested the existence of a dry weather source within the tunnel, which would be of concern to BSA. BSA conducted an investigation and discovered a malfunctioning weir plate at a sewer control point, which was repaired. However, for model calibration purposes a dry weather source needed to be included to properly match the data. The source was characterized by a fecal coliform density of 1,000,000 CFU/100 mL, representing raw sanitary sewage, and a flow rate of 0.5 cfs. These parameters provided a reasonable match for the dry weather data. A comparison of simulated fecal coliform bacteria and sampling results is presented in Appendix G. The results indicated that model is adequately predicting fecal coliform bacteria along the length of Scajaquada Creek during dry weather.

The wet weather calibration of fecal coliform bacteria was performed for both wet weather events in 2009. Time series comparisons of model-predicted fecal coliform bacteria are compared with the sampling results at stations SCJ RBWQ2, SCJ RBWQ3 and SCJ RBWQ4 in Figure 3-13, Figure 3-14, and Figure 3-15, respectively. Similar to the DO plots, the data indicate a drop in concentration between the first and second rainfall occurrences during this event that is not completely captured by the model. Again, kinetic parameters were adjusted to better reproduce the apparent drop in bacteria density but not beyond reasonable ranges. The grab samples themselves do not tell an entirely consistent story between sampling sites; for example, the occasional non-detect results at various stages of the event are difficult to explain. The model does do a reasonable job of reproducing the highest bacteria densities when they occur, however, which is an important quality. Note that the scheduled 72-hour sample was not taken at the Scajaquada Creek stations, as it was decided during sampling that the occurrence of the second rainfall would not represent the “falling limb of hydrograph” as was originally intended.

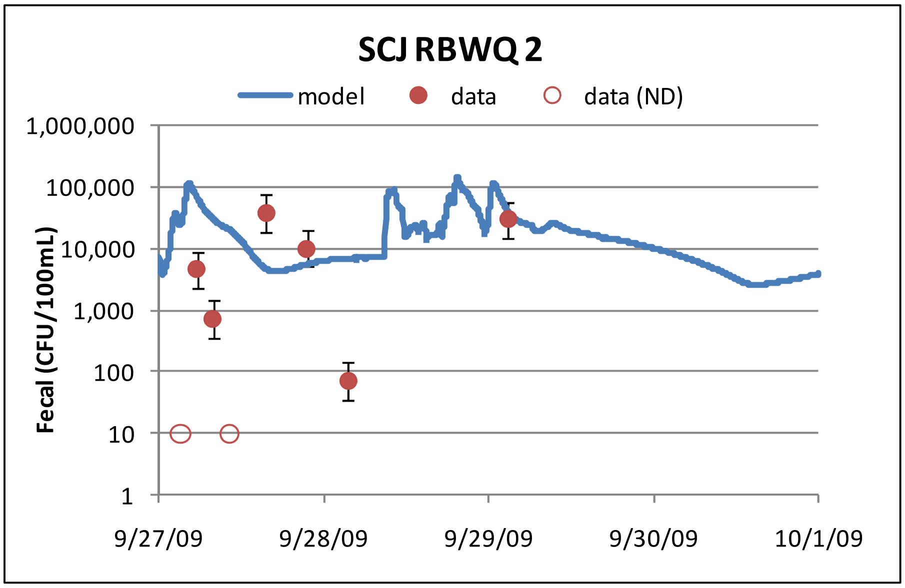


Figure 3-13: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ2 during the September 27, 2009 Event

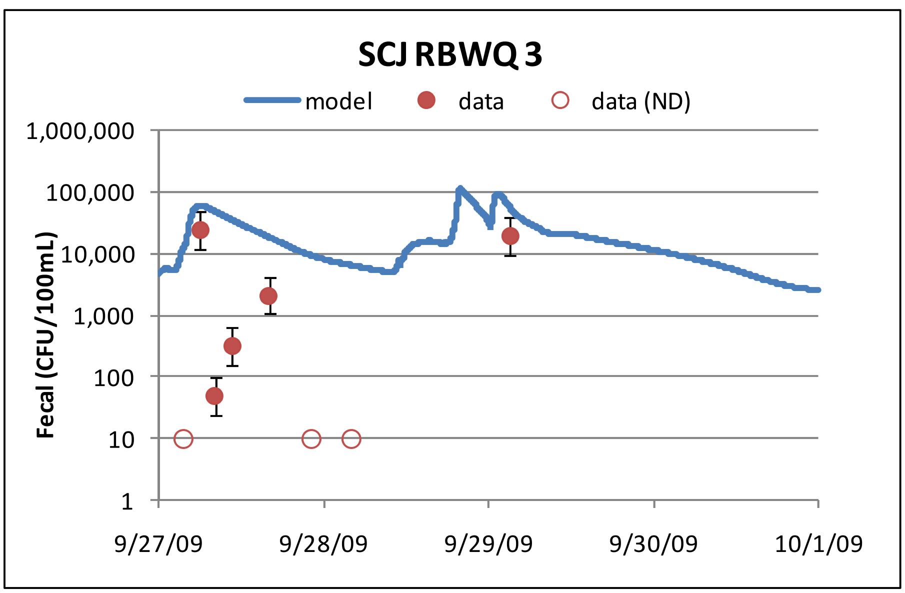


Figure 3-14: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ3 during the September 27, 2009 Event

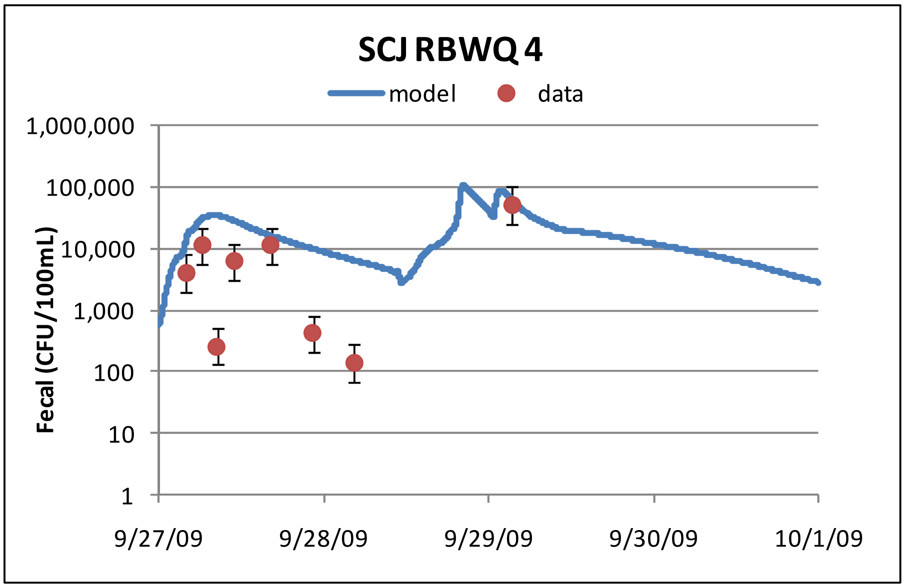


Figure 3-15: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ4 during the September 27, 2009 Event

The next group of figures (Figure 3-16, Figure 3-17 and Figure 3-18) presents fecal coliform bacteria results for the second wet weather event. With the exception of a few data points, the model is in very good agreement with the data at all three stations. The model captures the peak densities as well as the relatively slow decay in density over time.

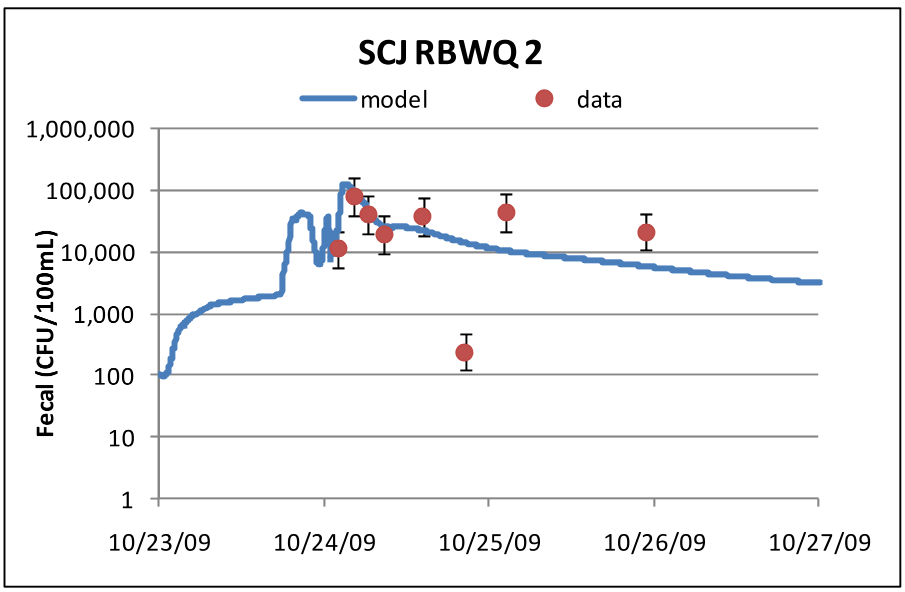


Figure 3-16: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ2 during the October 23, 2009 Event

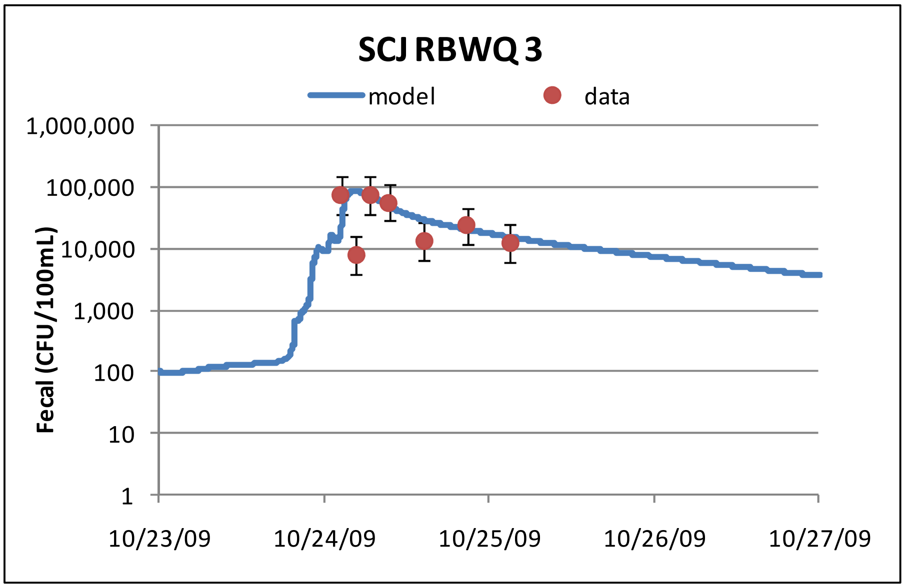


Figure 3-17: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ3 during the October 23, 2009 Event

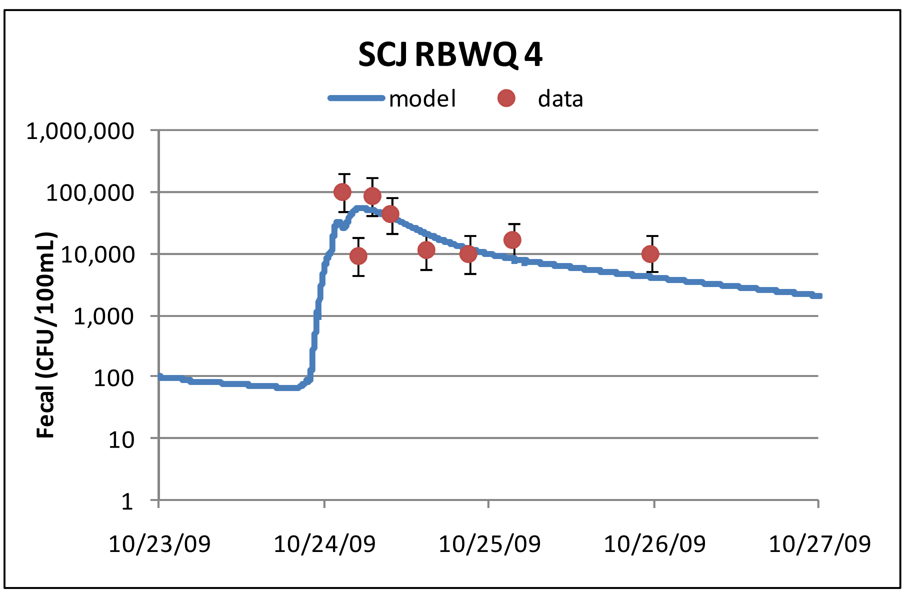


Figure 3-18: Temporal Profile of Observed and Simulated Fecal Coliform at Station SCJ RBWQ4 during the October 23, 2009 Event

Scatter plots of modeled bacteria versus sampling results are shown in Figure 3-19 and Figure 3-20. These figures illustrate the model's performance in reproducing the general range of observed bacteria densities, including peaks. The individual points represent the model result from the time of sample collection, and the error bars represent the range of modeled results within a two-hour window of the sample collection time. This allows for some imprecision in the recording of sample collection times as well as the timing of the forcing functions in the model. The plots also include a 1:1 line (grey). Points which fall directly upon the 1:1 line would indicate a perfect fit. The plot also includes lines that bracket a factor of two (dark blue) and an order of magnitude (light blue). The factor of two brackets is intended to encompass uncertainty in analytical results, whereas the factor of ten brackets encompasses all sources of uncertainty in the observed data, including factors such as in-stream variability and sample collection and handling.

The plots show that the overall agreement between model and data is better for the second event than for the first. The points that fall outside the order-of-magnitude bracket for the first event are generally those that occur between the two rainfall occurrences of that event, where the data are difficult to explain. For the second event, over half the points are within the factor-of-two bracket and over 90% are within the order-of-magnitude bracket.

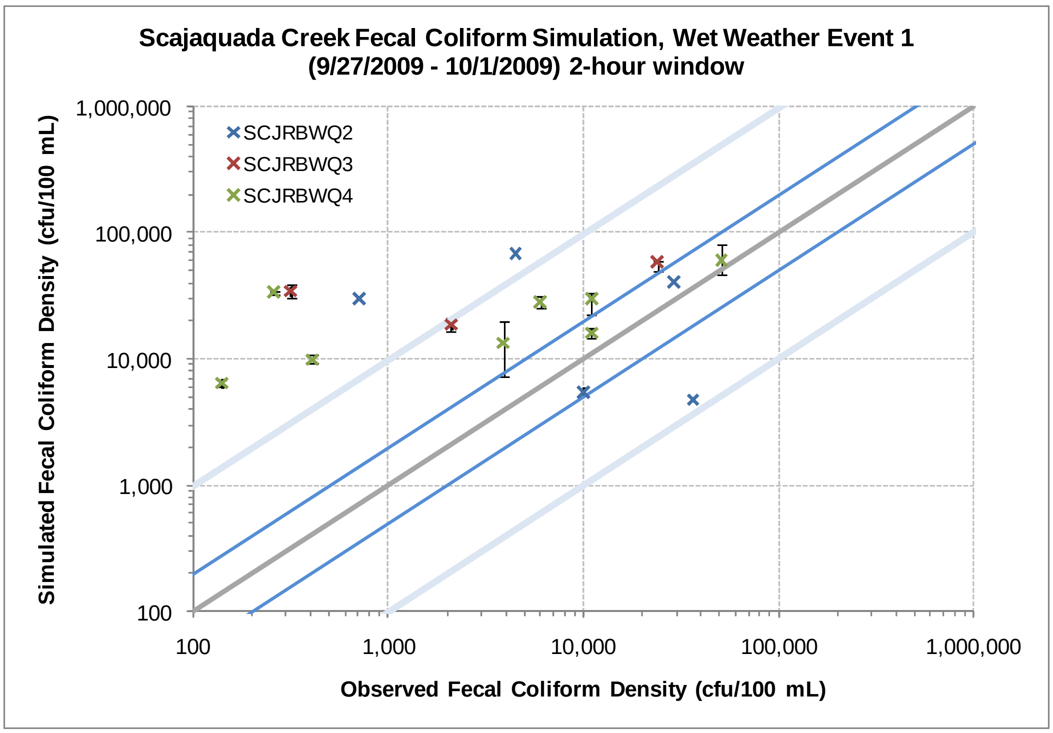


Figure 3-19: Comparison of In-Stream Observed and Simulated Fecal Coliform Densities during the September 27, 2009 Event at All Locations on Scajaquada Creek

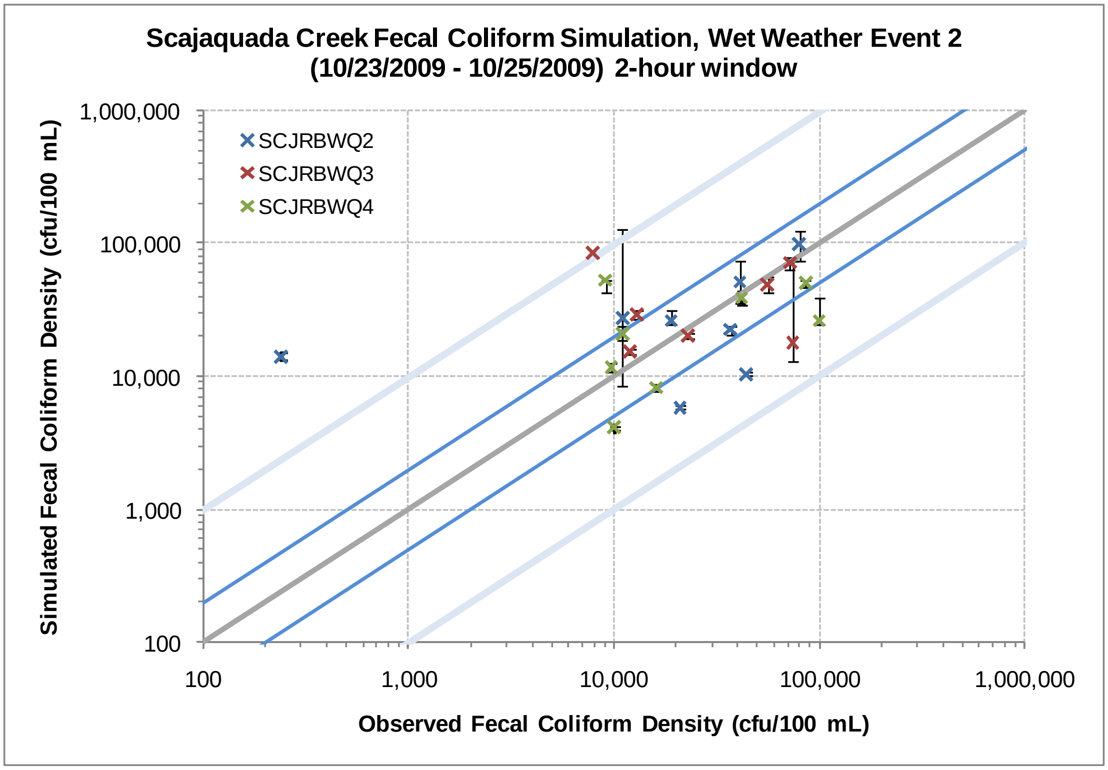


Figure 3-20: Comparison of In-Stream Observed and Simulated Fecal Coliform Densities during the October 23, 2009 Event at All Locations on Scajaquada Creek

3.2.5 Calibration Summary

In general, the Scajaquada Creek water quality model is able to reasonably reproduce the magnitude and range of both dissolved oxygen and fecal coliform bacteria measurements at each location for both wet weather calibration events. For dissolved oxygen, the model captured the increase in DO during each storm event followed by decreasing DO levels during the storm recession due to SOD. In general the calibration resulted in predicted DO concentrations which did not understate the effects of wet weather flows on DO levels. Limitations of the DO simulation include potential diurnal variations in measured DO that are not included in the model formulation.

The Scajaquada Creek model predicted the increase in fecal coliform bacteria during each storm event, followed by decreasing populations during the storm recession. The second wet weather event (which was not influenced by a subsequent precipitation event) resulted in a better calibration than was obtained for the first wet weather event. In general the fecal coliform bacteria calibration resulted in predicted concentrations that do not understate the effects of wet weather flows.

4. NIAGARA RIVER MODEL

A water quality model was calibrated for Niagara River for the section from the downstream end of Lake Erie to the approximate northern municipal boundary of the City of Buffalo. The calibrated hydrodynamic model extends further downstream from the Lake Erie boundary to Niagara/American Falls. Both models also include Black Rock Canal from the Erie Basin Marina to the Black Rock Lock, and the segment of Scajaquada Creek downstream of the Grant Street dam. The Black Rock Canal portion of the Niagara River model simulates hydrodynamics and bacteria. As described in Section 5 below, a separate Black Rock Canal model was constructed to model dissolved oxygen. The Niagara River model domain is depicted in Figure 4-1.

4.1 MODEL DEVELOPMENT

The Niagara River model has been designed to answer the following questions specific to the Niagara River (LimnoTech, 2008):

- What is the spatial and temporal distribution of bacteria in the Niagara River following an overflow event?
- What are the impacts of Scajaquada Creek and Black Rock Canal CSOs on Niagara River water quality, with respect to bacteria?
- How will CSO discharges and flows from the Buffalo River move in the Niagara River; under what conditions will these flows “hug” the eastern bank?
- What effect will considered CSO control projects have on water quality in the Niagara River, relative to current conditions?

The two-dimensional Black Rock Canal model, as part of the Niagara River model, has been designed to answer the following questions regarding bacteria:

- What is the impact of BSA’s CSO discharges to bacteria concentrations in Black Rock Canal?
- What effect will considered CSO control projects have on water quality in the Black Rock Canal, relative to current conditions?

The Niagara River model developed and calibrated under this project can be used to meet these objectives. The following sections describe the development and calibration of the model.

Figure 4-1: Niagara River Model Domain

4.1.1 Model Selection and Background

The USEPA-supported Environmental Fluid Dynamics Code (EFDC) was selected as the model to simulate water quality in the Niagara River and Black Rock Canal. It was also selected as the model for the Buffalo River as described in Section 3. This model was first developed in the 1980s and has been publicly available since 2002. The version used in this project is Version 1.01 (USEPA, 2007).

EFDC is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions. It has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic models in the world (USEPA, 2007).

EFDC was selected for the Niagara River model for the following reasons:

- EFDC readily allows linkage between one-dimensional (i.e. Scajaquada Creek) and two-dimensional reaches (Niagara River);
- EFDC can readily be used to simulate dissolved oxygen (Black Rock Canal) and bacteria fate and transport;
- The Matlab application SeaGrid and accompanying GIS processing tools developed by LimnoTech provide for simplified model grid construction and refinement compatible with EFDC; and
- LimnoTech has already developed a model processing and visualization utility for EFDC that will facilitate presentation and evaluation of model results.

In order to provide flexibility and efficiency when simulating the impact of fecal coliform loading from a variety of sources, the EFDC water quality sub-model was enhanced by LimnoTech to incorporate two additional state variables for CBOD and fecal coliform, including a unique set of input coefficients for these variables. For the Niagara River and Black Rock Canal model simulations, the three state variables were used to represent upstream (i.e., above city boundaries), combined sewer overflow (CSO), and separate stormwater sources to the model domain. The EFDC model reports predicted concentrations for each individual state variable, as well as the total constituent concentration. The multi-variable approach effectively provides a "built-in" component analysis for all model cells which will be useful during the model application phase.

4.1.2 Domain and Segmentation

The Niagara River model is a two-dimensional model which is vertically averaged and laterally segmented. The model grids for both the hydrodynamic and water quality portions of the Niagara River model are shown in Figures 4-2 and 4-3, respectively. Enlarged versions of these maps are provided in Appendix E. The upper and lower boundaries of the Niagara River model domain were chosen based on available data sets and system features. For both hydrodynamic and water quality simulations, the model's upstream boundary was set sufficiently upstream of the City of Buffalo's CSO sources. The downstream model boundaries differ for hydrodynamic and water quality simulations. The lower hydrodynamic boundary was set to correspond with available surface elevation data. The downstream water quality boundary was set to the southern end of Grand Island, extending beyond all CSO outfalls in the Buffalo Sewer Authority system.

Both model grids include Black Rock Canal from its southern end at the Lake Erie Basin Marina to the Black Rock Lock, as well as the segment of Scajaquada Creek downstream of the Grant Street dam. The grid is designed to allow simulation of hydrodynamic circulation in and around Black Rock Canal, to capture gradients in bacteria in the transition of classification zones of the river, and to simulate flow from the mouth of Scajaquada Creek into Black Rock Canal. The model is also designed with sufficient detail to accurately simulate hydrodynamic conditions in Black Rock Canal, given operation records for the lock during model simulation period.

It should be noted that the Niagara River/Black Rock Canal hydrodynamic model does not include a representation of the culverts in the breakwater between the Niagara and the Black Rock Canal. There are two reasons for this:

- The breakwater was represented in the model as an internal boundary and in order to model the culverts in EFDC, it would have been necessary to specify a flow series or function at that boundary. This would have been very difficult given the potentially complex and dynamic nature of flow through the culverts during high water events.

- Communication with the USACE Buffalo District regarding the culverts indicated that flow through the culverts occurs only rarely and that water levels typically do not reach the culvert inverts.

The Niagara River model grid is designed with approximately 100 m (328 ft) horizontal grid spacing and incorporates masking features to allow for the representation of the numerous islands in the river, a non-homogenous coastline, and breakwater features near the mouth of the Niagara and along Black Rock Canal. Grid spacing is variable in certain areas to allow for the model grid to be merged spatially with the grids for the Buffalo River and Black Rock Canal, and to provide for increased resolution near the mouth of the Buffalo River. The entire two-dimensional model grid consists of over 4,000 active grid cells, including Black Rock Canal and the downstream segment of Scajaquada Creek.

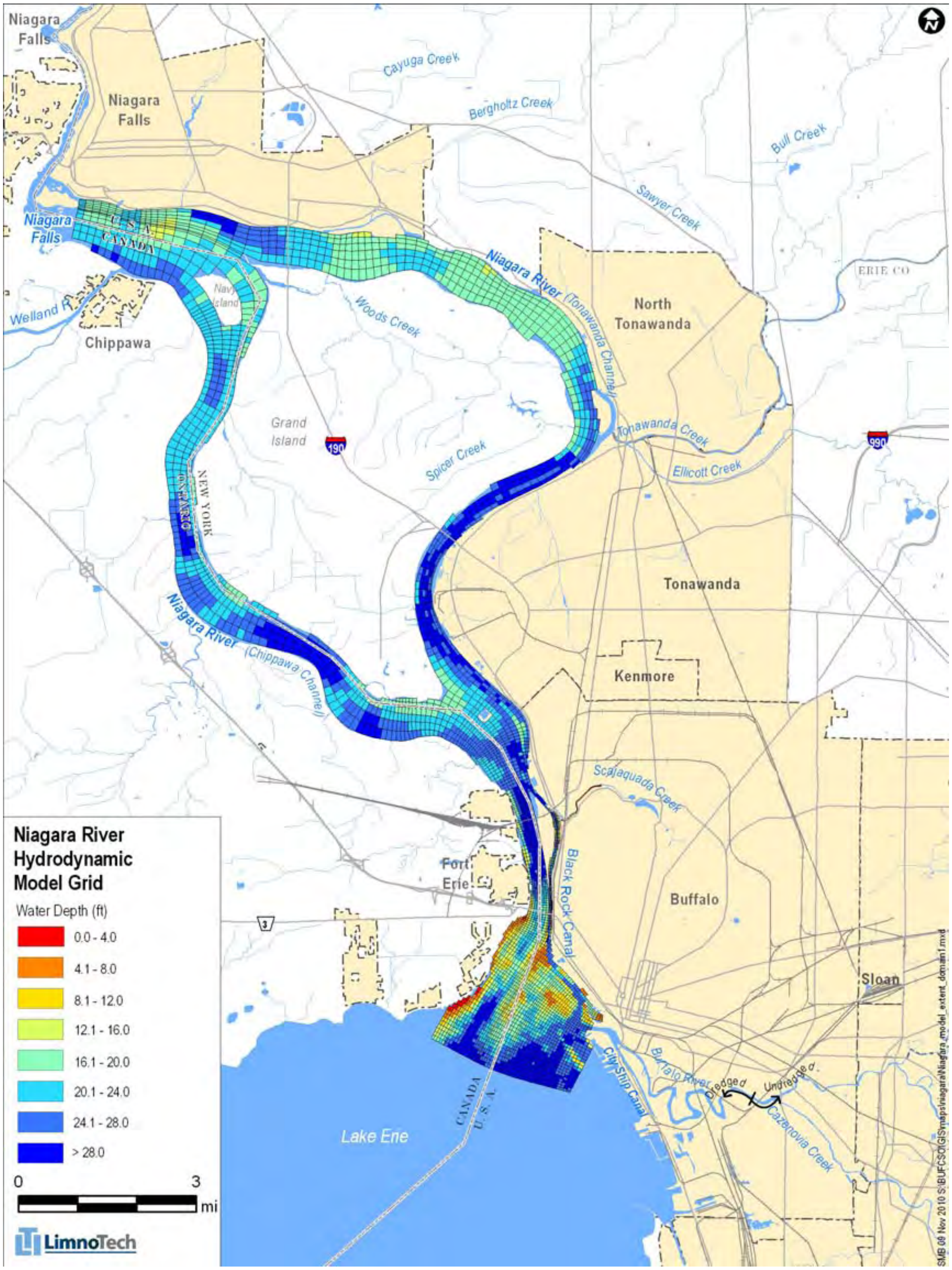


Figure 4-2: Niagara River Hydrodynamic Model Grid

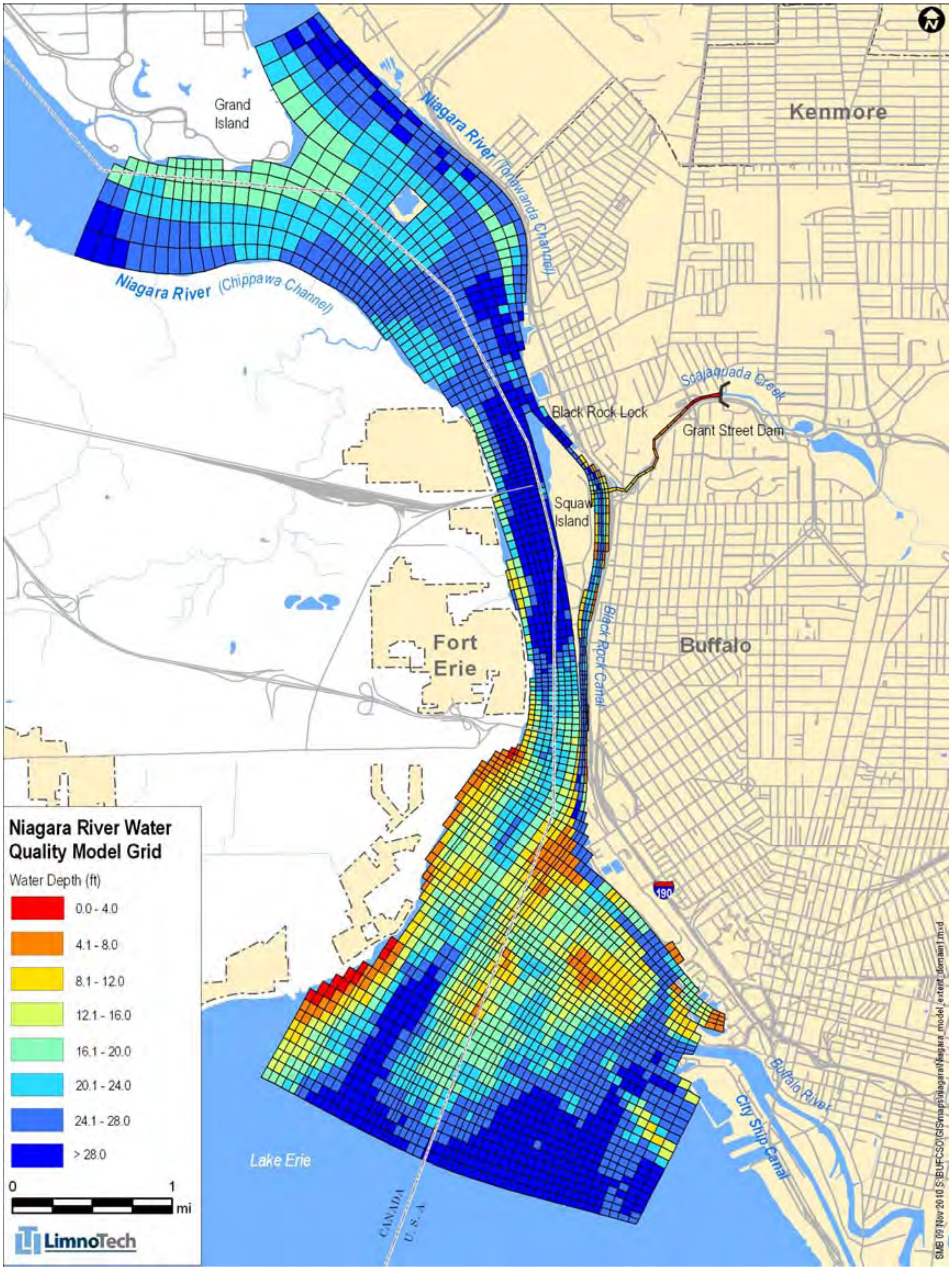


Figure 4-3: Niagara River Water Quality Model Grid

4.1.3 Model Input Development

The following sections describe model inputs for the Niagara River model.

4.1.3.a System Data

The primary source of bathymetric data to characterize the Niagara River and Black Rock Canal was obtained from NOAA's National Geophysical Data Center (NGDC). This dataset provided fine-scaled bathymetry data (reported as depth) for a portion of the eastern Lake Erie basin and Niagara River from its mouth to Niagara Falls. Measured depths were converted to true elevations using the IGLD85 datum. Gaps or regions of sparse data coverage in the Niagara River were supplemented with bathymetric data measured by others (e.g., TVGA Consultants, Delcan Corporation, and Nicholls).

Black Rock Canal bathymetry within the model was based on data from the U.S. Army Corps of Engineers (USACE), who conducted bathymetric surveys in 1999 and took detailed soundings in the canal in August 2008.

In areas with a high density of bathymetric data, all data points were averaged within each model segment or cell to calculate an average bottom elevation. In areas with sparse bathymetric data, the bottom elevation was estimated using available data and adjusted to be consistent with upstream and downstream segments. All datasets were converted to a consistent datum for use in this study.

4.1.3.b Boundary Conditions

The upstream boundary of the Niagara River hydrodynamic and water quality model is near the downstream end of Lake Erie, approximately one mile above the mouth of the Buffalo River and over 1.5 miles above the first monitoring station (NIA RBWQ 1a). Hourly flow data at the upstream boundary were calculated based on a United States Geological Survey (USGS) rating curve applied to 6-minute water level data at NOAA Station 9063020, located at the mouth of the Buffalo River (Figure 4-1). Water level data were obtained in units of feet IGLD 85 and converted to discharge (Q, cfs) using the following conversion and rating equation:

$$IGLD85 - 0.67 = IGLD55$$

$$Q = 260.5(H - 550.11)^{2.2}$$

Water quality in the Niagara River at the upstream model boundary is influenced by Lake Erie. The Buffalo Water Authority monitors *E. coli* and total coliform bacteria concentrations at the City of Buffalo water intake. The intake is located approximately mid-channel on the Niagara River, just west of the mouth of the Buffalo River. Total coliform samples are taken between 15 and 20 times per month, on average, while *E. coli* samples are typically only taken a few times per month. For the two wet weather events in 2009 (September 27-28 and October 24-25), complete monitoring data were not available. In October 2009, most sample results were reported as “Present” or “NEG” rather than as a numerical value. Sampling data from September-October 2008 were used to supplement the September-October 2009 Buffalo Water Authority data. These data ranged from 0 to 80 CFU/100 mL. An average value of 10 CFU/100mL was calculated and used to represent the background coliform concentration on Lake Erie at the upstream model boundary.

Hydrodynamic boundary conditions for the Black Rock Canal were established based on output from the calibrated hydrodynamic models of Scajaquada Creek/Delavan Drain, Buffalo River, and Niagara River.

The water quality of Black Rock Canal is influenced by upstream sources of fecal coliform from both Scajaquada Creek/Delavan Drain and the Buffalo River during dry weather, and primarily by CSO and stormwater sources in wet weather. Water quality output from the individual models for Scajaquada Creek and the Buffalo River were used to define boundary conditions for Black Rock Canal.

The downstream boundary of the Niagara River hydrodynamic model is driven by water level data at Niagara Falls. Water level on the upper Niagara River, upstream of the International Control Structure, is measured in real-time by New York Power Authority (NYPA) and Ontario Power Generation (OPG) at nine locations: NYPA's intake, the Sir Adam Beck intake (OPG), the LaSalle Yacht Club, Tonawanda Island, Huntley Station, Fort Erie, Frenchman's Creek, Black Creek, Slater’s Point, and the Material Dock gauges (Crissman et al. 1993). Hourly water level data were obtained from OPG for these nine stations, and helped to inform both the downstream boundary condition for the Niagara River hydrodynamic model as well as numerous calibration points throughout the model domain. Downstream water quality boundary conditions for the Niagara River were not required.

4.1.3.c Loads to System

Direct loads to the Niagara River within the model domain include CSOs, non-CSO stormwater, tributary loads, and wastewater treatment plant effluent.

Wet weather CSO volumes were simulated with the updated collection system model. The collection system model relied on a full network of rain gages installed for the 2000 and 2009 monitoring programs to calculate CSO flows for the 2000 data for the Buffalo River and the 2009 data for the remaining receiving stream models. Time series of flows from each CSO outfall simulated by the model (15 minute frequency) were used directly in the Niagara River and Black Rock Canal water quality model.

CSO concentrations were based in part on event sampling conducted in 2000, and in part by adjustment during model calibration. Loads of fecal bacteria, BOD, and DO from CSOs were calculated using these flows from the collection system model and event mean concentration (EMC) data collected during the sampling program under the previous LTCP effort (Malcolm Pirnie, 2004a, b). As described in the 2004 LTCP, analytical water quality and flow data collected during the year 2000 were combined to calculated mass pollutant loadings under wet weather conditions.

System-wide average EMCs were calculated to be 92,500 #/100mL for fecal coliform bacteria and 24.1 mg/L for BOD (Malcolm Pirnie, 2004b Table 3-1). These system-wide EMCs were used as initial inputs and adjusted as needed during calibration. Selection of EMCs (versus applying measured concentrations) facilitates credible use of the model for forecasting purposes. Fecal coliform concentrations in CSO discharges were typically an order of magnitude higher than in stormwater discharges.

There are five non-CSO stormwater discharges to Black Rock Canal (not including stormwater sources from Scajaquada Creek and Delavan Drain) and one discharge to the Niagara River. Flow time series for stormwater discharges were provided from the collection system model for the 2009 wet weather events. Fecal coliform event mean concentrations were applied to the estimated volume to develop a loading time series for the model.

Tributary inputs to the Niagara River model include the Buffalo River, Scajaquada Creek, and Delavan Drain. Water quality inputs to the Niagara River from the Buffalo River are defined by monitoring data collected by Malcolm Pirnie at station BUF RBWQ 1, at the mouth of the Buffalo River, during 2008 and 2009. Flow inputs from the Buffalo River to the Niagara River are defined based on output from the calibrated Buffalo River hydrodynamic model. Flow and water quality inputs to Black Rock Canal from Scajaquada Creek and Delavan Drain are determined from model output, calibrated to monitoring data collected by Malcolm Pirnie in 2008 and 2009. Table 4-1 summarizes the inflow sources that were included in the Niagara River model based on outputs from the collection system model as well as the Buffalo River and Scajaquada Creek models.

Table 4-1: Summary of Inflow Sources in the Niagara River Model

CSO Source	Receiving Water	Total Overflow Volume (MG)	
		Wet Weather Event 1 (Sept. 23-25, 2009)	Wet Weather Event 2 (Oct. 24-25, 2009)
CSO-004	Black Rock Canal	4.70	6.48
CSO-005	Black Rock Canal	0.10	0.13
CSO-008	Black Rock Canal	1.53	1.12
CSO-010	Black Rock Canal	2.39	2.01
CSO-012	Black Rock Canal	13.32	12.23
CSO-013	Black Rock Canal	5.84	2.87
CSO-014	Black Rock Canal	13.94	3.74
CSO-015	Black Rock Canal	5.08	1.16
CSO-016	Black Rock Canal	1.81	0.52
CSO-061	Black Rock Canal	20.52	5.99
CSO-063	Black Rock Canal	0.45	0.26
CSO001a	Niagara River	0	0
CSO003	Niagara River	0.07	0.25
CSO011	Niagara River	0	0
CSO054	Niagara River	0	0.05
CSO055	Niagara River	89.72	73.00
Stormwater Source	**Receiving Water**	**Total Overflow Volume (MG)**	
		Wet Weather Event 1	**Wet Weather Event 2**
BlkRck2	Black Rock Canal	2.30	1.69
BlkRckCa	Black Rock Canal	1.03	0.58
BLRHarbr	Black Rock Canal	13.49	5.62
CSO-008 (storm)	Black Rock Canal	1.76	0.84
CSO-054 (storm)	Niagara River	1.52	1.21
Tributary Source	**Receiving Water**	**Total Overflow Volume (MG)**	
		Wet Weather Event 1	**Wet Weather Event 2**
Delavan Drain (CSO-006)	Black Rock Canal	453.21	80.69
Scajaquada Creek	Black Rock Canal	275.29	62.25

Table 4-2: CSO and Storm Water Pollutant Concentrations for Niagara River and Black Rock Canal summarizes the concentrations used to calculate wet weather loads for CSO and stormwater sources.

Table 4-2: CSO and Storm Water Pollutant Concentrations for Niagara River and Black Rock Canal

Parameter	Units	CSO	Stormwater
Fecal Coliform	#/100 mL	100,000	10,000

An additional load to the Niagara River is the Bird Island Wastewater Treatment Plant effluent. The treatment plant is located on Squaw Island, south of the International Bridge, and during wet weather events, it is not uncommon for the plant to discharge partially treated or untreated effluent to the Niagara River. Data were obtained from BSA to estimate the partially treated wastewater load that was discharged to the Niagara River during the wet weather events. Continuous flow measurement data and discrete grab sample results for fecal coliform were incorporated into the model at the locations of the primary (001) and secondary treatment (002) outfalls. The maximum fecal coliform concentration measured at outfall 001 during the event was 8,000 CFU/100mL. The maximum concentration at outfall 002 was 170 CFU/100mL. The maximum flow rate measured at outfall 001 was 450 cfs, and the maximum flow rate at outfall 002 was 418 cfs (Buffalo Sewer Authority, 2010).

Receiving water sampling data on the Niagara River for the first wet weather event suggested the presence of a significant source of bacteria on the west side of the channel, near the Niagara Peninsula, Ontario, Canada. Possible sources of elevated bacteria levels were investigated and include several small wastewater treatment facilities and stormwater runoff. In 2008, the Niagara Peninsula Conservation Authority published a report in which they estimated fecal coliform bacteria loads in runoff from creeksheds on the peninsula. These estimates were used to attempt to quantify Canadian sources of bacteria in the Niagara River model for both wet weather events. Further information on the Canadian bacteria sources investigation is included in Appendix B.

4.1.3.d Reaction Rates

Reaction rates were initially based on literature and judgment, and subsequently modified as needed during the calibration process. A literature review, sensitivity analysis, and general knowledge of the Niagara River system showed that the primary loss mechanism for bacteria on the Niagara River is transport, rather than decay or settling. The Niagara River system is dominated by advection due to high velocities and flow volumes such that "flushing" becomes the primary sink for bacteria loads. Bacteria modeling in the Niagara River included only a single loss rate, rather than specification of particulate fraction and settling in addition to decay. A value for the first order loss rate was selected based on the literature, sensitivity analysis, and best judgment.

Based on a literature review, the primary loss mechanism for bacteria in Black Rock Canal is decay rather than transport. Flow inputs from sensitivity analyses of dry and wet weather events, combined with literature and best judgment, were used to assign an appropriate fecal coliform bacteria loss rate for the Black Rock Canal. More detail on these parameters is provided in the subsequent model calibration section of this report.

4.2 MODEL CALIBRATION

Hydrodynamic and water quality data collected in 2008 and 2009 were used to calibrate the Niagara River model. Due to the unusual characteristics of the first wet weather event, which included a subsequent precipitation event, the calibration of the Niagara River model was focused on the second wet weather event (from October 21-28, 2009). This is discussed in more detail in Section 4.2.3. Water quality sampling locations in Niagara River and Black Rock Canal are depicted in Figure 4-4.

