Nicholasville Water Quality Calibration Report

Developed by The University of Kentucky and KYPIPE LLC

Prepared for the

National Institute of Hometown Security

368 N. Hwy 27

Somerset, KY 42503

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Nicholasville Water Quality Calibration Report

Project Title: Studying Distribution System Hydraulics and Flow Dynamics to Improve Water Utility Operational Decision Making

Water Distribution System: Nicholasville, Kentucky

Project No.: 02-10-UK

Grant No.: HSHQDC-07-3-00005

Organization: University of Kentucky

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Scott Yost ____________________ ____________
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Danny Johnson
Water Distribution Superintendent

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Signature Date

Jim McDaniel
WTP Shift 1 Operator

____________________ ____________
Signature Date

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ATSDR- Agency for Toxic Substance and Disease Registry
DHS- Department of Homeland Security
DVD – Digital Versatile Disk
Ft- Feet
GIS – Geographical Information System
GPM – Gallons per Minute
ID- Identification
In- Inches
KYPIPE – Hydraulic Modeling Software
MCL – Maximum Contaminant Level
MG/L – milligrams per liter
MGD – Million gallons per day
NPT- National Pipe Thread
PRV- Pressure Reducing Valve
PSI – Pounds Per Square Inch
QAPP- Quality Assurance Project Plan
QA/QC – Quality Assurance/ Quality Control
RPD – Relative Percent Difference
SCADA- Supervisory Control and Data Acquisition (SCADA) system
SDG – Sample Delivery Group
SOP- Standard Operating Procedure
SPADNS- (Sulfophenylazo) dihydroxynaphthalene-disulfonate
USEPA – United States Environmental Protection Agency
WDS- Water Distribution Superintendent
WTP – Water Treatment Plant

1.0 Project Management

1.1 Distribution List

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1.2 Project Organization

The roles and responsibilities of project participants are listed below. Refer to Figure 1 for the project organization chart.

Lindell Ormsbee, Director
Kentucky Water Resources Research Institute
University of Kentucky
Role: Project Manager
Responsibilities: Oversee data, Project Manager

Scott Yost, Associate Professor
Department of Civil Engineering
University of Kentucky
Role: Field Manager
Responsibilities: Manage data collection activities; ensure data collection conducted consistent with QAPP

Tom Calkins, Public Utilities Director
Nicholasville Water Department
City of Nicholasville
Role: Primary Contact for the Nicholasville Water Department
Responsibilities: Provide assistance in obtaining data for the Nicholasville System. Serve as liaison for Nicholasville personnel

Danny Johnson, Water Distribution Superintendent (WDS)
Nicholasville Water Department
City of Nicholasville
Role: Assist field crews and oversee field testing activities
Responsibilities: Provide personnel for field testing, oversee training of field crew

Jim McDaniel, Operator of Water Treatment Plant
Nicholasville Water Department
City of Nicholasville
Role: WTP Shift 1 Operator
Responsibilities: Help coordinate and collect real time data from the WTP during field testing (i.e. pump discharges, tank water levels).

Mr. Morris Maslia
Research Environmental Engineers
Agency for Toxic Substances and Disease Registry (ATSDR)
National Center for Environmental Health
Role: Tracer Analysis Consultant
Responsibilities: Provide guidance on conducting tracer study

Joe Goodin
Graduate Research Assistant(s)
Department of Civil Engineering
University of Kentucky
Role: Data acquisition oversight
Responsibilities: Collect field data from hydrant testing; troubleshoot field equipment; undertake corrective measures as needed to develop and calibrate hydraulic model of the water distribution system.

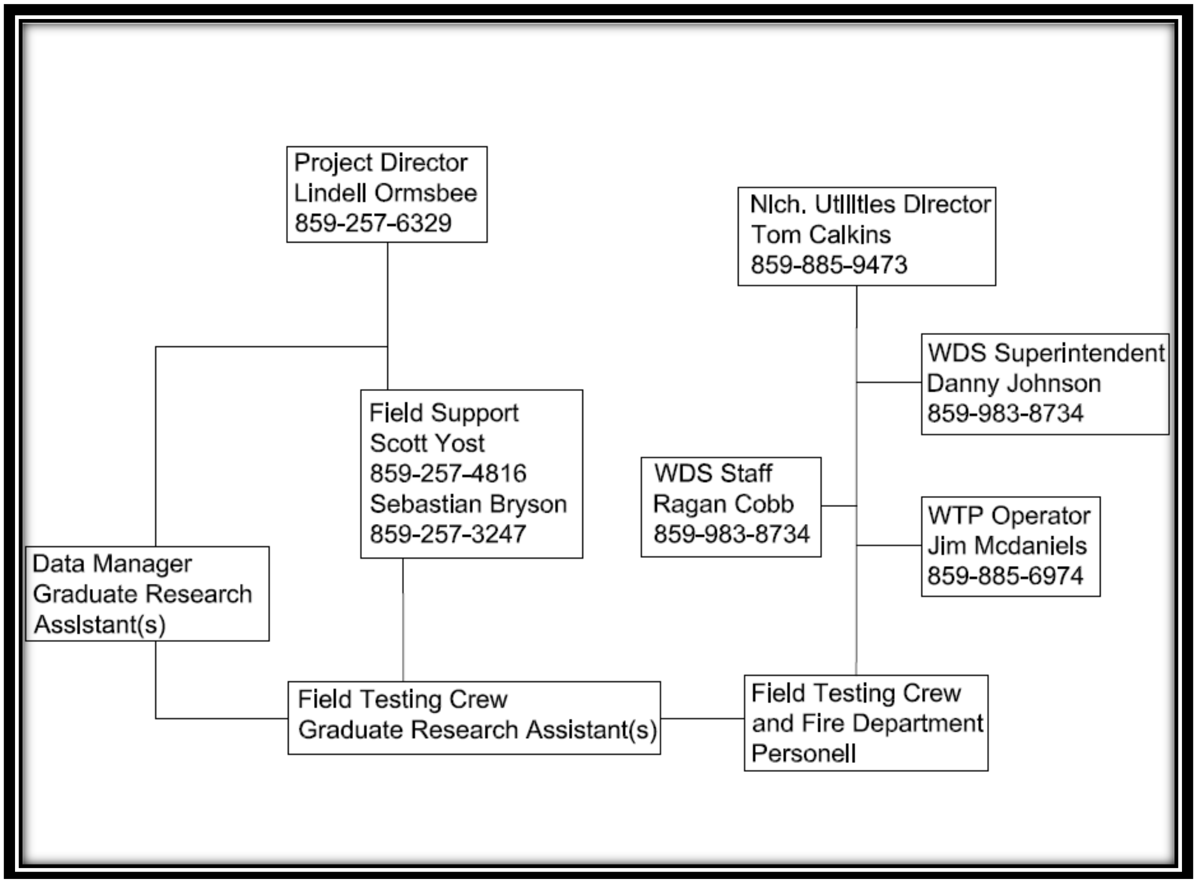

Figure 1 Project Organization Chart

2.0 Problem Definition and Background

2.1 Project Background

The United States Department of Homeland Security (DHS) has established 18 sectors of infrastructure and resource areas that comprise a network of critical physical, cyber, and human assets. One of these sectors is the water sector. The Water Sector Research and development working group has stated that water utilities would benefit from a clearer and more consistent understanding of their system flow dynamics. Understanding flow dynamics is important to interpreting water quality measurements and to inform basic operational decision making of the water utility. Such capabilities are critical for utilities to be able to identify when a possible attack has occurred as well as knowing how to respond in the event of such an attack. This research will seek to better understand the impact of water distribution system flow dynamics in addressing such issues.

In particular this project will: (1) test the efficiency and resiliency of the real-time hydraulic/water quality model using stored Supervisory Control and Data Acquisition (SCADA) data in order to understand the potential accuracy of such models, and understand the relationship between observed water quality changes and network flow dynamics, and (2) develop a toolkit for use by water utilities to select the appropriate level of operational tools in support of their operation needs. The toolkit is expected to have the following functionality: (a) a graphical flow dynamic model, (b) guidance with regard to hydraulic sensor placement, and (c) guidance with regard to the appropriate level of technology needed to support their operational needs.

Primary objectives of this project include:

1. Develop an improved understanding about the impact of flow dynamics changes on distribution system water quality, and the potential benefits of using real-time network models to improve operational decisions – including detection and response to potential contamination events.
2. Develop an operational guidance toolkit for use by utilities in selecting the appropriate level of operational tools needed to support their operational needs.
3. Develop a flow distribution model that will allow small utilities to build a basic graphical schematic of their water distribution system from existing geographical information system (GIS) datasets and to evaluate the distribution of flows across the network in response to basic operational decisions.

This project has been broken down into 12 different project tasks as shown in Table 1. The associated project deliverables are shown in Table 2. This Water Quality Calibration Report addresses Task 6 of the project which is defined as “develop and calibrate hydraulic and water quality computer models.”

Table 1 Summary of Project Tasks

Task #	Project Task
1	Establishment of an Advisory Group
2	Select Water Utility Partner
3	Survey and Evaluate SCADA Systems
4	Build Laboratory Scale Hydraulic Model of Selected Water Distribution System
5	Develop Graphical Flow Distribution Model
6	Develop and Calibrate Hydraulic and Water Quality Computer Models
7	Quantify Flow and Water Quality Dynamics Through Real-Time Modeling
8	Develop Sensor Placement Guidance
9	Develop Toolkit
10	Test and Evaluate Toolkit
11	Validate Toolkit
12	Write Report

2.2 Problem Definition

The objective of Task 6 of the overall project is to create a calibrated hydraulic and water quality model for the City of Nicholasville, Kentucky. Previous work has been performed on the Nicholasville system to create a hydraulic model. This report will discuss some of the procedures and results of a tracer study that was conducted to assists with the creation of a water quality computer model for the City of Nicholasville.