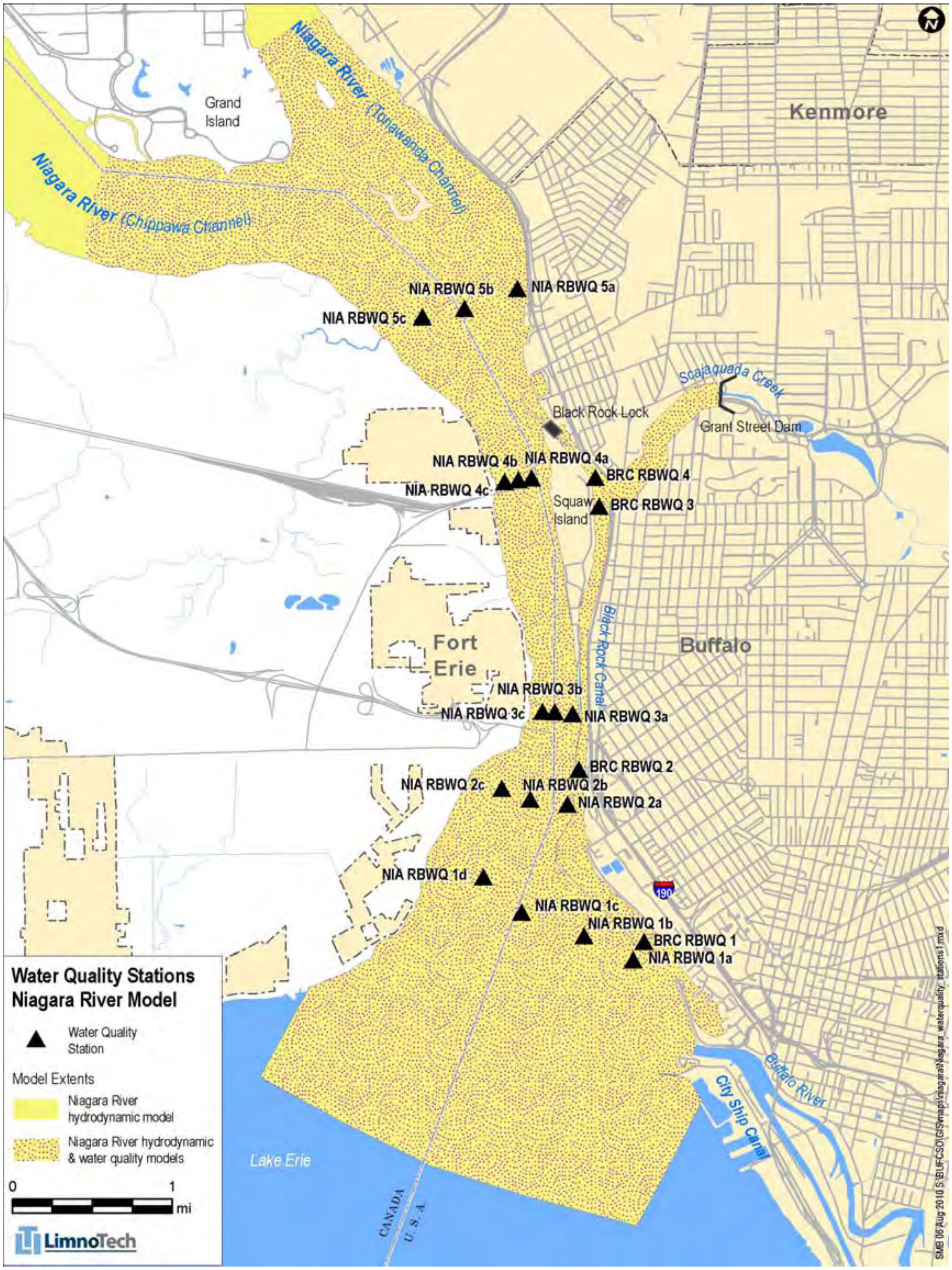


Figure 4-4: Niagara River Water Quality Stations

4.2.1 Approach

Calibration of the Niagara River model focused on verifying that the model reasonably estimates peak concentrations observed in the data at each sampling location, reasonably estimates the timing of the river response to bacteria CSO loads observed in the data, and reasonably estimates the range of observed concentrations over the duration of the wet weather event.

The calibration process consisted of comparing simulated model output with measured water level and fecal coliform bacteria data. Both kinetic parameters and event mean concentrations of pollutants in CSOs and stormwater discharges were varied during the calibration. Evaluation methods to determine the adequacy of calibration included temporal profiles at sampling locations, scatter plots, statistical summaries, and animations of spatial profiles over the duration of the event which summarized the model output versus observed data. Table 4-3 shows the final calibrated values of the kinetic parameters. All reaction rates used in the model are within ranges found in published literature such as Chapra (1997), USEPA (1987), and USEPA (1985). Although the calibrated fecal coliform bacteria loss rate is somewhat lower than the rate used in other CSO receiving water modeling studies, it is well within the acceptable range of values. Furthermore, use of a lower decay rate is conservative and the decay rate used here allowed better model calibration than a higher rate. Calibration results are presented in the sections below.

Table 4-3: Summary of Kinetic Parameters for the Niagara River and Black Rock Canal EFDC Model

Parameter	Units	Pre-Calibration Range	Calibrated Value
Fecal Coliform - CSO Sources			
Decay Rate	day^{-1}	0.0 – 2.0	0.5
Fecal Coliform - Stormwater Sources			
Decay Rate	day^{-1}	0.0 – 2.0	0.5
Fecal Coliform - Upstream Sources			
Decay Rate	day^{-1}	0.0 – 2.0	0.5

4.2.2 Hydrodynamics

Calibration of the Niagara River hydrodynamic model was performed to verify that the model accurately reproduces hydrologic conditions on the River. A reasonable hydrodynamic calibration is a necessary precursor to water quality calibration, as it provides confidence that the model will accurately simulate bacteria fate and transport.

The hydrodynamic model was calibrated to water level measurements provided by the Ontario Power Group (OPG) at nine stations on the Niagara River distributed throughout the model domain (Figure 4-5). Hourly water level data were provided by

OPG for the year 2008, and model hydrodynamics were calibrated for the entire year to encompass a wide range of hydrologic events.

The months of April 2008 and October 2008 were determined to represent relatively "wet" and relatively "dry" months, respectively, with regard to flow on the Niagara River. These time periods were selected to present results of the hydrodynamic calibration. Water level calibration results for April (Figure 4-6) and October (Figure 4-7) are shown for three locations on the Niagara River; upstream (Fort Erie station), midstream (Huntley station), and downstream (American Falls station). The locations of these stations are shown in Figure 4-5.

Figure 4-5: OPG water level measurement stations on the Niagara River

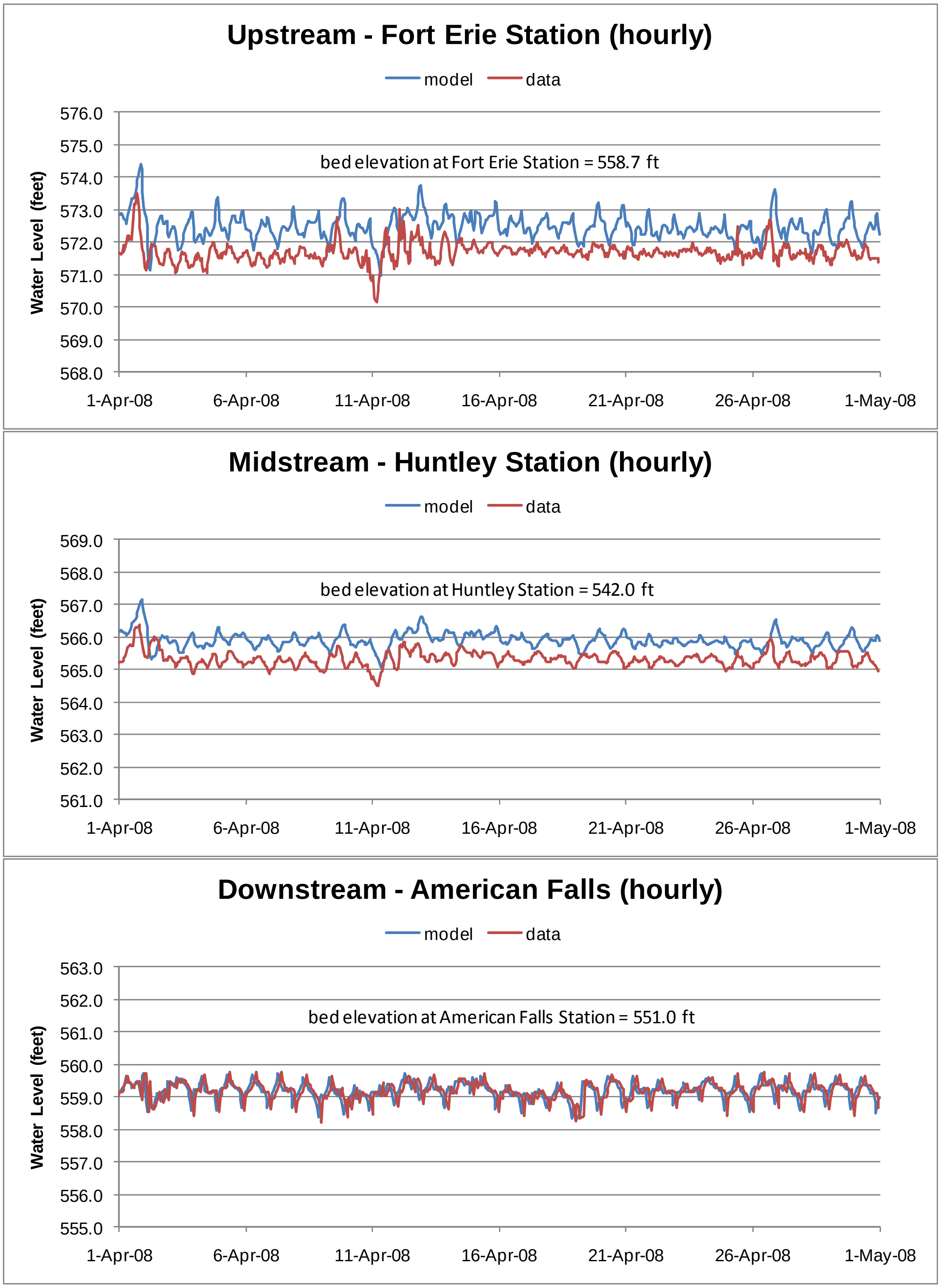


Figure 4-6: Water Level Calibration at Three Locations in the Niagara River, April 2008 (wet period)

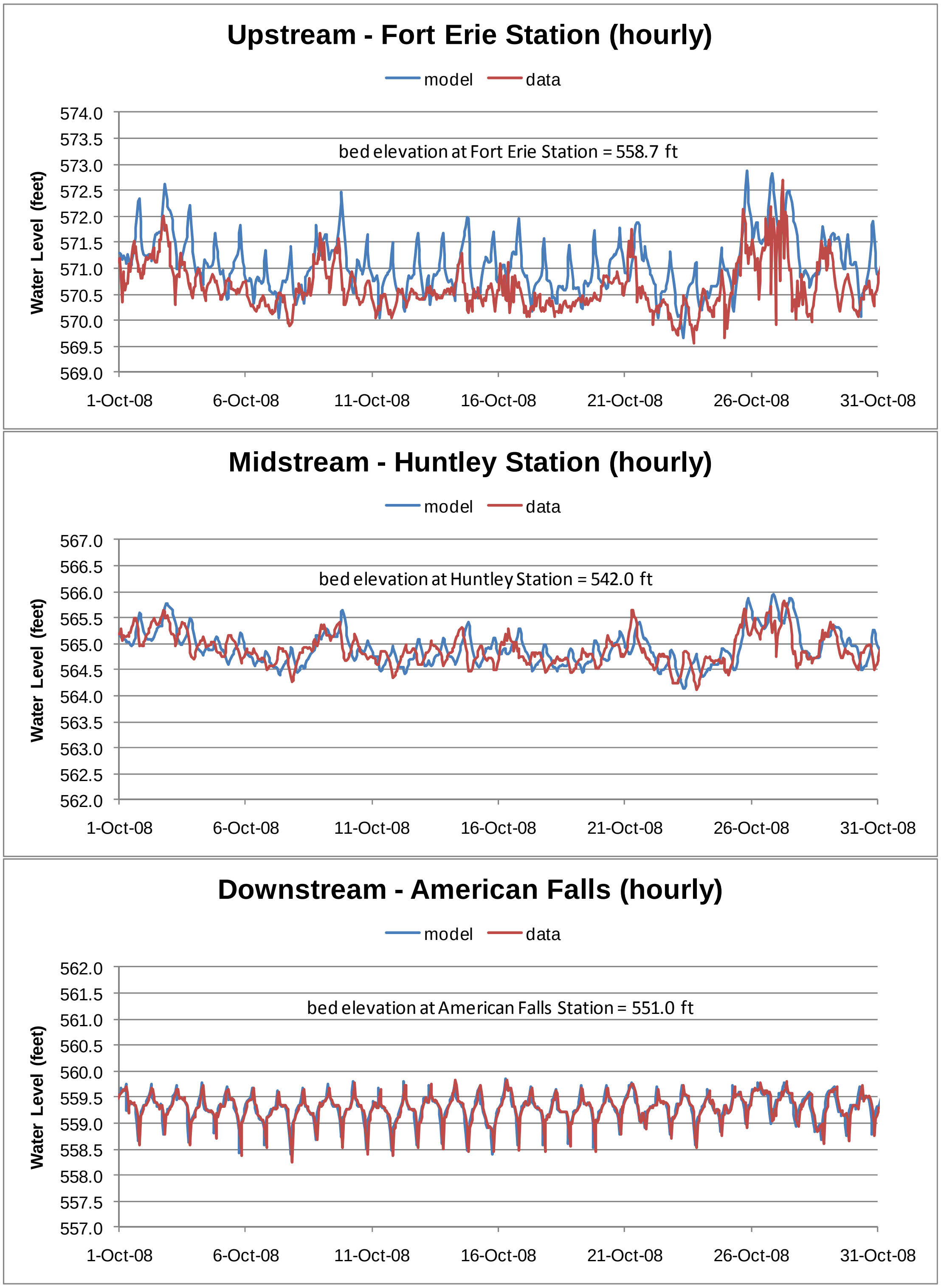


Figure 4-7: Water Level Calibration at Three Locations in the Niagara River, October 2008 (dry period)

As evidenced in Figures 4-6 and 4-7, the model performs reasonably well, even during the “driest” and “wettest” times of the 2008 simulation year. During both model periods, the model tended to slightly overpredict water level, with the greatest discrepancy occurring at the downstream-most station (Fort Erie). The value of this discrepancy was typically less than 1 ft, and the variation is insignificant relative to the overall water depth. For example, in April 2008, the average discrepancy between the measured and simulated water levels at Fort Erie was 0.8 feet, or approximately 6 percent of the average total water depth. At Huntley, there appears to be a slight phase shift in simulated versus observed levels, but the average discrepancy was 0.6 feet - less than 3 percent of the average total water depth. Furthermore, the model output represents an average condition over a large grid cell (hundreds of feet across). The observed data reflects a single point within the river. The actual variation in water surface elevation over a grid cell area may exceed the model/data deviation. There is no reason to believe this deviation significantly affects the model's ability to simulate water quality conditions.

4.2.3 Bacteria

Modeled fecal coliform bacteria concentrations for the calibration event were compared to all available water quality stations in Niagara River and Black Rock Canal (19 stations in total). Although the model was calibrated to both the first and second wet weather events collectively, more emphasis was placed on the second event for several reasons. The first event included a second wet weather peak before a complete recession of the initial event, and the dataset included unexpected anomalies. In particular, concentrations were unexpectedly high for stations west of the City of Buffalo shoreline (e.g., “B”, “C”, and “D” locations). Additionally, due to unsafe conditions on the Niagara River, the final round of sampling for event 1 could not be carried out.

Figures 4-8 to 4-17 show a time series comparison of simulated and observed fecal coliform data for all of the “A” (eastern channel) and “B” (mid-channel) locations in the Niagara River for the second wet weather event. These locations were selected due to their proximity to the area of interest for BSA. Time series calibration plots for “C” locations and “D” locations (first transect only) on the Niagara River are included in Appendix H. Appendix H also contains results for the first wet weather event.

The model reasonably reproduces the temporal profile observed with the data during the event at each sampling location. Error bars represent a deviation of +/- two times the data value (factor of two), which is a typical margin of error associated with fecal coliform sampling and analysis. Comparison of the model with data from station NIA RBWQ 3a indicates a slight mismatch with timing; however, range of observed data is captured well by the model. At station NIA RBWQ 1a, the model reasonably predicts the high values seen in the data, but tends to over-predict low values. When comparing “A” stations to “B” stations, the model adequately captures the decreased bacteria concentration that was observed moving from the eastern edge to the middle of the channel. The model also successfully captured a notable increase in bacteria concentration observed at transect 5. This region of the Niagara River is most strongly impacted by the Bird Island Wastewater Treatment Plant and by nearby CSO-055.

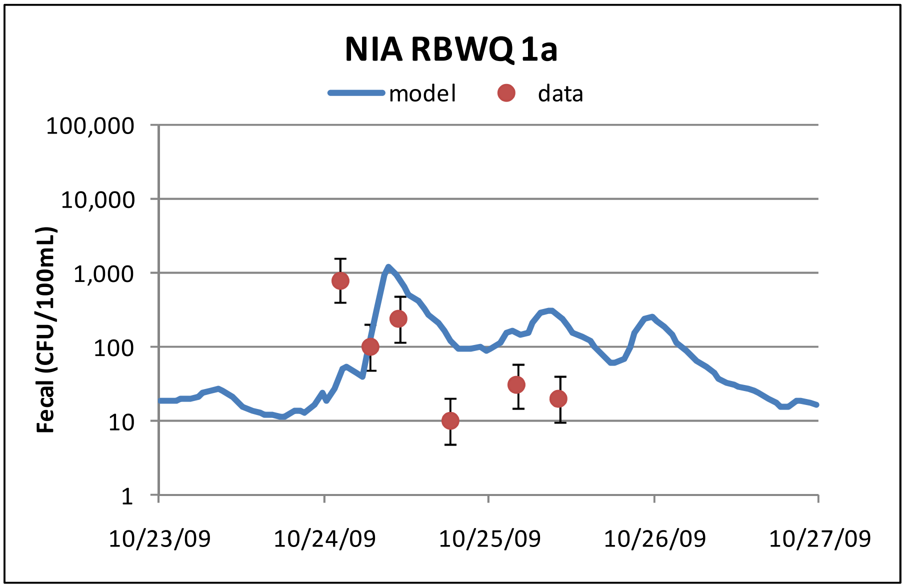


Figure 4-8: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 1a during the October 23, 2009 Event

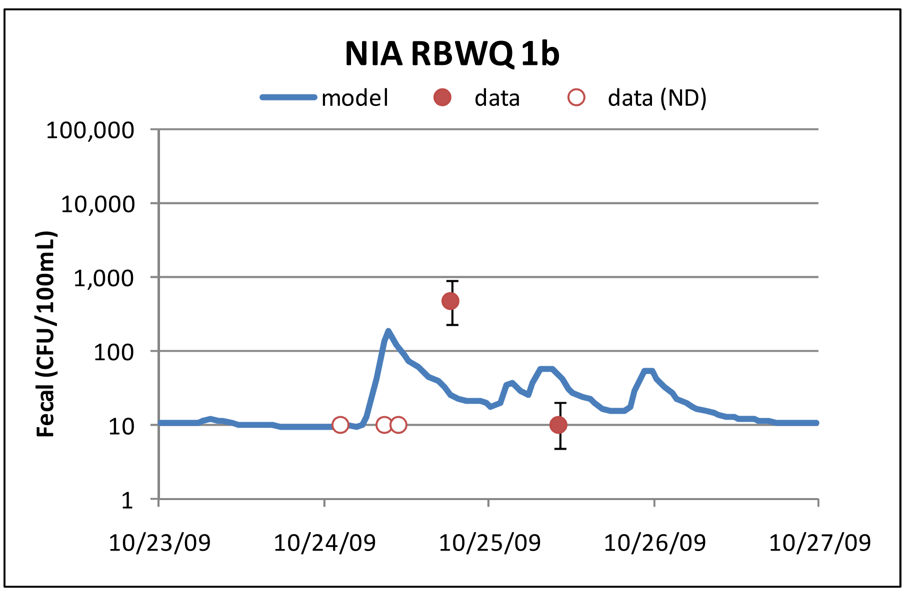


Figure 4-9: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 1b during the October 23, 2009 Event

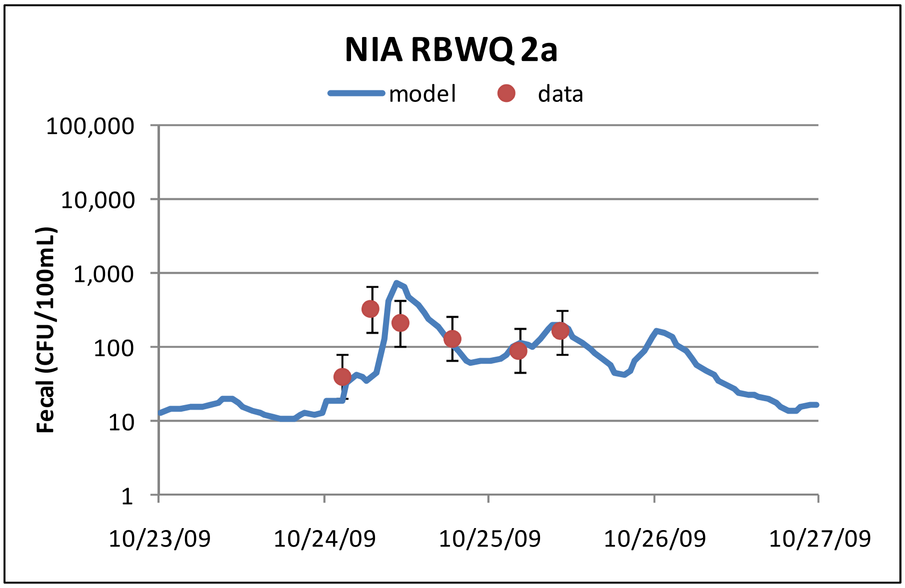


Figure 4-10: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 2a during the October 23, 2009 Event

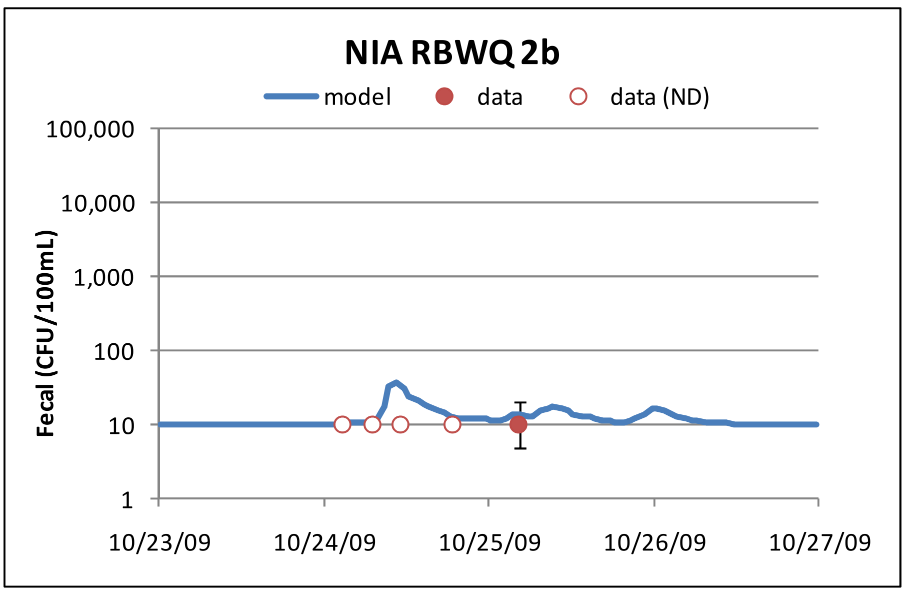


Figure 4-11: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 2b during the October 23, 2009 Event

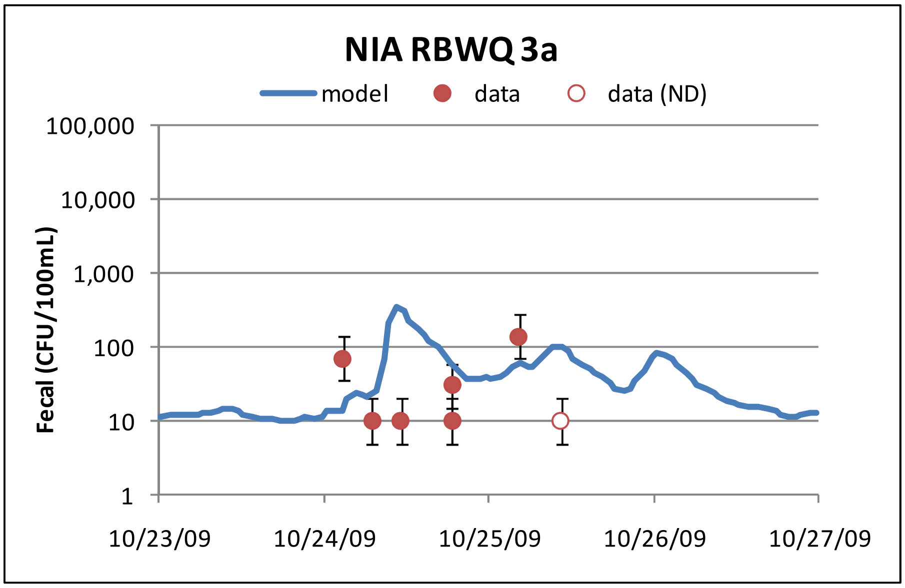


Figure 4-12: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 3a during the October 23, 2009 Event

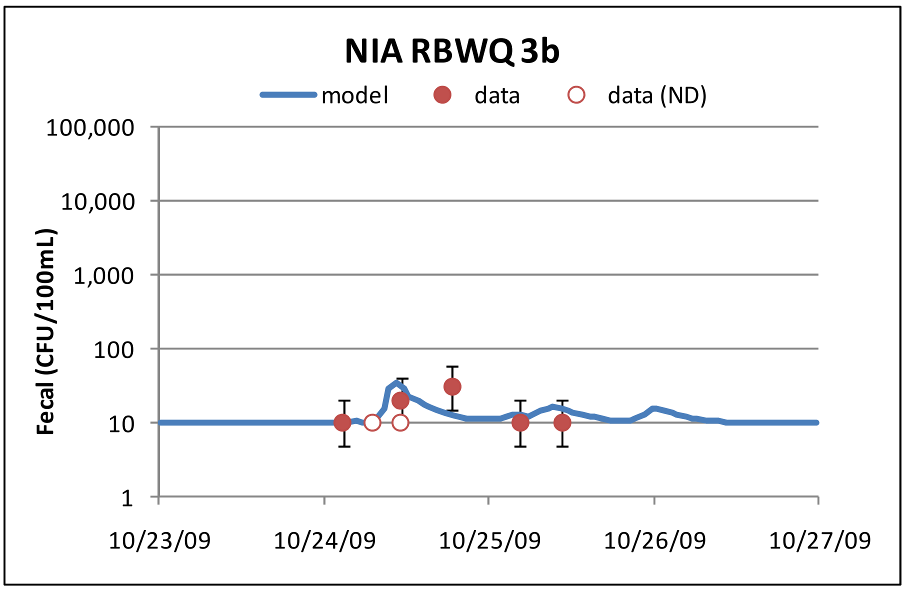


Figure 4-13: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 3b during the October 23, 2009 Event

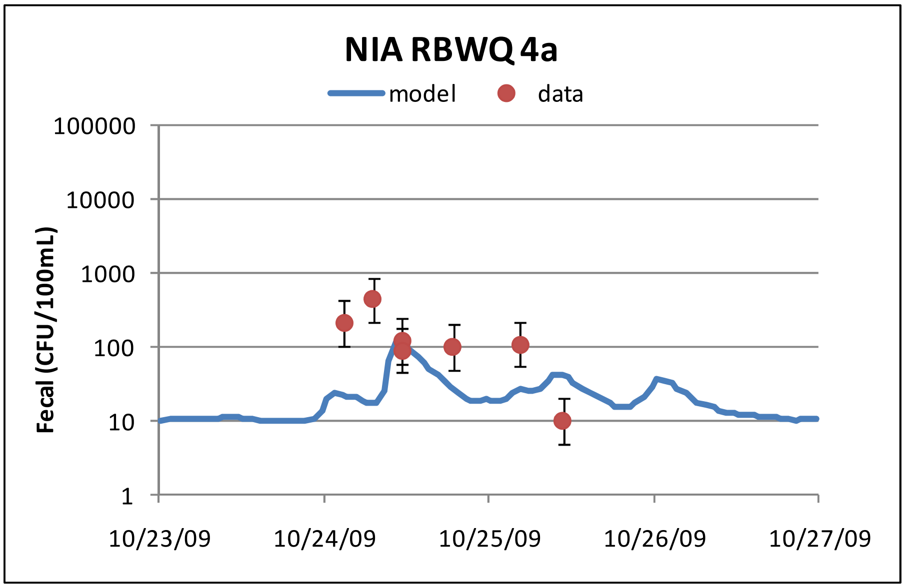


Figure 4-14: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 4a during the October 23, 2009 Event

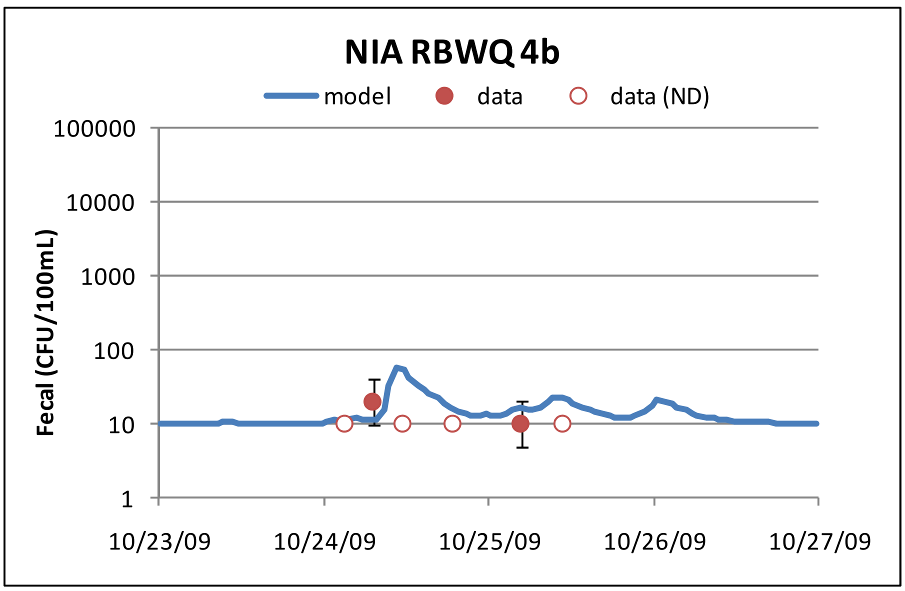


Figure 4-15: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 4c during the October 23, 2009 Event

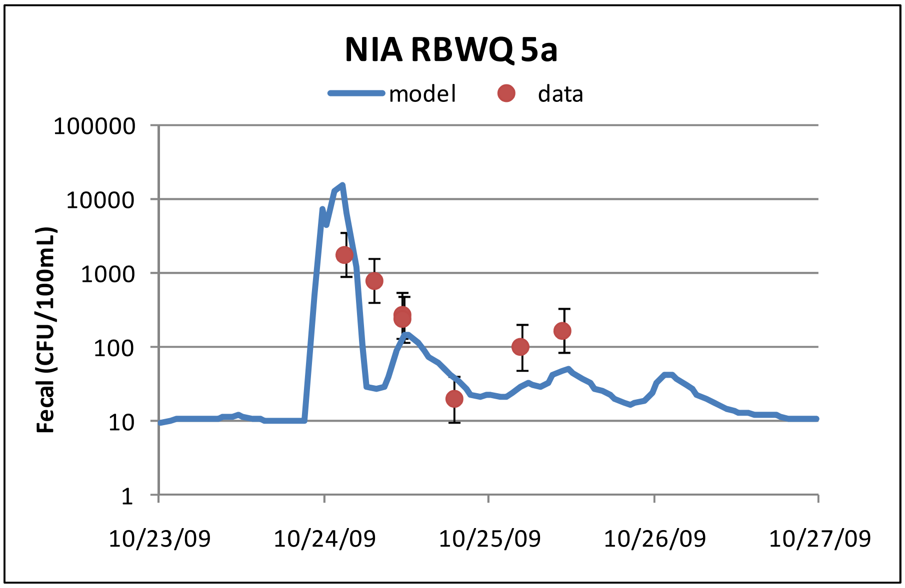


Figure 4-16: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 5a during the October 23, 2009 Event

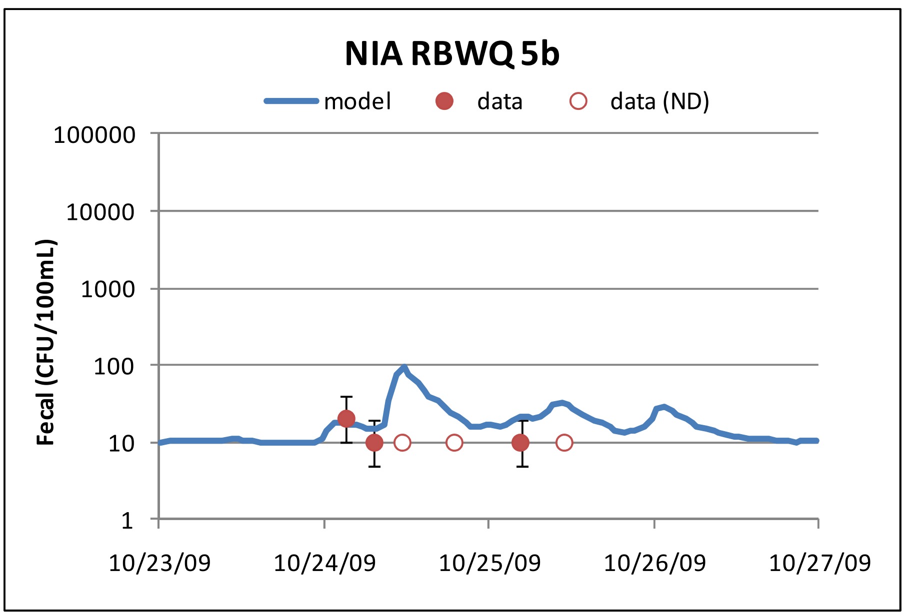


Figure 4-17: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station NIA RBWQ 5b during the October 23, 2009 Event

Figures 4-18 through 4-21 show a time series comparison of simulated versus observed fecal coliform bacteria in the Black Rock Canal at the four monitoring locations the second wet weather event. Results for the second wet weather event show that the model generally reproduces the timing and magnitude of the observed data at each location. Of all the stations, simulation at the location which corresponds to station BRC RBWQ 2 showed the greatest deviation from observed data. A review of system characteristics did not provide information to support why concentrations at this location would likely be approximately one order of magnitude less than stations BRC RBWQ 3 and BRC RBWQ 4. Attempts to adjust EMCs to reflect the concentration at these locations compromised the overall model-to-data fit for other locations. With the exception of station BRC RBWQ2, the fecal coliform bacteria calibration resulted in a good match between the simulated and observed concentrations. Predicted concentrations at BRC RBWQ 2 are conservative and do not understate the effects of wet weather flows.

Appendix H contains results for the simulation of fecal coliform bacteria in the Black Rock Canal during the first wet weather event.

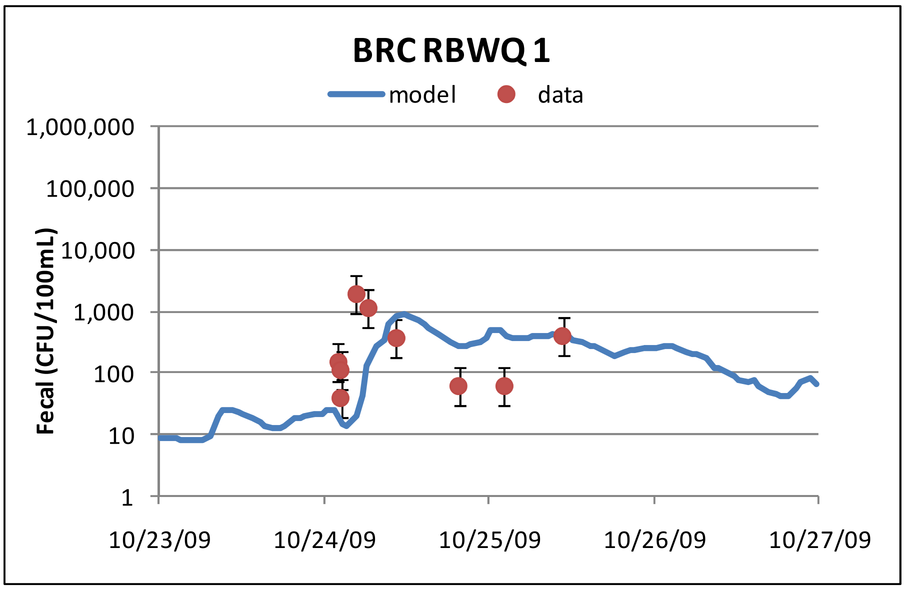


Figure 4-18: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station BRC RBWQ 1 during the October 23, 2009 Event

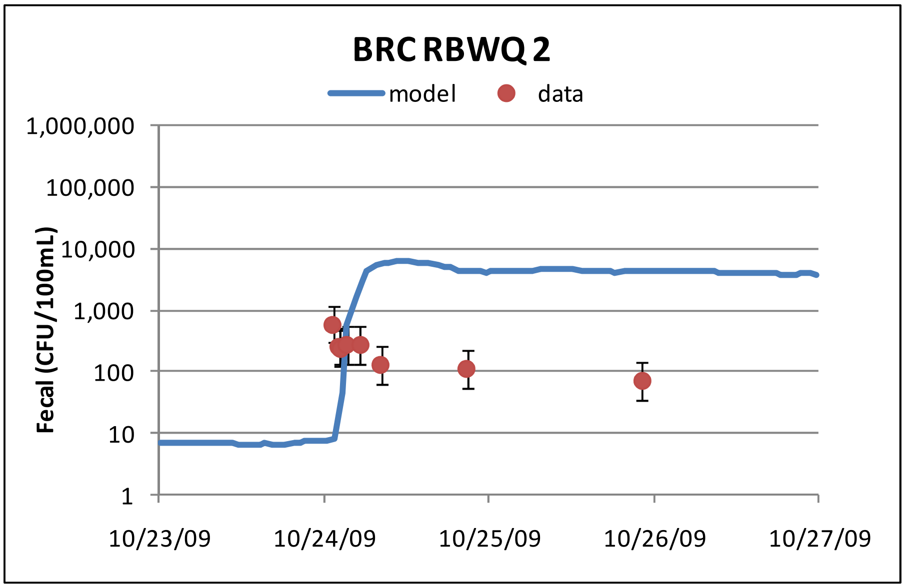


Figure 4-19: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station BRC RBWQ 2 during the October 23, 2009 Event

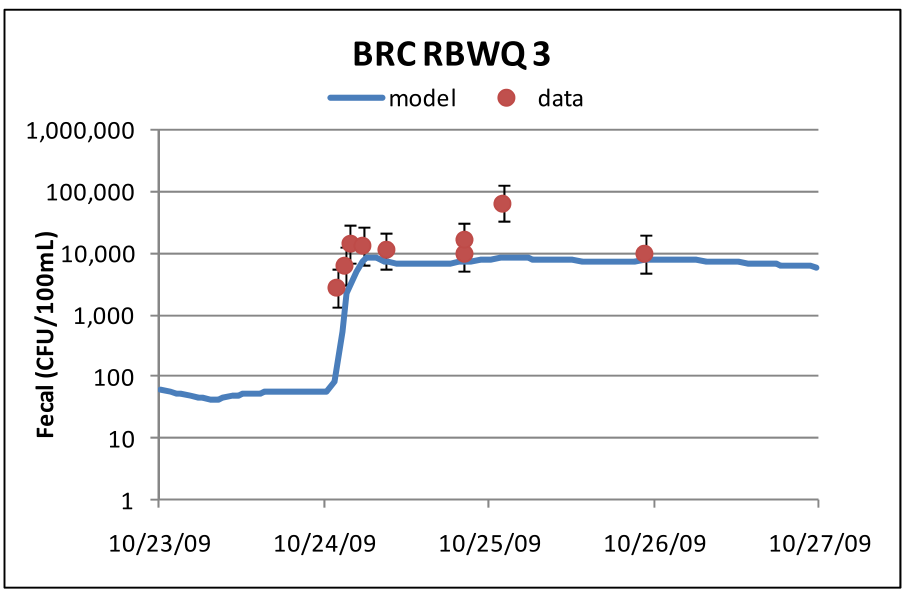


Figure 4-20: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station BRC RBWQ 3 during the October 23, 2009 Event

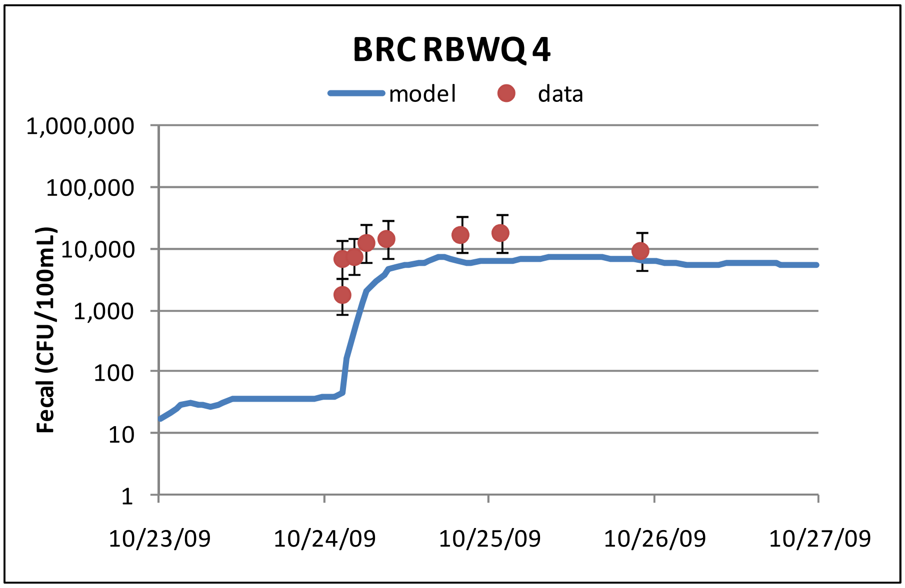


Figure 4-21: Temporal Profile of Observed and Simulated Fecal Coliform Concentrations at Station BRC RBWQ 4 during the October 23, 2009 Event

Figure 4-22 is a scatter plot showing a regression of model versus data at all of the "A" and "B" sampling locations on the Niagara River, and Figure 4-23 is a scatter plot for all locations on Black Rock Canal for the second wet weather event.

These figures illustrate the model's performance at reproducing the range of observed concentrations, including peak concentrations. The points show the model result at the same date-time that the corresponding concentration was measured. The error bars represent the range in simulated concentrations over the duration of the sampling round within a two-hour window of the sample collection time. The plots also include a 1:1 line (grey). Points which fall directly upon the 1:1 line would indicate a perfect fit. The plot also includes lines that bracket a factor of two (dark blue) and an order of magnitude (light blue). The factor of two brackets is intended to encompass uncertainty in analytical results, whereas the factor of ten brackets encompasses all sources of uncertainty in the observed data, including factors such as in-stream variability and sample collection and handling.

For the Niagara River, approximately 42% of the model simulated concentrations fall within the 2X confidence interval and approximately 88% of the simulated concentrations fall within the 10X confidence interval. For the Black Rock Canal, approximately 26% of the model simulated concentrations fall within the 2X for the confidence interval and approximately 65% of the simulated concentrations fall within the 10X confidence interval. If station BRC RBWQ 2 is removed from the analysis, then 73% of simulated concentrations meet this objective for Black Rock Canal.

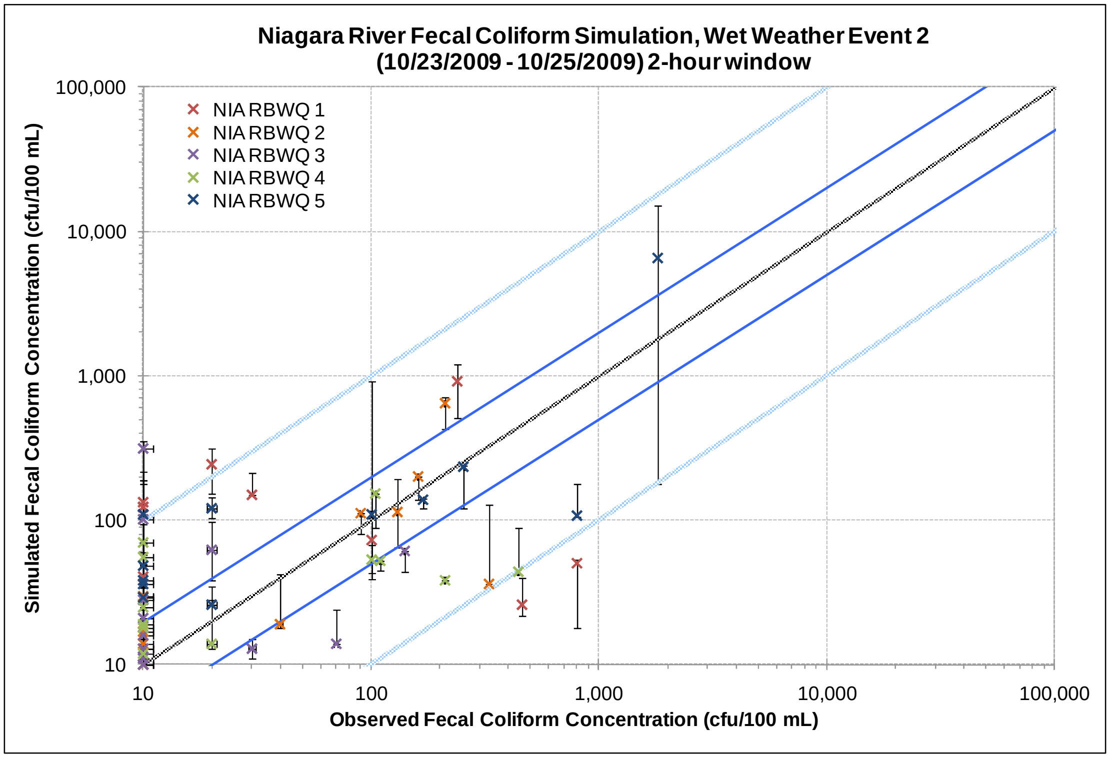


Figure 4-22: Comparison of In-Stream Observed and Simulated Fecal Coliform Concentrations during the October 23, 2009 Event at Selected Locations ("A" and "B" stations) on the Niagara River

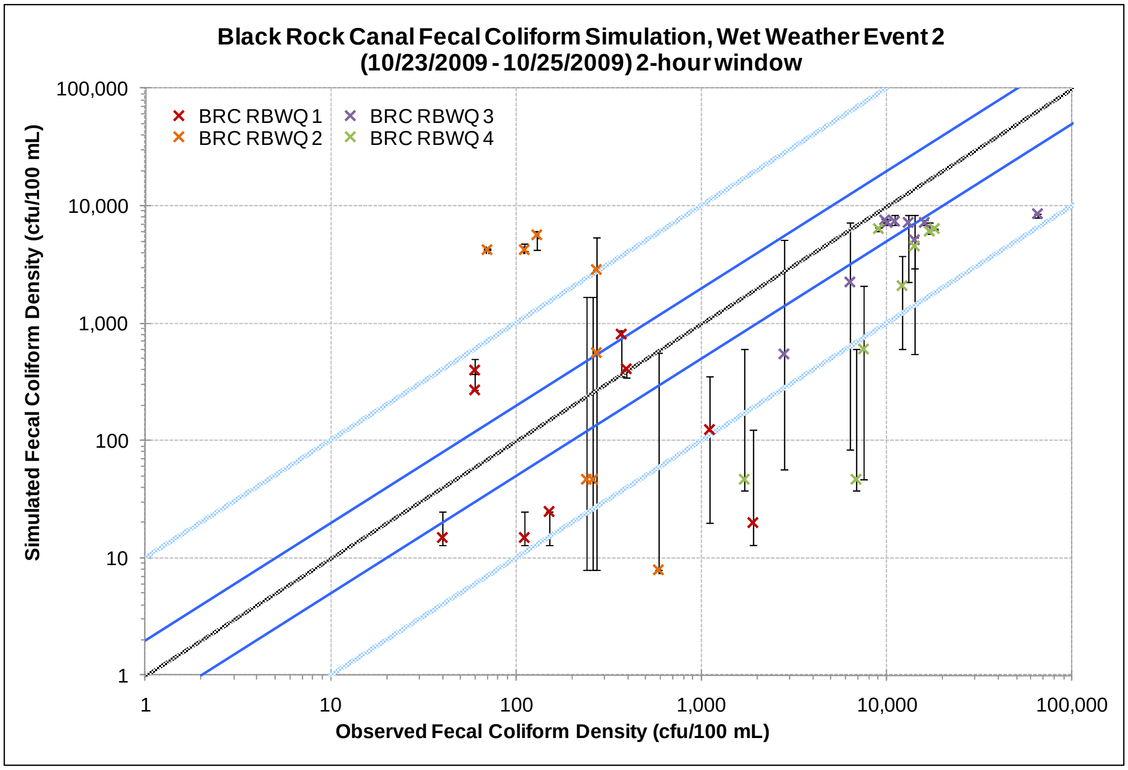


Figure 4-23: Comparison of In-Stream Observed and Simulated Fecal Coliform Concentrations during the October 23, 2009 Event at All Locations on Black Rock Canal

4.2.4 Calibration Summary

In general, the Niagara River water quality model is able to reasonably reproduce the magnitude and range of fecal coliform data at each location for the calibration event (wet weather event 2). For some locations, the timing of the peak fecal coliform bacteria concentration during the event was not accurately reproduced. Factors which could be contributing to this pattern include uncertainty with respect to the distribution of flow at the model's upstream boundary, and uncertainty associated with fecal coliform bacteria data collection and analysis. The model tends to slightly under-predict fecal coliform when compared to the highest values measured at stations NIA RBWQ 4a and 5a. A possible reason for this may be incomplete accounting of all fecal coliform sources (both point and non-point) to the river which could be located upstream of these monitoring sites.