This report will document the data collected during the tracer study as well as the travel times of fluoride throughout the system. This report will document the results of the measurements collected in the field compared to the model predictions. This report will address additional calibration steps to the hydraulic model and present recommendations for future water quality calibrations.

2.3 Water Distribution System Description

The City of Nicholasville is located in Jessamine County, Kentucky, southwest of the City of Lexington. The population was 28,015 for the 2010 census making it the 12th largest city in the state. According to the U.S. census bureau, the city has a total area of 8.5 square miles which is serviced by the Nicholasville Water Treatment Plant. The Nicholasville Water Treatment Plant is supplied by surface water from Pool 8 of the Kentucky River. The treatment facility is a conventional turbidity removal plant that utilizes chemical coagulation, flocculation, settling and filtration to remove suspended particles from the raw water (See Figure 2). The water distribution plant has a capacity of 9 million gallons per day (MGD). In 2010 the average day demand was approximately 4.4 MGD. Plant operations are monitored and controlled by a computer based Supervisory Control and Data Acquisition (SCADA) system. The SCADA system monitors and controls pumps, chemical feeds, treatment equipment, flow rates, water levels, etc.

Figure 2 Nicholasville Water Treatment Plant

The Nicholasville water distribution system consists of an intake pumping facility, a water treatment plant, a high service pumping facility, and transmission and distribution systems. The treatment plant serves approximately 10,500 retail customers and two wholesale customers. The treated water transmission and distribution system consists of a grid of mains ranging from 2 to 24 inches in diameter and has a total elevated storage of 3 million gallons (3 Tanks). (Nicholasville, 2009-2011) The topography of the area varies from a maximum elevation of ~1042 feet to a minimum elevation of ~560 feet. A schematic of the distribution system is shown in Figure 3.

The distribution system model contains approximately 278.8 miles of pipeline. PVC pipes make up the majority of the material of the pipes in the system followed by asbestos cement and cast iron. This system would best be defined as a branched system. The interior and downtown section of the city is looped but as you move out into the rural areas it becomes a branched system.

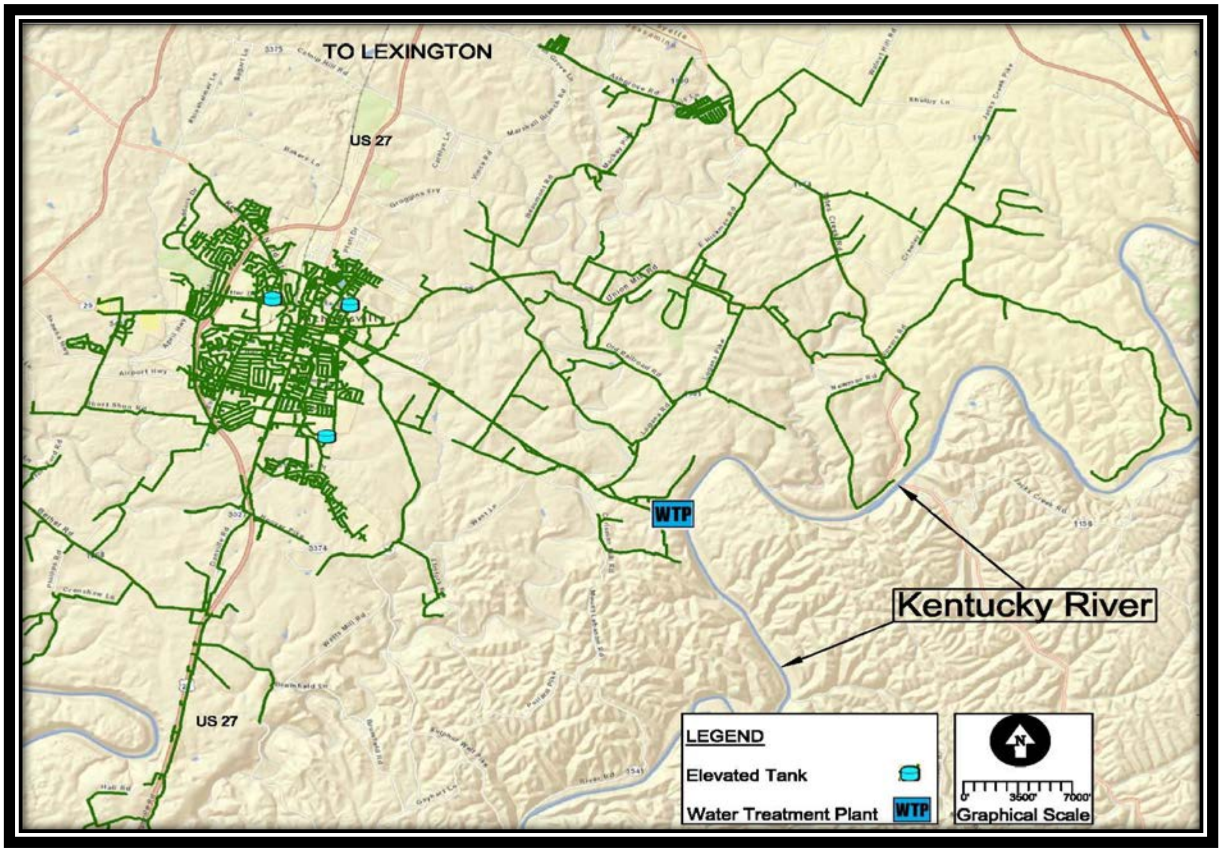

Figure 3 Schematic of Nicholasville Water Distribution System

2.4 Present Day Operations

The Water Treatment Plant (WTP) is located at an elevation of approximately 870 feet msl. The distribution system contains three elevated storage tanks as shown in Figure 3 and summarized in Table 2. When demand causes water levels in these tanks to drop below a minimum water-level mark, high service pumps are turned on at the Nicholasville WTP.

The SCADA system at the Nicholasville WTP provides real time data for pumping operations as well as tank levels, pump flows and pump pressures. This data will be obtained during field testing through communication with the Nicholasville Water Department and will be utilized to help calibrate the hydraulic model.

Table 2 Elevated Storage Tank Identification and Elevations

Elevated Storage Tank Identification, and Elevations*			
Name	Lake Street	Capital Court	Stephens Drive
Size (gallons)	750,000	1,500,000	750,000
Elevation of Bottom of the Tank	1025.75	952.5	966.5
Minimum Level (ft)	1105.75	1111.5	1109.5
Max Level (ft)	1143.75	1151	1148
Shape	Ovaloid	Composite	Ovaloid
Inside Diamter (ft)	60 ft	86 ft	68 ft
*Data from Nicholasville Water Utility Department			

At the Nicholasville WTP, raw water is pumped from the river into a chemical mix basin. Once it has passed through the chemical mix basin it continues through a series of flocculation basins to the settling basins. After the treatment process of coagulation and sedimentation, the clarified water flows into dual media filter beds to remove any remaining solids. After filtration, fluoride is added to the treated water to help improve dental hygiene. Prior to pumping the water into the distribution system, the water is disinfected with chloramines.

Continuous water quality testing is performed at the Nicholasville WTP. Water is tested for turbidity, alkalinity, hardness, iron, manganese, fluoride, pH, corrosiveness and disinfectant residual (Nicholasville, 2009-2011). In February 2011, the monthly average of flouride concentration of samples measured at the tap was .92 milligrams per liter (mg/L). In the 2011 Annual Water Quality report the range for fluoride detection was .74 mg/L to 1.19 mg/L (McDaniel, 2010).

2.5 Prior Hydraulic Model Calibration

In 2011, work was performed to create and calibrate a hydraulic model of the Nicholasville system. The hydraulic model was calibrated by performing a series of C-factor and fire flow tests. The performance of the hydraulic model was verified by performing a series of 24-hour extended period simulations (EPS) to measure the tank levels in the model compared to the corresponding SCADA data. For more information regarding the hydraulic calibration see the previous report entitled “Water Distribution System Calibration Report.” (Ormsbee L. , 2012)

3.0 Tracer Studies

A tracer study is a method for observing and measuring the time it takes for water or an associated chemical to travel through a water distribution system. This information can then be used to further adjust pipe roughness coefficients or calibrate the decay coefficients associated with model chemical constituents (e.g. chlorine). The tracer chemical that was chosen for this experiment was fluoride. Fluoride, a conservative chemical (i.e. one that does not readily decay over time) is monitored leaving the water supply at the water treatment plant and the resulting concentrations are then measured at specific points in the water distribution system in order to determine the transient time from the water treatment plant to the point of interest. By comparing the observed transient time with the time predicted by the computer model, model parameters can then be adjusted (or calibrated) until the predicted and observed travel times and associated constituent concentrations are equivalent. Additional details on procedures for conducting a tracer study are described in Clark et al. (2004). Field data was collected at predetermined locations within the system by grab sampling.

3.1 Selection of Tracer: Fluoride

Fluoride is also a conservative chemical which will not easily decay over time. Fluoride can also be stored in glass or plastic bottle for at least 7 days when cooled at 39º F without decay. From a logistics perspective this was essential to have a compound that would not decay from the time a sample was collected in the field to the time when the sample could be analyzed in the lab.