The Black Rock Canal fecal coliform bacteria simulation also produced a reasonable calibration to data at four stations, given the level of uncertainty in the system. The model reasonably reproduced measured data at stations BRC RBWQ 3 and 4, which indicates that it can successfully simulate bacteria fate and transport near the mouth of Scajaquada Creek using output from the calibrated Scajaquada Creek/Delavan Drain model. The model was also able to reasonably reproduce measured data at station BRC RBWQ 1, which indicates that it is capable of simulating hydrodynamic conditions and the relative impacts from the Buffalo and Niagara Rivers on the south end of Black Rock Canal. A limitation of the Black Rock Canal model is its inability to reproduce measured fecal bacteria concentrations at station BRC RBWQ 2. Model predictions were as high as one to two orders of magnitude greater than measured data. This is likely attributed to uncertainty in hydrodynamic conditions at this location on the canal, uncertainty with respect to data collection and analysis, and uncertainty with respect to loading sources on the canal.

5. BLACK ROCK CANAL MODEL

The domain of the Black Rock Canal model extends from the canal's southern boundary at the Lake Erie Basin Marina northward to the Black Rock Lock, and includes the segment of Scajaquada Creek downstream of the Grant Street dam. This domain was used to simulate dissolved oxygen for the 2009 wet weather events. A sub-domain was used to simulate dissolved oxygen for a long-term simulation in 2008, which covers both dry weather events. Figure 5-1 depicts these domains. Simulation of fecal coliform bacteria in Canal is presented in Section 4 as part of the Niagara River model.

The development and calibration of the model as well as a discussion regarding the use of two model domains are included in the following sections.

5.1 MODEL DEVELOPMENT

The specific objectives for the Black Rock Canal model are to allow the following uses (LimnoTech, 2008):

- Assess the impact of BSA's CSO discharges to dissolved oxygen concentrations.
- Determine how DO will change as a result of CSO discharge controls.
- Determine whether CSO controls alone can achieve target DO levels.

The model developed and calibrated under this project can be used to meet these objectives.

5.1.1 Model Selection and Background

The United States Environmental Protection Agency (USEPA) supported Environmental Fluid Dynamics Code (EFDC) model was selected as the model to simulate water quality in the Black Rock Canal. This model was first developed in the 1980s and has been publicly available since 2002. The version used in this project is Version 1.01 (USEPA, 2007).

Figure 5-1: Black Rock Canal Model Domain

EFDC is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions. It has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic models in the world (USEPA, 2007).

EFDC was selected for the Black Rock Canal model for the following reasons:

- EFDC readily allows linkage between one-dimensional (i.e. Scajaquada Creek), two-dimensional depth-averaged (Niagara River), and two-dimensional laterally-averaged reaches (Black Rock Canal).

- EFDC can readily be used to simulate dissolved oxygen.

- GIS processing tools developed by LimnoTech provide for simplified model grid construction and refinement compatible with EFDC.

- LimnoTech has already developed a model processing and visualization utility for EFDC that will facilitate presentation and evaluation of results such as model to data comparisons in the vertical dimension, which is important for the Black Rock Canal.

In order to provide flexibility and efficiency when simulating the impact of CBOD and fecal coliform loading from a variety of sources, the EFDC water quality sub-model was enhanced by LimnoTech to incorporate two additional state variables for CBOD and fecal coliform, including a unique set of input coefficient for these variables. For the Niagara River and Black Rock Canal model simulations, the three state variables were used to represent upstream (i.e., above city boundaries), combined sewer overflow (CSO), and separate stormwater sources to the model domain. The EFDC model reports predicted concentrations for each individual state variable, as well as the total constituent concentration. The multi-variable approach effectively provides a "built-in" component analysis for all model cells which will be useful during the model application phase.

5.1.2 Domain and Segmentation

The Black Rock Canal model grid is two-dimensional, laterally averaged and vertically stratified. The domain of the Black Rock Canal model extends from the canal's southern boundary at the Lake Erie Basin Marina northward to the Black Rock Lock, and includes the segment of Scajaquada Creek downstream of the Grant Street dam. The full-model grid was used to simulate dissolved oxygen for the 2009 wet weather events. A smaller model grid, a subset of the full grid, was used to simulate dissolved oxygen for a long-term simulation in 2008, which covers both dry weather events. The extents of the full- and sub-model domains are shown in Figure 5-2. An enlarged version of this map is provided in Appendix E.

In each simulation, the model's southern boundary was fixed to data collected by the southernmost long-term hydrolab. In 2008, this hydrolab was located at BRC RBWQ

2, just south of the Peace Bridge. In 2009, this hydrolab was located at Buoy R10, located midway between stations BRC RBWQ 1 and BRC RBWQ 2. Therefore, the sub-model grid was used for the 2008 long-term simulation, with the southern boundary fixed to the hydrolab data taken at BRC RBWQ 2. The full-model grid was used for the 2009 wet weather events, with the southern boundary simply fixed to the hydrolab data taken at Buoy R10.

The model grid is designed to have up to 16 vertical grid layers with approximately 0.5 m (1.64 ft) vertical grid spacing. The grid is laterally averaged. Longitudinal grid spacing of the model (e.g., cell length) is variable to allow for the model grid to be merged spatially with the grid for the Niagara River. The cells range from approximately 27 to 191 m in length and 46 to 184 m in width. The model grid allows simulation of hydrodynamic circulation in and at the boundaries of the Canal and also accurately simulates hydrodynamic conditions, given operation records for the lock during the model simulation period. The full-model grid consists of 64 active grid cells, including Black Rock Canal, the Lake Erie Basin Marina, and the downstream segment of Scajaquada Creek. The sub-model grid includes 44 grid cells.

5.1.3 Model Input Development

The following sections describe inputs and boundary conditions incorporated into the model.

5.1.3.a System Data

Bathymetric data for the Canal were obtained from numerous sources. The primary source of bathymetric data was obtained from NOAA's National Geophysical Data Center (NGDC). This dataset provided fine-scaled bathymetry data for a portion of Canal. Bathymetric data from the U.S. Army Corps of Engineers (USACE), who conducted bathymetric surveys in 1999 and took detailed soundings in the canal in August 2008, were also incorporated.

All available bathymetry points were averaged within each model segment or cell to calculate an average bottom elevation. In areas with sparse bathymetric data, the bottom elevation was estimated using available data and then adjusted to be consistent with upstream and downstream segments. All datasets were converted to a consistent datum (IGLD 1985) for use in this study.

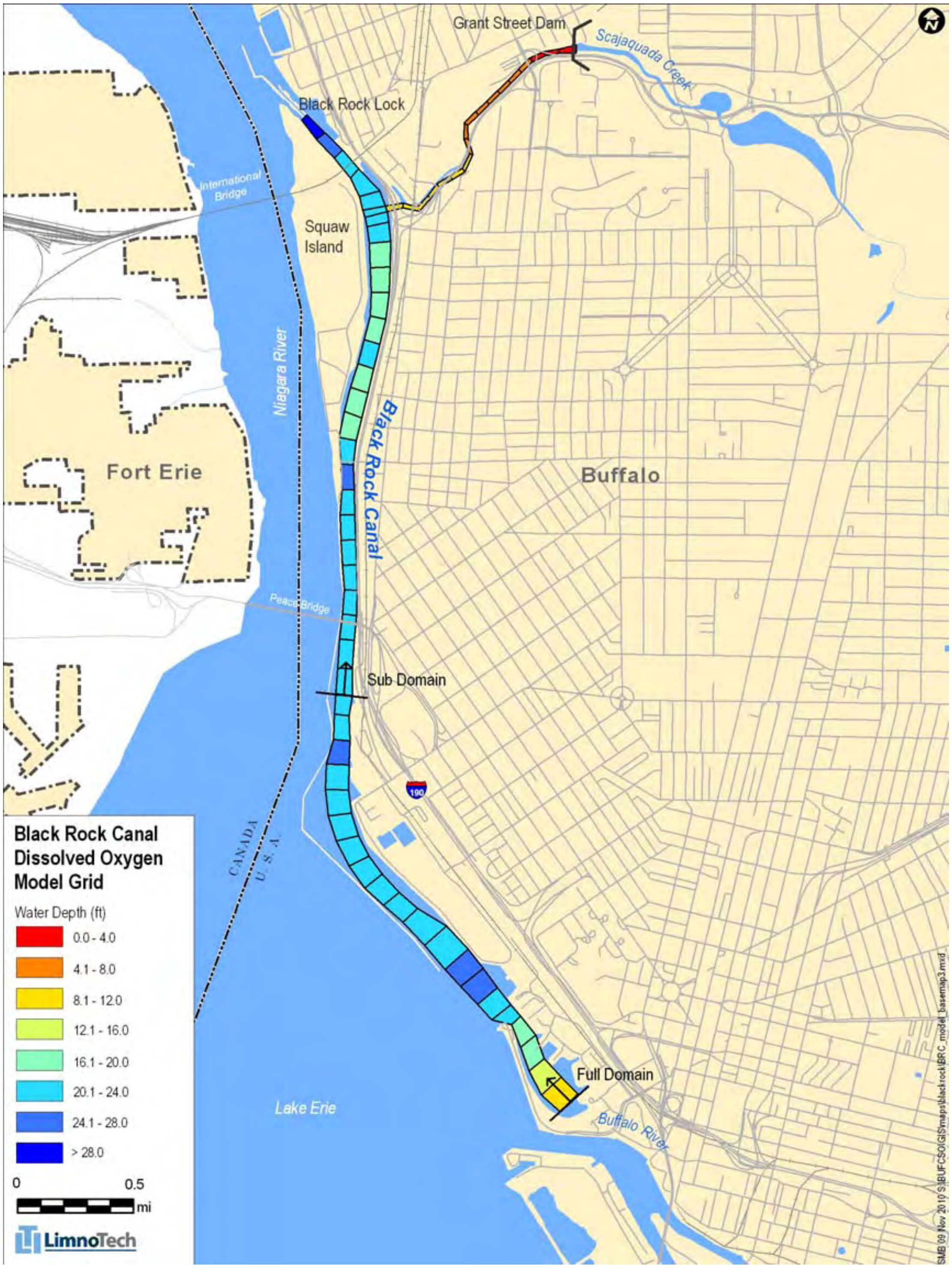


Figure 5-2: Black Rock Canal Model Grid

Meteorological data obtained from three separate sources were used to define climate boundary conditions for the Buffalo River model. Hourly surface data including rainfall and relative humidity were obtained from the National Climatic Data Center

(NCDC) for the Buffalo Niagara International Airport (COOP ID 725280). Air temperature, cloud cover, and barometric pressure data were obtained from the Great Lakes Environmental Research Laboratory (GLERL). Typical year solar radiation data obtained from Capella Energy (Capella Energy, 2010) were applied for the 2008 and 2009.

5.1.3.b Boundary Conditions

There are three boundaries within the Canal that were defined with flow data: Scajaquada Creek below Grant Street Dam, the south end of Black Rock Canal near the mouth of the Buffalo River, and the north end of the canal at the Black Rock Lock. Simulated flows predicted by the Scajaquada Creek and Niagara River models were used to define hydrodynamic boundary conditions at the confluences with those water bodies. At the north end of the model domain, a flow series for the Black Rock Lock was generated from lock logs during dry and wet weather events.

Black Rock Canal is approximately 5.5 feet higher in elevation than the Niagara River at the lock; therefore, lock operation results in a loss of water from the Canal to the Niagara River. Based on lock dimensions and water elevation differentials, this loss is approximately 260,000 ft^3 (1.9 MG or 288.9 cfs) per 15 minute cycle. The operators of the lock, US Army Corps of Engineers, provided logs for the dates corresponding with the 2008 and 2009 dry and wet weather events that were modeled (USACE, 2010). Overall, there were six cycles during dry weather event 1 (7/16/2008), one cycle during dry weather event 2 (9/3/2008), 18 cycles during wet weather event 1 (9/27/2009 to 10/1/2009), and five cycles during wet weather event 2 (10/23/2009 to 10/28/2009).

Considerations of on- and off-season locking frequencies were taken into account to generate average flow through the lock for the 2008 long-term simulation. A time series incorporating lock logs during the 2009 wet weather events was incorporated into the 2009 simulations.

For the first wet weather event, the volume of the Black Rock Canal ranged from 1303.8 to 1611.6 MG and the volume of water discharged through the lock during the five day period was roughly 2.5% of the total canal volume. For the second wet weather event, the volume of the Black Rock Canal ranged from 1191.7 to 1459.7 MG and the volume of water discharged through the lock during the five day period was less than 1% of the total canal volume.

Water quality boundary conditions near the north and south ends of the model domain were specified using data collected during 2008 and 2009.

For all simulations, temperature data collected by the Buffalo Water Authority at a station located in Lake Erie near the upstream end of the Niagara River were applied both the north and south boundaries. Dissolved oxygen concentration boundary conditions were based on hydrolab data collected by Malcolm Pirnie at stations BRC RBWQ2 in 2008 and Buoy R10 in 2009. The dissolved oxygen data was near 8 mg/L for the September and near 10 mg/L for the October event. These data were applied to both the north model boundary at Black Rock Lock and the south model boundary at the Niagara River. Since water does not enter the canal from the north, using data from a region to the south was determined to be sufficient. The model showed little sensitivity to variation in these boundary conditions.

Constant BOD and fecal coliform concentrations consistent with the Niagara River model were applied at the north and south boundaries for all modeling periods. For BOD, a concentration of 2 mg/L was applied because sampling data were either ND (non detect) or 2 mg/L during the period of interest. Fecal coliform bacteria boundary conditions were set at a constant 10 CFU/100 mL to be consistent with many recorded measurements of less than the detection limit of 10 CFU/100 mL.

Water quality boundary conditions for the interface with Scajaquada Creek and Delavan Drain, such as dissolved oxygen and CBOD, were developed based on output from the Scajaquada Creek model.

5.1.3.c Loads to System

Direct loads to the Black Rock Canal include CSOs and storm water loads. CSO volumes were simulated with the updated collection system model. The collection system model relied on a full network of rain gages installed for the 2000 and 2009 monitoring programs to calculate CSO flows for the 2000 data for the Buffalo River and the 2009 data for the remaining receiving stream models. Time series of flows from each CSO outfall simulated by the model (15 minute frequency) were used directly in Black Rock Canal model. Table 5-1 summarizes the inflow sources that were included in the model based on outputs from the collection system model as well as the Scajaquada Creek model.

Concentrations of DO and CBOD in CSOs were based in part on event sampling conducted in 2000, and in part by adjustment during model calibration. Loads of fecal bacteria, BOD, and DO from CSOs were calculated using these flows from the collection system model and event mean concentration (EMC) data collected during the sampling program under the previous LTCP effort (Malcolm Pirnie, 2004a, b). As described in the 2004 LTCP, analytical water quality and flow data collected during the year 2000 were combined to calculate mass pollutant loadings under wet weather conditions. System-wide average EMCs were calculated to be 92,500 #/100mL for fecal coliform bacteria and 24.1 mg/L for BOD (Malcolm Pirnie, 2004b Table 3-1). These system-wide EMCs were used as initial inputs and adjusted as needed during calibration. CBOD concentrations in CSO discharges were typically an order of magnitude higher than in stormwater discharges. Table 5-2 summarizes the concentrations used to calculate wet weather loads for CSO and stormwater sources.

A search of NPDES data revealed that there were no point sources discharging directly to Black Rock Canal in 2008 or 2009.

It should be noted that the long-term simulation for 2008 did not include CSO or storm water inputs.

Table 5-1: Summary of Inflow Sources in the Black Rock Canal Model

CSO Source	Total Overflow Volume (MG)	
	Wet Weather Event 1 (Sept. 23-25 2009)	Wet Weather Event 2 (Oct. 24-25 2009)
CSO-004	4.70	6.48
CSO-005	0.10	0.13
CSO-008	1.53	1.12
CSO-010	2.39	2.01
CSO-012	13.32	12.23
CSO-013	5.84	2.87
CSO-014	13.94	3.74
CSO-015	5.08	1.16
CSO-016	1.81	0.52
CSO-061	20.52	5.99
CSO-063	0.45	0.26
Stormwater Source	**Total Overflow Volume (MG)**	
	Wet Weather Event 1	**Wet Weather Event 2**
BlkRck2	2.30	1.69
BlkRckCa	1.03	0.58
BLRHarbr	13.49	5.62
CSO-008 (storm)	1.76	0.84
Tributary Source	**Total Overflow Volume (MG)**	
	Wet Weather Event 1	**Wet Weather Event 2**
Delavan Drain (CSO-006)	453.21	80.69
Scajaquada Creek	275.29	62.25

Table 5-2: CSO and Storm Water Pollutant Concentrations for Black Rock Canal

Parameter	Units	CSO	Stormwater
CBOD	mg/L	40.0	8.0
Fecal	#cfu/mL	100,000	10,000
DO	mg/L	5.0	8.0

5.1.3.d Reaction Rates

Reaction rates were initially based on literature and professional judgment, and subsequently modified as needed during the calibration process.

The primary calibration parameters include SOD, CBOD decay rate, and reaeration rate. As described in Appendix D, SOD measurements were collected in Black Rock canal to support model development. Corrected SOD measurements at 20°C ranged from 1.96 g/m^2/day at a northern location near the Peace Bridge to -0.051 g/m^2/day at southern location near the confluence with Scajaquada Creek. SOD values ranging from 0 to 2 were used in model calibration. A value of 1.5 for the north and 1.0 for the south produced the most reasonable results for both the long-term and wet weather simulations.

A second calibration parameter, the reaeration rate, was investigated using both wind-induced and non-wind-induced rates. The use of wind-induced reaeration produced the most reasonable results in the model. Because the canal is somewhat shielded from the wind, relative to larger open water bodies, the wind was scaled down to 62%.

CBOD reaction parameters, including decay rate and settling velocity were set to match parameters implemented in the Scajaqduda Creek model. These parameters yielded reasonable results in the Black Rock Canal model. More detail on these parameters is provided in the subsequent model calibration section of this report.

5.2 MODEL CALIBRATION

The model was calibrated to event (short-term) and continuous (long-term) data collected in 2008 and 2009. Event data were collected at stations BRC RBWQ 1-4. Continuous data were collected at stations BRC RBWQ 2 and 4 in 2008 and at Buoy R10 and BRC RBWQ 4 in 2009. These locations are shown in Figure 5-3 and summarized in Table 5-3. Event data included two dry weather periods in 2008 and two wet weather periods in 2009. Event and continuous data for 2008 were used to calibrate the steady-state behavior of the model. The transient, wet weather response of the model was calibrated to wet weather event data collected in 2009.

Table 5-3: Summary of Water Quality Monitoring Stations on Black Rock Canal

Station ID	Location	Latitude	Longitude
BRC RBWQ 1	Upstream end of the breakwater	-78.895	42.881
BRC RBWQ 2	Between USGS gage at Anderson and Bird Island WWTP	-78.903	42.904
BRC RBWQ 3	Upstream of confluence with Scajaquada Creek	-78.900	42.928
BRC RBWQ 4	Upstream of International Bridge and canal locks	-78.901	42.930
Buoy R10	Between BRC RBWQ 1 and BRC RBWQ 2, on Buoy R10[1]	-78.900	42.893

[1]Approximate Coordinates

Figure 5-3: Black Rock Canal Water Quality Sampling Locations

5.2.1 Approach

Calibration of the model first focused on the 2008 continuous data to characterize surface dissolved oxygen in the long-term simulation. Calibration to the dry weather event profile data in this simulation allowed for parameterization of the sediment oxygen demand (SOD) within the system. The degree of stratification measured under dry weather conditions was used as a calibration target for the 2008 simulations.

A second step of the calibration was comparison of model output with wet weather surface and profile data to ensure adequate prediction of water quality response under CSO and stormwater loads. Table 5-4 shows the final calibrated values of kinetic parameters. All reaction rates used in the model are within ranges found in published literature such as Chapra (1997), USEPA (1987), and USEPA (1985).

Table 5-4: Summary of Kinetic Parameters for the Black Rock Canal Model

System	Parameter	Units	Pre-Calibration Value	Background Value	CSO Value	Storm Water Value
CBOD	Deoxygenation Rate	day^{-1}	0.1	0.21	0.5	0.4
CBOD	Deoxygenation Rate Temperature Correction Factor	--	0.041	0.041		
CBOD	Half Saturation Constant	mg/L O_2	1.5	1.5		
CBOD	Settling Velocity	m/day	0.5	0.125	4.0	1.0
Wind	Reaeration Rate (K_a)	day^{-1}	0.022 (average)	0.5 (average)		
SOD	Sediment Oxygen Demand	$(g/m^2/d)$	1.0	1.0 to 1.5		

SOD values for the northern region of the model domain were assigned higher values than the southern region due to increased pollutant loads relative to the south. The division of the north and south region lies approximately 0.2 miles north of the Peace Bridge. In the north region, loads from Scajaquada Creek, Delavan Drain, and CSOs enter Black Rock Canal. Only a few CSOs enter in the south. The model was more sensitive to SOD than any other parameter listed in the above table. Also, the reaeration rate was characterized by the O'Connor Dobbins formula, which includes wind-induced reaeration.

Inconsistencies were observed between the 2009 wet weather and long-term hydrolab dissolved oxygen measurements near the surface. The long-term samples measured a

DO of approximately 2 mg/L lower than the wet weather event samples at similar depths and similar times. According to a personal communication with Dr. Kim Irvine of Buffalo State College, it was believed "that the stationary site DO data are more reflective of true conditions in the Black Rock canal than the DO profiles collected during the storm events. Dissolved oxygen data discrepancies exist between the 2009 long-term hydrolab and wet weather data taken at the surface. This discrepancy is on the order of 2 mg/L, with higher DO values associated with the wet weather events" (Buffalo State, 2010).

Based on these recommendations, long-term DO data were favored over event data as a basis for calibration. In many instances of discrepancy between the datasets, the event data concentrations were greater than expected saturation levels. For example, during the September 2009 wet weather event, to DO profile measurement closest to surface was approximately 14 mg/L. For the range of surface water temperatures experienced during the event, dissolved oxygen saturation at the surface ranges from approximately 9 to 10.5 mg/L. Therefore, wet weather event data were considered erroneously high, with concentrations greater than saturation. Also, calibrating to the dataset with lower dissolved oxygen concentrations is a more conservative approach.

Therefore, dissolved oxygen simulations under wet weather conditions were primarily calibrated to the long-term surface hydrolab measurements rather than the event measurements. The degree of stratification observed in the wet weather event data was used as a secondary calibration target for the events.

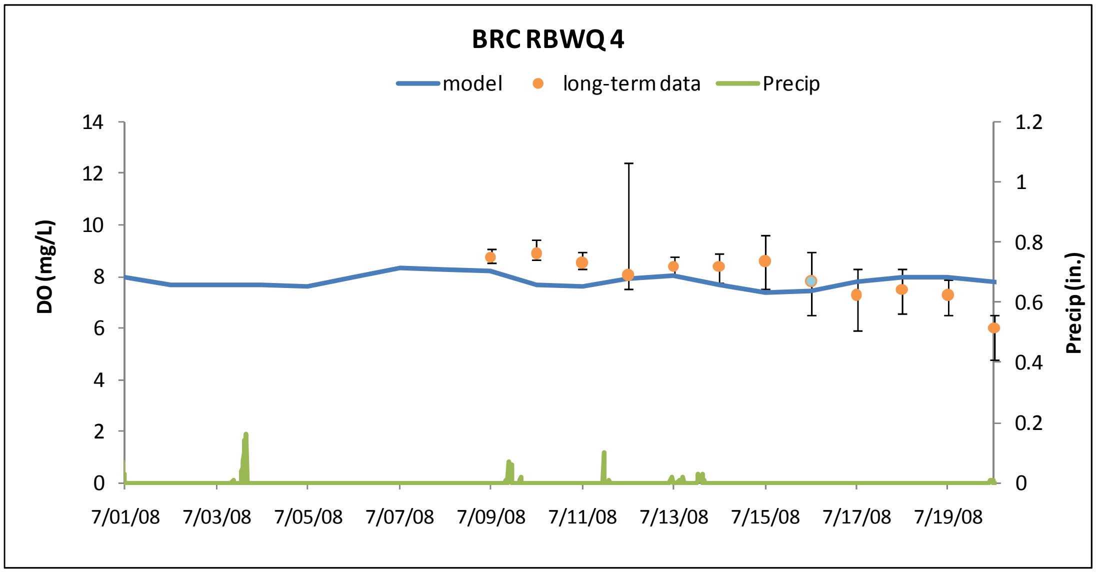
5.2.2 Hydrodynamics

Calibration of hydrodynamic conditions was not performed in this model; however, all hydrodynamic model coefficients are the same as those used in the Niagara River model. The Niagara model was calibrated to water level data collected at stations throughout the River. A source of water level data collected in the Black Rock Canal was not identified.

5.2.3 Dissolved Oxygen

Calibration of dissolved oxygen was conducted by comparing model output to both continuous surface concentrations and profile measurements collected over a range of depths. For the 2008 long-term simulation calibration, the model was run with assumed dry weather boundary conditions, and no explicit wet weather sources from CSOs or stormwater were included. Model-predicted dissolved oxygen is compared with the sampling results for the two dry weather periods at station BRCRBWQ4 (Figure 5-4). These figures present the surface DO for two discrete periods during the summer of 2008. A plot of corresponding precipitation is also included on the plot. Note that data points represent an average of DO sampled over a day and the error bars on the data points represent the range.

For both dry weather periods, the model reproduces the general fluctuation of DO values as well as mean dissolved oxygen values. Observed data station BRCRBWQ4 shows a wide range of DO measurements, possibly due to a diurnal swing of DO throughout the day. This pattern is not captured by the model, and this is possibly attributed to the model formulation not simulating diurnal DO impacts from aquatic vegetation or algae. The largest discrepancy between daily average simulated and measured DO occurs after a notable precipitation event on August 25, 2008, suggesting the possible effects of antecedent rainfall. The sudden drop in DO is not captured by the model, likely because wet weather flows and loads were not included during this representative dry weather simulation.



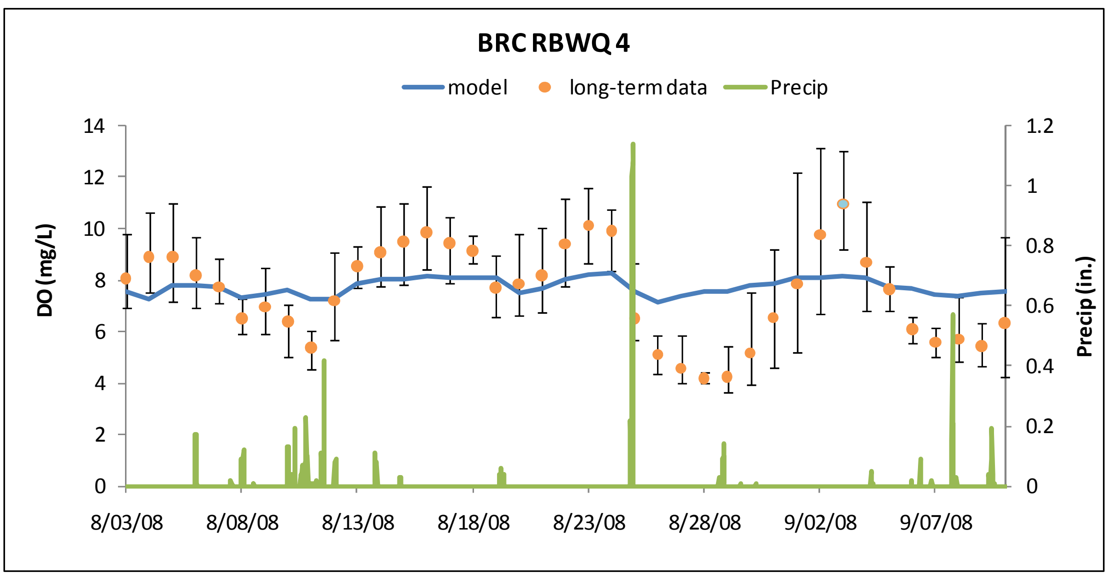


Figure 5-4: Temporal Profile of Observed and Simulated Dissolved Oxygen at BRC RBWQ 4 during the two dry weather event periods of 2008

Figures 5-5 and 5-6, compare simulated and observed DO over the depth of the canal for the two dry weather events sampled in 2008. Long-term data are plotted at the surface and dry weather event data are plotted throughout the water column. For the 2008 simulation period, long-term data are available at stations BRC RBWQ2 and BRC RBWQ4 only. For the July period, both model and data show little stratification at station BRCRBWQ2 (near the south end of the canal) and slight stratification at the other locations. For the September period, both model and data show slightly more stratification at all locations though the surface dissolved oxygen concentration is underpredicted by the model at both stations BRC RBWQ3 and BRC RBWQ4.

It is unlikely that the increased level of stratification observed in the September dry weather event can be attributed to strong temperature stratification because observed temperature throughout the water column only varied over a range of 1.5° F. Instead, high dissolved oxygen values at the surface during the September dry weather event may be attributed to algal growth in the northern region of the model domain. Photosynthesis and respiration of algae can produce a high diurnal swing, as was observed with surface hydrolab measurements at station BRC RBWQ 4. Depending on when the profile data were collected, the peak DO of the diurnal swing could have been captured in the data.

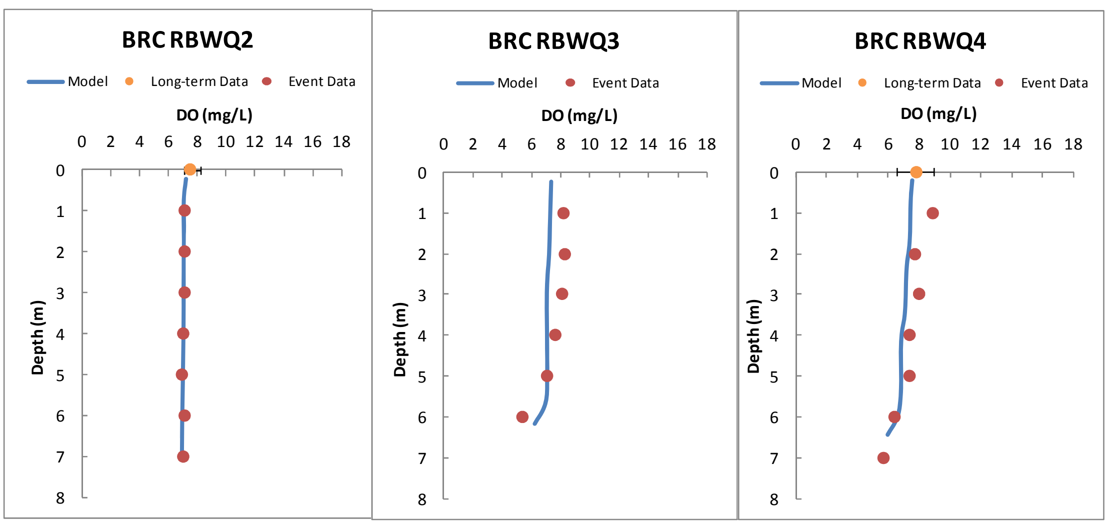


Figure 5-5: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 2, 3, and 4 during the July 16, 2008 Dry Weather Event

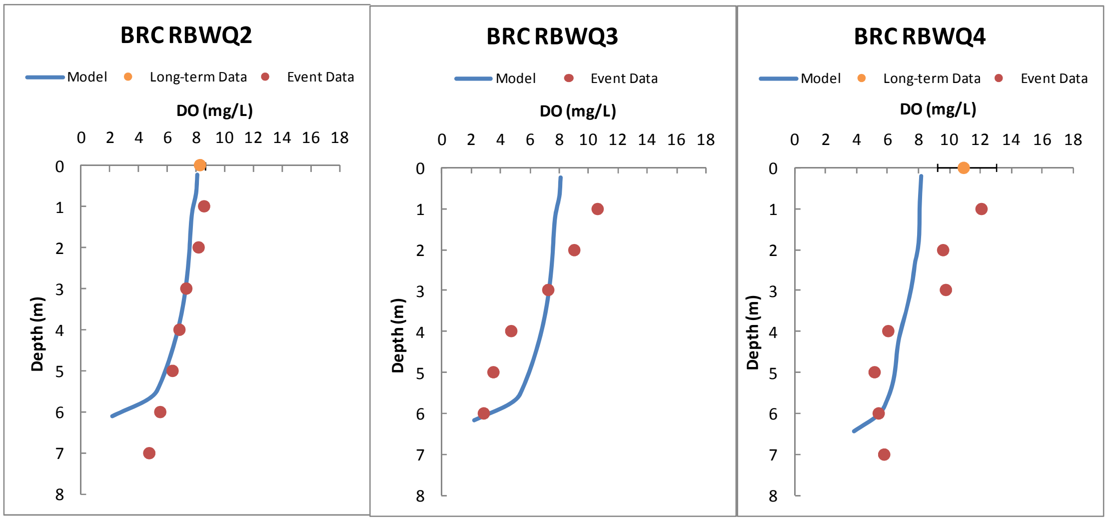


Figure 5-6: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 2, 3, and 4 during the September 3, 2008 Dry Weather Event

The Black Rock Canal model was also calibrated under wet weather conditions. For the first wet weather event sampled in 2009, the model-predicted dissolved oxygen surface concentrations are compared with the sampling results at station BRC RBWQ4 (Figure 5-7). Note that the error bars on the data points represent the range of dissolved oxygen values sampled over an hour. Discontinuities in sampling data are indicative of times the hydrolabs were calibrated. The model tends to predict surface DO values within 2 mg/L of the data values during the event.

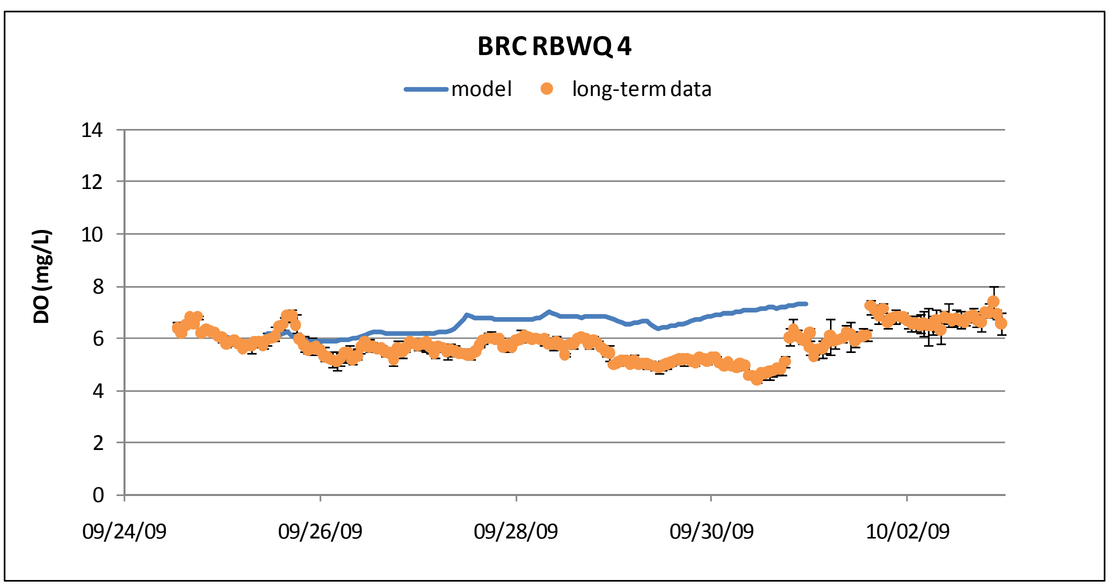


Figure 5-7: Temporal Profile of Observed and Simulated Long-term Surface Dissolved Oxygen at Station BRC RBWQ 4 during the September 27, 2009 Wet Weather Event

Figure 5-8 is a spatial profile plot of model-predicted dissolved oxygen values during a given day. Dips in the model DO profile at approximately 0.4 miles and 0.9 miles from the Black Rock Lock correspond with the decline in DO due to pollutant loadings from Scajaquada Creek and the Delavan Drain.

This figure illustrates a discrepancy with the dataset mentioned in Section 5.2.1. Specifically, the long-term hydrolab DO samples were approximately 2 mg/L lower than the wet weather event samples at similar depths and similar times. The error bars surrounding the data points correspond to the range of values over a day. This data inconsistency was discussed with Buffalo State College and it was noted that that the stationary site DO data are more reflective of true conditions in the Black Rock canal than the DO profiles collected during the storm events (Irvine, 2010). Therefore, dissolved oxygen simulations were calibrated to the long-term surface hydrolab measurements rather than the event measurements. The degree of stratification observed in the wet weather event data was used as a calibration target for the events, the absolute values of the profile measurements.

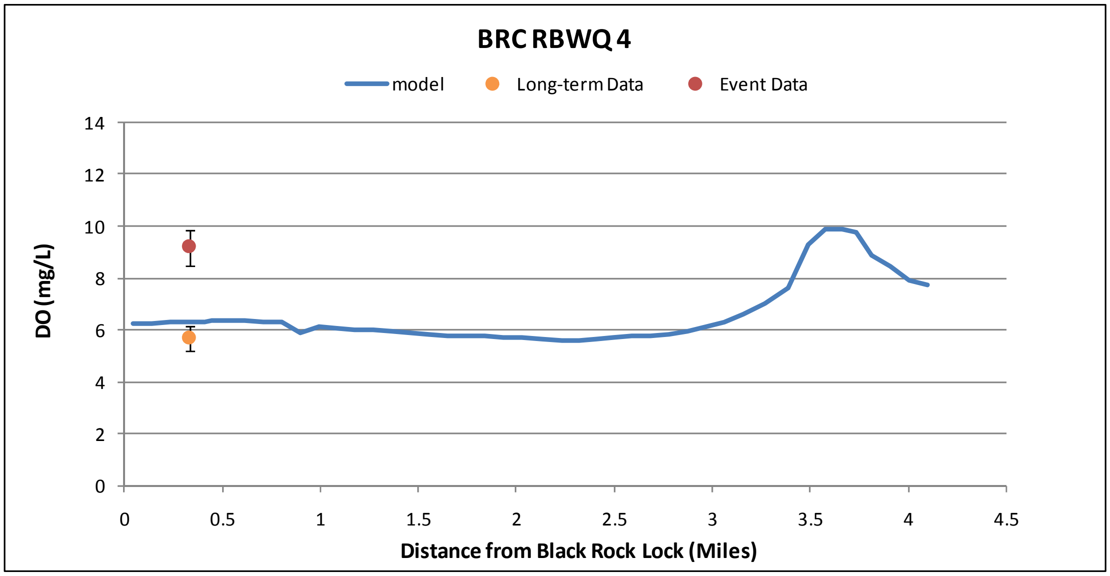


Figure 5-8: Spatial Profile of Observed and Simulated Near-surface Dissolved Oxygen at BRC RBWQ 4 during the September 27, 2009 Wet Weather Event

Figures 5-9 to 5-12, provide a profile depth comparison of simulated and measured DO for the first wet weather event at four sampling stations. For the 2009 simulation period, long-term data are available at buoy R10 and station BRC RBWQ4 only. Buoy R10 recorded surface DO data only; therefore, profiles are not shown for that station. For all four locations, the model represents the level of DO stratification over time well, but underpredicts the magnitude of DO values by several mg/L. As discussed previously, the calibration goals for the 2009 wet weather events include matching the extent of stratification, the shape of the profiles, rather than the values themselves. This is due to the abnormally high values recorded by the hydrolabs for the wet weather events. The predicted DO values for the first wet weather event tend to lie in between the continuous and event data near the surface.

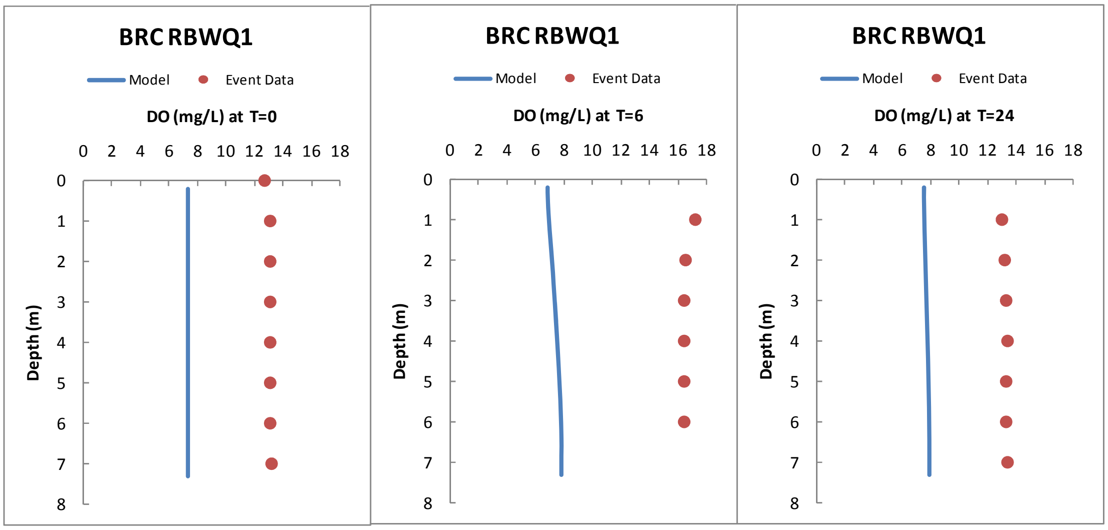


Figure 5-9: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 1 during the September 27, 2009 Wet Weather Event

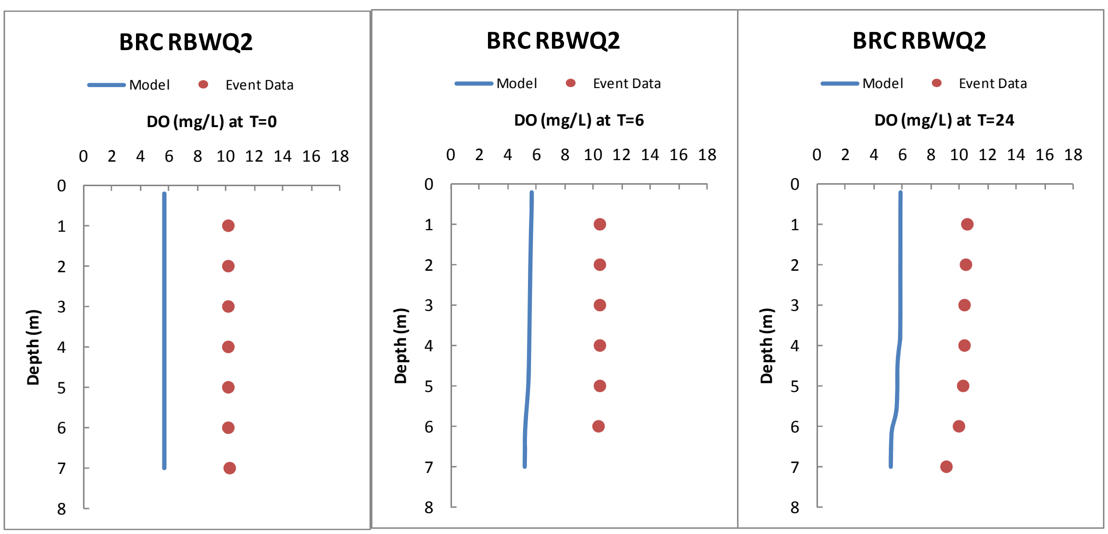


Figure 5-10: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 2 during the September 27, 2009 Wet Weather Event

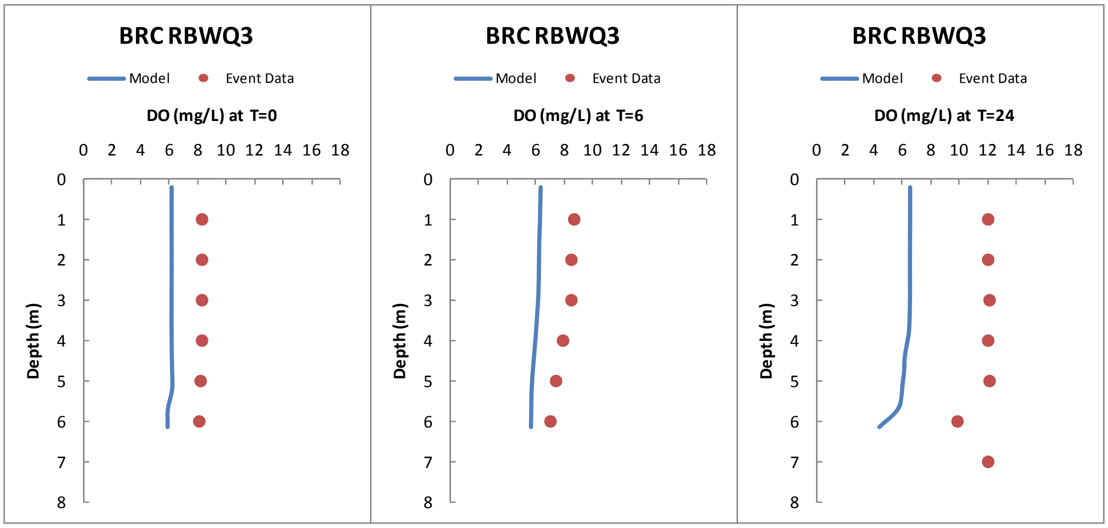


Figure 5-11: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 3 during the September 27, 2009 Wet Weather Event

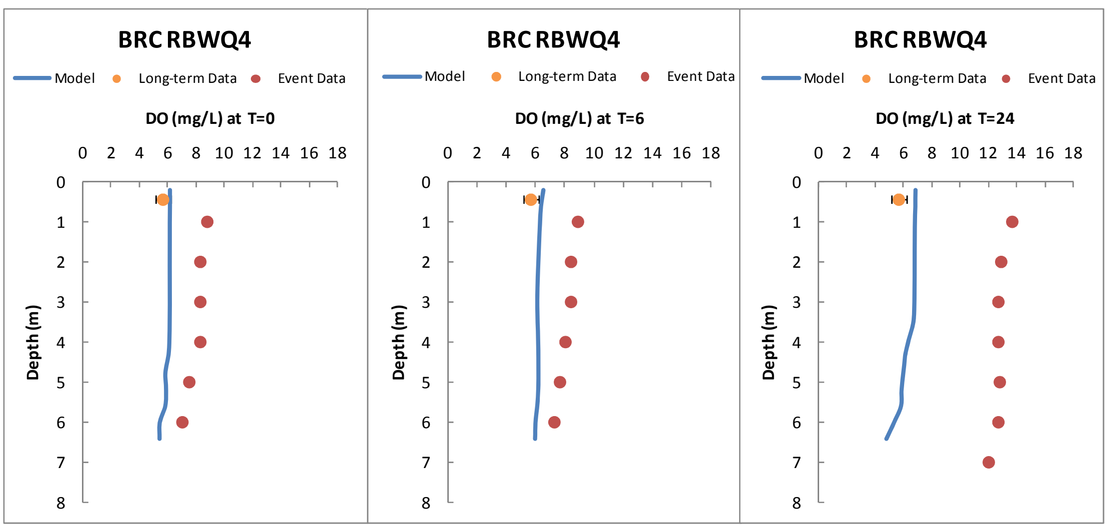


Figure 5-12: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 3 during the September 27, 2009 Wet Weather Event

Results for the second wet weather event are shown as time series comparisons of model-predicted dissolved oxygen at station BRC RBWQ4 in Figure 5-13. Note that the error bars on the data points represent the range of dissolved oxygen values sampled over an hour. The range in sampled data is very small for this time period. The model tends to match the surface DO values well during the event, with slight over-prediction of minimum values after 10/25/2009. Based on an evaluation of the measured surface DO dataset and discussions with Buffalo State College, it is suspected that the steady drop in measured DO over this time period could be attributed to an instrument "drift".