The Nicholasville water distribution system currently uses fluoride in its water distribution system. The fluoride is injected via a peristaltic pump which is controlled by a computer system at the Nicholasville water treatment plant. The computer system allows the user to determine the concentration of fluoride to be introduced into the system. During the tracer test the pump can be turned off until the background fluoride concentration can be obtained. Once this concentration has been obtained the peristaltic pump can be turned back on and will pump the user designated fluoride concentration into the system. To assure the public's health and safety, an upper limit fluoride concentration for the tracer study will be set at 1.2 mg/L. This value falls within the range (.7 mg/L to 1.2 mg/L) for the U.S. Public Health Services "optimal level" fluoride content in drinking water and below the maximum contaminant level goal of 4 mg/L and a secondary maximum contaminant level of 2 mg/L. (Lowes, 2011)

Fluoride is also a conservative chemical which will not easily decay over time. Fluoride can also be stored in glass or plastic bottle for at least 7 days when cooled at 39º F without decay. From a logistics perspective this was essential to have a compound that would not decay from the time a sample was collected in the field to the time when the sample could be analyzed in the lab.

3.2 Field Collections Methods: Grab Sampling

Grab samples can be obtained from several locations in the water distribution system. Different types of sampling locations include fire hydrants, storage tanks, pumping stations, commercial buildings, public buildings and private residences. For this study all of the chosen sampling sites were located at hydrants or blow off valves. These locations were selected based upon the application of the sample and the accessibility of the site.

Each hydrant was equipped with a gate valve and was set to flow at a constant rate of 2 gpm throughout the data collection process. This ensured that the water that was being sampled was a representative of the main and not from buildup of water collected in the hydrant lines. Figure 4 below shows a setup of one of the sampling locations.

Figure 4 Hydrant Setup

3.3 Tracer Study Testing Locations

The sampling locations for the tracer study were chosen based upon several factors. These factors include:

- Geographical distribution throughout the system. Sample sites were spread out among the distribution system.
- Previous or anticipated water quality data and knowledge of the flow regimes through the existing system.
- All sampling locations are either hydrants or blow offs which allowed for 24 hour access to each sampling location.
- Sampling sites located along the main flow path were given priority which also served the purpose of fine tuning the calibration of the hydraulic model.
- Sampling sites were generally chosen in areas of high typical demand. Areas of low water usage may affect the quality of the sample due to lack of water circulation. However, areas with large commercial users such as a golf course may impact the study events. (EPA, 2005)
- Proximity to tanks and water treatment plant. Some sampling sites were specifically chosen to measure the inflow and outflow lines of tanks.

Twelve (12) sampling locations were chosen. The hydraulic model was utilized to determine the adequacy of each sampling location. Table 3 gives a brief description of why each site was chosen for the Tracer study. Figure 5 displays the locations of all 12 sampling sites.

Table 3 Testing Locations Descriptions

Site ID	Description of Site
WQ1	This site is located directly off the inflow to the Capital Court Tank
WQ2	This site is located near the Stephens Drive Tank
WQ3	This site is located near the outflow of the Lake Street Tank
WQ4	This site is located near the inflow of the Lake Street Tank
WQ5	This site is located to the South of the Capital Court tank. This site is located in a residential neighborhood directly downstream from an Industrial Park.
WQ6	This site is located downtown. This site is located off of the large transmission main the delivers water directly from the WTP.
WQ7	This site is located directly off the large 20" transmission main at the entrance to a residential neighborhood.
WQ8	This site is located in a residential neighborhood. The hydraulic model indicates this area is fed from water that has passed through downtown.
WQ9	This site is located in a residential neighborhood in the far northwest. This location was choosen to get a good distribution of the entire system.
WQ10	This site is located in the far west. This site was chosen to give a good distribution of the entire system.
WQ11	This site is located in the far east. This site is located in a rural area and was chosen to give an idea about the maximum time it takes the tracer to travel through the entire system.
WQ12	This site is located in the far south. This site is located in a rural area and was chosen to give an idea about the maximum time it takes the tracer to travel through the entire system.

Figure 5 Water Quality Site Locations

3.4. Test Equipment/Special Personnel Training

Equipment utilized for the tracer study enabled the gathering of data for the water quality calibration. Listed below is a description of the monitoring equipment that was used to perform the tracer study. See Appendix A for a complete list as well as photos of all equipment to be used.

3.4.1 Continuous Pressure Recorder

Tank levels can be measured via a Pollard continuous pressure recorder (see Figure F.3 in Appendix F). The continuous pressure recorder was placed on a hydrant near a specified location and recorded pressures every 10 seconds. The data was then extracted via cables and a flash drive onto a computer and stored for further use. The continuous pressure recorder was also be used in other applications similar to the hydrant static pressure gauge.

3.4.2 Hach Fluoride Pocket Colorimeter II Testing Kit

The Hach Fluoride Pocket Colorimeter II is designed to go anywhere and is suitable for extended field work or quick on the spot process monitoring. The colorimeter uses the AccuVac method or the SPADNS method for determining the fluoride concentration of a sample. Both these methods are EPA approved. For this study the AccuVac method was used. Once a 250 ml grab sample has been obtained, 50 mL is needed for the AccuVac method. Once the test were performed using the colorimeter, the fluoride concentration appears on the screen in mg/L.

3.4.3 Gate Valves

Gate valve can be applied to individual hydrants and opened or closed as needed to help collect field grab samples. Since grab sampling occurred at hydrants, it is important to obtain the water quality sample from the transmission main and not from the water collected near the hydrant. To help improve sampling, the gate valve can be opened so water is allowed to flow. This will ensure the sample collected is representative of the water distribution system.

3.4.4 Grab Sampling Bottles

250 mL plastic bottles will be used for collecting grab samples of the tracer's concentration. The 250 mL plastic bottles will be provided by the lab at UK.

4.0 Test Procedures and Measurements

4.1 Data Collection

Data was collected from a variety of sources. SCADA data was collected throughout the tracer study to record tank levels and pump flows. In addition to recording tank levels from SCADA, a continuous recording pressure gauge was placed in the field to record additional pressures in the field. Fluoride concentrations were measured throughout the distribution system through grab sampling and the concentrations were measured as they entered the WTP. Measurements were taken two different times. When the fluoride was turned off at the WTP, fluoride measurements were taken. These measurements will be referred to as “Step Down” measurements. The actual tracer measurements when fluoride is turned up will be referred to as “Step Up” measurements.

4.2 “Step Down” Fluoride Measurements

The staff at the Nicholasville WTP was instructed to measure fluoride concentration levels of the finished water immediately after it had entered the distribution system from the high service pumps. Due to the layout of the Nicholasville WTP the fluoride was injected right before it entered the clear wells. There were 6 different clear wells that the fluoride could be mixed in before it entered the distribution system. Due to the complexity of modeling this particular treatment facility, it was determined that the best way to collect data would be to directly measured the fluoride as it leaves the high service pumps instead of attempting to model the injection concentration and mixing of the clear wells. Figure 6 schematic shows the complex configuration of the Water Treatment Plant.