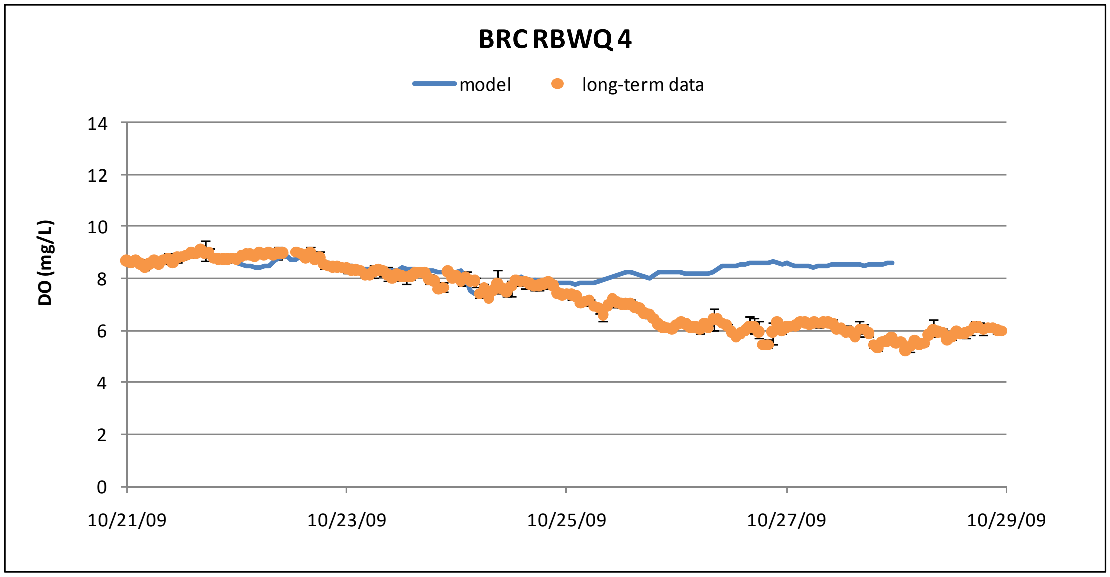


Figure 5-13: Temporal Profile of Observed and Simulated Long-term Surface Dissolved Oxygen at Station BRC RBWQ 4 during the October 23, 2009 Wet Weather Event

Figure 5-14 is a spatial profile plot of model-predicted dissolved oxygen values during a given day for the second wet weather event. Dips in the model DO profile at approximately 0.4 miles and 0.9 miles from the Black Rock Lock correspond with the decline in DO due to pollutant loadings from Scajaquada Creek and the Delavan Drain.

This figure illustrates the data discrepancy that was discussed above. There is an approximately 2 mg/L difference between long-term and event sampled dissolved oxygen values near the surface at the same location at a similar time during the second wet weather event. The error bars surrounding the data points correspond to the range of values over a day.

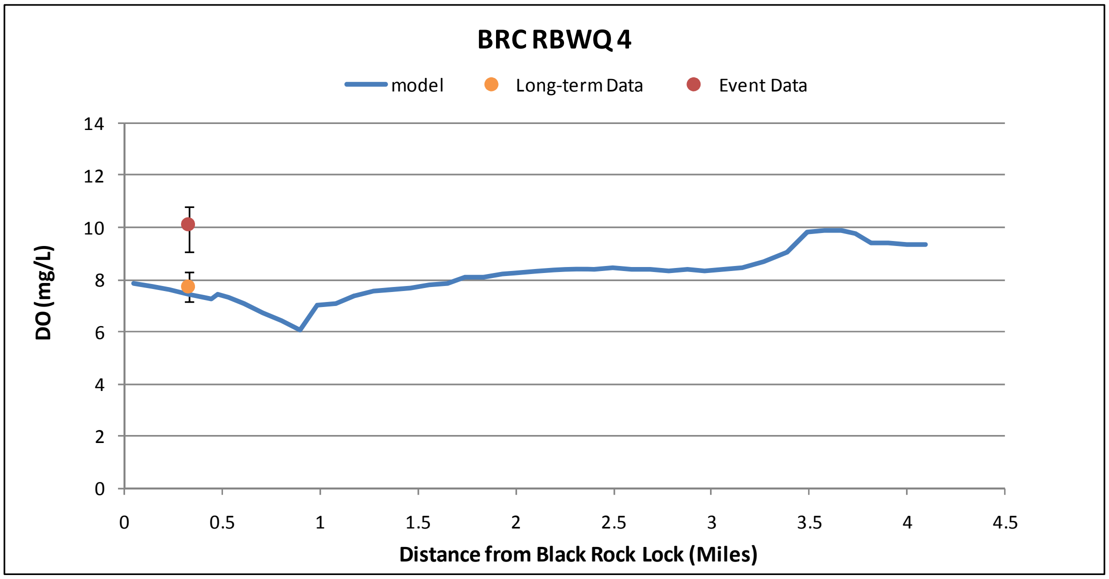


Figure 5-14: Spatial Profile of Observed and Simulated Near-surface Dissolved Oxygen at Station BRC RBWQ 4 during the October 23, 2009 Wet Weather Event

Figures 5-15 to 5-18, provide a profile depth comparison of simulated and measured DO for the second wet weather event at four sampling stations. For the 2009 simulation period, long-term data are available at buoy R10 and station BRC RBWQ4 only. Buoy R10 recorded surface DO data only; therefore, profiles are not shown for that station. In general, the model represents the level of DO stratification over time well, but under-predicts the magnitude of DO values by up to several mg/L. As discussed previously, the calibration goals for the 2009 wet weather events include matching the extent of stratification, the shape of the profiles, rather than the values themselves. This is due to the abnormally high values recorded by the hydrolabs for the wet weather events. The predicted DO values for the first wet weather event tend to lie closer to the continuous data than the event data near the surface.

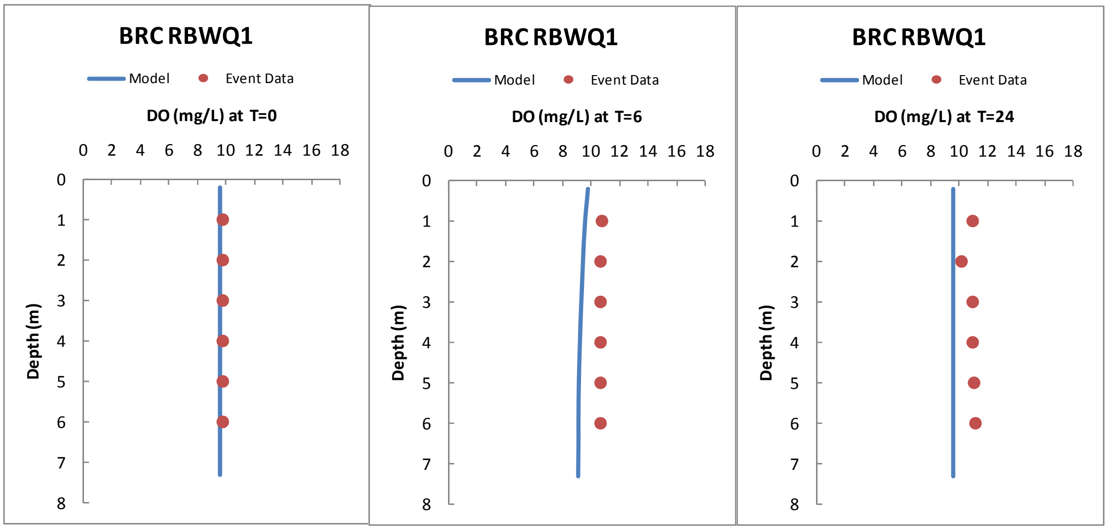


Figure 5-15: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 1 during the October 23, 2009 Wet Weather Event

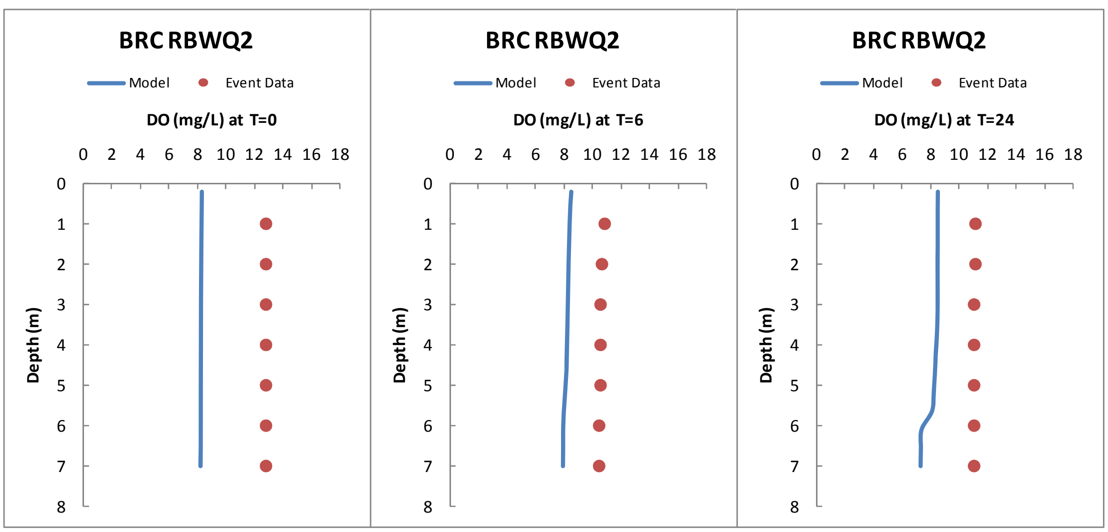


Figure 5-16: Depth Profiles of Observed and Simulated Dissolved Oxygen at Station BRC RBWQ 2 during the October 23, 2009 Wet Weather Event

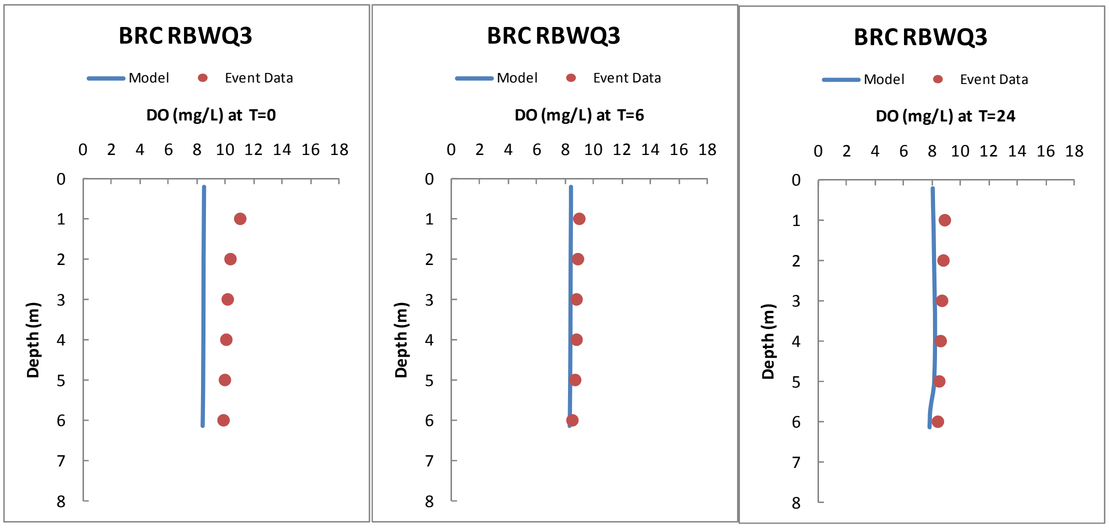


Figure 5-17: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 3 during the October 23, 2009 Wet Weather Event

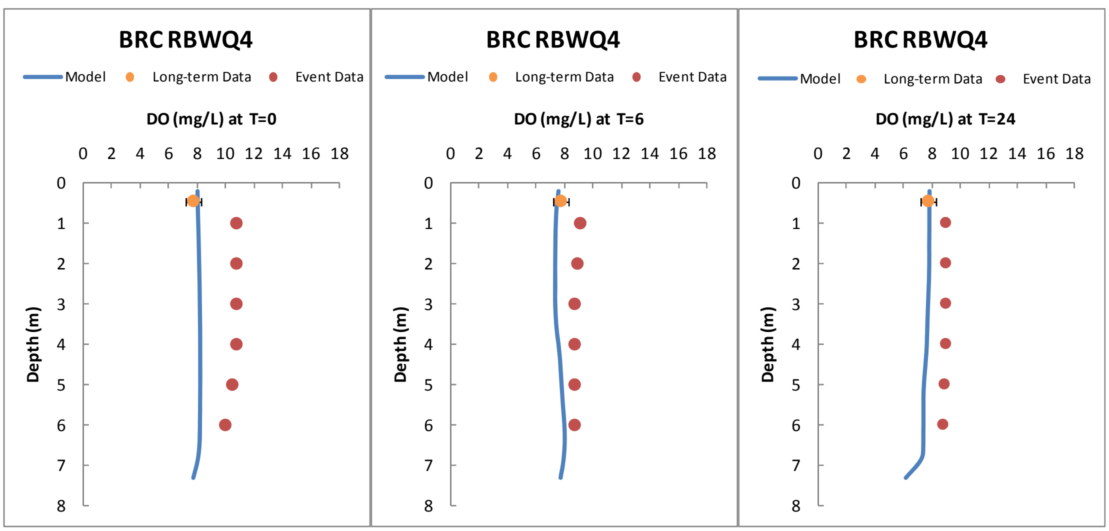


Figure 5-18: Depth Profiles of Observed and Simulated Dissolved Oxygen at BRC RBWQ 4 during the October 23, 2009 Wet Weather Event

5.2.4 Calibration Summary

In general, the Black Rock Canal dissolved oxygen model reasonably reproduces the magnitude and extent of dissolved oxygen stratification experienced in the canal for both steady-state and transient conditions. Limitations of the DO simulation include potential diurnal variations in measured DO that are not captured by the model formulation. This can possibly be attributed to the model formulation not simulating diurnal DO impacts from aquatic vegetation or algae.

The model reproduced DO measurements taken from the stationary hydrolab at BRC RBWQ 4 for 2008 and 2009 simulations. The model reasonably reproduces the magnitude and extent of stratification of dissolved oxygen during the dry weather period and the extent of stratification for the wet weather events. The magnitude of DO measurements taken for the wet weather events was determined erroneously high; therefore, the magnitudes for these events were not matched.

The most sensitive parameters during calibration included SOD and the reaeration rate**.** In addition, the vertical mixing predicted by applying 100% of the wind magnitude measured at the Buffalo Airport seemed unreasonably high and was therefore scaled back to account for wind-shielding effects. Overall the model predicts DO stratification during low flow periods, but the stratification is quickly overcome under higher flow conditions.

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6. SUMMARY

Water quality models have been developed for the Buffalo River, Scajaquada Creek, Niagara River, and Black Rock Canal, for use in evaluating CSO control alternatives. The Buffalo River and Scajaquada Creek models simulate bacteria and dissolved oxygen conditions; the Niagara model simulates bacteria fate and transport in the Niagara River and Black Rock Canal; and the Black Rock Canal model simulates dissolved oxygen in the Black Rock Canal. All models are capable of simulating time-variable conditions on an event or continuous basis and are designed to provide reasonable spatial detail for analysis of receiving water conditions.

These water quality models have been specifically designed and calibrated for use in evaluating receiving water quality effects of CSO control alternatives. With the completion of the calibration process, they are ready for use in this application.

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APPENDIX A: WATER QUALITY MODELING WORK PLAN

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Water Quality Modeling Work Plan For Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek

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Prepared On Behalf Of
The Buffalo Sewer Authority

May 30, 2008
Updated: January 22, 2010

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1. INTRODUCTION

This work plan describes development of water quality models of the Niagara River, Buffalo River, Black Rock Canal, and Scajaquada Creek, to address recent comments from the New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA) on the *System-Wide Long Term Control Plan for CSO Abatement* prepared by Malcolm Pirnie, Inc., on behalf of the Buffalo Sewer Authority (Malcolm Pirnie, 2004a, b). LimnoTech prepared this work plan on behalf of the Buffalo Sewer Authority (BSA), under subcontract to Malcolm Pirnie. The work plan was originally submitted to NYSDEC and USEPA in May 2008. It was updated in January 2010 to reflect identified changes to the modeling tasks.

1.1 BACKGROUND

The government agencies involved in reviewing the Long Term Control Plan (LTCP) have suggested the need for the Buffalo Sewer Authority (BSA) to conduct receiving water quality modeling of waterways potentially affected by combined sewer overflows (CSOs). Specifically, modeling of the Niagara River, the Buffalo River, and Scajaquada Creek was requested in a letter to BSA (Palumbo, 2007) to evaluate specific concerns regarding bacteria, biochemical oxygen demand (BOD), and effects on dissolved oxygen (DO) in these waterways. Subsequent discussions with government agencies have identified concerns regarding dissolved oxygen impacts in Black Rock Canal. BSA, in conjunction with the University of Buffalo, conducted previous water quality modeling to evaluate dissolved oxygen conditions in the Buffalo River. The modeling work described in this work plan will build on the previous Buffalo River modeling and will involve development of new receiving water models to enhance BSA's understanding of the impacts of CSOs on these receiving waters. These models will be used in the future to evaluate the benefits of proposed CSO control projects.

1.2 OBJECTIVES

The overarching objectives for development of receiving water quality models for the Buffalo waterways are to improve the understanding of the impacts of CSOs on receiving water quality and to support decision-making regarding CSO control alternatives. Discussions with the NYSDEC and USEPA have defined a set of questions to be answered by the receiving water quality models described in this work plan.

1.2.1 General Questions Applicable to All Models

Several questions have been formulated that describe general water quality model needs for all of the models. These include the following:

- What is the relative contribution of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters during and following a CSO event relative to other watershed sources, such as direct runoff, other tributary sources, and sources in the watershed above the city?

- What are the effects of BSA CSO discharges to the bacteria and BOD concentrations in receiving waters in the hypothetical absence of other contributions or potential reductions of other contributions?

- What effect will proposed Phase 1 CSO control projects have on receiving water quality, relative to current conditions?

The water quality models developed under this work plan will allow evaluation of the impacts of BSA's CSOs on water quality in the absence of other sources and under varying upstream loads and other sources. The models will allow evaluation of attainment of existing water quality standards, where appropriate. The models will also support use attainability analysis (UAA) but, because of the nature of UAAs, may not be sufficient by themselves. In addition to the general questions listed above, several waterway-specific questions have been identified, as described below.

1.2.2 Waterway Specific Questions

In addition to the general questions listed above, the following waterway-specific questions have been identified:

Niagara River

- What is the spatial and temporal distribution of bacteria in the Niagara River following an overflow event?

- What are the impacts of Scajaquada Creek and Black Rock Canal CSOs on Niagara River water quality, with respect to bacteria?

- How will CSO discharges and flows from the Buffalo River move in the Niagara River; under what conditions will these flows "hug" the eastern bank?

- What effect will proposed Phase 1 CSO control projects have on water quality in the Niagara River, relative to current conditions?

Buffalo River

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in the Buffalo River? How will SOD and the resulting DO in the Buffalo River change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in the Buffalo River?

- What is the effect of CSOs on water quality in the Buffalo River, specifically with respect to bacteria? How will this change with CSO controls?

- How is BOD and bacteria loading to the Inner Harbor affected by Buffalo River CSOs?

Scajaquada Creek

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in Scajaquada Creek? How will SOD and the resulting DO in Scajaquada Creek change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in Scajaquada Creek?

- What controls are necessary for the Scajaquada Creek CSO discharges in order to meet standards in that part the system designated as Class B with regard to designated uses?

- What will the bacteria loads to the Black Rock Canal and Niagara River be from Scajaquada Creek during various storm events with and without CSO controls?

Black Rock Canal

- What is the impact of BSA's CSO discharges to dissolved oxygen concentrations in Black Rock Canal?

- What is the impact of BSA's CSO discharges to bacteria concentrations in Black Rock Canal?

- What is the long-term contribution of BSA's CSOs to sediment oxygen demand (SOD) in Black Rock Canal? How will SOD and the resulting DO in Black Rock Canal change as a result of CSO discharge controls? Can CSO controls (consider planned phase 1 projects and potential phase 2 projects) alone achieve target bacteria and DO levels in Black Rock Canal?

This work plan covers the development and calibration of water quality models to answer the questions above, but does not specifically include the assessment of CSO control alternatives which may be necessary to answer the questions. The application of the models to CSO control alternatives is to be conducted after USEPA acceptance of the models.

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2. DESCRIPTION OF WATER QUALITY MODELS

Four receiving water quality models will be developed to meet the objectives and answer the questions outlined in section 1.2 of this work plan. The models will rely on CSO loading data generated from BSA's collection system model, as well as other datasets. Each of the receiving water quality models is described below. The relative locations and spatial extents of the models are depicted on Figure 1.

2.1 BUFFALO RIVER MODEL

A model of the Buffalo River, including the ship canal, will be developed to facilitate understanding of CSO impacts on DO and bacteria conditions in the river. The original modeling work plan (dated May 30, 2008) proposed using a modified version of the existing Buffalo River model developed at the University at Buffalo by Drs. Atkinson and DePinto (now with LimnoTech) to meet the objectives identified in section 1.2. However, a detailed review of the existing Buffalo River model provided by Dr. Atkinson revealed significant limitations in applying the model as originally intended, including the following:

- It is technically infeasible to modify the existing two dimensional model to extend it from the downstream, dredged, portion of the river to the upstream shallower reaches where a one-dimensional model is needed;

- The existing Buffalo River model code is not well documented, making modifications very difficult and time-consuming; and

- The existing model does not have a user interface, making model calibration and application much more time-consuming than originally expected.

In light of these challenges, development of a new Buffalo River model, using the USEPA-supported Environmental Fluid Dynamics Code (EFDC) is planned. This new EFDC model offers several advantages over the original modeling approach:

- An EFDC-based model can readily link a downstream two-dimensional section with upstream one-dimensional reaches;

- The generalized vertical coordinate (GVC) system available in EFDC is superior to the sigma vertical coordinate system in the existing Buffalo River model, particularly for stratified systems with rapid bathymetric changes, both of which occur in the Buffalo River;

- EFDC is already planned for use on the Niagara River and Black Rock Canal and an EFDC model of the Buffalo River will facilitate system-wide simulations and linkages;

- EFDC can readily be used to simulate dissolved oxygen and bacteria fate and transport; and

- LimnoTech has already developed a model processing and visualization utility for EFDC that will facilitate presentation and evaluation of model results.

LimnoTech has discussed this recommendation, as well as the challenges and limitations of the existing model, with Dr. Atkinson and he concurs with this approach. A description of the model and information on planned calibration of the model are presented below.

2.1.1 Model Description

As described above, the Buffalo River model will be developed using the USEPA Environmental Fluid Dynamics Code (EFDC). The Buffalo River model will be time-variable, two-dimensional, and laterally averaged. It will simulate BOD and DO and bacteria. In order to capture all CSOs on the Buffalo River within the model, and to provide the capability to examine water quality impacts from individual CSOs on the Buffalo River, the Buffalo River model domain will extend upstream along the Buffalo River and Cazenovia Creek branches to approximately the Buffalo municipal boundary (see Figure 2).

The model will be used to simulate bacteria fate and transport, as well as BOD/DO dynamics. The model will have the ability to independently track BOD and fecal coliform from upstream, CSO, and stormwater sources. This feature will provide the capability to estimate the relative contribution of particulate BOD deposition to long term changes in sediment oxygen demand. Where applicable, model reaction rates and kinetic formulations will be similar to those applied with Dr. Atkinson's Buffalo River model.

2.1.2 Boundary Conditions

As described above, the Buffalo River model will extend roughly from the Buffalo City boundary on the upstream ends of the Buffalo River and Cazenovia Creek, downstream to the inner harbor. The upstream boundary on Cazenovia Creek will be set just slightly downstream of the Buffalo City Boundary (near Cazenovia Parkway) to better account for an abrupt drop in the channel due to Cazenovia Falls. In order to account for potential flow reversals near the upstream boundary and near CSOs, the upstream boundary for the hydrodynamic model will be set to points just upstream of the confluence of Cayuga Creek and Buffalo Creek. The water quality model boundary condition along the Buffalo River will be at the Buffalo City boundary. The boundary conditions for the model are described below:

- Flows at the upstream boundary will be based on the measured flows at USGS gages on the Buffalo River (USGS gage No. 04214500) and Cazenovia Creek (USGS gage No. 04215500).

- Downstream stage will be specified using data collected at the NOAA gage near the river mouth.

- Water quality at the upstream boundary will be specified using existing data from water quality monitoring stations on the Buffalo River (station No. SCD RBWQ 1) and Cazenovia Creek (station No. SCD RBWQ 6). Existing data will be used for model calibration and validation.

- The lower Buffalo River is subject to flow reversal under certain conditions; if necessary, water quality at the downstream boundary will be specified using existing or new data from the water quality monitoring station at the mouth of the Buffalo River (station No. SCD RBWQ 5).

CSO loads to the Buffalo River model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model.

2.1.3 Calibration & Validation

The Buffalo River model will be calibrated and validated for BOD/dissolved oxygen, and bacteria fate and transport with existing data from a previous monitoring effort during 2000. River hydraulics will be calibrated against 2008 data collected under a separate effort (a Great Lakes Legacy Act Agreement project). Additional data to be used for supplemental calibration and validation of the Buffalo River model are described in Section 3.1.

2.2 SCAJAQUADA CREEK MODEL

A model of Scajaquada Creek will be developed to facilitate understanding of CSO impacts on DO and bacteria conditions in the Creek, as well as to simulate BOD/DO and bacteria loading to Black Rock Canal. Description of the Scajaquada Creek model and its calibration are provided below.

2.2.1 Model Description

The Scajaquada Creek model will be developed as a one-dimensional hydrodynamic and water quality (BOD/DO dynamics and bacteria fate and transport) model to simulate water quality response in the Creek to CSO loading and to compute pollutant loading time series to Black Rock Canal during CSO events. The Scajaquada Creek model will also be designed and applied to estimate the relative contribution of particulate BOD deposition to long term changes in sediment oxygen demand in the Creek.

The U.S. Geological Survey (USGS) Full Equations Model (FEQ) will be used to model hydrodynamics in Scajaquada Creek. The creek geometry data needed to develop this model will be obtained from existing sources such as FEMA Flood Insurance Studies. The hydrodynamic model will extend downstream as far as the

Grant Street dam. The portion of Scajaquada Creek below the dam will be included in the Black Rock Canal model as described in Section 2.4. The Scajaquada Creek water quality model will be a time-variable, one-dimensional model, developed using the USEPA-supported Water Quality Analysis Simulation Program (WASP). The model domain will extend from the upstream end of the Scajaquada Drain tunnel, down to the Grant Street dam (see Figure 3). The Scajaquada Creek model will be capable of computing pollutant loading time series to Black Rock Canal during overflow events and it will have the ability to evaluate water quality response to varying CSO and upstream pollutant loads. The model will take into account the dynamic nature of Scajaquada Creek and Drain.

2.2.2 Boundary Conditions

The Scajaquada Creek model will extend from the upstream end of the Scajaquada Drain tunnel to the Grant Street dam on the downstream end. Boundary conditions for the Scajaquada Creek model will be specified as follows:

- Upstream hydraulic boundary conditions will be specified using data collected specifically for this purpose. The data collection required for this is described in Section 3.2. Downstream hydraulic boundary conditions will be determined by the dimensions of the Grant Street dam, which will be simulated as a freely overflowing weir.

- Water quality at the upstream boundary will be specified using new data collected for this project. These data will include BOD/DO and bacteria measurements for both dry weather and wet weather conditions.

CSO loads to the Scajaquada Creek model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model.

2.2.3 Calibration & Validation

The hydrodynamic model will require calibration and the data to be used for calibration and validation of the Scajaquada Creek model is described in Section 3.2.

The Scajaquada Creek water quality model will be calibrated and validated for BOD, dissolved oxygen, and bacteria, which will require the collection of new data. The Scajaquada Creek model will be calibrated to one dry-weather event and one wet-weather event. One dry-weather and one wet-weather event will be used for model confirmation. It is assumed that collection of new water quality, hydraulic, and sediment oxygen demand data to support calibration and validation of the Scajaquada Creek model will be coordinated with other data collection activities and is not included in this scope of work.

2.3 NIAGARA RIVER MODEL

The Niagara River Model will be designed to simulate bacteria fate and transport and to provide hydrodynamic simulation output for subsequent use in the Black Rock Canal DO/BOD model, described in section 2.4 of this work plan. Further details are provided below.

2.3.1 Model Description

The Niagara River bacteria model, which will include Black Rock Canal, will be developed using the USEPA Environmental Fluid Dynamics Code (EFDC). The Niagara River model will be time-variable, two-dimensional, and vertically averaged.

The hydrodynamic model domain of the Niagara River model will extend from Lake Erie to Niagara Falls, as shown on Figure 4. The model domain of the Niagara River water quality model will be smaller than the domain of the hydrodynamic model. As shown on Figure 4, the upstream boundary of the water quality model will coincide with the hydrodynamic boundary, but the downstream boundary of the water quality model will only extend to the southern end of Grand Island. It is expected that the water quality model will be calibrated to a sampling transect near the northern Buffalo municipal boundary, because of uncertainty with respect to loads downstream of that point. Therefore, the model will not include inputs from Tonawanda and Ellicott Creeks.

The model grid will be designed to allow simulation of hydrodynamic circulation in and around Black Rock Canal and will extend upstream on Scajaquada Creek to the Grant St. Dam to capture gradients in bacteria in the transition of classification zones of the river. The model will also be designed with sufficient detail to accurately simulate hydrodynamic conditions in Black Rock Canal, given operation records for the lock during model simulation period.

2.3.2 Boundary Conditions

Boundary conditions for the Niagara River model will be specified as follows:

- Stage at the downstream boundary will be specified using available stage data from the International Niagara Committee and other agencies.

- Flow at the upstream boundary conditions will be specified using existing measurements of flow at Niagara Falls provided by the International Niagara Committee.

- Water quality at the upstream boundary of the water quality model will be estimated using both new data collected for this project and existing data collected in Lake Erie by other agencies near the outlet to the Niagara River. Approximate monitoring locations are depicted on Figure 4. A sensitivity analysis will be performed to quantify the relative impact of this upstream boundary condition on modeled bacteria concentrations.

- Flow from the Buffalo River will be transferred from the Buffalo River bacteria model.
- Concentrations of bacteria measured as part of this study at the mouth of the Buffalo River will be associated with the flow coming from the Buffalo River to provide bacteria loads for calibration/confirmation.

CSO loads to the Niagara River model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model. Tributary flows and pollutant loads from the Buffalo River and Scajaquada Creek will be generated using the Buffalo River and Scajaquada Creek models.

2.3.3 Calibration & Validation

It is expected that the hydrodynamic model of the Niagara River will be calibrated using available stage, flow, or velocity data from the International Niagara Committee, the U.S. Army Corps of Engineers, or other agencies. Calibration and validation of the Niagara River hydrodynamic model will not rely on dry-weather vs. wet-weather conditions because the size of the river makes it generally unresponsive to short-term weather events.

The bacteria fate and transport component of the Niagara River model will be calibrated to one dry weather event and one wet weather event. One dry-weather and one wet-weather event will be used for validation.

2.4 BLACK ROCK CANAL MODEL

A separate dissolved oxygen model of the Black Rock Canal will be developed to run independently of the Niagara River EFDC model, to focus specifically on the regions of interest for dissolved oxygen. This will be computationally more efficient than modeling dissolved oxygen throughout the entire Niagara River model domain. Bacteria fate and transport in the Black Rock Canal will be addressed using the Niagara River EFDC model.

2.4.1 Model Description

Hydrodynamics in the Black Rock Canal will be modeled as part of the Niagara River hydrodynamic EFDC model, discussed in section 2.3, and transferred to the upstream end of the model domain. The Black Rock Canal water quality model will be a two-dimensional, laterally averaged model designed to simulate BOD/DO dynamics in the canal. The spatial domain of the Black Rock Canal water quality model will extend from the southern end of the Black Rock Canal breakwater to a point near the northern end of Squaw Island as shown on Figure 5. Due to the lock at the northern end of the canal, flow in the canal general runs in a north to south direction (opposite of the Niagara River) during wet weather events.

2.4.2 Boundary Conditions

Boundary conditions for the DO/BOD model of Black Rock Canal will be specified as follows:

- Hydrodynamic boundary conditions at the southern end will be extracted from the full Niagara River EFDC model that covers both the Niagara River and Black Rock Canal. The flow exchange specified across the interface between the vertically averaged 2D Niagara River model (1 vertical layer) and laterally averaged 2D Black Rock Canal model (multiple vertical layers) will be distributed in order to generate reasonable boundary conditions.

- Water quality at the southern model boundary will be specified using new data collected for this project. These data will include DO and BOD data collected during both dry-weather and wet-weather conditions.

- Flow and loads of DO and BOD over the Grant St. dam on Scajaquada Creek will be transferred from the FEQ/WASP model of Scajaquada Creek.

- Water quality at the northern boundary will be specified using water quality data collected at the lock near the northern end of Squaw Island. These data will include event-based BOD/DO measurements.

CSO loads to the Black Rock Canal model will be generated using existing monitoring data and CSO flows estimated using the existing collection system model. Tributary flows and pollutant loads from Scajaquada Creek will be generated using the Scajaquada Creek model.

2.4.3 Calibration & Validation

Hydrodynamic calibration and validation of the Niagara River model will be relied upon for simulation of hydrodynamic conditions in Black Rock Canal. The Black Rock Canal dissolved oxygen model will be calibrated using BOD/DO data collected during the same data collection events as Scajaquada Creek. Data collection locations are depicted in Figure 5. Sediment oxygen demand data will be collected during dry weather conditions.

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3. DATA NEEDS

Existing data will be used, to the extent practicable, in developing the models described in this work plan. However, review of the available data indicates that existing data alone will not be sufficient for calibration and validation of all the models. The expected data needs for model development are summarized below.

3.1 BUFFALO RIVER MODEL

It is expected that very little new data will be required to support the Buffalo River model because dry-weather and wet-weather BOD and bacteria data collected during past planning efforts appear to be sufficient for calibration and validation. The data collected from the 2000 water quality monitoring program will be used for this purpose. It is expected that the May 4, 2000 dry weather event and the June 9-11, 2000 wet weather event will be used for calibration, and the September 7, 2000 dry weather event and the August 23-25, 2000 wet weather event will be used for validation.

Collection of new sediment oxygen demand (SOD) data is not planned for the Buffalo River. SOD data have been collected from the lower Buffalo River in the past by the New York Department of Environmental Conservation (NYDEC) and have been used in previous modeling efforts by the University of Buffalo. In the model reaches upstream of the Cazenovia Creek confluence, Cazenovia Creek and the Buffalo River are relatively shallow and DO conditions are likely dominated by reaeration and temperature, so SOD data will not be collected there.

Existing data will, however, be supplemented in the Buffalo River as follows:

- Bacteria data will be collected near the mouth of the Buffalo River, where it interfaces with the Niagara, in order to validate the Buffalo River model's predicted loads during Niagara River calibration events. For this purpose, bacteria data will be collected from the mouth of the Buffalo River, roughly collocated at the water quality monitoring location used in past monitoring activities by BSA (SCD RBWQ 5). Bacteria data will be collected at this location during each dry-weather and wet-weather event.
- Hydrodynamic calibration will be verified with data collected by LimnoTech under contract to Honeywell as part of Great Lakes Legacy Act Agreement (GLLA) between Honeywell and the Buffalo River GLLA project coordination team in 2008.

At this time, no other new data are required from the Buffalo River.

3.2 SCAJAQUADA CREEK MODEL

Development of the Scajaquada Creek model will require collection of the following new data:

- Hydrodynamic calibration of the Scajaquada Creek model will require collection of flow, stage, and/or velocity data at various locations in the Scajaquada Creek system. Continuous data were collected between June and October 2008 immediately upstream of the Scajaquada Drain using a side-looking acoustic Doppler current profiler (ADCP). In addition, continuous stage data were collected at two downstream locations. These data will be used for model hydrodynamic calibration. These data will also be used to develop a stage-discharge relationship for Scajaquada Creek. Stage data collected during the 2009 wet weather season will be used in conjunction with this relationship to calculate upstream flows during the 2009 wet weather events, which will be used for water quality calibration.

- Water quality data will be required for model calibration and validation from four locations in Scajaquada Creek: upstream of the upstream end of the Scajaquada Drain tunnel; downstream of the downstream end of the Scajaquada Drain tunnel; downstream of the lake at Forest Lawn Cemetery; and upstream of the Grant Street dam (near previous data location SJD RBWQ 2). The approximate locations of these stations are shown on Figure 2. Data collected at these stations should include BOD/DO and bacteria data, collected during two dry-weather and two wet-weather events.

- The Scajaquada Creek model will also require collection of sediment oxygen demand data from two locations. The SOD monitoring locations were determined after initial field inspection and are shown in Figure 2.

Channel bathymetry data will be required to accurately model hydraulics in Scajaquada Creek. Through inquiry with the U.S. Army Corps of Engineers' Buffalo District and the New York Department of Environmental Conservation (NYDEC), it is understood that hydraulic modeling of Scajaquada Creek was previously conducted for the Federal Emergency Management Agency (FEMA) flood mapping program and that a new flood study is underway. These flood mapping studies require channel cross-section surveys which will be used for the Scajaquada Creek model in this project.

3.3 NIAGARA RIVER MODEL

Calibration and validation of the Niagara River water quality model will require collection of bacteria data from several transects. These transects consist of three stations aligned across the river channel as shown on Figure 4. In some cases, an additional easternmost station will be aligned with the Niagara River transects, but will actually fall within the Black Rock Canal. Data collected at these transects should include bacteria (fecal coliform) data collected during two dry-weather and two wet-weather events.

3.4 BLACK ROCK CANAL MODEL

The Black Rock Canal model will require the data collection described below:

- Event-based sampling of BOD/DO data will be required for calibration and validation of the Black Rock Canal model. These data will be collected at four locations within the canal: near the southern end of the breakwater; near the downstream end of Squaw Island; at the confluence of Scajaquada Creek; and in the vicinity of International Bridge and the canal locks. Data should be collected at these stations during two dry-weather and two wet-weather events. It should be noted that bacteria will also be sampled in the Black Rock Canal but will be used with the Niagara River EFDC model.

- Continuous dissolved oxygen data should be collected using hydrolabs at two locations in Black Rock Canal: one hydrolab will be deployed at or near the southern end of the Black Rock Canal breakwater (for specification of the upstream boundary condition) and the other will be deployed at an intermediate location in Black Rock Canal to be determined after field inspection (to support model calibration).

- The Black Rock Canal model will also require collection of sediment oxygen demand (SOD) data from two locations. The SOD monitoring locations will be determined after initial field inspection.

At this time, it does not appear necessary to collect any new bathymetric or hydrodynamic data to support development of the Black Rock Canal model.

3.5 RECEIVING WATER LOADING SOURCES

For each receiving water model, additional datasets and/or model output will be used to characterize the following bacteria and BOD loading sources into the system:

- Malcolm Pirnie will provide CSO flows and loadings (bacteria and BOD) for all calibration events based on output from their collection system model.

- NPDES permitted point source loads will be characterized based on data from NYDEC and EPA's Permit Compliance System (PCS) database. Flows reported in discharge monitoring reports (DMRs) will be reviewed, and any significant point sources, relative to the receiving water flow, will be included in the model.

- If any significant non-CSO storm water discharges are identified, flows and loadings from these sources will be included in the model based on estimates provided by Malcolm Pirnie.

- Point source, tributary, and CSO bacteria loads entering the Niagara River from the Canadian side will be investigated and estimated to the extent practicable. If these loadings are determined to be significant, they will be included in the model.

4. DELIVERABLES

For each of the water quality models described in this plan, calibration will be conducted using data from one dry weather and one wet weather event. As part of the model development process, a written report will be produced and submitted which documents the model development process and calibration. At a minimum, the **Final Modeling Report** will document the following aspects of model development for each of the models:

- Model code/software used
- Model inputs and assumptions
- Boundary conditions
- Plots of model output versus field data for each calibration and confirmation event
- Tabular and narrative summaries of degree of calibration achieved

This deliverable will be provided in both hard copy and electronic formats to facilitate distribution and review.

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5. SCHEDULE

Based on the data needs for the modeling effort and the expected schedule for collection of those data, an overall model development schedule of approximately 24 months is expected, in keeping with previous discussions with BSA and regulatory agencies. It is expected that model development will begin after approval of this work plan, on or about June 1, 2008.

Model development activities can proceed in parallel with data collection activities, but completion of all model calibration and validation tasks will depend on the timing of wet weather events and therefore cannot be predicted with accuracy. The two required dry weather events were sampled in 2008; however, data collection for the two required wet weather events did not occur until fall 2009.

Given the start date and timing for the wet weather data collection, delivery of the final modeling report would be targeted for not later than September 30, 2010.