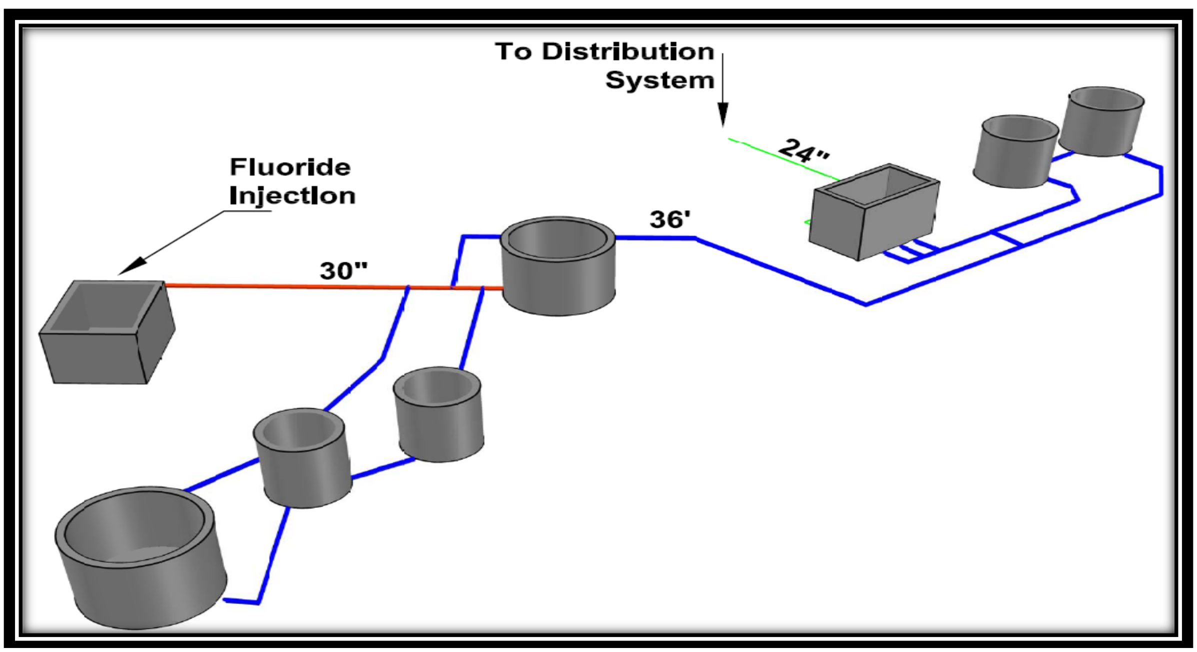

Figure 6 Water Treatment Plant Schematic

4.2.1 WTP Measurements During "Step Down"

For planning and scheduling purposes it was essential to know how quickly the fluoride concentration leaving the station would increase or decrease. Due to the amount of clear wells it would have been hard to model exact mixing within the water treatment plant. In order to accurately predict how much the fluoride concentration would increase during the tracer study, measurements were taken when the fluoride was shut off. On July 11th 2012 the fluoride was turned off at the water treatment plant and the decrease in fluoride concentration was measured over time. These measurements gave a general idea of the time frame for mixing within the clear wells. The raw water pump rate and the high service pump rate were recorded as well to help estimate residence times within the clear wells. These measurements were also put in place to record the background fluoride levels in the raw water. For this particular week the background fluoride levels were approximately 0.2 mg/L. Table 4 below displays this data for the step down fluoride measurements.

Table 4 "Step Down" Fluoride Measurements

Date	Time	Fluoride Measurement (mg/L)	Temp (F°)	Pump Rate of Raw Water Pumps (gpm)	Pump Rate of High Service Flows (gpm)
7/11/2012	8:00*	0.94	85	4778	4500
7/11/2012	8:00	0.93	85	4778	4500
7/11/2012	8:15	0.94	85	4778	4500
7/11/2012	8:30	0.97	85	0	4500
7/11/2012	8:45	0.92	85	0	4500
7/11/2012	9:00	0.97	85	0	3340
7/11/2012	9:30	0.93	85	4812	3341
7/11/2012	10:00	0.8	85	4812	3341
7/11/2012	10:30	0.93	85	4800	3341
7/11/2012	11:00	0.96	85	4800	3341
7/11/2012	11:30	0.81	85	4800	3341
7/11/2012	12:00	0.88	85	4788	3341
7/11/2012	13:00	0.76	85	4780	3341
7/11/2012	14:00	0.58	84	4780	4477
7/11/2012	15:00	0.29	84	4780	4560
7/11/2012	16:00	0.4	85	4780	4560
7/11/2012	18:00	0.36	85	4780	4560
7/11/2012	23:15	0.19	85	4780	4510
7/12/2012	8:30	0.2	N/A	4780	0
7/12/2012	10:45	0.21	85	0	0
7/12/2012	12:00	0.21	N/A	4000	0
7/12/2012	16:00	0.21	N/A	N/A	3300
7/13/2012	10:00	0.21	N/A	N/A	N/A
7/14/2012	10:45	0.25	85	N/A	N/A

*Measurement taken before fluoride was shut off

4.2.2 Field Measurements During “Step Down”

Field measurements were also taken while the “Step Down” fluoride measurements were occurring (7-11-2012). These field measurements were taken at all 12 water quality testing sites. This preliminary field testing served many purposes. One purpose was to train personnel on procedure and to familiarize everyone with the location of each site. It was also a time to teach all personnel about the proper techniques for obtaining a representative sample. Equipment was installed on each hydrant and was tested for operability.

Once each hydrant was setup and the crews had been instructed on procedure, a trial run of the tracer study was performed. This trial run was used to help simulate the events of a the actual tracer study but this occurred while the fluoride was being turned down. Previous work had been performed using the hydraulic model to help predict the decrease in the fluoride concentrations throughout the distribution system. This trial run was also used to assess the accuracy of this initial modeling effort. Unfortunately the time for fluoride to decrease throughout the system was drastically under predicted and a decrease in fluoride was not measured during the first few hours of testing.

A second day (7-12-2012) was set aside to again go out and test each site to see if a significant drop in fluoride could be measured for each site. This was necessary to identify sites that may provide bad data during the actual tracer study due to unforeseen circumstances such as pipes with flow reversals. This pre-testing was beneficial in a sense that it allowed for several problems to be identified so that fine tuning of sampling times could be adjusted as well as improved logistics for the entire process. Table 5 below shows the fluoride concentrations (in mg/L) taken at each sites during these first two days of preliminary testing.

Table 5 "Step Down" Fluoride Field Measurements

Date	Time	WQ 1	WQ 2	WQ 3	WQ 4	WQ 5	WQ 6	WQ 7	WQ 8	WQ 9	WQ 10	WQ 11	WQ 12
7/11/2012	8:00	WTP Turns Off Fluoride and Begins Sampling Fluoride Concentrations											
7/11/2012	10:30											0.95	
7/11/2012	11:00	1.08	1.07	1.04	1.06	1.08	1.11	1.03	1.05		1.02		
7/11/2012	11:30		1.06	1.04	1.1		1.05			1.05	1.14		
7/11/2012	12:00		0.78	1.08		1.09	1.11	1.05	1.06			1.08	
7/11/2012	12:30												1.1
7/11/2012	13:00												
7/11/2012	13:30												
7/11/2012	14:00	1.09	1.04	1.1	1.11	1.11	1.11	1.03	1.07				
7/12/2012	2:00												
7/12/2012	2:15						0.79						
7/12/2012	2:30			0.98	0.88				0.77				
7/12/2012	2:45		0.84			0.62		0.8					
7/12/2012	3:00									0.72		0.97	
7/12/2012	3:15	0.88									0.46		1.04

4.3 "Step Up" Fluoride Testing

After analyzing data from the "Step Down" fluoride testing along with other factors such as expected weather, estimated demand, and new model predictions, a new schedule for field testing was created. This "Step Up" testing is considered to be the tracer study.