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FIGURES

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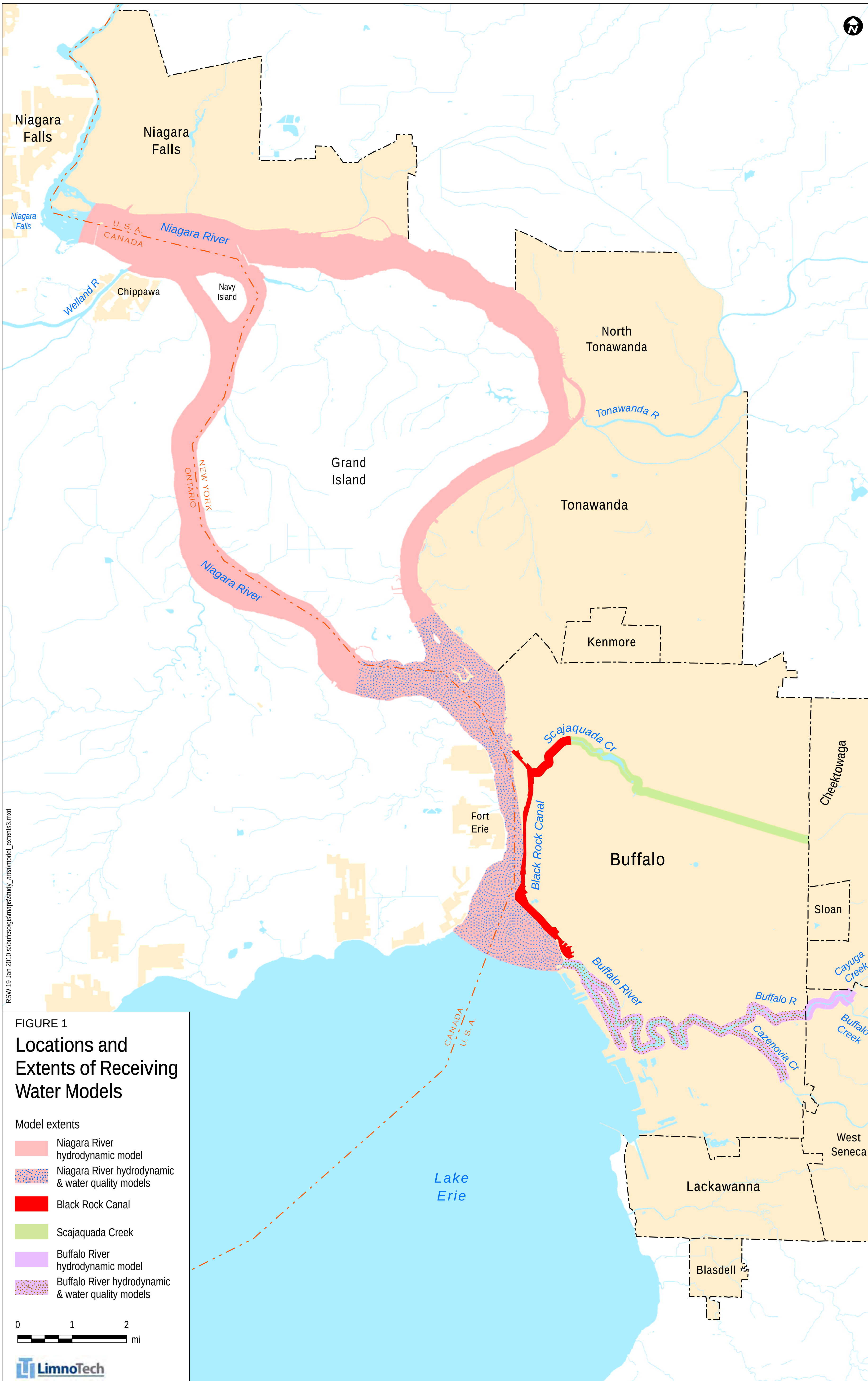

FIGURE 1
Locations and Extents of Receiving Water Models

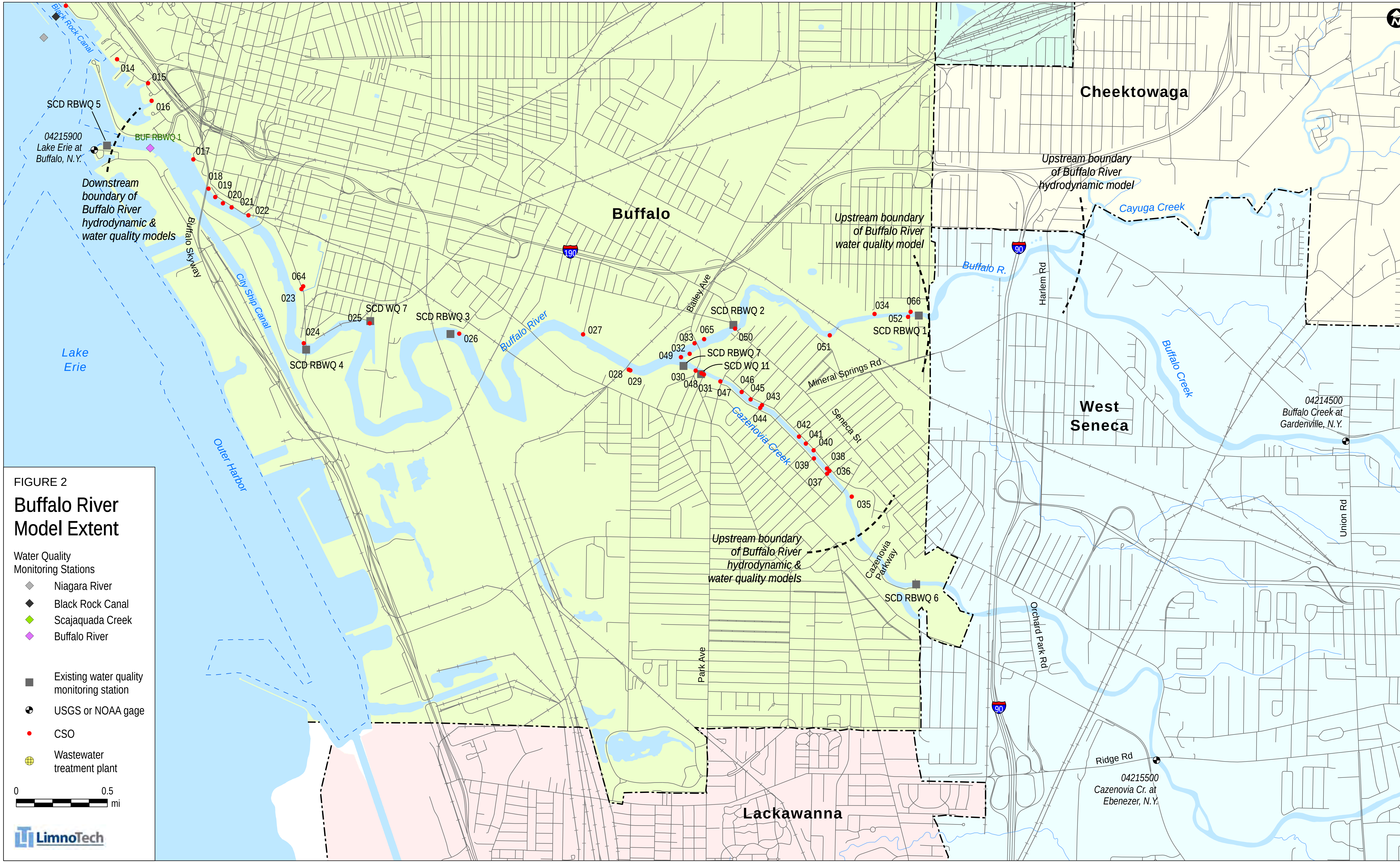

FIGURE 2
Buffalo River Model Extent

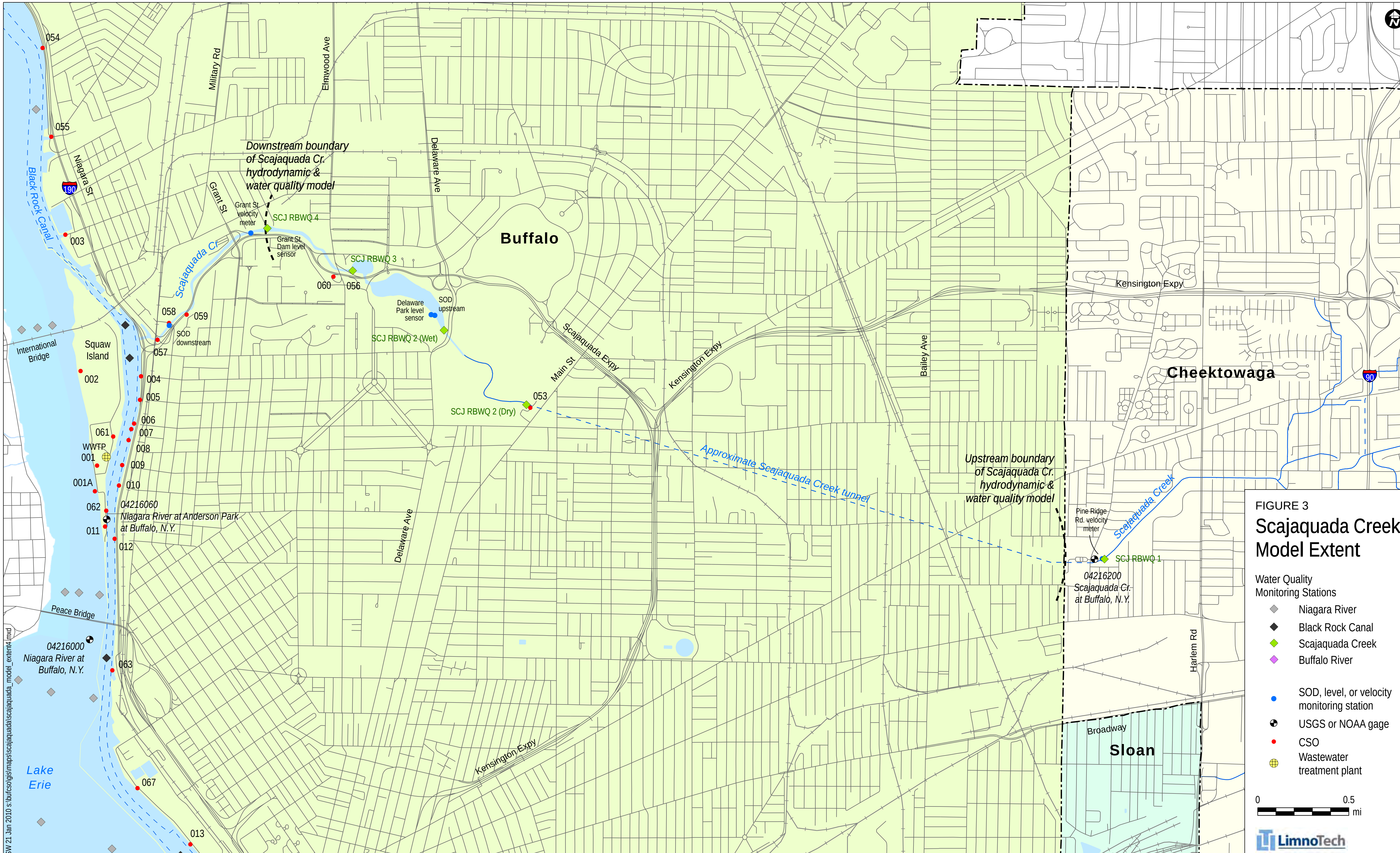
FIGURE 3
Scajaquada Creek Model Extent
Water Quality Monitoring Stations
Niagara River
Black Rock Canal
Scajaquada Creek
Buffalo River
SOD, level, or velocity monitoring station
USGS or NOAA gage
CSO
Wastewater treatment plant
0
0.5
mi
LimnoTech
Buffalo
Cheektowaga
Sloan
Lake Erie
Black Rock Canal
Squaw Island
International Bridge
Peace Bridge
Niagara St
Grant St
Military Rd
Elmwood Ave
Delaware Ave
Main St
Scajaquada Expy
Kensington Expy
Bailey Ave
Harlem Rd
Broadway
Scajaquada Cr
Scajaquada Creek
Approximate Scajaquada Creek tunnel
Downstream boundary of Scajaquada Cr. hydrodynamic & water quality model
Upstream boundary of Scajaquada Cr. hydrodynamic & water quality model
Grant St velocity meter
Grant St Dam level sensor
Delaware Park level sensor
SOD upstream
SOD downstream
Pine Ridge Rd. velocity meter
SCJ RBWQ 4
SCJ RBWQ 3
SCJ RBWQ 2 (Wet)
SCJ RBWQ 2 (Dry)
SCJ RBWQ 1
04216060 Niagara River at Anderson Park at Buffalo, N.Y.
04216000 Niagara River at Buffalo, N.Y.
04216200 Scajaquada Cr. at Buffalo, N.Y.
WWTP
001
001A
002
003
004
005
006
007
008
009
010
011
012
013
053
054
055
056
057
058
059
060
061
062
063
067
190
90
RSW 21 Jan 2010 s:\bufcso\gis\maps\scajaquada\scajaquada_model_extent4.mxd

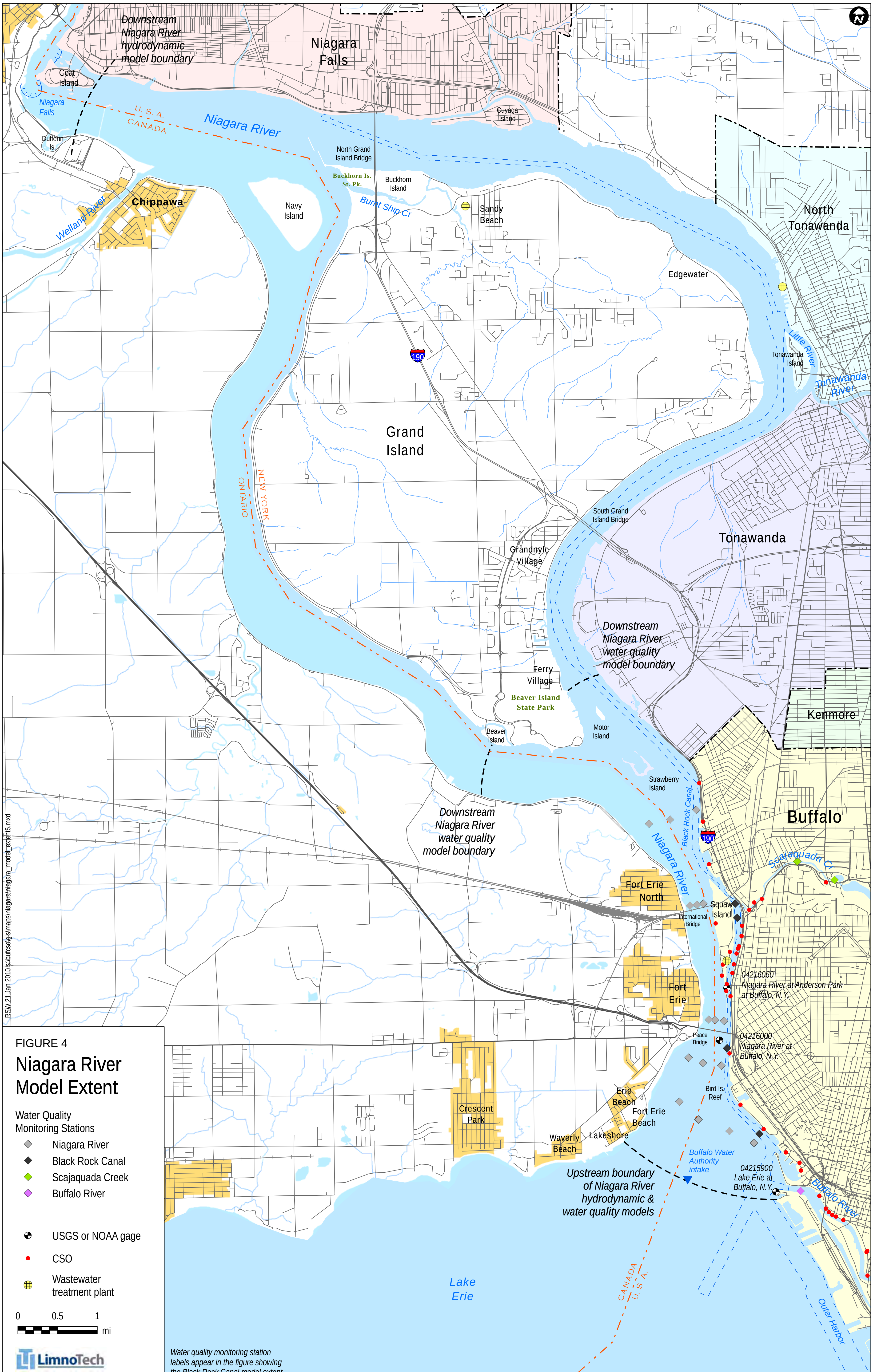

FIGURE 4

Niagara River Model Extent

FIGURE 5
Black Rock Canal Model Extent

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APPENDIX B: WATER BODY DESCRIPTIONS

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Appendix B: Water Body Descriptions

This section presents a general description of each of the water bodies modeling by LimnoTech, to provide context for subsequent discussions of model development and calibration. The relative locations of these water bodies are depicted in Figure B-1.

B.1 BUFFALO RIVER

The Buffalo River begins at the junction of Cayuga and Buffalo Creeks near the Buffalo city limits and flows east an additional 8.5 miles until reaching Lake Erie at the head of the Niagara River. Cazenovia Creek enters the Buffalo River 5.9 miles upstream from Lake Erie. The river is approximately 150 feet wide near the eastern City of Buffalo limits and expands to 350 feet wide in the lower dredged portions of the river. The Buffalo River has a drainage area of 431.5 square miles spread across Erie, Wyoming, and Genesee counties in western New York. The gradient of the river is very slight, less than one foot per mile. Buffalo River watershed elevations range from 571 ft near Lake Erie to a 1942 ft near the headwaters along the southern edge of the watershed.

Previous water quality models of the system have only included the dredged portion of the river. In order to account for all CSO's within the City of Buffalo domain, the model current modeling of the Buffalo River includes all portions of the Buffalo River within the Buffalo city limits, including the City Ship Canal and Cazenovia Creek. To correctly simulate hydrodynamics at the Buffalo city limit the model domain of the hydrodynamic model was extended up to the confluence of Buffalo and Cayuga Creeks.

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Figure B-1: Study Area Map.

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B.1.1 System Hydrology

In 2000, the average daily flow of the Buffalo River was 726 cfs. During that year, the river experienced a low flow of 58 cfs and a peak flow of 12,500 cfs. Flood Insurance Studies by the Federal Emergency Management Agency estimate that the 100-yr flow for the Buffalo River is 37,290 cfs. During periods of low upstream flows, the downstream end of the river is influenced by variation in the level of Lake Erie. The backwater influence of Lake Erie typically extends upstream near the Buffalo City Limits, but it can extend as far as the confluence of Cayuga and Buffalo Creeks under extreme low flow conditions and high lake levels.

B.1.2 System Modifications

The Buffalo River is a heavily modified system, with industrial and urban development dating back to the mid 1800's. Most of Buffalo's heavy industry was clustered along the banks of the river, but many facilities have since closed. There are 45 inactive hazardous wastes sites in the watershed.

The natural river channel of the lower 5.2 miles of the river has been heavily modified to support commercial shipping. Through dredging, the USACE maintains a depth of 22 feet within the federally authorized navigation channel. In addition, the City Ship Canal was constructed in 1850 near the mouth of the river to accommodate large lake going vessels. This canal is 125 feet wide, 5,500 feet in length, and is dredged to a depth of 23 feet. The USACE estimates that upstream sections of the navigation channel are dredged every two to three years, while other portions of the river are dredged less frequently (Table B-1).

Table B-1: Estimated Dredging Frequency in the Buffalo River (USACE 2005)

Channel Reach	General Dredging Frequency
Upstream limit to South Park Bridge	Every cycle (2-3 years)
Around Buffalo Color Peninsula	Every 2-3 cycles (4-9 years)
Buffalo Color Peninsula downstream to Ohio Street Bridge	Every 4-5 cycles (8-15 years)
Ohio Street Bridge downstream to river mouth	Every 2-3 cycles (4-9 years)
City Ship Canal	Every 2-3 cycles (4-9 years)
Outer Harbor Channels	Every 4-5 cycles (8-15 years)

B.1.3 Loading Sources

The Buffalo River receives flows and constituent loads from several sources including upstream flows, CSOs, direct storm water runoff, regulated point source discharges, and industrial flow diversions managed by the Buffalo River Improvement Corporation (BRIC). The flow and loading sources are described in more detail below.

B.1.3.a Upstream Flows

The City of Buffalo lies at the downstream end of the Buffalo River watershed. Because the watershed area within the City of Buffalo boundary accounts for only a small percentage of the total watershed area, upstream loads of pollutants are an important consideration. Water quality data and preliminary collection system model results for two wet weather events in 2000 show that upstream loads can account for a significant part of the total bacteria load and the total BOD load to the Buffalo River (Malcolm Pirnie, 2004b Table 3-4). Discharge monitoring data from NYSDEC indicate the presence of a sanitary overflow discharge into the Buffalo River approximately one mile upstream from the Buffalo city limits. The above information was used to characterize upstream boundary conditions of the Buffalo River model in this study.

B.1.3.b CSOs

There are 39 CSOs that discharge within lower Cazenovia Creek and the Buffalo River. Sixteen of the CSOs discharge into Cazenovia Creek, while the remaining 23 CSOs, and the majority of the CSO volume, discharge directly into the Buffalo River (Malcolm Pirnie, 2004a,b). All CSOs within the Buffalo City limits are included in the Buffalo River water quality model as point source inputs.

B.1.3.c Direct Storm water Runoff

Relatively little direct storm water runoff enters the Buffalo River within the Buffalo city limits, mainly because of the presence of the combined sewer system. Sewer maps show that most major storm sewers feed into the combined system. No direct storm water inputs are included in the Buffalo River model.

B.1.3.d Buffalo River Improvement Corporation Flows

The Buffalo River Improvement Corporation (BRIC) was originally designed to supply 120 million gallons per day (mgd) of Lake Erie water for industrial use and discharge along the Buffalo River. Due to industrial plant closures and process shutdowns, PVS Chemicals, Inc. is the only company that continues to use BRIC flows. Recent data indicate PVS Chemicals uses an average flow of approximately 5 MGD for non-contact cooling water (Buffalo River RAP 2006 Update Report). While PVS Chemicals, Inc. has no future projections for BRIC usage, it can be assumed that it will be similar to previous years (4-6mgd). For loading estimation purposes, concentrations of DO, BOD, and bacteria are expected to be similar to that of Lake Erie.

B.1.3.e Permitted Point Source Discharges

The number of point sources that discharge to the Buffalo River has changed over the past decade as businesses have closed or changed operations. According to data obtained electronically from NYSDEC for the 2000 and 2008-2009 time periods, there are only two significant NPDES facilities that discharge directly to the Buffalo River within the model domain. During the 2000 period, PVS Chemical (NY0110043) and Buffalo Color Corp (NY0002470) withdrew water from Lake Erie through the Buffalo River Improvement Corporation (BRIC) intake and discharged into the Buffalo River at river mile five. These two facilities are located close together and their effluent was applied to the same model cell. The primary use of the water is for non-contact cooling water. The discharge monitoring reports (DMR) for the 2000 period recorded average flows of 6.4 MGD for Buffalo Color Corp and 3.81 MGD for PVS chemicals. For modeling purposes, a total discharge of 10 MGD was applied to the model cell at river mile 5. Concentrations of DO, BOD, and bacteria for the discharge were assumed to be the same as Lake Erie.

Review of the 2000 and 2008 to 2009 data indicated that an additional permit holder, Linde, Inc. (NY0085294), formerly known as BOC Gases, currently discharges into the Buffalo River at river mile three. Flow data from 2000 and 2009 show that flows are very low (typically less than 14,000 gallons per day), and therefore this point source was not included in the model.

B.1.4 Previous Models of the System

The following list summarizes past hydrodynamic and water quality models developed for the Buffalo River:

- Atkinson and Blair (1992) – A numerical simulation model was developed to understand the causes of low dissolved oxygen in the lower Buffalo River, and to evaluate potential remediation options. The model extends from just downstream of Cazenovia Creek to Lake Erie.

- Wight (1995) – Wight updated previous work by Atkinson and Blair to further examine dissolved oxygen conditions in the Buffalo River. The updated model incorporated more recent data and included CSO and other point discharges, seiche effects, BOD-DO kinetics, and stratification effects.

- Gu (1998) - A three-dimensional hydrodynamic model, HYDRO3D, was used to compute flow conditions on an 8 km reach of the Buffalo River between Lake Erie and its confluence with Cazenovia Creek. A rating-curve approach serves to link flow information provided by the hydrodynamic model to a contaminant transport model.

Though none of these models were deemed appropriate to directly support the needs of this project, the work was reviewed to support development and parameterization of the current model.

B.2 SCAJAQUADA CREEK

Scajaquada Creek is a small stream of approximately 13 miles in length, with a total watershed of about 29 square miles. The stream is highly urbanized, including several channelized sections and one section that is totally enclosed within a tunnel (also known as the Scajaquada Drain). The four mile long tunnel, which starts at the municipal boundary, was constructed in the 1920s, a time when the stream was highly polluted by direct discharge of untreated sanitary sewage. Near the outlet of the tunnel a diversion structure captures a portion of the dry weather flow from the creek, and wet weather flows up to about 700 cfs, and diverts this flow to the Delavan Avenue Sewer. This sewer receives other wet weather flows, including CSO discharges, along its way to Black Rock Canal.

After exiting the enclosed tunnel portion, Scajaquada Creek winds through Delaware Park, with minor hydraulic modifications. At the west end of Delaware Park, the creek was originally dammed to form Hoyt Lake in the 1880s; the creek has since been hydraulically separated from the lake and is diverted through a square culvert. Downstream of Hoyt Lake, the creek ultimately empties into Black Rock Canal. The Scajaquada Creek Expressway follows the creek closely along this final portion, resulting in a number of hydraulic modifications to accommodate bridges and ramps.

B.2.1 System Hydrology

Recorded streamflows at the upstream end of the tunnel indicated a log-normal distribution and therefore do not suggest a high degree of "flashiness" associated with development in the watershed. It is noted, however, that the exceedance plot does not reflect trends in high flows resulting from more recent development. Discharge data were collected during 2008 and 2009 at this same location as part of the CSO LTCP Update study.

B.2.2 System Modifications

Scajaquada Creek has considerable modifications throughout almost its entire length. Beginning at the downstream end, its mouth has been submerged by construction of the Black Rock Canal and lock, such that flow reversals occur regularly in response to seiche activity in Lake Erie. These reversals have been observed all the way upstream to the Grant Street weir, a distance of just over one mile. Consequently, the portion of Scajaquada Creek below the Grant Street weir was included in the Black Rock Canal model.

The Grant Street weir (located about 1,000 feet upstream from the Grant Street bridge) extends about 140 feet across the creek, at a height of about three feet above the creek bed. The weir is topped with a finger-type debris rack (Figure B-2)

Figure B-2: Grant Street Weir at the Lower End of Scajaquada Creek

The next significant modification is the diversion around Hoyt Lake, which consists of a 10-foot-square box culvert. At the upstream end, the creek is separated from Hoyt Lake by an earthen embankment, after which it enters the culvert through a bar screen; this configuration is shown in Figure B-3.

Figure B-3: Inlet to Underground Diversion of Scajaquada Creek Around Hoyt Lake

The box culvert opens up into the original creek bed, where the creek is again separated from the other end of Hoyt Lake, this time by a serpentine concrete wall (see Figure B-4).

Figure B-4: Scajaquada Creek (left) at Downstream End of Hoyt Lake (right)

Moving further upstream, the next major physical modification to the creek is the enclosed portion known as Scajaquada Drain. The structure has an arched cross section with a flat bottom that varies in width from 24.5 feet to 33.5 feet. Figure B-5 shows the outlet of the drain at the east end of Delaware Park, and Figure B-6 shows the inlet at the east end. Several vertical concrete debris barriers have been placed in this location to prevent large objects from entering the enclosed drain.

Close to the outlet (western end) of the drain there is a diversion at which a portion of the dry weather flow is directed to the Delavan Avenue Sewer, with the remainder continuing through the Scajaquada Drain on to the Delaware Park outlet. A weir diverts wet weather flows up to approximately 700 cfs to the sewer, which ranges in width from 8.5 feet to 11.0 feet. When wet weather flows exceed 700 cfs, the excess continues through Scajaquada Drain and on to the creek.

Figure B-5: Scajaquada Creek at Outlet of Enclosed Drain

Figure B-6: Scajaquada Creek at Inlet of Enclosed Drain

B.2.3 Loading Sources

Flows and constituent loads to Scajaquada Creek come from upstream flows, CSOs, and regulated point source discharges. These sources are described in more detail in the main body of the report.

B.2.4 Previous Models of the System

No past water quality models of Scajaquada Creek were identified. A HEC-2 hydraulic model was developed to support floodplain mapping for a 1981 flood insurance, which was updated in 1999. A county-wide update was performed in 2007, although the Scajaquada Creek model was not updated at this time. The bathymetric data used to describe the channel cross sections in this model represent the most up-to-date data available, and were used to support the hydrodynamic component of the water quality model.

B.3 NIAGARA RIVER

The Niagara River begins at the outflow of Lake Erie near Fort Erie, Ontario and travels a distance of 37 miles before emptying into Lake Ontario at Niagara-on-the-Lake, Ontario (Malcolm Pirnie, 2004 a,b). The Niagara River drains a watershed of approximately 264,000 square miles. Diverse development of areas surrounding the river includes industry, small and mid-size cities, villages, townships, and rural communities (Beljan 2007).

B.3.1 System Hydrology

With an average flow of over 200,000 cfs, the Niagara River accounts for nearly 85% of the total inflow to Lake Ontario (Blair and Atkinson, 1993). The river consists of an upstream and downstream reach, which are divided by Niagara Falls. Over its length the river drops 328 feet in height. More than half of this drop occurs at Niagara Falls, providing excellent conditions for hydropower production.

Seven major United States tributaries and five Canadian tributaries drain into the Niagara River; however, their total combined flow contributes less than one percent of the Niagara River flow. Two of the largest tributaries include Tonawanda Creek and the Buffalo River. The Buffalo River and Scajaquada Creek are the only tributaries that lie within the Buffalo Sewer Authority (BSA) service area. One unique hydraulic feature of the Niagara River is the split of flow around Grand Island. Blair and Atkinson (1993) found that 56% of the flow moves through the 11 mile long Chippewa Channel to the west and 44% moves through the 15 mile long Tonawanda Channel to the east.

It has been noted that tributary inflow into the Niagara River at Lake Erie from Buffalo Creek and Smokes Creek tends to stay along the eastern lake shore due to strong currents and a prevailing southwesterly wind, with little cross-mixing (Malcolm Pirnie, 2004).

B.3.2 System Modifications

Although the downstream boundary for the Niagara River hydrodynamic model is set at Niagara Falls, it is important to consider hydraulic modifications to the system both upstream and downstream of the Falls, as they can significantly impact water level and flow throughout the course of the river.

The New York Power Authority (NYPA, United States) and Ontario Power Generation (OPG, Ontario, Canada) operate major hydropower production facilities on the Niagara River, as well as massive storage reservoirs for public water supply.

The Niagara Power Project of NYPA and the Sir Adam Beck generating stations of OPG divert water for power production from control structures in the Grass Island Pool, just upstream of Niagara Falls. The combined generating capacity of the U.S. and Canadian stations is about 4,600 MW (Lu et al. 1999). Returns, or the tailrace of power production, occur downstream of the whirlpool and rapids resulting from Niagara Falls (Beljan 2007).

Another important feature related Niagara River hydrodynamics is the Black Rock Canal. Due to the strong currents in the Niagara River, the Black Rock Canal was built to allow for safe navigation. The Black Rock Canal lies adjacent to the western shoreline and is formed by a breakwater that separates it from the Niagara River. The breakwater ends at the southern tip of Bird Island, which then extends the canal northward to the United States Army Corps of Engineers' locks at the northern end of Squaw Island. The canal is roughly 19,000 ft long, and water levels in the canal are controlled by the locks. Flow in the canal can occur in either direction but primarily occurs in the north-to-south direction during wet weather events (opposite of Niagara River flows). A portion of the Black Rock Canal is dredged to allow passage for larger vessels and is approximately 20 feet deeper than the non-dredged portions of the canal (Malcolm Pirnie 2004).

B.3.3 Loading Sources

Flows and constituent loads to Scajaquada Creek come from upstream flows, CSOs, and regulated point source discharges. These sources are described in more detail below.

B.3.3.a CSOs

Of the 59 combined sewer overflows (CSOs) in the Buffalo Sewer Authority service area, 16 were determined to be "hydraulically significant" and spatially relevant to the Niagara River system (Table B-2). CSOs 011, 054, and 001A which discharge directly to the Niagara River collectively contributed less than three percent of the annual overflow volume in the BSA system.

Table B-2: CSOs in BSA System Discharging to the Niagara River and Adjacent Water Bodies

(derived from Malcolm Pirnie, 2004)

CSO Outfall ID	Receiving Water	Predicted Annual Total Overflow Volume (cu. ft.)
006	Black Rock Canal	85,887,600
012	Black Rock Canal	18,314,700
011	Niagara River	13,933,300
004	Black Rock Canal	13,041,300
014	Erie Basin	7,980,000
013	Buffalo Harbor	5,910,700
015	Erie Basin	3,942,500
061	Black Rock Canal	3,920,300
010	Black Rock Canal	3,042,700
008	Black Rock Canal	2,650,900
003	Black Rock Canal	2,140,800
016	Erie Basin	1,524,600
054	Niagara River	837,000
063	Black Rock Canal	542,300
005	Black Rock Canal	236,000

B.3.3.b Point Sources

Based on data obtained from the New York State Department of Environmental Compliance (NYSDEC) for the years 2008-2009, there are currently 13 NPDES permitted dischargers to the Niagara River (NYSDEC, 2010). The two largest dischargers are Huntley Generating Station (average flow rate of 83.4 MGD) and the Bird Island Wastewater Treatment Facility (average flow rate of 11.5 MGD), based on 2008-2009 monthly monitoring data.

B.3.3.c Upstream Sources

A combination of CSOs, urban runoff, and tributary loads from the City of Buffalo have been identified as potential contributors of pollutants to the upper Niagara River. Potential upstream sources of bacteria (*E. coli* and fecal coliform), BOD, and other water quality parameters of interest include any sources from Lake Erie and point and nonpoint sources from Canada near the mouth of the Niagara River.

Results from instream monitoring of two wet weather events in 2009 on the upper Niagara River identified a potential source of bacteria on the Canadian (west) side of the River. Sampling stations located closest to Canada, or the Niagara Peninsula specifically, include stations 1d, 2c, 3c, 4c, and 5c.

During the September 27, 2009 wet weather event, elevated concentrations of fecal coliform bacteria were observed at stations 1d, 2c, 3c, and 5c. These concentrations peaked at 8,300; 50,000; 1300 and 490 CFU/100 ml, respectively. Concentrations at station 4c peaked at 134 CFU/100 ml. During the October 24, 2009 wet weather event, fecal coliform bacteria were detected at these stations, but nowhere near the levels measured on September 27th. Table B-3 summarizes the peak fecal coliform bacteria concentrations recorded at these stations during both events.

Table B-3: Summary of Peak Fecal Coliform Concentrations at "Canadian" Stations on Upper Niagara River, Wet Weather 2009 Events

	9/27/2009		10/24/2009	
Station	**Peak FC (CFU/100 ml)**	**Sampling Round (# of 5)**	**Peak FC (CFU/100 ml)**	**Sampling Round (# of 6)**
NIA RBWQ 1d	8,300	1	40	1
NIA RBWQ 2C	50,000	1	20	5
NIA RBWQ 3C	1,300	1	20	3
NIA RBWQ 4C	134	1	150	1
NIA RBWQ 5C	490	1	30	1

There are three primary wastewater treatment facilities on the Niagara Peninsula near the Niagara River that may have contributed to elevated fecal bacteria levels (i.e. a plant overflow may have occurred): Fort Erie (Anger Avenue) WWTP, Crystal Beach WPCP, and Stevensville/Douglastown Lagoon. Another possible contributor to bacteria levels is overland stormwater runoff. The Niagara Peninsula Conservation Authority estimated fecal bacteria loading from creeksheds on the peninsula, and these estimates were used by LimnoTech to quantify potential bacteria loads in the Niagara River EFDC model. However, including these loads in the model had relatively little impact on simulated bacteria concentrations. Further investigation into high wet weather bacteria concentrations on the Canadian side of the channel is certainly warranted.

B.3.4 Previous Models of the System

Numerous studies of the Niagara River, primarily hydrodynamic in nature, have been previously undertaken. These studies may provide valuable input to the present model, help infer specific model parameters, or at minimum provide useful background information on the system. Some relevant previous works are summarized below.

Blair and Atkinson (1993) constructed a numerical model to simulate one-dimensional transport of a conservative tracer through the Niagara River from Fort Erie to Niagara-on-the-Lake. The primary purpose was to study the effect that flow splits and large-scale diversions for hydropower have on contaminant transport and residence time.

Crissman et al. (1993) developed a hydraulic routing model for forecasting Niagara River flow in the upper Niagara River (Fort Erie to Niagara Falls) due to ice. The model was designed primarily to aid in the optimization of hydropower generation.

Halfon and Allan (1995) conducted predictive modeling of two persistent toxic organic chemicals (PCBs and Mirex) from the Niagara River to Lake Ontario using TOXFATE, with an emphasis on transport and fate in Lake Ontario.

Lal (1995) employed singular value decomposition to calibrate Manning's roughness coefficient for the Niagara River, from Fort Erie to Niagara Falls, in a one-dimensional unsteady flow model. Calibration was repeated with different numbers of parameter ("roughness") groups.

DePinto et al. (1998) developed a three-dimensional water column and sediment model (LOTOX2) to simulate circulation, vertical mixing, and sediment resuspension in Lake Ontario in response to PCB loading. The overall purpose is the simulation of PCB fate and transport dynamics in the lake in response to various management scenarios.

Lu et al. (1999) constructed a two-dimensional numerical model of the Niagara River from Fort Erie to Niagara Falls to simulate the dynamics of surface ice transport and ice jams on the river, with the capability of evaluating potential measures for mitigating ice jams that adversely affect hydropower operations.

Beljan (2007) with LimnoTech applied a one-dimensional WASP5 model from Fort Erie to Niagara-on-the-Lake, with the specific purpose of providing input to Lake Ontario for a PCB TMDL and featuring additional modifications (LimnoTech) to allow a hydrologic flow routing linkage and volatilization functions, especially at Niagara Falls.

B.4 BLACK ROCK CANAL

Due to the strong currents in the Niagara River, the Black Rock Canal was built to allow for safe navigation. The Black Rock Canal lies adjacent to the western shoreline and is formed by a breakwater that separates it from the Niagara River. The breakwater ends at the southern tip of Bird Island, which then extends the canal northward to the United States Army Corps of Engineers' locks at the northern end of Squaw Island. The canal is roughly 19,000 ft long, and water levels in the canal are controlled by the locks. Flow in the canal can occur in either direction. A portion of the Black Rock Canal is dredged to allow passage for larger vessels. This shipping channel is used by both commercial shipping and leisure craft (Malcolm Pirnie 2004). The navigation channel is at least 200 feet wide at all points and is dredged to a depth of 21 feet (USACE, 2006).

B.4.1 System Hydrology

In the first four miles of the Niagara River, the water level falls approximately 5.5 feet. The water level in the Black Rock Canal is maintained near the level of Lake Erie, and the lock raises and lowers ships over the 5.5 feet difference. The Black Rock Canal diverts approximately 1,100 cfs of the flow from the Niagara River (USACE, 1921). There are no flow monitoring stations located on the Black Rock Canal; therefore, the flow rate of the canal was calculated by the model.

Major tributaries to the Black Rock Canal include the Niagara River and Scajaquada Creek, with a major portion of the canal's flow from the Niagara River originating from the Buffalo River. According to the USGS, the drainage area for Black Rock Canal is 263,700 square miles. This corresponds to the Niagara River watershed (USGS, 2008).

B.4.2 System Modifications

Some engineered modifications are relevant to understanding the Niagara River system and are discussed below as background information.

B.4.2.a Old Erie Canal

According to a 1921 report by the U.S. Army Corps of Engineers, water from Lake Erie is diverted around the head of the Niagara River through the Black Rock Canal for a distance of about 4 miles. At the lower end of the canal, some of the water passes into the head of old Erie Canal. The rest passes through Black Rock Lock out into Niagara River. In addition to these two quantities, whatever water flows in the Lake Erie Canal at Black Rock is diverted down the Black Rock Canal. Note that in the 1800's, Lake Erie Canal extended south of its present day position, reaching the Black Rock Canal. The Erie Canal was established in 1825. The Erie Canal as improved to form the barge canal now receives its western water supply from Niagara River at Tonawanda, downstream of Black Rock Canal (USACE, 1921). Figure B-7 shows the present-day and nineteenth century New York Canal system.

Figure B-7: Present-day and Nineteenth Century New York Canals (Lake Champlain Maritime Museum)

B.4.2.b Dredging

Re-dredging of the original Lake Erie Canal occurred periodically beginning in 1916, after soundings taken in 1915-1916 revealed shoals in the canal. Restoration of the canal to the project depth of 21 feet, and dredging in the Lake Erie entrance to Black Rock Harbor and Erie Basin was conducted (USACE, 1917). Subsequent re-dredging of this region, the present-day Black Rock Canal, has been conducted as needed.

B.4.2.c Black Rock Lock

There has been a lock at Black Rock since 1833 when the state of New York built one as part of the Erie Canal. The present lock, constructed by the Corps of Engineers from 1908-1913, provided the capacity to accommodate large Great Lakes vessels. Through the years those vessels have carried commodities essential to business and industry in Western New York. In 1975, the first major rehabilitation of the lock was completed. Major rehabilitation of the guard gates and the operating system took place from 1984-1986. In 1991-92, cavities between the lock's concrete monoliths and the bedrock were filled with high pressure cement grout to stabilize the foundation. Since the mid 1990’s, ongoing construction has included the widening and capping of all concrete approach walls, refurbishing of the lock houses, and the installation of new fencing, railing and ladders to provide a safer, more secure, work environment.

Figure B-8: Photograph of Black Rock Lock (Groundspeak, 2010)

The upper end of Black Rock Lock is at Lake Erie level, with no water control structure. The channel at the lower end reenters the Niagara River. There is not a constant flow of water either through or around the lock from the channel. The lock chamber is 650 feet by 70 feet, enlarged by approximately 100 feet during pump-out with guard gates closed. The average lock lift is 5.5 feet with a draft of 21.5 feet over the sills at low water depth, and the lock is serviced by 6-feet culverts in both walls. Lateral culverts run from the main culverts into the chamber. Each operating gate has two gate valves. Actual lock lift time is 12 to 15 minutes. The lock has no gauge wells or transducers (USACE, 2010).

B.4.3 Loading Sources

A combination of CSOs, urban runoff, and tributary loads from the City of Buffalo has been identified as contributors of pollutants to the Black Rock Canal. No point sources were identified as contributing pollutant loads during the modeling periods.

B.4.3.a Upstream

Upstream sources of bacteria (*E. coli* and fecal coliform), BOD, and other water quality parameters of interest include sources from the Upper Niagara River, Scajaquada Creek, and the Delavan Drain. Pollutant loads were extracted from the Niagara River and Scajaquada Creek models for input into the Black Rock Canal dissolved oxygen model.

B.4.3.b CSOs

There are a total of 59 combined sewer overflows (CSOs) in the Buffalo Sewer Authority service area. A total of 47 of these CSOs were determined to be "hydraulically significant" through modeling efforts by Malcolm Pirnie (2004). Of these 47 CSOs, nine are identified as discharging directly to the Black Rock Canal, as well as three CSOs discharging to the Erie Basin Marina and one to the Buffalo Harbor, adjacent to the Black Rock Canal. Three CSOs discharge to Scajaquada Creek within the Black Rock Canal model grid. These CSOs and their respective receiving water are identified in Table 2 (Malcolm Pirnie, 2004). CSOs 007, 009, 062, and 067 which discharge to the Black Rock Canal model grid were not modeled by Malcolm Pirnie.

Table B-4: CSOs in BSA System Discharging to the Niagara River and Adjacent Water Bodies

Sorted by total annual flow contribution (based on year 2000 modeling)

CSO Outfall ID	Receiving Water	Predicted Annual Total Overflow Volume (cu. ft.)
006	**Black Rock Canal**	85,887,551
012	**Black Rock Canal**	18,314,667
004	**Black Rock Canal**	13,041,333
014	Erie Basin	7,980,000
013	Buffalo Harbor	5,910,667
059	Scajaquada Creek	5,745,333
015	Erie Basin	3,942,533
061	**Black Rock Canal**	3,920,267
010	**Black Rock Canal**	3,042,667
008	**Black Rock Canal**	2,650,933
003	**Black Rock Canal**	2,140,813
016	Erie Basin	1,524,613
058	Scajaquada Creek	673,067
063	**Black Rock Canal**	542,267
057	Scajaquada Creek	368,880
005	**Black Rock Canal**	235,972

B.4.3.c Permitted Point Source Discharges

A facility called "Water Filtration Plant/Col Ward. P.S." was listed by the NYSDEC as the lone point source to the Black Rock Canal. Correspondence with Bud Tozer at the NYSDEC indicated that this facility no longer reports discharge information to the NYSDEC (Personal Communication, NYDEC, 2010). There are no records on EPA's Permit Compliance System (PCS) database for this facility. Due to this information, no point sources were included in the Black Rock Canal model.

B.4.4 Previous Models of the System

No past water quality models of the Black Rock Canal were identified. However, there were several studies of the canal.

Irvine (2005) summarized the results of Buffalo, New York Hydrolab monitoring and illustrated how continuous monitoring of conventional parameters such as dissolved oxygen, pH, temperature, conductivity, and turbidity can enhance understanding of watershed response to storm events and the effects of CSOs on receiving water quality.

McLaren (2009) conducted a sediment trend analysis of the outer Buffalo River harbor. Objectives of the study were to collect 375 sediment grab samples from the outer Buffalo River area, including the upstream portion of Black Rock Canal and analyze them. The goal was to distinguish, if possible, between river, plume, and lake sediments with respect to their transport pathways and textural properties and compare the results with earlier STA studies.

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APPENDIX C: DATA USED TO SUPPORT MODELING

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C. DATA USED TO SUPPORT MODELING

Several data sets were acquired to serve as model boundary conditions and support model calibration. Because many of these datasets were used by more than one model, they are described in general in this report section. In addition, some discussion of data which are specific to a single model is presented in this appendix. Some data sets discussed below were collected specifically for this project while others were obtained from external sources.

C.1 BOUNDARY CONDITIONS AND CALIBRATION DATA

C.1.1 Hydrologic/Hydrodynamic Data

C.1.1.a USGS

The majority of the flow data for hydrodynamic modeling applications were obtained from the United States Geological Survey (USGS) via their public data domains. High-frequency (15 minute) flow data were downloaded from the USGS Instantaneous Data Archive (IDA) (http://ida.water.usgs.gov/ida/). If historic instantaneous data were not available for a site, daily data were used and were obtained from the USGS National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis).

Where the location of flow monitoring did not correspond with an associated model boundary location for a particular system, a drainage area relationship was used in order to scale the available flow data to represent the proper location.

In the Buffalo River system, three USGS stations were used to represent upstream hydrodynamic boundary conditions; station 04214500 (Buffalo Creek at Gardenville, NY), 04215000 (Cayuga Creek near Lancaster, NY), and 04215500 (Cazenovia Creek at Ebenezer, NY). Table C-1 outlines descriptive information regarding these stations.

Table C-1: USGS Stations Used to Define Hydrodynamics for the Buffalo River

Station ID	Station Description	Location (NAD27)		Drainage Area
		Lat	Long	(sq. miles)
04214500	Buffalo Creek at Gardenville, NY	42°51'17"	78°45'19"	142.0
04215000	Cayuga Creek near Lancaster, NY	42°49'47"	78°46'31"	135.0
04215500	Cazenovia Creek at Ebenezer, NY	42°53'24"	78°38'43"	96.4

The USGS does not currently operate any stations on Scajaquada Creek. Previously, station 04216200 (Scajaquada Creek at Buffalo, NY) was in operation beginning in 1957 and was taken offline in 1994. Flow data for Scajaquada Creek were calculated based on cross-section geometry data measured by field crews, and velocity and water level data recorded by horizontal acoustic Doppler current profiler (HADCP) devices. The details of these data collection efforts are outlined in Appendix D.

C.1.1.b NOAA

Hydrodynamic boundary conditions for the Buffalo River and Niagara River models required the use of high-frequency water level data. Six-minute water level data for Lake Erie (station 9063020 Buffalo, NY) for the years 2000 (Buffalo River model) and 2008-2009 (Niagara River model) were obtained from the National Oceanic and Atmospheric Administration (NOAA) via their public domain, Tides & Currents (http://tidesandcurrents.noaa.gov/).

C.1.1.c Ontario Power Group

The Ontario Power Group (OPG) provided water level and flow data for the Niagara River for portions of 2008 and 2009 (OPG 2010). Hourly water level data was obtained from stations at American Falls, Material Dock, Slater's Point, Black Creek, Frenchman's Creek, and Fort Erie. In addition, OPG estimates the hourly flow at the following locations: flow over Niagara Falls and diversions from the Niagara River above Niagara Falls to the Moses and Beck reservoirs by U.S. and Canadian companies for power generation. The flow data are reported to the International Joint Commission in order to meet the requirements of the 1950 Niagara Treaty. Flow data were used as forcing function in the Niagara River model, while water level data were used for calibration of the Niagara River model.

C.1.1.d BSA 2008-2009 Sampling

Hydrodynamic data for the Buffalo Sewer Authority (BSA) collection system were collected during two wet weather events in 2000 and two wet weather events in 2009. Wet weather CSO and storm water flows for these events were ultimately provided by Malcolm Pirnie, who simulated the 15-minute flow discharging from each outfall using a calibrated model of the collection system which they developed. This model was applied by inputting high-frequency rainfall data during the monitored storm events to generate 15-minute CSO and storm water flow inputs for the receiving water models (5-minute inputs were used for the Buffalo River model).

The two wet weather events in 2000 were similar in magnitude and duration. The first rainfall event on June 9, 2000 had a duration of about three hours, and the second event on August 23, 2000 lasted for about 3.6 hours. The average rainfall depth for event 1 in 2000 was 0.8 inches, and for event 2 was 0.92 inches. These data are based on monitoring conducted by Malcolm Pirnie.

Based on NOAA hourly surface data at Buffalo Niagara International Airport, the two rainfall events in 2009 can be described as follows: event 1 occurred on September 26, 2009 with the majority of rainfall occurring over a 12 hour period. The total depth of rain was 2.78 inches. Event 2 occurred on October 23, 2009 and was also a large event; the majority of rainfall occurred over a 15 hour period, and the total depth of rain was 1.92 inches.

C.1.1.e Scajaquada Hydrodynamic Monitoring

Because of the lack of flow and stage data on Scajaquada Creek, it was necessary to collect data to establish the upstream boundary condition of the Scajaquada Creek model. This data collection effort is described in greater detail in Appendix D, but the use of the data to establish a stage-discharge relationship is discussed below. Level and velocity data were collected from July through November, 2008, using a pressure transducer and an acoustic Doppler current profiler. During the subsequent wet weather sampling in 2009, only stage data were collected, and the stage-discharge relationship was used to compute the flows for the wet weather events. A plot of the average cross-sectional velocity versus stage is shown in Figure C-1 for the 2008 data collection period. The stage-discharge relationship consists of three expressions for velocity versus depth, for three different intervals, and a linear relationship between depth and cross-sectional area. The velocity relationships are as follows:

V = 0.101061*H; H <= 0.9

V = 1.5711*H - 1.3017; H < 2.0120

V = 1.1345*H0.712; H >= 2.0120

where

V = velocity (fps); and

H = depth (ft).

Cross-sectional area is given by

A = 56.97 + 32.09*H

where

A = area (ft^2).

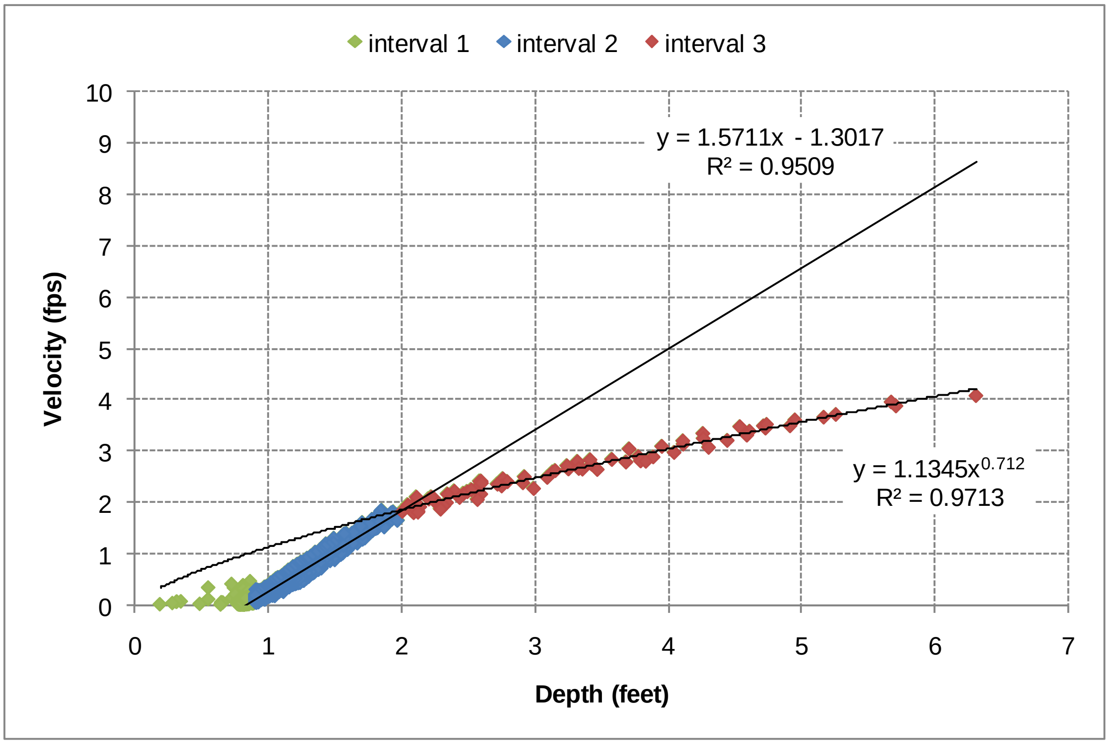

Figure C-1: Depth and Velocity Data from Upstream Boundary of Scajaquada Creek

C.1.2 Water Quality Data

C.1.2.a BSA - 2000 Sampling

Several water quality datasets were collected by Malcolm Pirnie and Buffalo State University in 2000 and were used to support modeling of the Buffalo River.

High frequency monitoring devices (Hydrolabs) were installed at the Buffalo City limits on the Buffalo River and Cazenovia Creek between March and November of 2000. The sensors recorded data in 15-min intervals with several significant data gaps (typically occurring in June and July 2000). Monitored parameters included dissolved oxygen (DO), pH, temperature, turbidity, and conductivity. A total of ten continuous monitoring Hydrolab stations were deployed throughout the Buffalo-Niagara River system.

In addition to the continuous monitoring data, Malcolm Pirnie also conducted wet weather sampling on receiving waters for the two wet weather events. Sampling stations were located on the Buffalo River, Cazenovia Creek, Black Rock Canal, and Scajaquada Creek. The sampling schedule for the year 2000 wet weather events is summarized in Table C-2. It should be noted that wet weather sampling in 2009 followed the same schedule.

Depending on the location and sampling schedule, water quality parameters were reported either at 15-minute intervals, or as averages of “first flush” and “rest of storm” time periods. Event mean concentrations (EMCs) for fecal coliform bacteria and biochemical oxygen demand (BOD) were calculated by Malcolm Pirnie based on these wet weather receiving water data.

Table C-2: Sampling Schedule for 2000 Wet Weather Receiving Water Sampling

Sample Location ID	Receiving Water Sample Location Description	Sampling Schedule: Hours after Storm Commencement
SCD RBWQ 01	Buffalo River City Line	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 02	Buff. Riv. u/s of confluence with Caz. Creek	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 03	Buffalo River d/s of Smith Street	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 04	Buffalo River at Ohio Street	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 05	Buff. Riv. at confluence with L. Erie/Niag. Riv.	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 06	Cazenovia Creek City Line	1, 2, 3, 4, 6, 12, 18, 24
SCD RBWQ 07	Caz. Creek u/s of confluence with Buff. River	1, 2, 3, 4, 6, 12, 18, 24
SCD RBWQ 08	Mouth of the Erie Basin Marina (Black Rock)	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 09	Black Rock Canal d/s of Albany Street	1, 2, 3, 4, 6, 12, 18, 24, 36, 48
SCD RBWQ 10	Black Rock Canal - d/s end	1, 2, 3, 4, 6, 12, 18, 24, 36, 48

Intensive sampling was also conducted in 2000 on five discrete days; May 4, June 9 (wet weather), August 7 (partial wet weather), August 23 (wet weather), and September 7. Parameters measured at intensive sites via grab sampling were temperature, DO, and pH. In-stream grab samples during wet weather events were also analyzed for fecal coliform bacteria and biochemical oxygen demand (BOD).

C.1.2.b BSA - 2008-2009 Sampling

Extensive water quality sampling was conducted by Malcolm Pirnie and Buffalo State University in 2008 and 2009 to support the modeling effort. A detailed description of this effort is beyond the scope of this report, but the events are summarized below.

Dry weather event sampling occurred during two discrete dry weather periods in 2008. Intensive sampling was conducted on July 16 and September 3, 2008. Dry weather sampling on the Niagara River included fecal coliform measurements (grab samples) at 16 locations. On Scajaquada Creek, fecal coliform bacteria and surface DO and BOD were measured at four locations. On Black Rock Canal, fecal coliform, DO, and BOD were measured at four locations; DO was recorded using a YSI profiler at depth increments of 1 meter and BOD was measured at three depths (“upper”, “middle”, and “lower”). The same procedures used for Black Rock Canal were carried out on the Buffalo River but only at one location, near the mouth.

In addition to discrete dry weather sampling, long-term hydrolabs were deployed at two locations on Black Rock Canal from April through October 2009 and provided continuous monitoring data for temperature, conductivity, DO, pH, and turbidity.

Wet weather sampling was conducted during two wet weather events in 2009. In-stream monitoring for event 1 occurred from September 26-29, 2009 and monitoring for event 2 occurred between October 23 and 25, 2009. Fecal coliform bacteria were measured at all locations on all receiving water bodies, and BOD was measured on Scajaquada Creek (surface only) and on the Buffalo River and Black Rock Canal (at three depths). Wet weather sampling locations were the same locations used during dry weather sampling, with the exception of station BRC RBWQ 2 on Black Rock Canal; this station was relocated farther south to buoy R10 during wet weather sampling due to the original buoy being replaced by the U.S. Coast Guard. Figure C-2 depicts BSA's 2008-2009 water quality sampling stations on the mentioned water bodies.

Event characteristics from the storm are summarized in Table C-3, along with characteristics for the two dry weather events (2008) and the first wet weather event in September 2009.

Table C-3: Event Characteristics of Sampling Events

Event ID	Dry 1	Dry 2	Wet 1	Wet 2
Dates (Dry 2008, Wet 2009)	7/16/08	9/3/08	9/26/09	10/23/09
Start Time	-	-	9/26/09 20:00	10/22/09 23:00
Total Rainfall (in.) by end of sampling	-	-	2.78	1.94
Maximum Intensity (in/hr)	-	-	0.52	0.25
Sampling duration (hrs)	-	-	27	36
Fecal Coliform Concentration Range (CFU/100mL)[1]				
Near mouth of Buffalo River (NIA RBWQ 1)	ND - 27	ND	ND - 62,000	ND - 800
Upstream of Peace Bridge (NIA RBWQ 2)	ND - 9	ND - 9	ND - 50,000	ND - 330
Downstream of Peace Bridge (NIA RBWQ 3)	ND	ND	ND - 46,000	ND - 140
Just D/S of International Bridge (NIA RBWQ 4)	ND	ND	ND - 7,500	ND - 440
Just downstream of CSO-055 (NIA RBWQ 5)	ND	ND	ND - 14,000	ND - 1,800
Near Erie Basin Marina (BRC RBWQ 1)	ND - 27	ND - 27	ND - 21,000	40 - 1,900
Upstream of Peace Bridge (BRC RBWQ 2)	18	ND	ND - 17,000	70 - 590
Just south of Scajaquada Creek mouth (BRC RBWQ 3)	18	18	ND - 36,000	2,800 - 65,000
Just north of Scajaquada Creek mouth (BRC RBWQ 4)	ND - 18	18 - 27	10 - 12,000	1,700 - 18,000

1 - ND indicates value below detection limit

Table C-4: Summary of Water Quality Monitoring Stations on Niagara River and Black Rock Canal

Station ID	Location	Latitude	Longitude
NIA RBWQ 1a	Downstream of Buffalo River mouth	-78.896	42.886
NIA RBWQ 1b	Downstream of Buffalo River mouth, 1/3 mile west of 1a	-78.902	42.889
NIA RBWQ 2a	0.4 mile upstream of Peace Bridge	-78.904	42.901
NIA RBWQ 2b	0.4 mile upstream of Peace Bridge, 1/4 mile west of 2a	-78.909	42.901
NIA RBWQ 3a	0.2 mile downstream of Peace Bridge	-78.903	42.909
NIA RBWQ 3b	0.2 mile downstream of Peace Bridge, 0.1 mile west of 3a	-78.906	42.909
NIA RBWQ 4a	Just downstream of International Bridge	-78.909	42.930
NIA RBWQ 4b	Just downstream of International Bridge, 0.1 mile west of 4a	-78.910	42.930
NIA RBWQ 5a	3/4 mile upstream of Strawberry Island, near CSO-055	-78.910	42.947
NIA RBWQ 5b	3/4 mile upstream of Strawberry Island, middle of river	-78.917	42.945
BRC RBWQ 1	Upstream end of the breakwater	-78.895	42.881
BRC RBWQ 2	Between USGS gage at Anderson and Bird Island WWTP	-78.903	42.904
BRC RBWQ 3	Upstream of confluence with Scajaquada Creek	-78.900	42.928
BRC RBWQ 4	Upstream of International Bridge and canal locks	-78.901	42.930

The use of the wet and dry weather sampling results is discussed in greater detail in the individual model sections of this report.

Figure C-2: BSA 2008-2009 Water Quality Stations

C.1.2.c 1994 Profile Sampling

Dissolved oxygen data collected for the Buffalo River in 2000 (by Malcolm Pirnie) only included measurements of DO near the surface (via continuous Hydrolab instruments). While this dataset had a very high temporal resolution, it did not capture the impact of sediment oxygen demand (SOD) on DO concentration in the deeper portions of the dredged channel.

To provide for a robust calibration, the Buffalo River model was run for a summer period during 1994 when vertical profiles of temperature and DO were available for several locations in the dredged portion of the Buffalo River. Vertical profile data were obtained for June and July of 1994 (Wight 1995). These data were originally collected by NYSDEC as part of the Remedial Action Plan for the Buffalo River.

C.1.2.d Buffalo Niagara Riverkeeper

The Buffalo Niagara Riverkeeper began monthly monitoring of water quality at approximately 40 sites throughout the Niagara River watershed in 2006. Measured parameters include pH, nitrate, phosphate, turbidity, DO, and BOD. Air and water temperature are also recorded.

The Riverkeeper's Riverwatch team also conducts regular (~monthly) testing for *E. coli* and total coliform bacteria at 22 different locations in the Niagara River watershed. Based on EPA water quality standards, a benchmark of 298 colonies/100 mL has been set as the maximum permissible level at which water is safe for swimming, boating, and other activities involving moderate full-body contact with water.

Riverkeeper monthly monitoring data on Scajaquada Creek were utilized to help diagnose a suspected source of bacteria within the Scajaquada Tunnel. Riverkeeper data demonstrated that levels of bacteria measured at the downstream end of the tunnel were significantly higher than levels at the upstream end. The subject of bacteria in Scajaquada Creek is discussed in greater detail in the section of this report dedicated to that model.

C.2 LOADS TO SYSTEM

C.2.1 CSOs

According to Malcolm Pirnie, "there are 258 Sewer Patrol Points (SPPs) or overflow chambers with the [Buffalo Sewer Authority] system, of which 68 are CSO discharge locations. (Malcolm Pirnie, 2001). Based on data received from Malcolm Pirnie in 2010, there are also numerous storm water discharges to the Buffalo-Niagara River system; a total of 43 storm water discharge locations were included in their collection system model in 2010.

C.2.1.a BSA - 2000 Sampling

In the year 2000, Malcolm Pirnie conducted flow monitoring in BSA's combined sewer system for the purpose of (1) characterizing the system, and (2) providing a dataset for calibration of the collection system model. The monitoring program was conducted from May 4, 2000 through July 21, 2000 and consisted of in-system flow monitoring, rainfall monitoring, and staff gage depth monitoring. A total of 85 flow monitors were installed in addition to 21 rain gages and 114 staff gages (installed and monitored only for CSO activation).

During the two wet weather events in 2000, overflow at selected outfalls was monitored in 5-minute increments. Additionally, numerous water quality constituents were monitored at overflow locations, including fecal coliform concentrations, BOD, and total suspended solids (TSS).

Data gathered during the water quality monitoring program were combined with data gathered during the flow monitoring period to calculate mass loadings of pollutants discharged by CSOs to the receiving water bodies for each of the two wet weather events. Event mean concentrations (EMCs) were calculated for each parameter by summing the incremental mass loadings of each pollutant at each overflow location for the whole event and dividing by the total volume of discharge (Malcolm Pirnie, 2004).

C.2.1.b Collection System Model

A model of the BSA collection system was developed to simulate response of the combined system to rainfall events, especially those that trigger overflow into receiving waters. The model was calibrated and validated using flow data measured during the flow monitoring period. CSO and storm water overflow time series are generated by the model by inputting high frequency rainfall data.

CSO loads for the Niagara River, Black Rock Canal, and Scajaquada Creek models for the wet weather simulation periods in 2009 were generated using monitoring data and CSO flows (15-minute) simulated by their existing model of the collection system. CSO flows for the Buffalo River model were informed by model output for the year 2000 and are in 5-minute intervals.

C.2.2 NPDES Permitted Discharges

Industries have been attracted to the Niagara River region by the relatively inexpensive energy supplied by hydroelectric generation (Blair and Atkinson 1993). There are 17 significant industrial users (SIUs) in the City of Buffalo that have permits allowing discharges to the Niagara River and its tributaries, and nine major U.S. wastewater treatment plants that discharge into the river and its tributaries.

Recent (2008 and later) monitoring data for NPDES/SPDES permitted discharges in the Buffalo-Niagara River system were obtained from the New York State

Department of Environmental Conservation (NYSDEC), the agency to which permitted facilities are required to submit monthly discharge monitoring reports (DMRs) to ensure their compliance to the permit requirements. Another source of NPDES data was the USEPA Envirofacts Water Discharge Permit Compliance System (PCS) website, which facilities downloading of older monitoring data and facilities information (http://www.epa.gov/enviro/html/pcs/index.html).

Based on data received from NYSDEC in 2009, there are over 50 facilities that discharge to the water bodies of interest in this study. Many were not included in the receiving water models simply because their discharge volumes were determined to be insignificant relative to the volume of the receiving water. The selection of facilities and their representation in the models is discussed in greater detail in the individual modeling sections of this report.

C.2.3 BRIC Flows

BRIC (Buffalo River Improvement Corporation) flows were introduced in the 1960s to alleviate high temperatures and acidity (due to heavy industrialization) in the Buffalo River so that it could serve as a source of cooling water for industry. A pumping station and service main were constructed so that Lake Erie water could be pumped from approximately 2 miles south of the mouth of the Buffalo River to be used by industries for cooling. The water was then returned to the Buffalo River to augment flow.

Historically BRIC flows accounted for about 20 percent of the total annual flow in the Buffalo River, although they are estimated to have contributed over 90% of the flow during summer low flow conditions. The BRIC system was originally designed to supply 120 MGD, but today only one company continues to use BRIC flows. PVS Chemicals, Inc. estimated in 2005 that flows will not exceed 5-6 MGD (7.7-9.3 cfs).

The new RiverWright Ethanol Plant is evaluating whether it wants to utilize BRIC flows for its operations. It is believed that the facility would use between 50 and 100 MGD (77.4-154.7 cfs) from Lake Erie, which would be much more hydraulically significant than the current use by PVS Chemicals and could also potentially have temperature impacts on the Buffalo River and downstream. However, the plant's operation, originally planned to begin in mid-2010, is currently on hold due to the sharp decrease in ethanol demand in recent months.

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APPENDIX D: SUPPLEMENTAL DATA COLLECTION ON SCAJAQUADA CREEK AND BLACK ROCK CANAL

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DATE: January 27, 2009

MEMORANDUM

FROM: Bob Betz, Laura Weintraub

PROJECT: Buffalo Sewer Authority CSO Revised LTCP

TO: David Barnes, (Malcom Pirnie)

CC: Scott Bell (LimnoTech)

SUBJECT: DRAFT: Black Rock Canal Sediment Oxygen Demand Data Collection

Summary

The purpose of this memo is to describe data collection performed by LimnoTech to support receiving water quality modeling of the Buffalo / Niagara River system. This work was performed as part of the Phase 2 Long-Term Control Plan for the Buffalo Sewer Authority (BSA) and was conducted in accordance with the following work plan:

- Malcolm Pirnie April 2008: *DRAFT Receiving Water Quality Sampling Work Plan, Buffalo Sewer Authority, Phase 2-Long Term Control Plan*

This memo describes the details of the data collection effort and also includes a summary of each data set.

Black Rock Canal Sediment Oxygen Demand

Sediment oxygen demand (SOD) surveys were conducted at an upstream and a downstream location of the Black Rock Canal (BRC) in Buffalo, New York, during October, 2008. The purpose of the SOD survey is to determine the rate that dissolved oxygen is consumed by benthic sediments.

Location

The detailed locations of the SOD surveys are described below. Figure 1 shows the monitoring locations in red font.

501 Avis Drive
Ann Arbor, MI 48108
734-332-1200
Fax: 734-332-1212
www.limno.com

Figure 1: Black Rock Canal SOD Monitoring Locations (Red Font)

BRC Upstream SOD

Black Rock Canal at Peace Bridge: Located approximately 50 feet downstream of the Peace Bridge and approximately 30 feet from the West bank (42° 54' 24.174" N, 78° 54' 05.924" W). Photos of the site follow.

Looking South (SOD location is on left side of channel, downstream of Peace Bridge)

Looking East toward SOD location between Bridge and downsream shrub

Looking West from SOD location toward Canada

BRC Downstream SOD

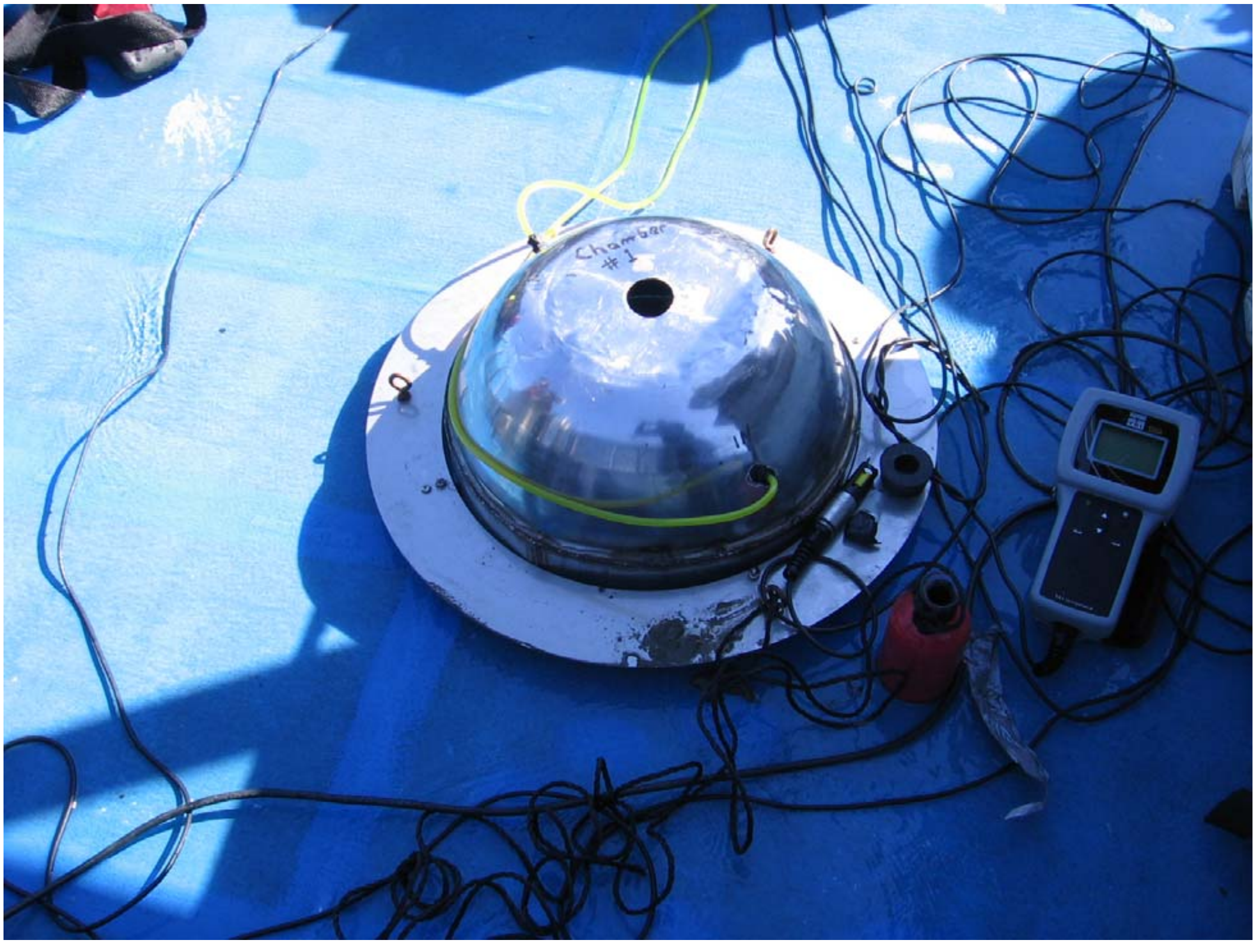
Black Rock Canal at Scajaquada Creek Mouth: Located approximately 20 feet downstream of the mouth of Scajaquada Creek and approximately 150 feet from the East bank (42° 55' 44.783" N, 78° 53' 59.572" W). Photos of the site follow.


Sampling Period and Frequency

The SOD surveys were conducted on October 10, 2008. A single SOD survey was conducted at the upstream and at the downstream SOD locations in the Black Rock Canal.

Methods

In-situ SOD was measured in bottom sediments at each location using a hemispherical stainless steel chamber (respirometer) to isolate a known volume of water over a specific area of streambed. A single respirometer was installed into the bottom sediments at each location by divers from the Buffalo Police Department Underwater Recovery Team. Water was gently mixed within the chamber using a sealed, recirculating pump system. The change in dissolved oxygen concentrations within the chamber over time was monitored with a YSI dissolved oxygen/temperature probe fitted into the chamber. SOD incubations ran for approximately two hours and depended on the time necessary to obtain an accurate rate of dissolved oxygen depletion. For each instrument, a dark bottle was filled with river water and incubated in the river simultaneously with the chamber to provide a correction for algal respiration and biochemical oxygen demand (BOD) within the water column. SOD was determined by subtracting the rate of change of dissolved oxygen within the dark bottle from the rate of change in the chamber. The resulting value was then corrected to a temperature of 20° C. A photo of the respirometer setup follows.



Summary of Data Collected

The SOD results are summarized in Table 1, below. The negative downstream SOD value results from a greater rate of change in the dark bottle than in the respirometer data used in the SOD calculations. This indicates that the algal respiration and biochemical oxygen demand (BOD) within the water column was greater than the SOD at the time of the downstream survey. Figure 2 shows the dissolved oxygen decline in each chamber during the upstream and downstream SOD surveys. Note that the SOD is calculated using only the linear portion of the dissolved oxygen curve from the respirometer data.

Table 1: SOD Results Summary

Date	Location	SOD (g/m2/day @ 20C)
10/10/2008	Black Rock Canal upstream at Peace Bridge	1.956
10/10/2008	Black Rock Canal downstream at Scajaquada Creek	-0.051

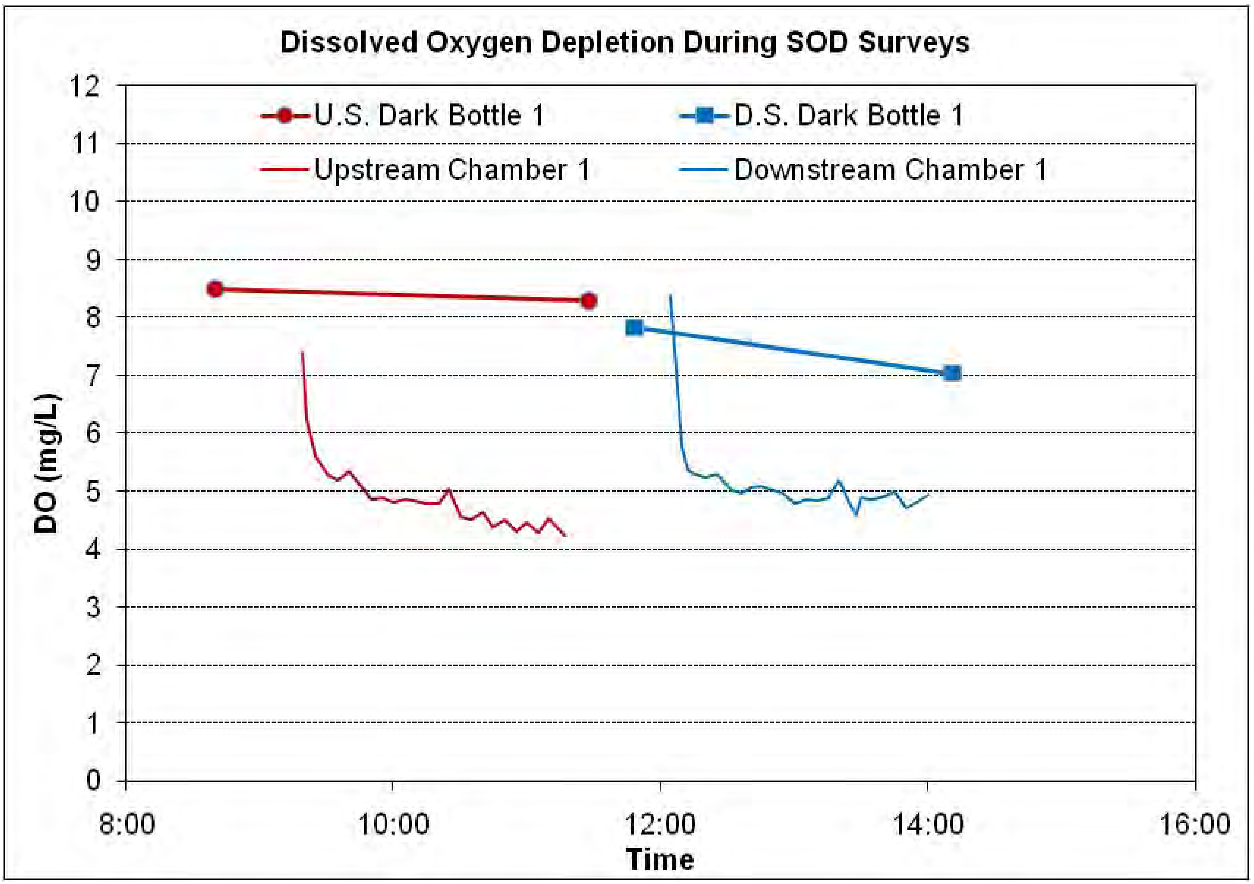


Figure 2: Dissolved Oxygen Decline in Respirometer Chambers

Issues and Data Limitations

There are no significant issues or data limitations.

DATE: January 27, 2009

MEMORANDUM

FROM: Bob Betz, Laura Weintraub

PROJECT: Buffalo Sewer Authority CSO Revised LTCP

TO: David Barnes, (Malcom Pirnie)

CC: Scott Bell, (LimnoTech)

SUBJECT: DRAFT: Scajaquada Creek Hydraulic and Sediment Oxygen Demand Data Collection

Summary

The purpose of this memo is to describe data collection performed by LimnoTech to support receiving water quality modeling of the Buffalo / Niagara River system. This work was performed as part of the Phase 2 Long-Term Control Plan for the Buffalo Sewer Authority (BSA) and was conducted in accordance with the following work plan:

- Malcolm Pirnie April 2008: *DRAFT Receiving Water Quality Sampling Work Plan, Buffalo Sewer Authority, Phase 2-Long Term Control Plan*

This memo describes the details of the data collection effort and also includes a summary of each data set.

Scajaquada Creek Hydraulic Data

Hydraulic monitoring instruments (water level sensors and horizontal acoustic doppler current profilers (HADCP)) were installed at upstream and downstream locations on Scajaquada Creek in Buffalo, New York, to record water levels and water velocities during the period of July through October 2008.

Monitoring Locations

There were upstream and downstream monitoring locations established for each type of instrument for a total of four locations. The detailed locations of the monitoring instruments are described further below, in order of upstream to downstream. Figure 1 shows the monitoring locations in red font.

501 Avis Drive
Ann Arbor, MI 48108
734-332-1200
Fax: 734-332-1212
www.limno.com

Figure 1: Scajaquada Creek Water Level, Velocity and SOD Monitoring Locations (Red Font)

Upstream HADCP (level and velocity data)

Scajaquada Creek at Pine Ridge Road: Located on the concrete channel wall of the North bank, approximately 330 feet upstream of Pine Ridge Road (42° 54’ 42.742” N, 78° 47’ 41.960” W). Photos of the installation follow.

Looking upstream at installation   Looking South at download box above installation

Upstream HADCP and mount

Upstream Level Sensor (level data)

Scajaquada Creek at Delaware Park: Located at Delaware Park, approximately 510 feet East of Delaware Avenue on the North end of the concrete channel wall that is at the South side of the stream tunnel entrance and at the East end of the broadcrested weir/lane between Scajaquada creek and the pond (42° 55’ 51.818” N, 78° 52’ 03.494” W). Photos of the installation follow.

Upstream level sensor installation (stilling well and download box on concrete wall left of tunnel grates

Looking Southeast toward download box, creek and pond

Downstream Level Sensor (level data)

Scajaquada Creek at Grant Street Dam: Located approximately two feet from the North bank sheet piling and approximately three feet upstream of Grant St. dam (45° 56’ 16.460” N, 78° 53’ 07.515” W). Photos of the installation follow.

Level sensor download box on North bank at Grant Street Dam

Level sensor stilling well at North bank (just upstream of dam)

Downstream HADCP (level and velocity data)

Scajaquada Creek at Grant Street: Located at the South bank on the concrete channel wall approximately 10 feet upstream of the West-bound Scajaquada Expressway Grant St. exit ramp bridge (42° 56' 14.924" N, 78° 53' 13.815" W). This location is approximately 465 feet downstream of the Grant Street Dam. Photos of the installation follow.

Looking West (downstream) at solar panel and download box next to expressway exit ramp

Looking east (upstream) at HADCP installation (Buffalo State College buildings in distance)

Downstream HADCP mounted on concrete wall

Sampling Period and Frequency

The monitoring instruments were deployed from July through October, 2008, to record data at 15-minute intervals. Buffalo State College students downloaded data from the instruments and transferred the data to LimnoTech on a weekly basis.

Methods

Water Level Monitoring

Water levels were monitored at all four locations. The In-Situ Level Troll 500 was deployed at the upstream and downstream Level Sensor locations. This instrument measures water depth above the sensor (using a pressure transducer). The HADCPs also measure water level above the instrument (using an acoustic transducer). All instruments were programmed to record data at 15-minute intervals.

An elevation survey was conducted in October, 2008, by a local Professional Land Surveyor at the Upstream and Downstream Level locations and the Downstream HADCP location to provide elevation control points for establishing water elevations using the instrument water level monitoring data.

Water Velocity Monitoring

Water velocities were monitored at the upstream and downstream HADCP locations. A SonTek Argonaut-SL3000 was deployed at the upstream location and a SonTek Argonaut-SL500 was deployed at the downstream location. The HADCP was programmed to measure and record the cross-channel average water velocity at a dry weather flow mid-water depth. Both instruments were programmed to record data at 15-minute intervals.

Channel bathymetry was measured at each HADCP location to provide additional data needed to calculate stream flow rates (discharge).

Summary of Data Collected

Data collected included water level and water velocity. Data summary statistics are presented in Tables 1 and 2. Plots of the water level and water velocity data are presented in Figures 2 and 3, below. Plots of calculated stream cross-sectional (XS) area and stream discharge are presented in Figures 4 and 5, below.

Discharge (Table 2 and Figure 5) is generally lower at the downstream location, especially during periods of higher flow. This is most likely attributable to the diversion of water from Scajaquada Creek to the Black Rock canal via the Delavan Avenue Sewer. Scajaquada Creek flows into the subsurface Scajaquada Drain at Pine Ridge Road. At Main Street, there is a weir that diverts a portion of the flow into the Delavan Avenue Sewer. The Delvan Avenue sewer discharges into the Black Rock canal

Periodic flow reversals were observed during field activities at both the upstream and downstream locations, and this is corroborated by the velocity and discharge data (Figures 3 and 5). At the upstream HADCP location (Pine Ridge Road), field observations during low flow conditions indicated that flow reversal may have had a wind-driven component. “Sewer gas” was also observed flowing upstream out the stream tunnel at Pine Ridge Road. Additionally, at the upstream HADCP location, eddies were observed along both sides of the channel with upstream current extending one to three feet out from the concrete channel wall. This occurred downstream of a constriction at the entrance to the concrete section of the channel.

Flow reversals recorded at the downstream HADCP location (downstream of the Grant Street Dam) occurred more frequently and with greater magnitude than was recorded at the upstream location. These reversals may be associated with hydraulic conditions caused by the operation of a shipping lock, which is located in Black Rock Canal, downstream of the Scajaquada Creek mouth. When the lock is closed, it is possible that flow in the Canal could be diverted up Scajaquada Creek as far as the Grant Street Dam. Lake Erie seiche may also be contributing to flow reversals in the lower Scajaquada Creek.

Table 1: Water Level Data Summary Statistics

	Date/Time	*Water Depth (ft above instrument)*	*Water Elevation (ft above MSL)*
Upstream: Scajaquada Cr. At Delaware Park			
Minimum	7/19/2008 18:00	1.62	574.65
Average		2.03	575.06
Maximum	10/30/2008 9:15	5.09	578.12
Downstream: Scajaquada Cr. At Grant St. Dam			
Minimum	7/19/2008 12:15	1.16	578.28
Average		1.57	578.69
Maximum	10/30/2008 9:00	3.61	580.73

Table 2: Water Velocity (HADCP) Data Summary Statistics

	Date/Time	*Downstream Water Velocity (ft/s)*	*Water Level (ft above instrument)*	*Cross-sectional Area (ft^2)*	*Flow Rate (ft^3/s)*
Upstream: Scajaquada Cr. Upstream of Pine Ridge Rd.					
Minimum	7/20/08 19:45	-0.10	-3.28	67.18	-8.44
Average		0.28	1.00	89.26	33.20
Maximum	11/4/08 10:45	4.18	6.36	267.07	1,110.73
Downstream: Scajaquada Cr. Upstream of Grant St.					
Minimum	7/30/08 15:30	-0.62	0.64	161.71	-127.90
Average		0.07	1.15	189.71	13.43
Maximum	11/4/08 16:30	0.87	1.70	220.36	178.13

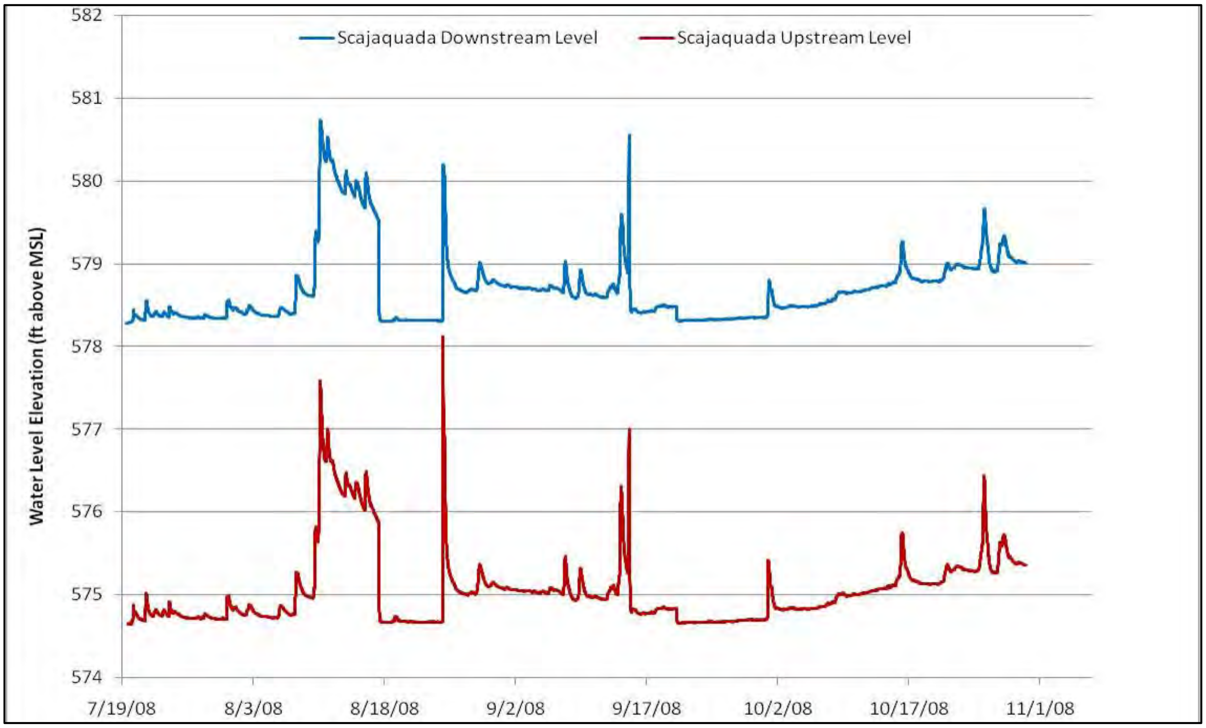


Figure 2: Comparison of Upstream and Downstream Scajaquada Creek Water Levels

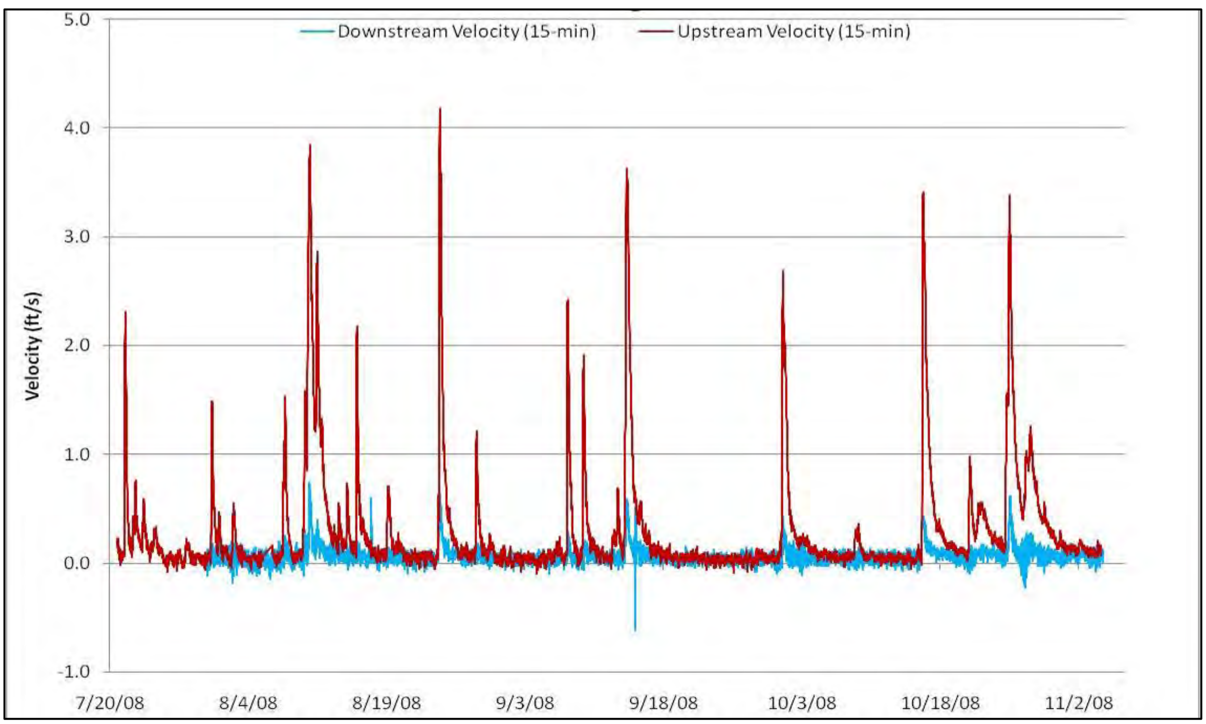


Figure 3: Comparison of Scajaquada Creek Velocities at Upstream and Downstream ADCP Monitoring Locations

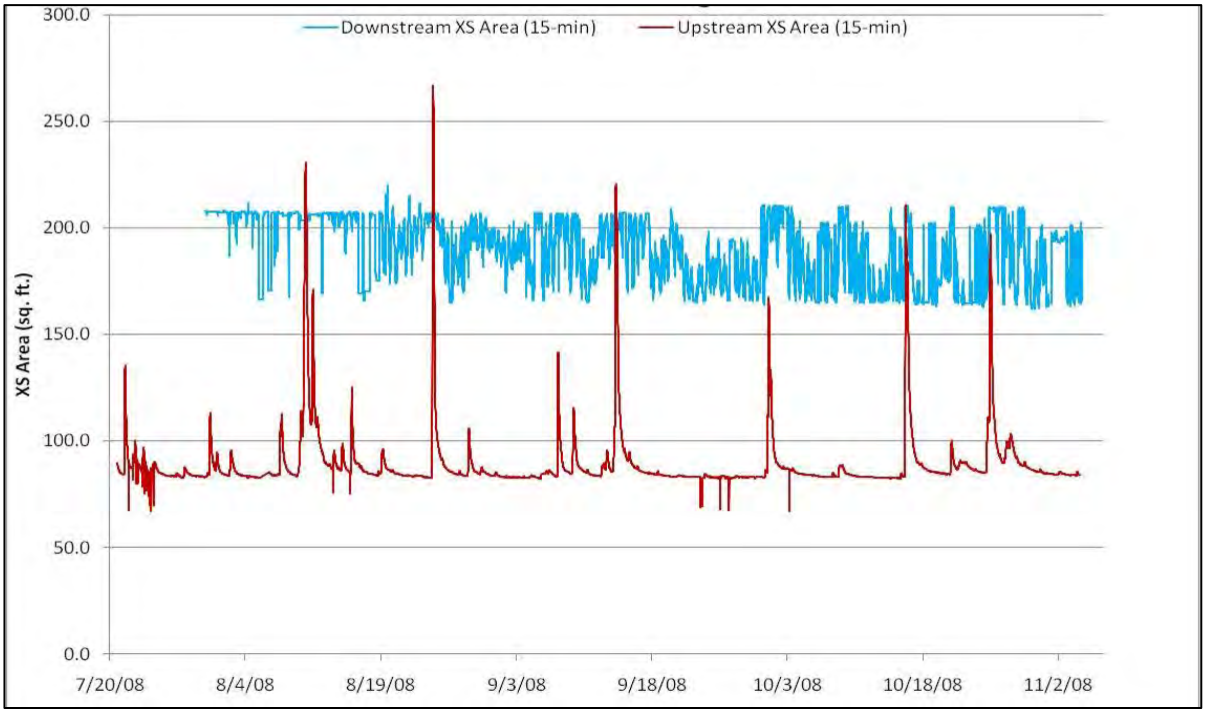


Figure 4: Comparison of Scajaquada Creek Cross-Sectional Areas at Upstream and Downstream ADCP Monitoring Locations

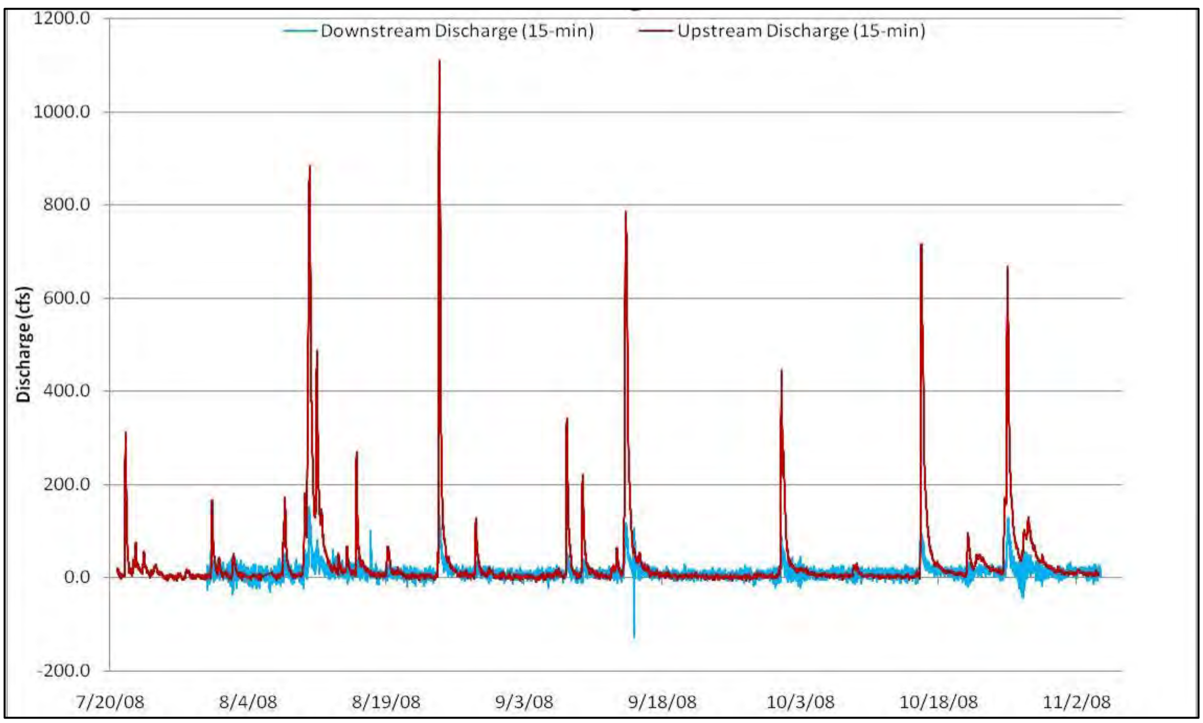


Figure 5: Comparison of Scajaquada Creek Discharge at Upstream and Downstream ADCP Monitoring Locations

Issues and Data Limitations

There are no significant issues or data limitations.

Scajaquada Creek Sediment Oxygen Demand

Sediment oxygen demand (SOD) surveys were conducted at an upstream and a downstream location of Scajaquada Creek (SC) in Buffalo, New York, during July 2008. The purpose of the SOD survey is to determine the rate that dissolved oxygen is consumed by benthic sediments.

Monitoring Locations

The detailed locations of the SOD surveys are described below and are also mapped in Figure 1 (labeled as SOD Upstream and SOD Downstream).

SC Upstream SOD

Scajaquada Creek at Delaware Park: Located in Delaware Park approximately 100 feet upstream of the stream tunnel entrance and approximately eight feet out from the North bank (42° 55’ 51.61” N, 78° 52’ 02.07” W). Photos of the installation follow.

Upstream SOD location looking downstream toward Scajaquada Creek tunnel at Delaware Park

Duplicate in-situ SOD chambers during upstream survey

SC Downstream SOD

Scajaquada Creek at West Avenue: Located approximately six feet from the Northwest bank and approximately 60 feet Southwest of West Avenue (approximately 35 feet Southwest of the downstream edge of the West Ave. bridge) (42° 55’ 48.46” N, 78° 53’ 45.48” W). Photos of the installation follow.

Downstream SOD location looking downstream toward West Avenue

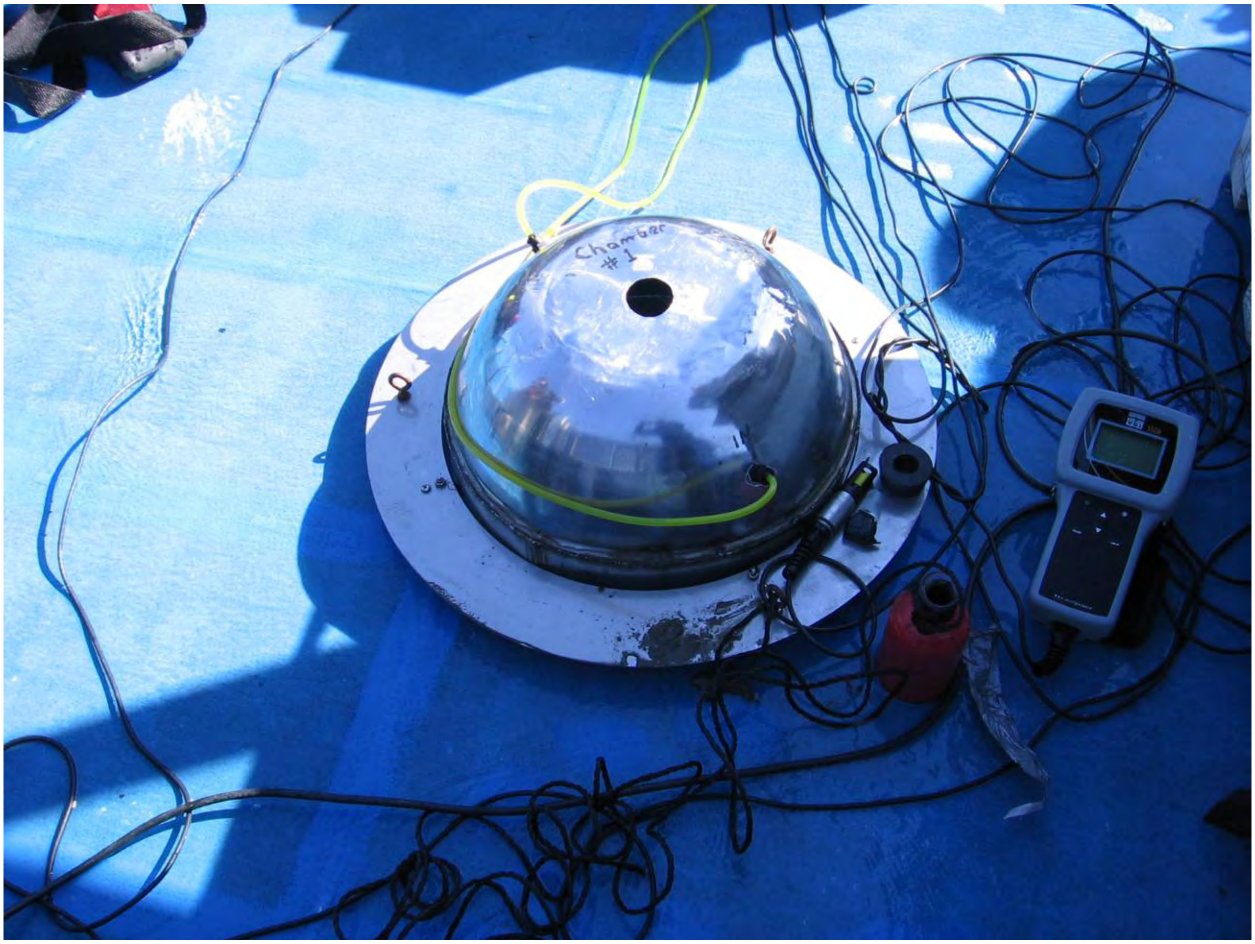
Duplicate in-situ SOD chambers during downstream survey

Sampling Period and Frequency

The SOD surveys were conducted on July 20, 2008. Duplicate surveys were conducted at both the upstream and downstream locations on Scajaquada Creek.

Methods

In-situ SOD was measured in bottom sediments at each location using a hemispherical stainless steel chamber (respirometer) to isolate a known volume of water over a specific area of streambed. Water was gently mixed within the chamber using a sealed, recirculating pump system. The change in dissolved oxygen concentrations within the chamber over time was monitored with a YSI dissolved oxygen/temperature probe fitted into the chamber. SOD incubations ran for approximately two hours and depended on the time necessary to obtain an accurate rate of dissolved oxygen depletion. For each instrument, a dark bottle was filled with river water and incubated in the river simultaneously with the chamber to provide a correction for algal respiration and biochemical oxygen demand (BOD) within the water column. SOD was determined by subtracting the rate of change of dissolved oxygen within the dark bottle from the rate of change in the chamber. The resulting value was then corrected to a temperature of 20° C. Duplicate chambers were deployed at each location, resulting in two calculated SOD values for each location. The final SOD value report for each location is the average of the duplicate results. A photo of the respirometer setup follows.



Summary of Data Collected

The SOD results are summarized in Table 3, below. A negative SOD value calculated for the upstream location in Chamber #1 results from a greater rate of change in the dark bottle than in the respirometer data used in the SOD calculations. This indicates that the algal respiration and biochemical oxygen demand (BOD) within the water column was greater than the SOD at the time of the downstream survey. Figure 6 shows the dissolved oxygen decline in each chamber during the upstream and downstream SOD surveys. Note that the SOD is calculated using only the linear portion of the dissolved oxygen curve from the respirometer data.

Table 3: SOD Results Summary

Date	Location	SOD Chamber #1 (g/m2/day @ 20°C)	SOD Chamber #2 (g/m2/day @ 20°C)	Average SOD (g/m2/day @ 20°C)
7/20/2008	SC Upstream SOD: Scajaquada Creek upstream at Delaware Park	-0.708	1.376	0.334
7/20/2008	SC Downstream SOD: Scajaquada Creek downstream at West Avenue	0.344	1.201	0.772

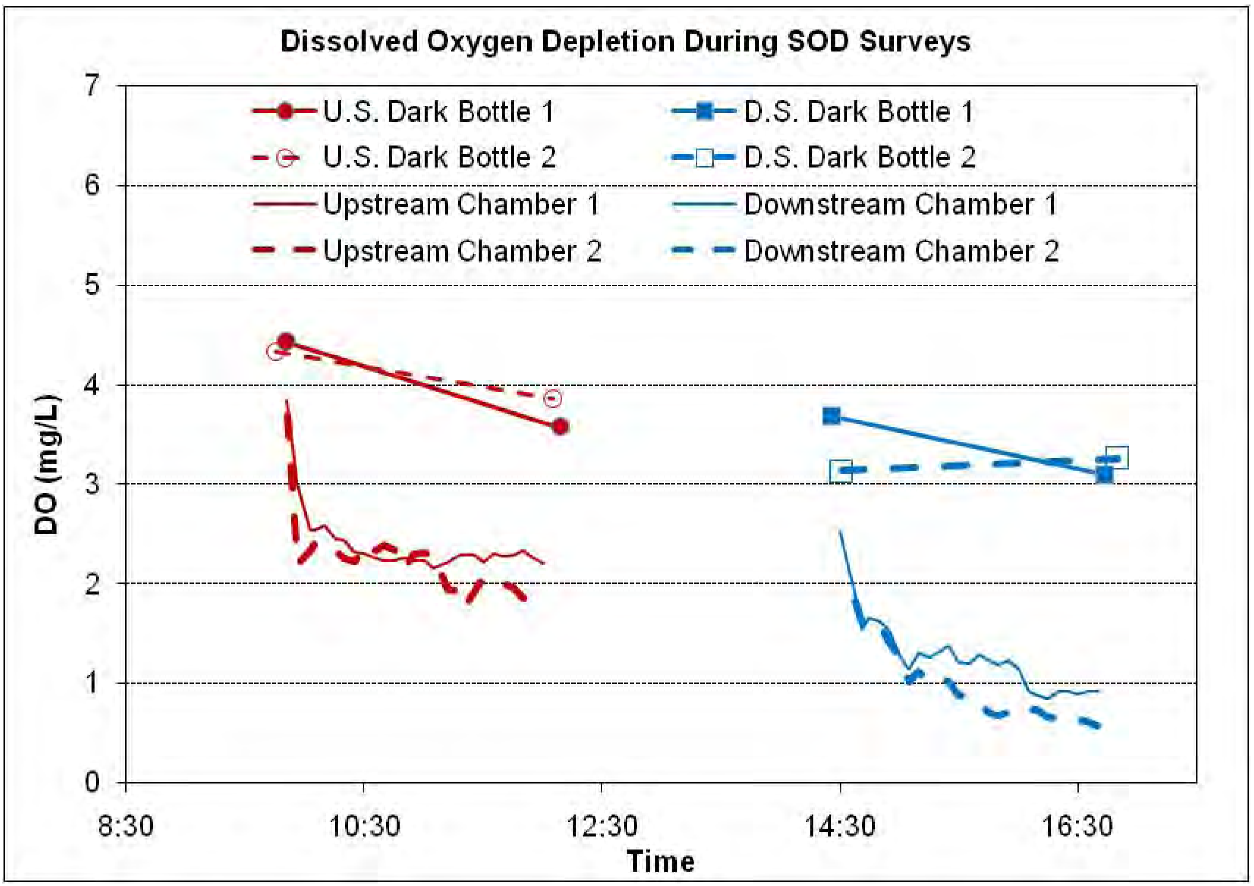


Figure 6: Dissolved Oxygen Decline in Respirometer Chambers

Issues and Data Limitations

There are no significant issues or data limitations.

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APPENDIX E: MODEL GRID MAPS

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Figure E-1: Buffalo River Hydrodynamic Model Grid

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Figure E-2: Buffalo River Water Quality Model Grid

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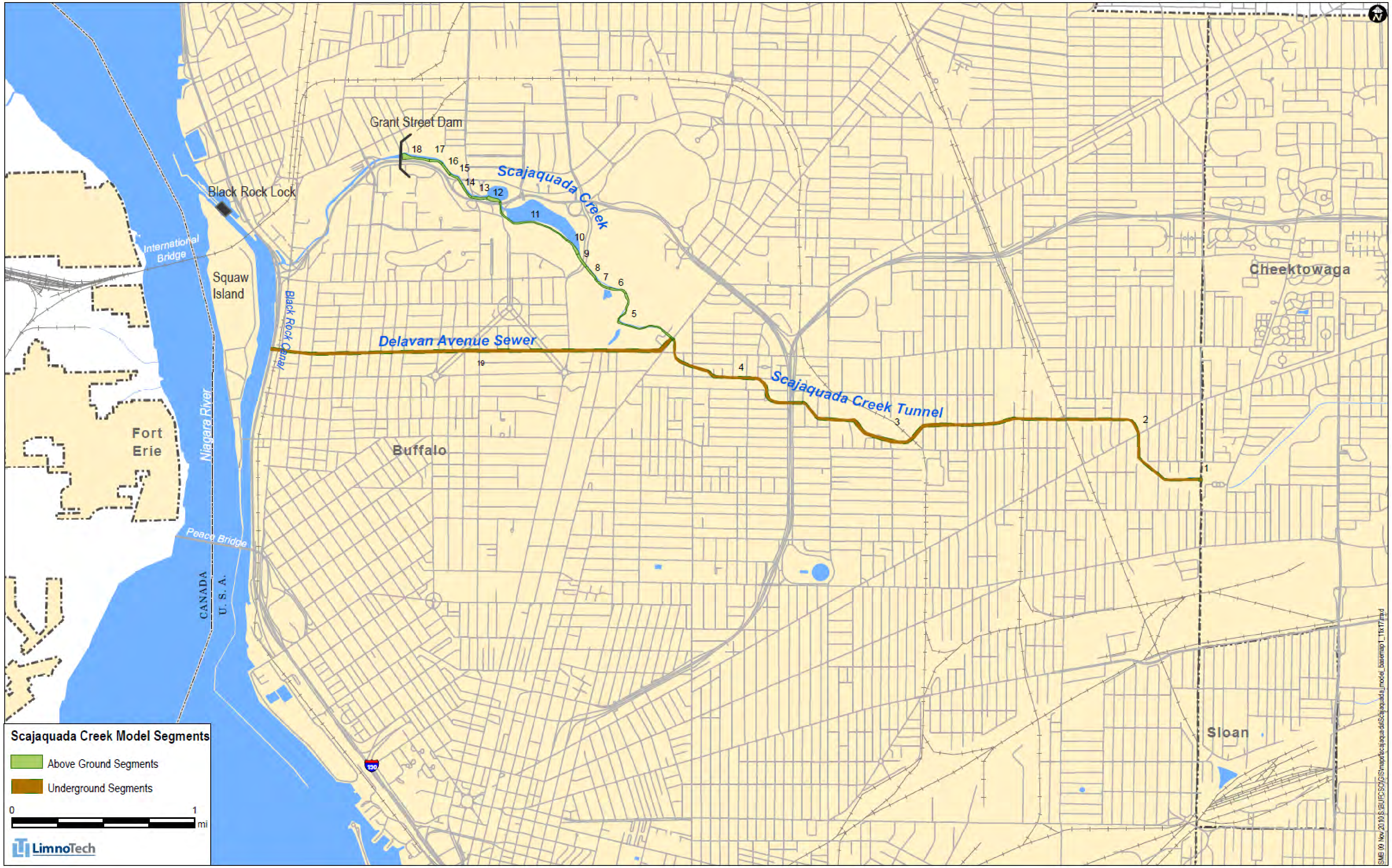

Figure E-3: Scajaquada Creek Model Domain and Segmentation

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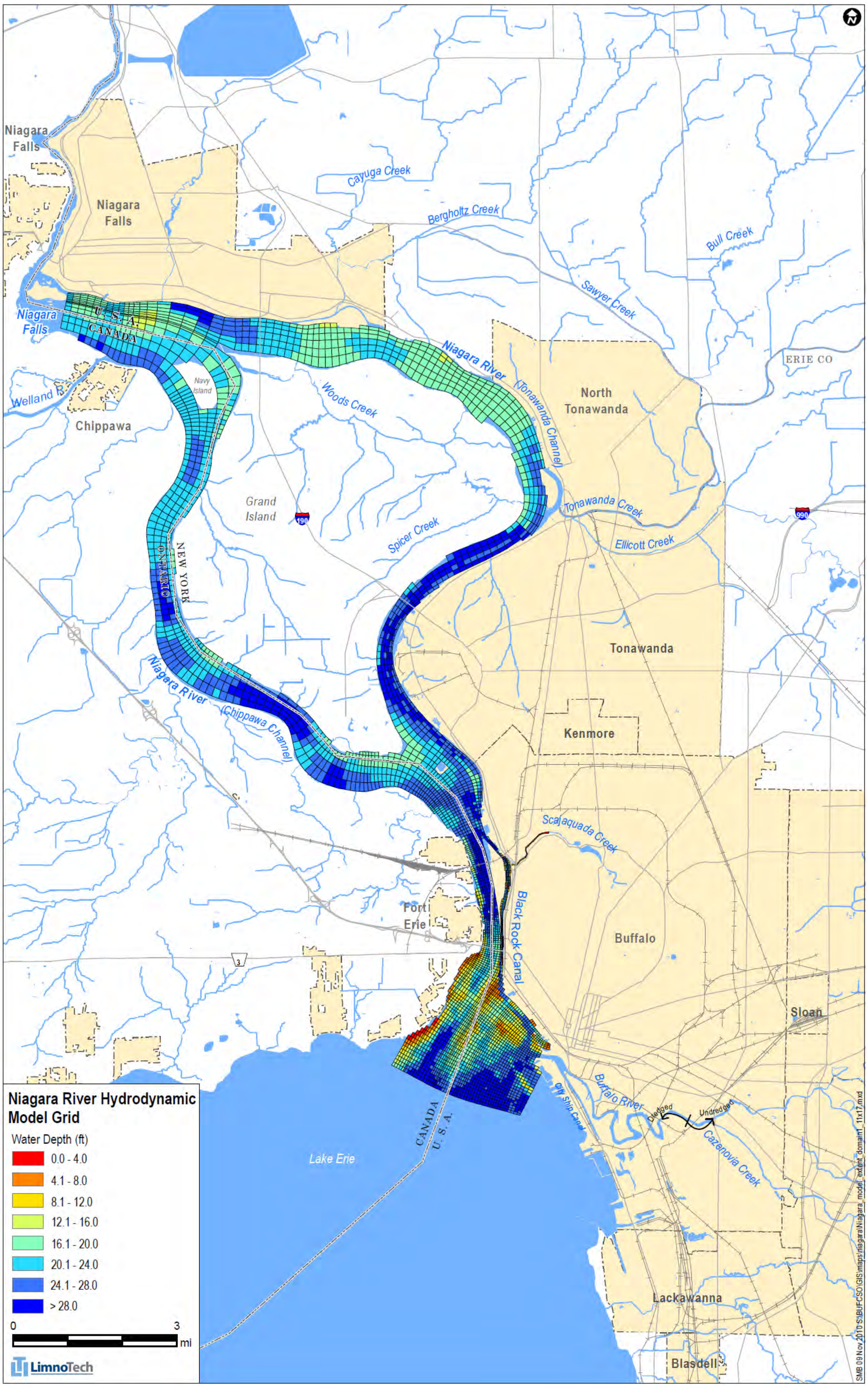

Figure E-4: Niagara River Hydrodynamic Model Grid

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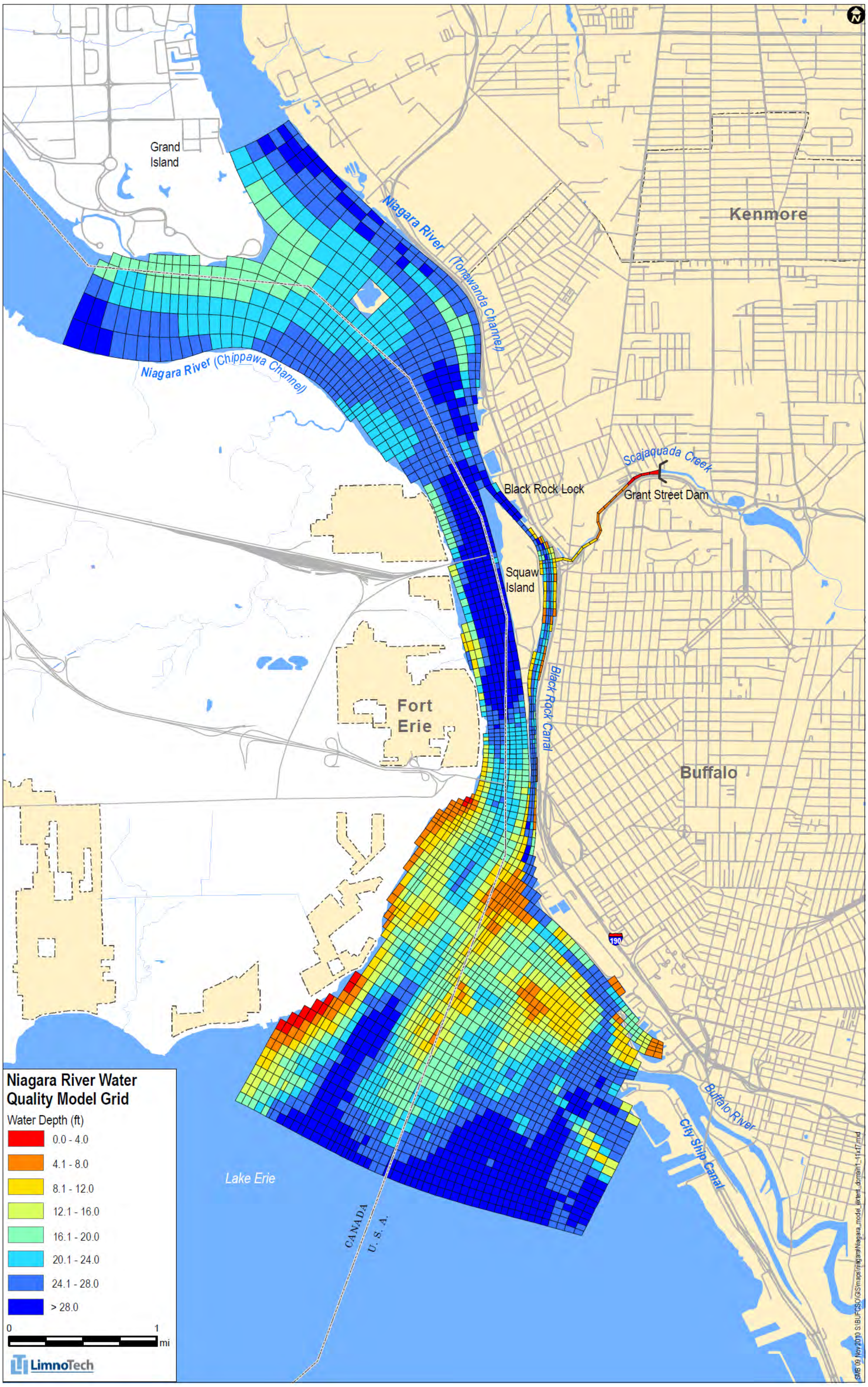

Figure E-5: Niagara River Water Quality Model Grid

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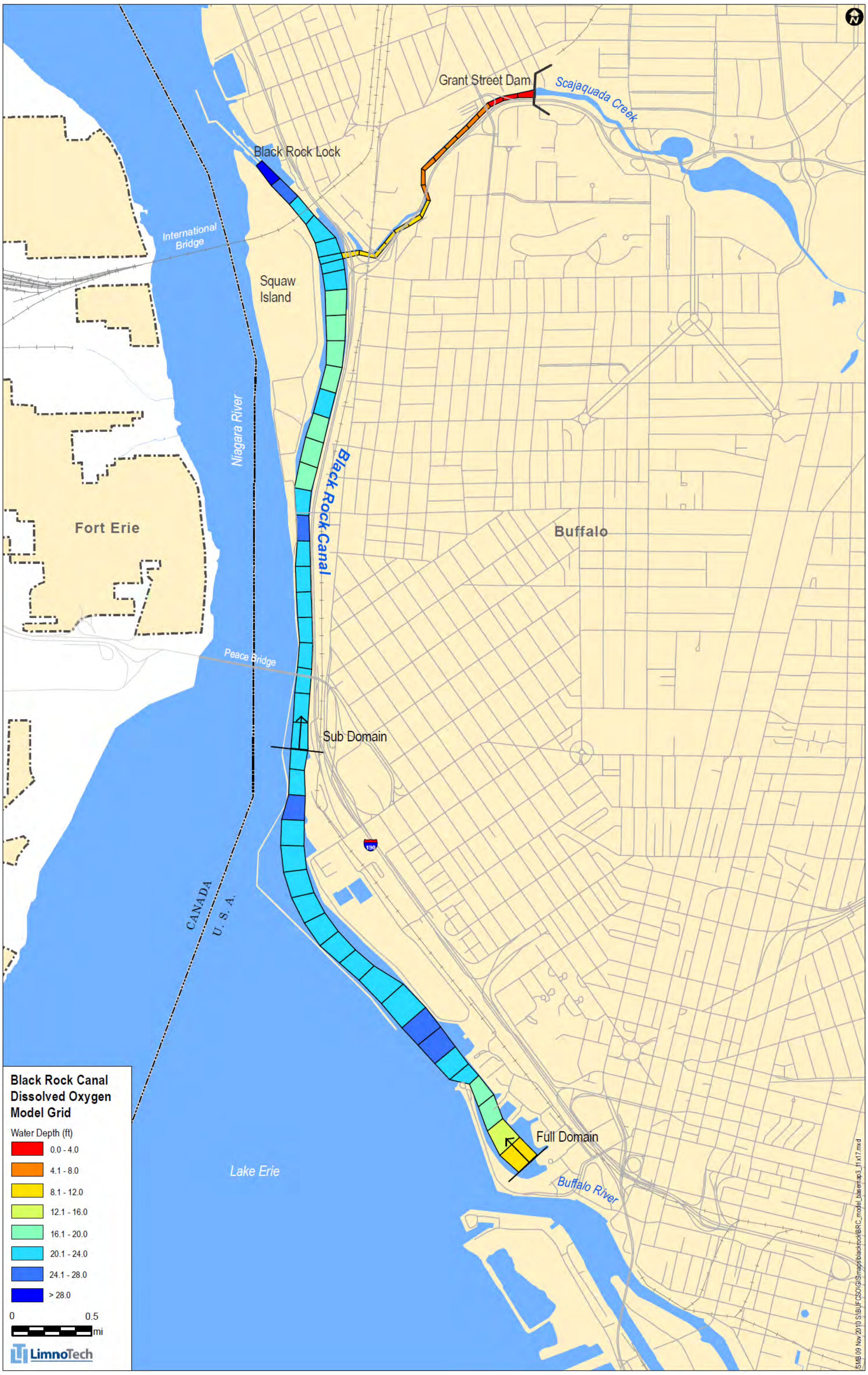

Figure E-6: Black Rock Canal Model Grid

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APPENDIX F: SUPPLEMENTAL BUFFALO RIVER MODEL GRAPHICS

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This appendix contains the following supplementary output for the Buffalo River water quality model:

- Water level and velocity data for the entire modeled period (F-1, F-2)
- Temperature calibration results for 2000 (F-3) and 1994 (F-9)
- Additional wet weather and dry weather DO results (F-4, F-5, F-6, F-7, F-8)
- Dry weather fecal coliform bacteria calibration results (F-10, F-11)

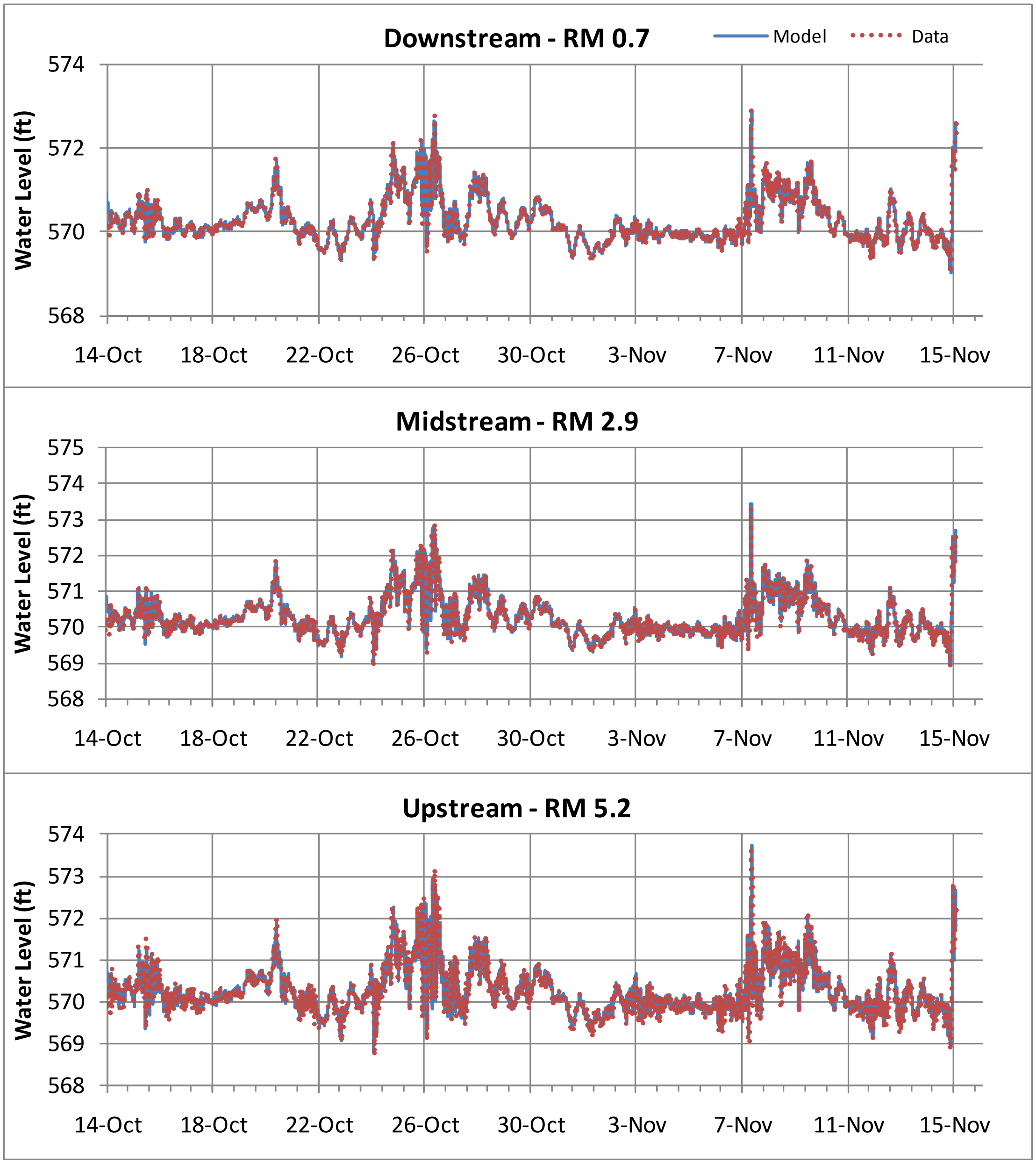

Figure F-1: Water Level at Three Locations in the Buffalo River from October 14, 2008 to November 16, 2008

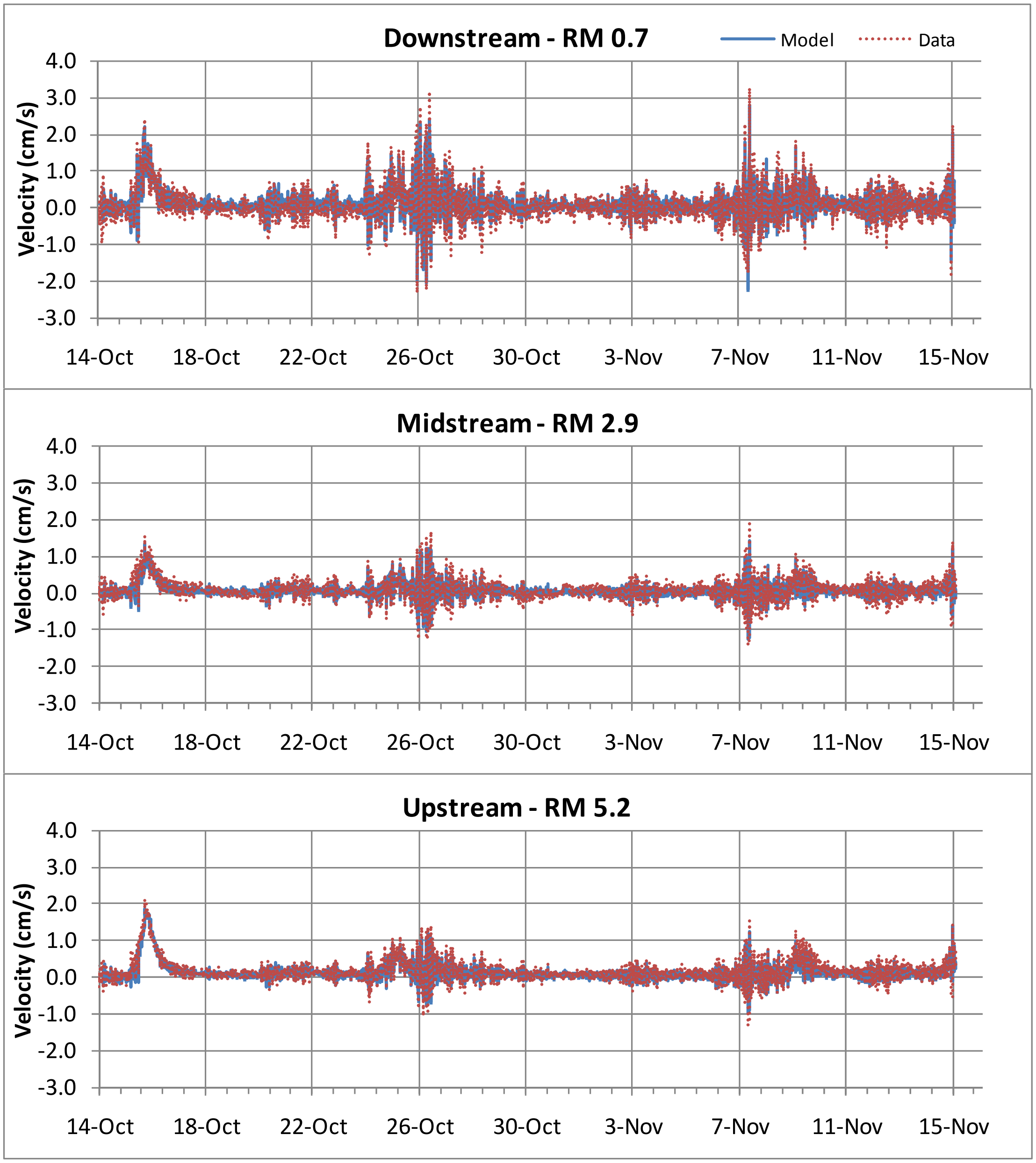

Figure F-2: Velocity at Three Locations in the Buffalo River from October 14 to November 16, 2008

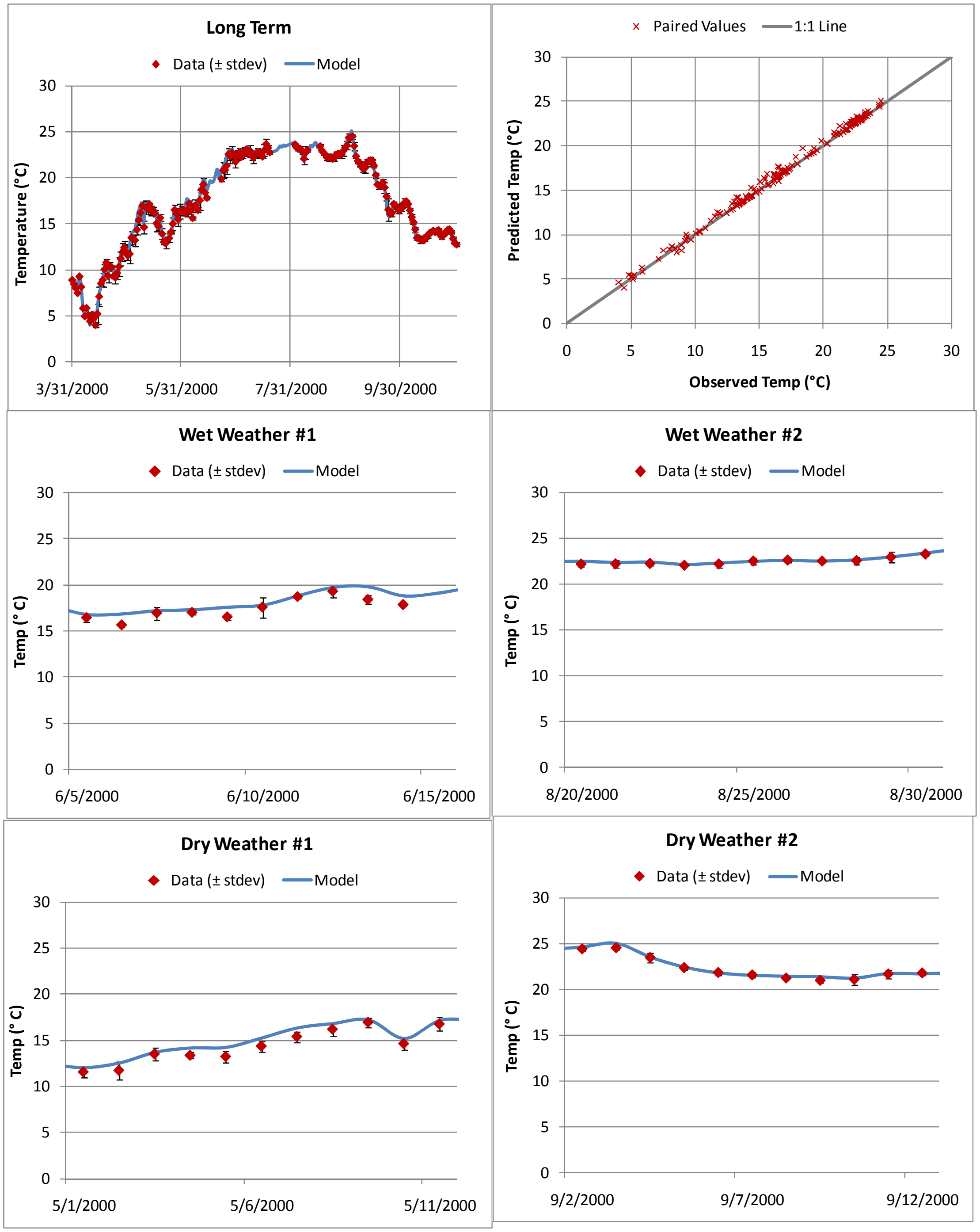

Figure F-3: Temperature Calibration Results for the Buffalo River in 2000.

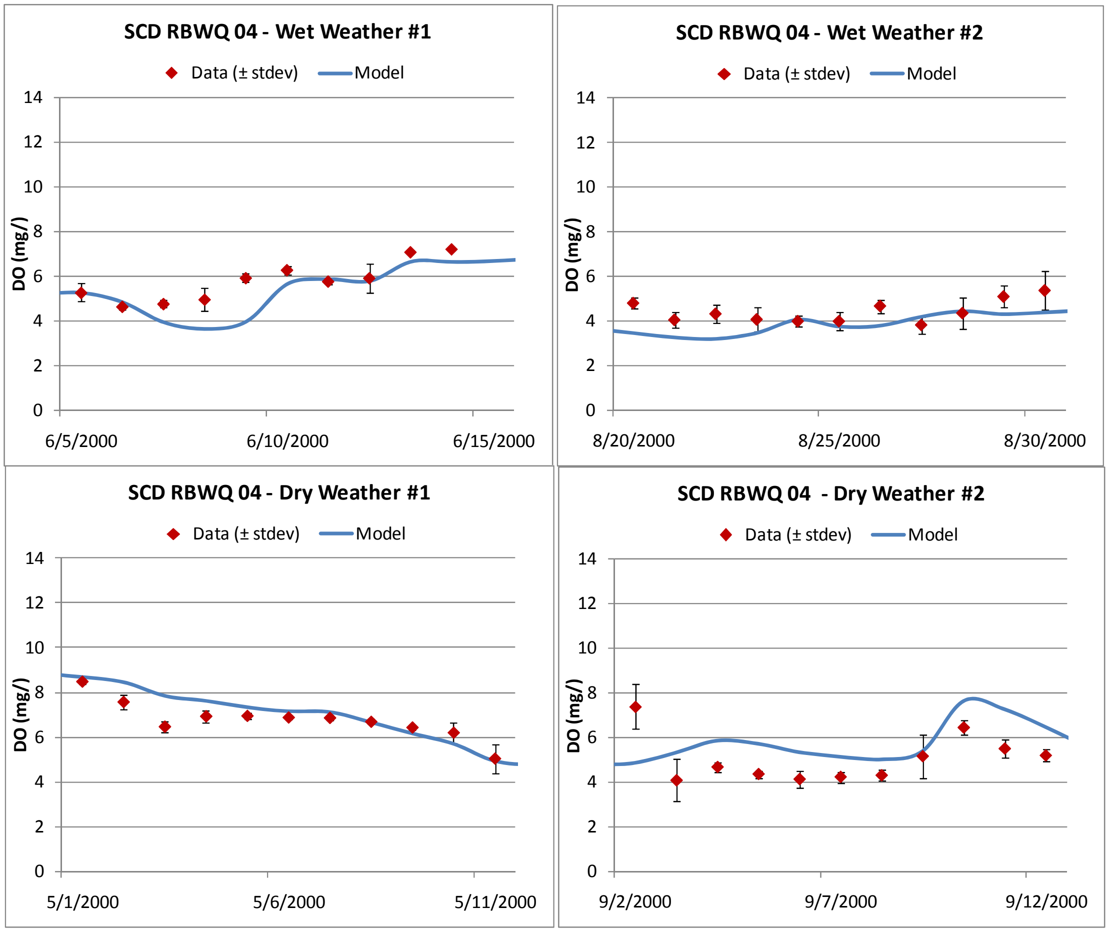

Figure F-4: Dissolved Oxygen Calibration Results for Surface DO at River Mile 3.74 (SCD RBWQ 04) in 2000.

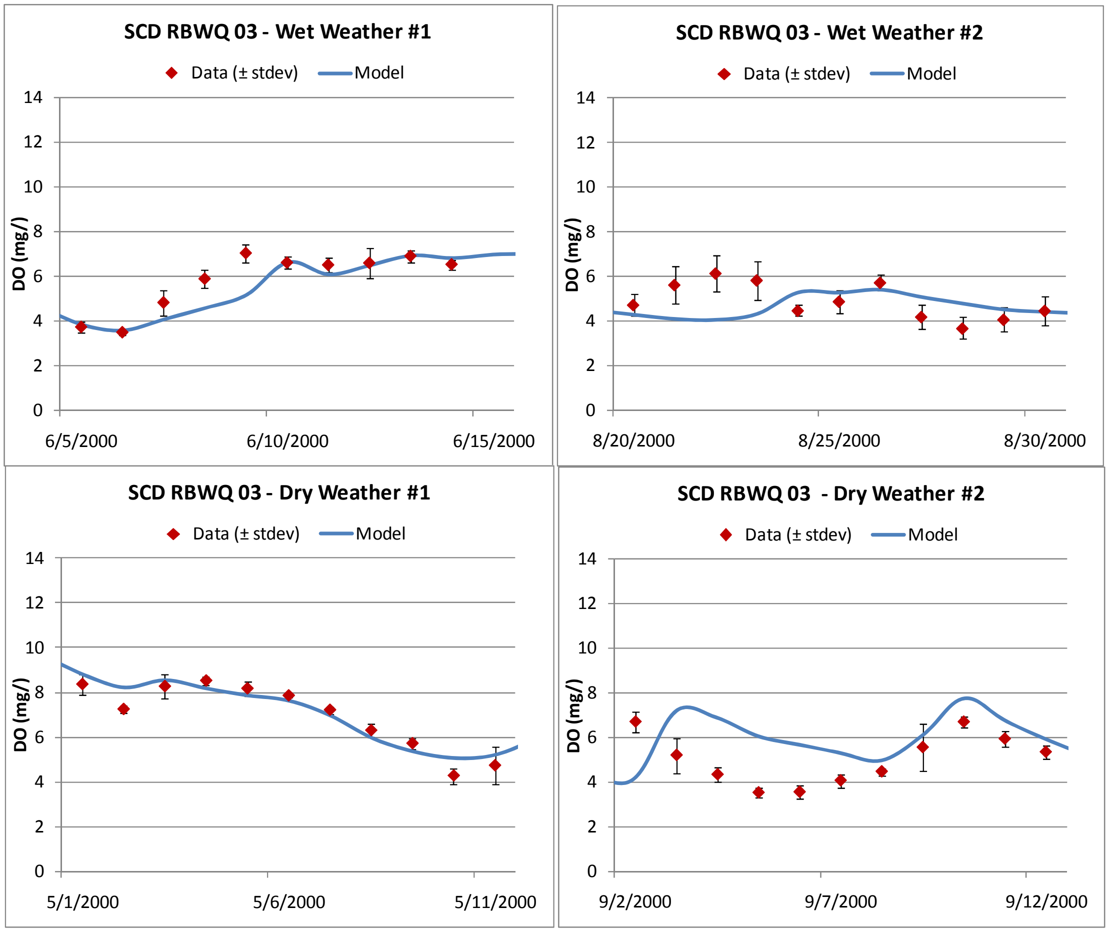

Figure F-5: Dissolved Oxygen Calibration Results for Surface DO at River Mile 1.75 (SCD RBWQ 03) in 2000.

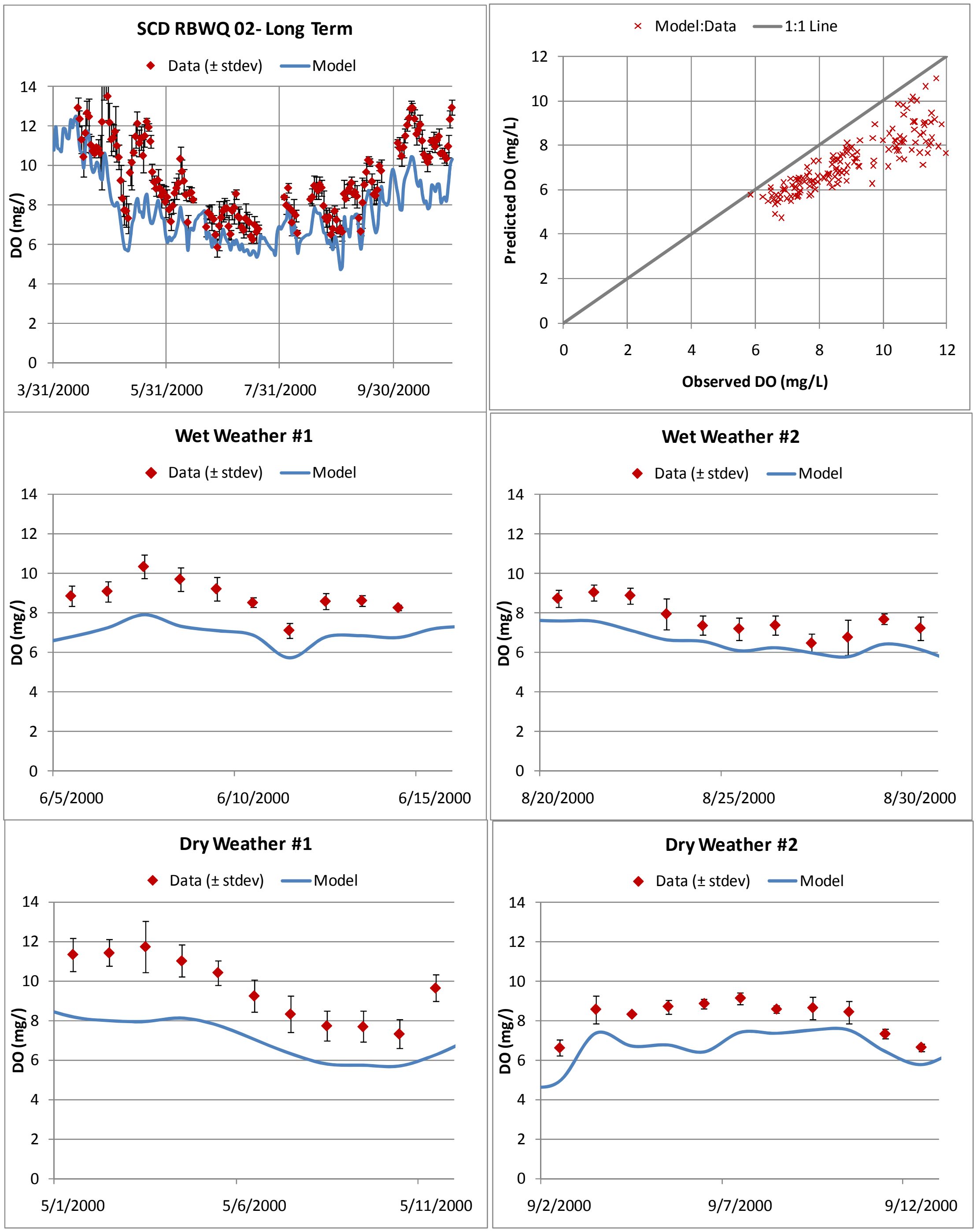

Figure F-6: Dissolved Oxygen Calibration Results for Surface DO at River Mile 6.11 (SCD RBWQ 02) in 2000.

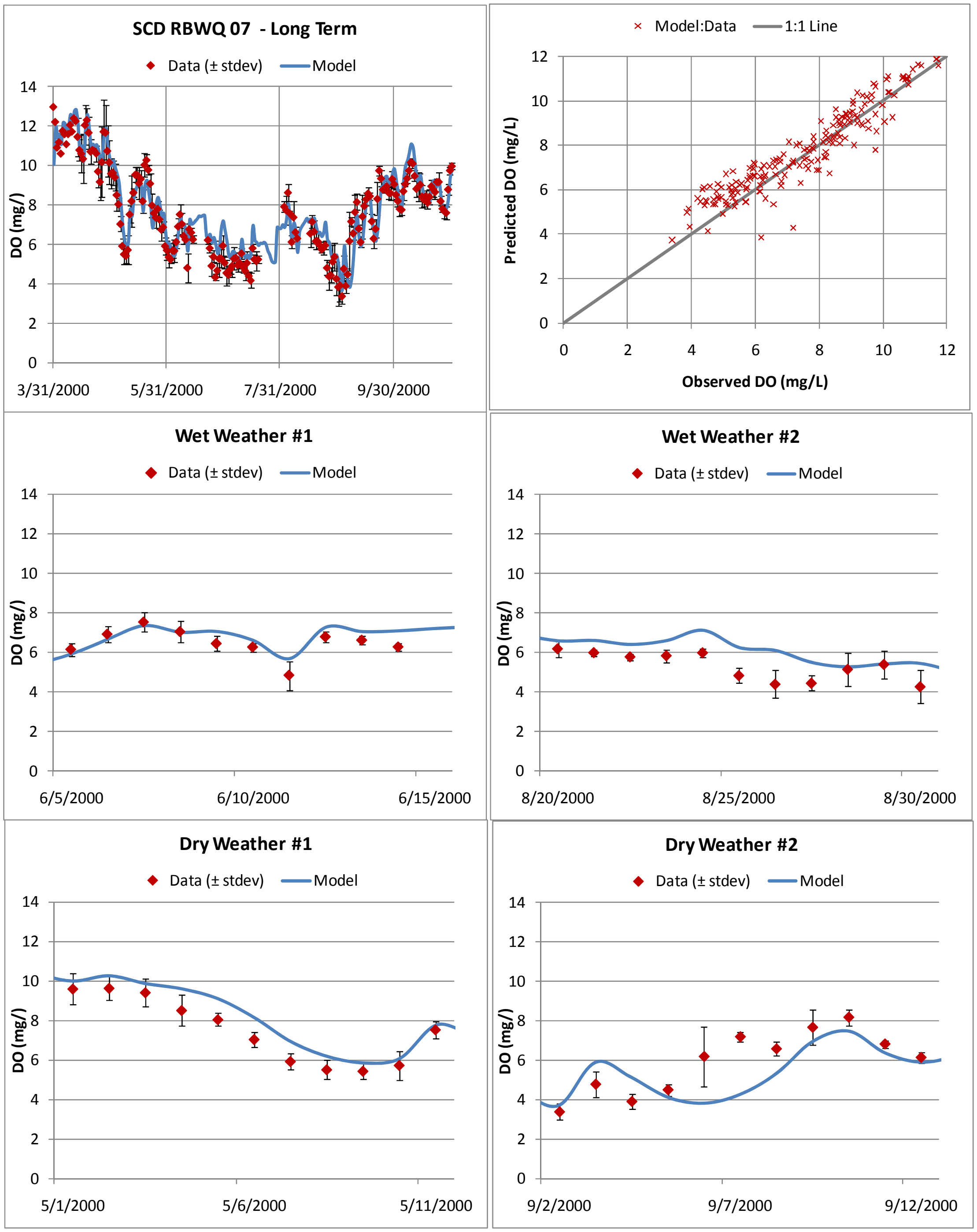

Figure F-7: Dissolved Oxygen Calibration Results for Surface DO at Cazenovia Creek Upstream of Buffalo River (SCD RBWQ 07) in 2000.

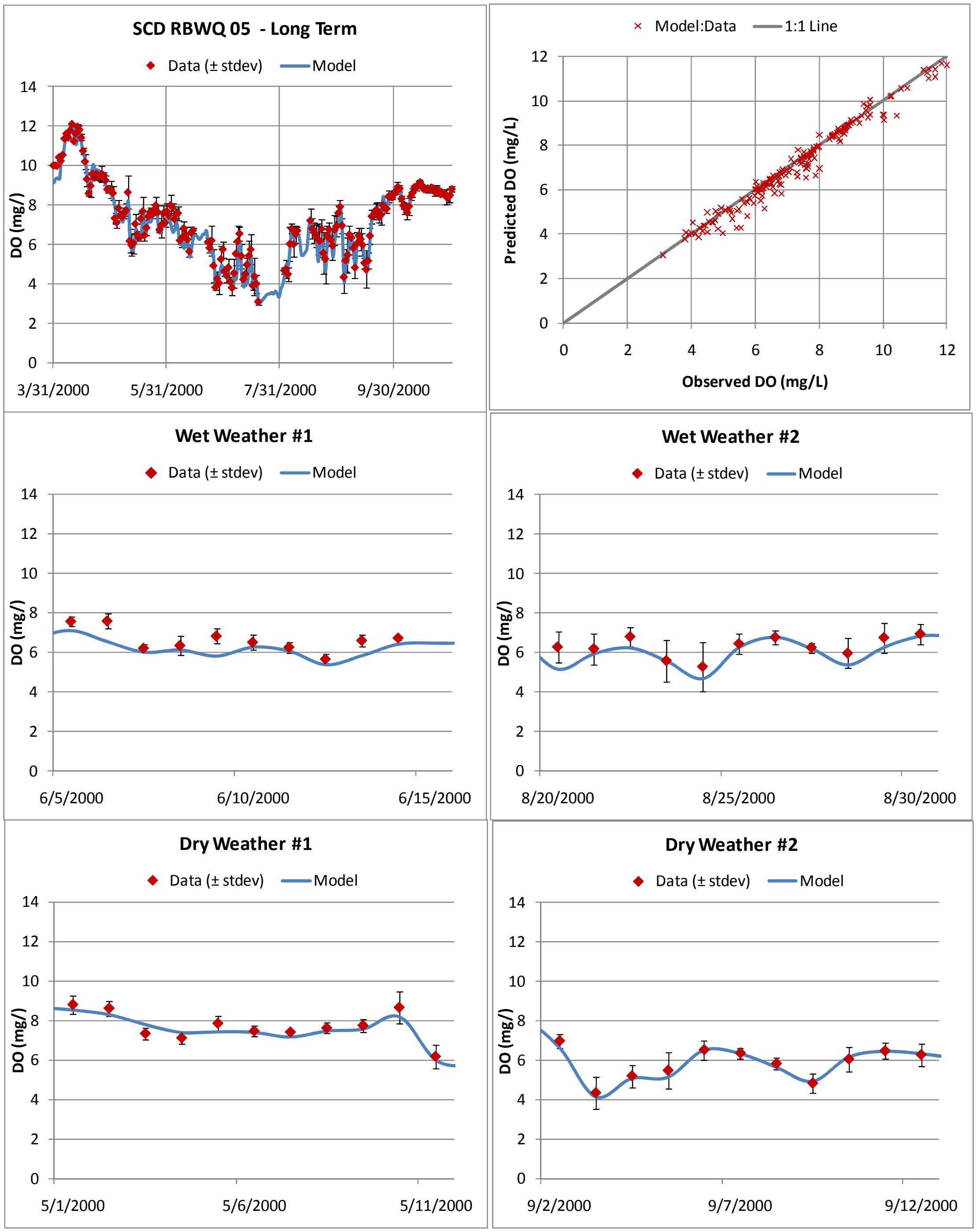

Figure F-8: Dissolved Oxygen Calibration Results for Surface DO at River Mile 0.05 (SCD RBWQ 05) in 2000.

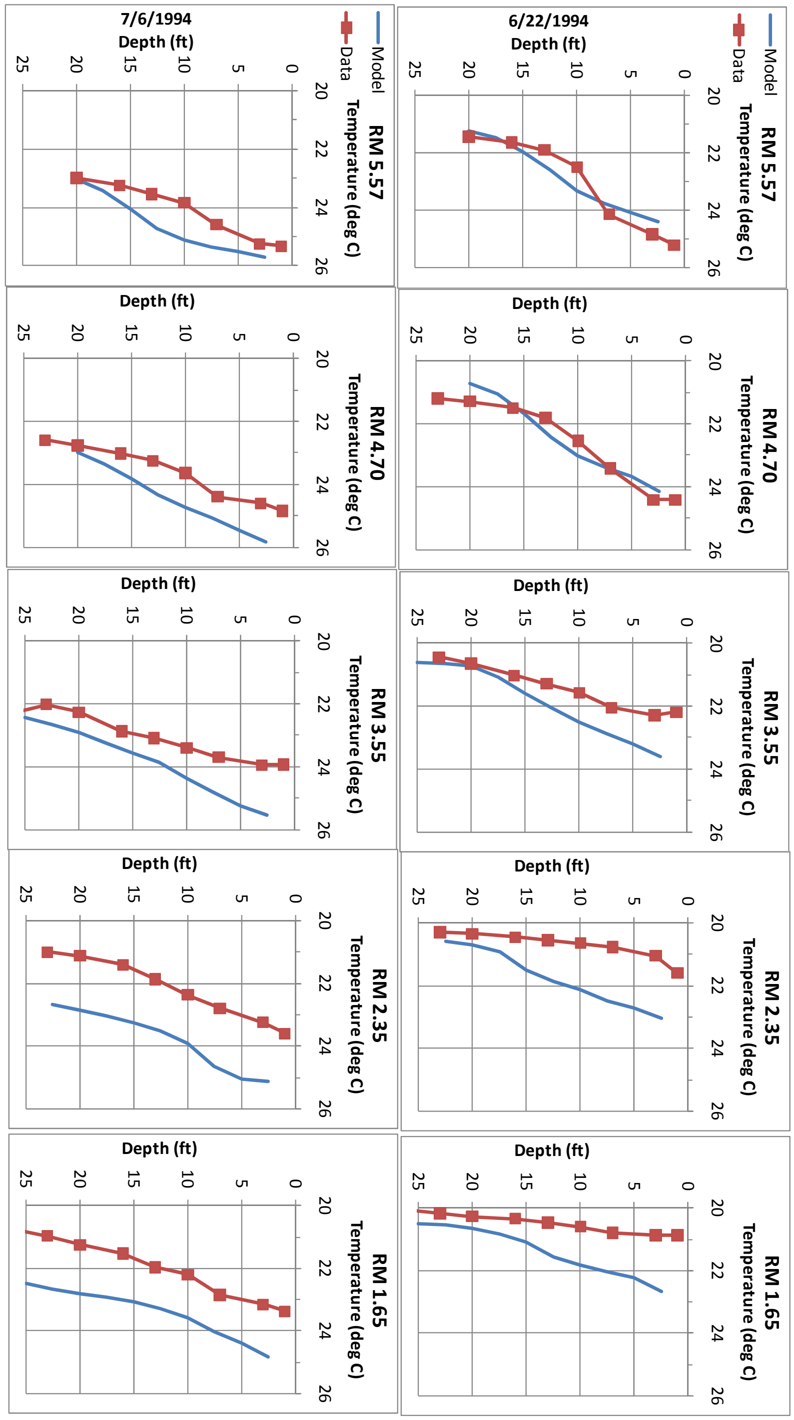

Figure F-9: Comparison of Model and Data Temperature Profiles on 6/22 and 7/6 of 1994 at Five Locations in the Dredged Portion of the Buffalo River.

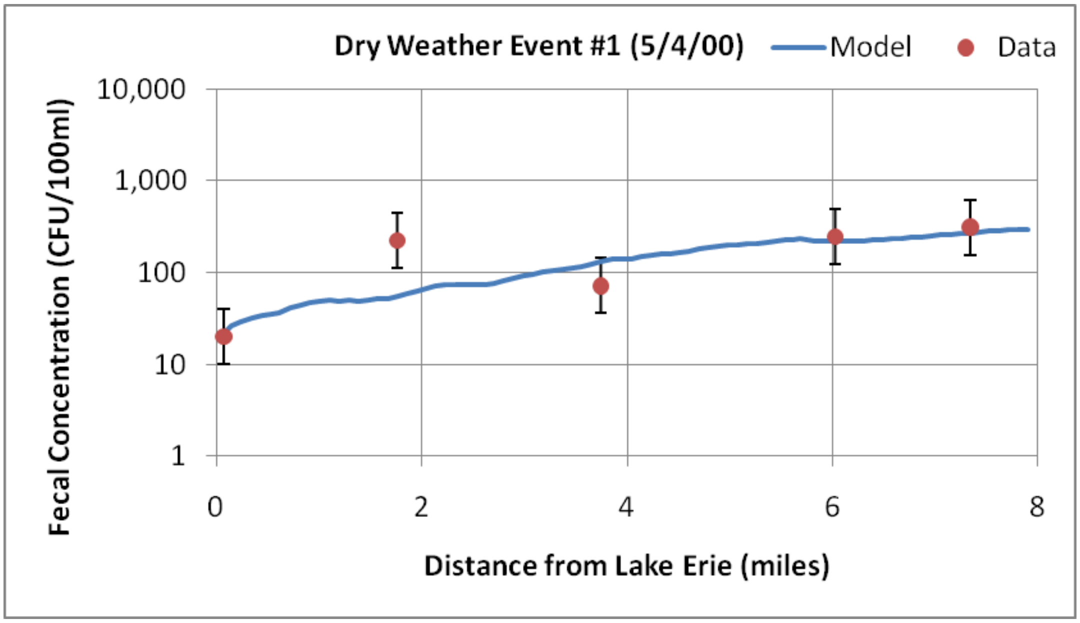

Figure F-10: Longitudinal Plot of Fecal Bacteria Calibration for Dry Weather Event in the Buffalo River.

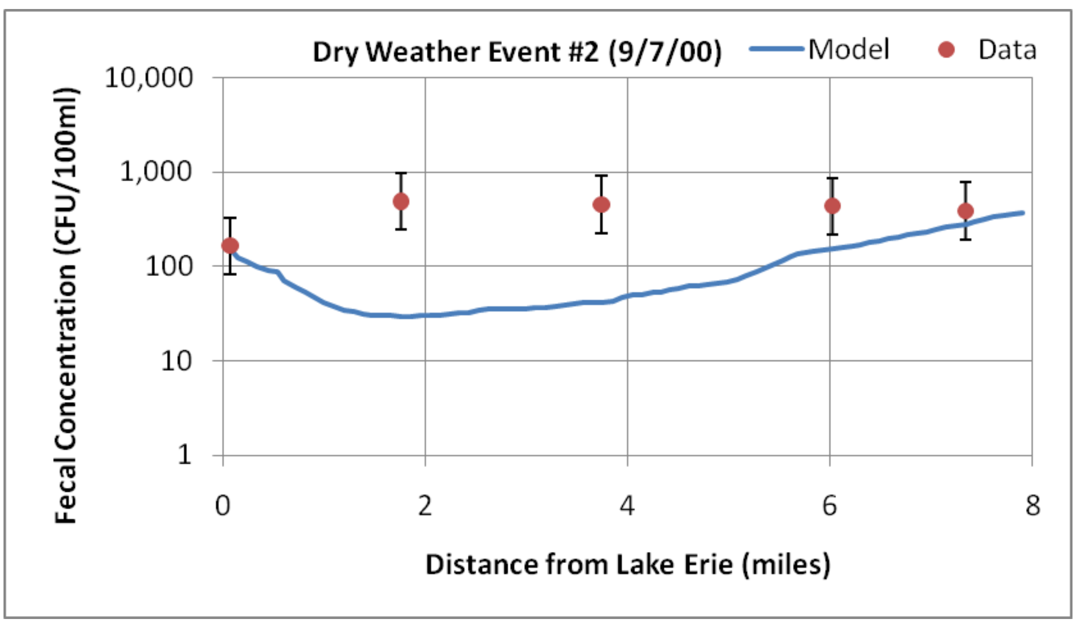

Figure F-11: Longitudinal Plot of Fecal Bacteria Calibration for Dry Weather Event in the Buffalo River.

APPENDIX G: SUPPLEMENTAL SCAJAQUADA CREEK MODEL GRAPHICS

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This appendix contains the following supplementary output for the Scajaquada Creek water quality model:

- Dry weather DO calibration (G-1)
- Dry weather fecal coliform bacteria calibration (G-2)
- Simulated and Observed DO and BOD and Measured Flow at SJC RWBQ2 for the First Wet Weather Event (G-3)

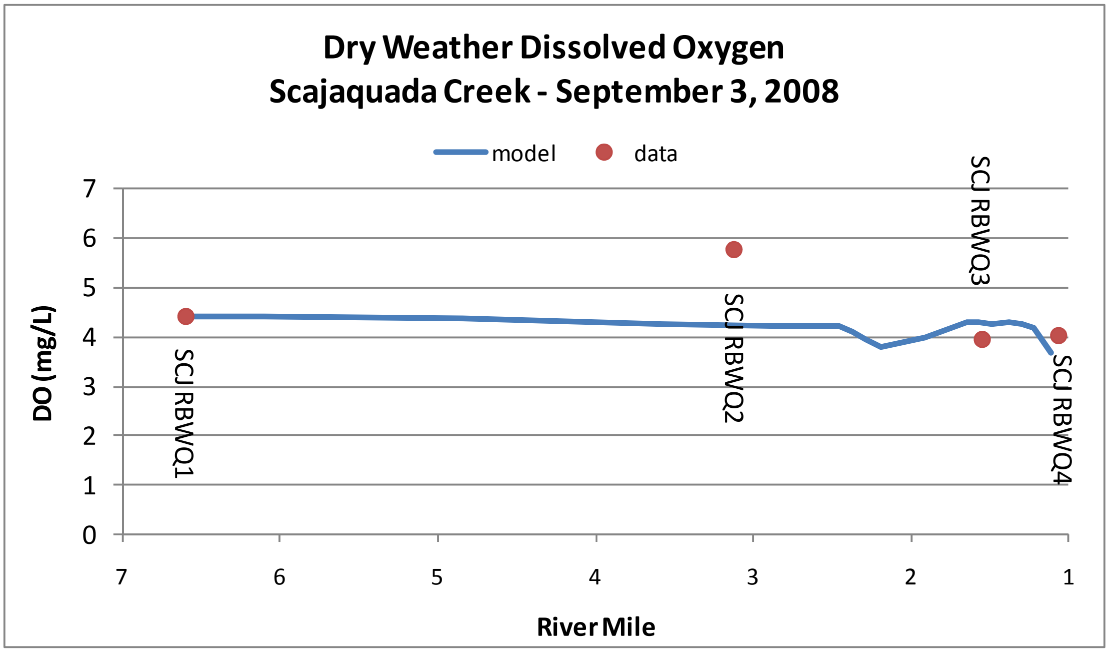

Figure G-1: Dry Weather Dissolved Oxygen Calibration for Scajaquada Creek, September 3, 2008.

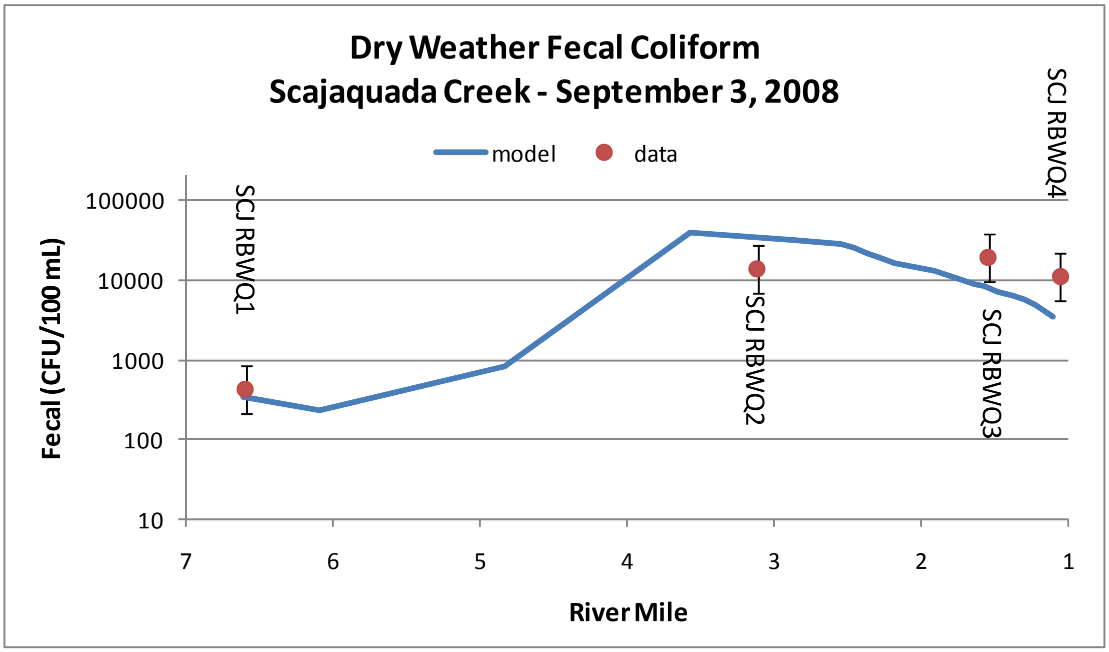

Figure G-2: Dry Weather Bacteria Calibration for Scajaquada Creek, September 3, 2008.

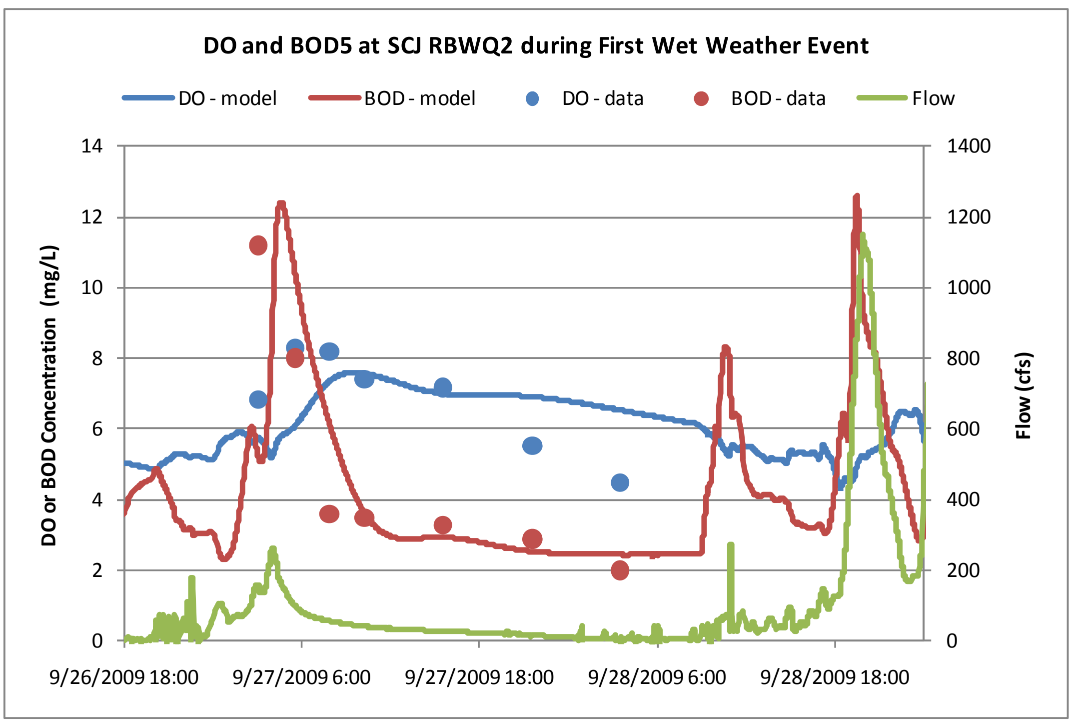

Figure G-3: Simulated and Observed DO and BOD and Measured Flow at SJC RWBQ2 for the First Wet Weather Event.

APPENDIX H: SUPPLEMENTAL NIAGARA RIVER MODEL GRAPHICS

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This appendix contains the following supplementary output for the Scajaquada Creek water quality model:

- Bacteria calibration results for Wet Weather Event 2, "C" and "D" Niagara River Locations (H-1)
- Bacteria calibration results for Wet Weather Event 2, Niagara River Locations (H-2, H-3)
- Bacteria calibration results for Wet Weather Event 2, Black Rock Canal Locations (H-4)

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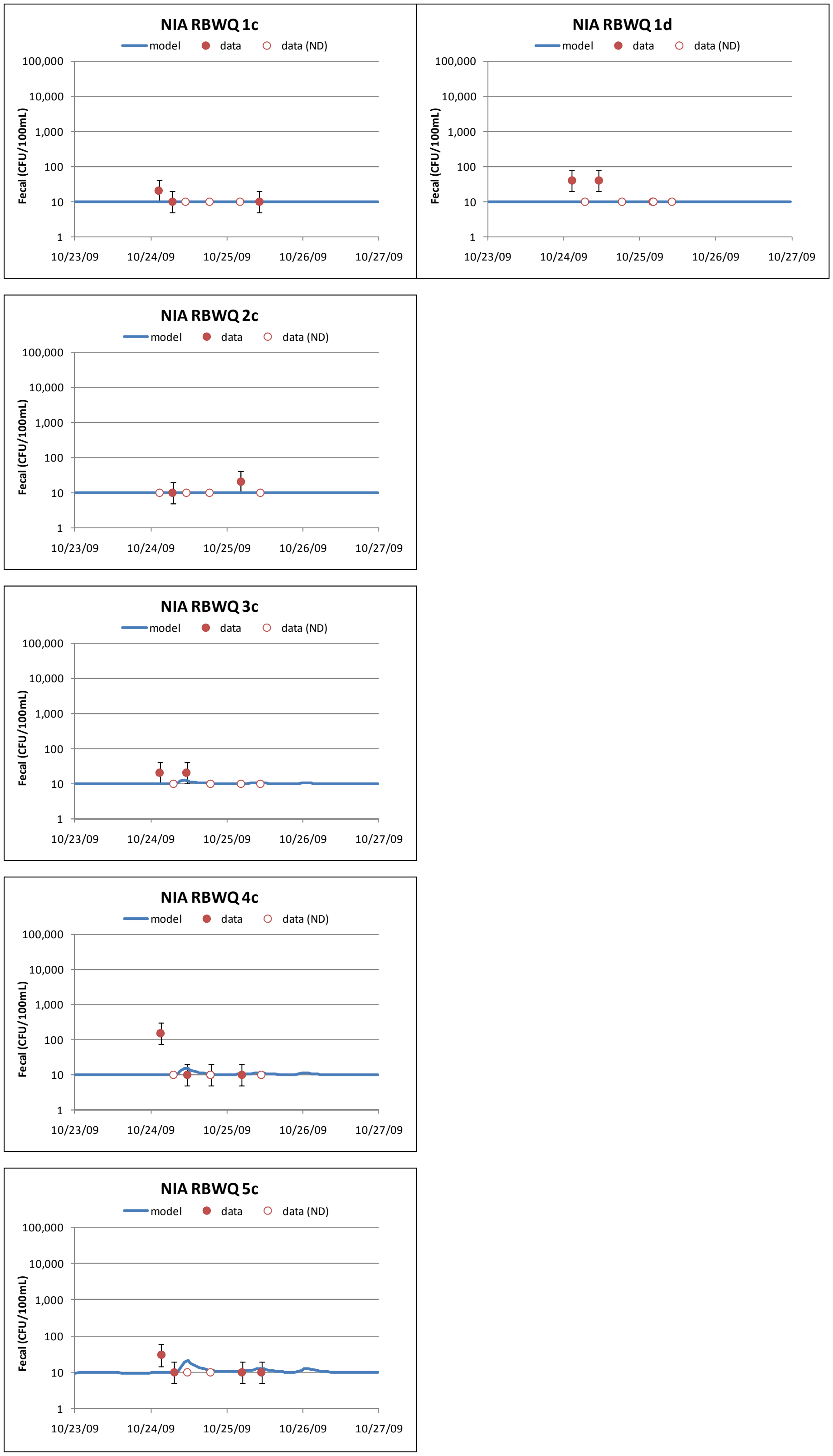

Figure H-1: Model Comparison to Data for Wet Weather Event 2, "C" and "D" Niagara River Locations.

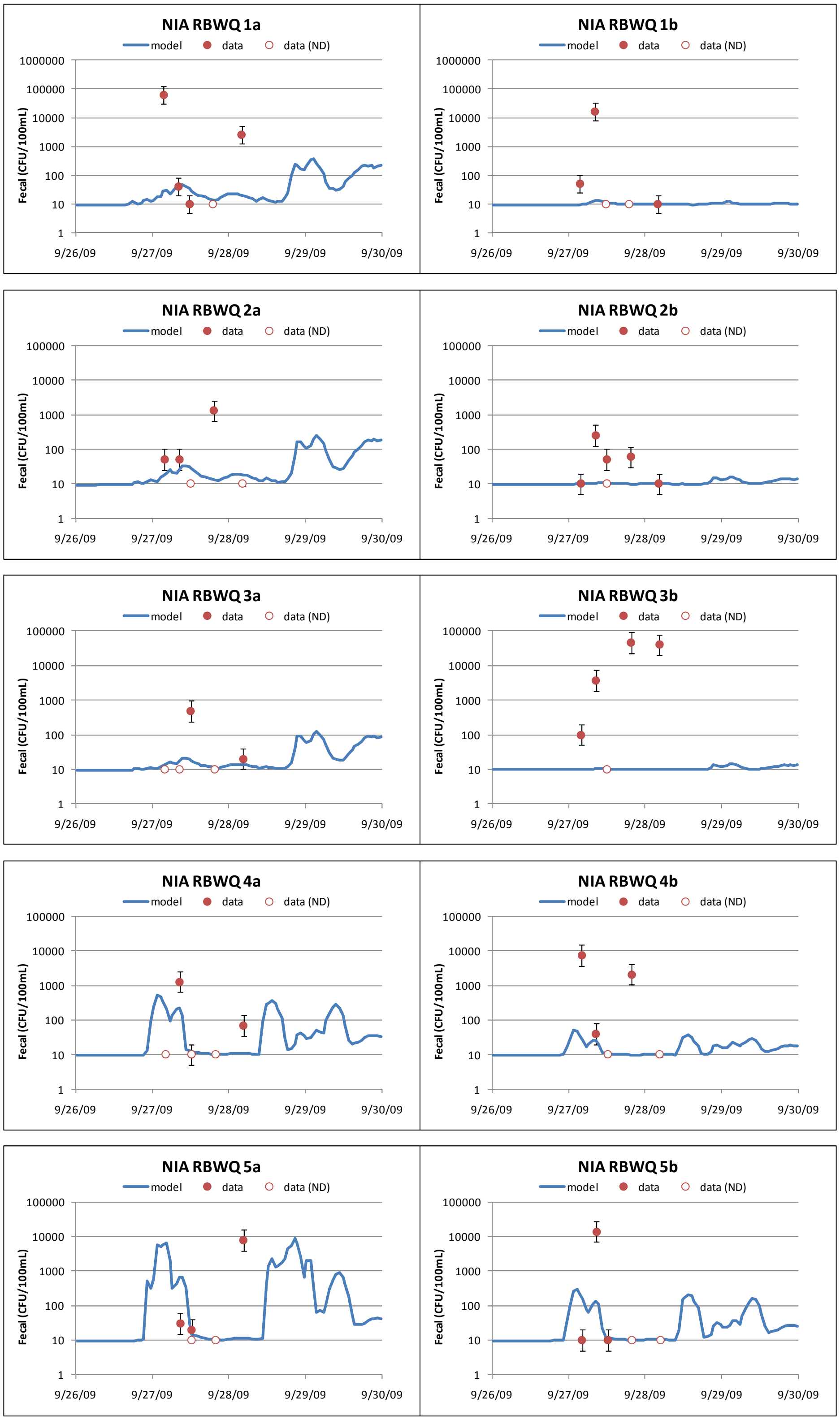

Figure H-2: Model Comparison to Data for Wet Weather Event 1, "A" and "B" Niagara River Locations.

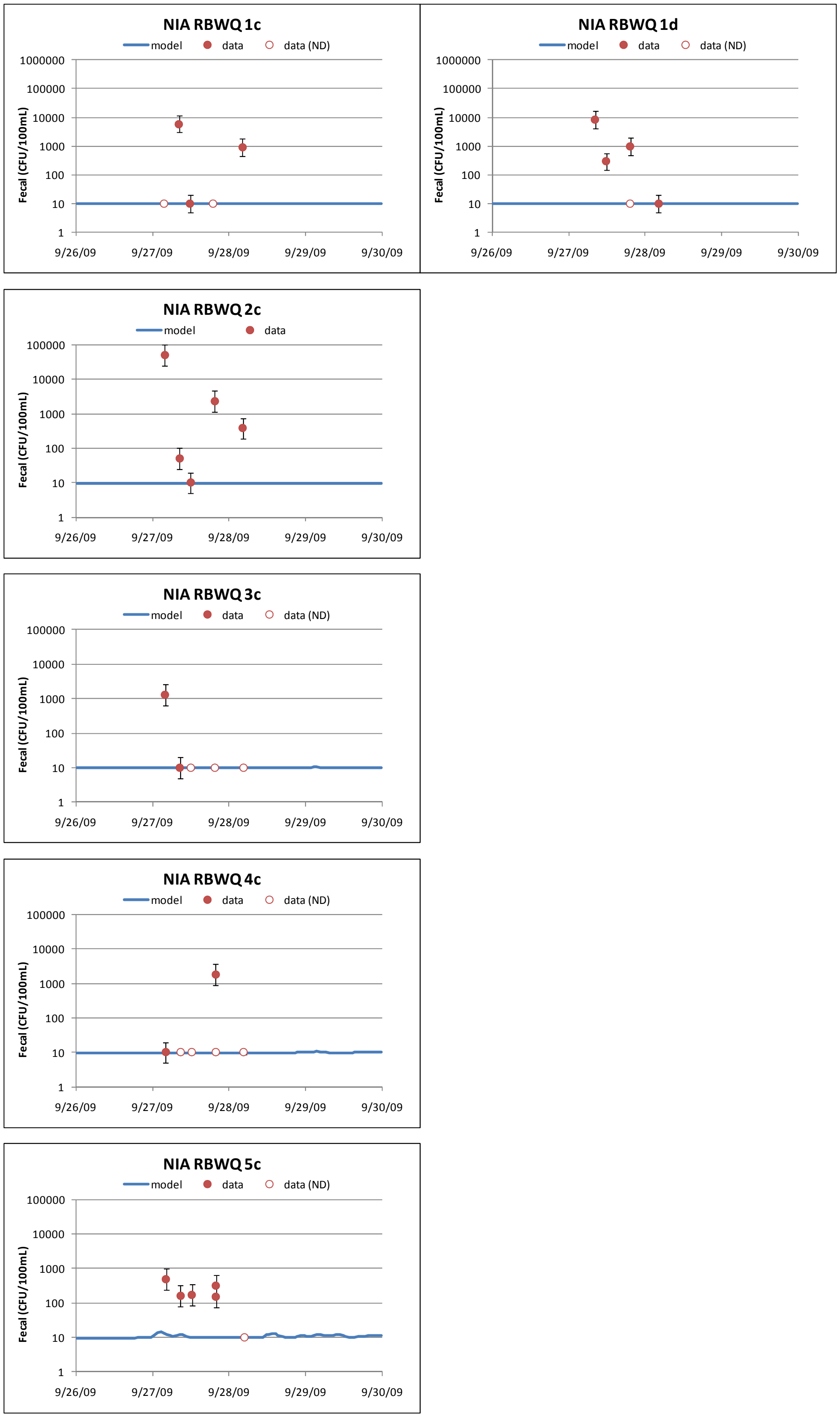

Figure H-3: Model Comparison to Data for Wet Weather Event 1, "C" and "D" Niagara River Locations.

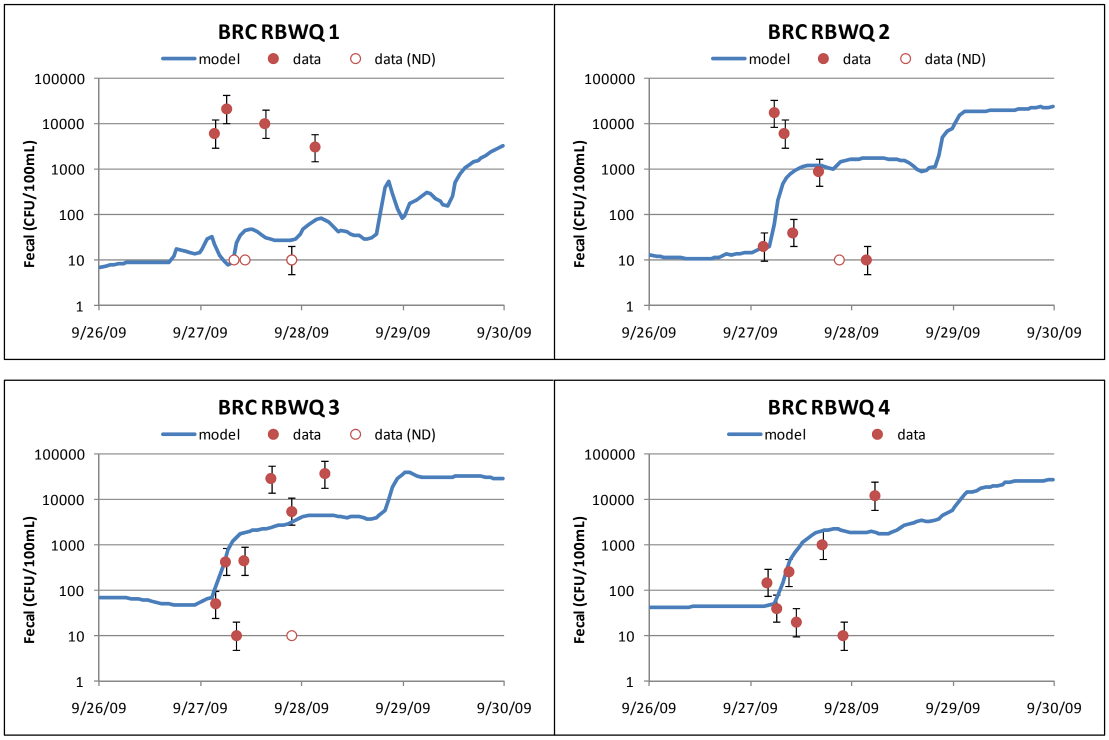

Figure H-4: Model Comparison to Data for Wet Weather Event 1, Black Rock Canal Locations.