4.3.1 WTP Measurements During "Step Up"

At 8:00 PM on 7-16-2012 the fluoride was turned back on at the WTP and sampling commenced. The WTP took fluoride samples every half hour, recorded the temperature of the water, and recorded the flowrates of both the raw water pumps and high service pumps. Table 6 and Table 7 shows the results of the fluoride measurements taken from the WTP.

During the Fluoride testing an equipment malfunction occurred causing the concentration at the WTP to drop instead of increase. It was determined that this caused the fluoride to drop after the hours of 15:00. At this time however the fluoride had already been injected into the distribution system and a decrease in injection concentration would have little effect on concentrations that were being measured at the sampling sites.

Table 6 Fluoride Measurements at WTP

Nicholasville Fluoride Turned On Measurements					
Date	Time	Fluoride Measurement (mg/L)	Temp (F◦)	Pump Rate of Raw Water Pumps (gpm)	Pump Rate of High Service Flows (gpm)
7/16/2012	20:00*	0.17	83	4143	4518
7/16/2012	20:00	0.18	83	4131	4505
7/16/2012	20:30	0.15	83	4118	4474
7/16/2012	21:00	0.24	83	4143	4476
7/16/2012	21:30	0.16	83	4130	4508
7/16/2012	22:00	0.13	83	4140	4488
7/16/2012	22:30	0.15	83	4173	4460
7/16/2012	23:00	0.31	83	4169	4472
7/16/2012	23:30	0.46	83	4147	4462
7/17/2012	0:00	0.61	83	4135	4432
7/17/2012	0:30	0.73	83	4134	4413
7/17/2012	1:00	0.73	83	4133	4416
7/17/2012	1:30	0.75	83	4129	4418
7/17/2012	2:00	0.83	83	4140	4433
7/17/2012	2:30	0.69	83	4138	4384
7/17/2012	3:00	0.87	83	4131	4385
*Measurement taken before Fluoride turned on					

Table 7 Fluoride Measurements at WTP

Nicholasville Fluoride Turned On Measurements					
Date	Time	Fluoride Measurement (mg/L)	Temp (F◦)	Pump Rate of Raw Water Pumps (gpm)	Pump Rate of High Service Flows (gpm)
7/17/2012	3:30	0.77	83	4138	4363
7/17/2012	4:00	0.83	83	4133	4390
7/17/2012	4:30	0.9	83	4138	4384
7/17/2012	5:00	0.79	83	4145	4371
7/17/2012	5:30	0.75	83	4146	4355
7/17/2012	6:00	0.79	83	4127	4362
7/17/2012	6:30	0.82	83	4150	3210
7/17/2012	7:00	0.8	83	4138	3252
7/17/2012	7:30	0.88	83	4126	3239
7/17/2012	8:00	0.9	83	4133	3247
7/17/2012	8:30	0.92	83	4136	3249
7/17/2012	9:00	0.97	83	4130	3273
7/17/2012	9:30	0.84	83	4145	3280
7/17/2012	10:00	0.82	83	4132	3276
7/17/2012	10:30	0.88	83	4120	3265
7/17/2012	11:00	0.84	83	4127	3225
7/17/2012	12:00	0.92	83	4114	3233
7/17/2012	13:00	0.9	83	4134	3228
7/17/2012	14:00	0.96	83	4125	3247
7/17/2012	15:00	0.87	83	4120	3237
7/17/2012	16:00	0.81	83	4114	3261
7/17/2012	16:45	0.77	83	4113	3296
7/17/2012	17:00	0.78	83	4131	3297
7/17/2012	17:30	0.73	83	4123	3271
7/17/2012	18:00	0.76	83	4138	3274
7/17/2012	18:30	0.75	83	4126	3276
7/17/2012	19:00	0.7	83	4115	4500
7/17/2012	19:30	0.78	83	4124	4511
7/17/2012	20:00	0.69	83	4121	4518
7/17/2012	20:30	0.74	83	4155	4498
7/17/2012	21:00	0.72	83	4115	4501
7/17/2012	21:30	0.83	83	3314	4477
7/17/2012	22:00	0.81	83	3315	4436
7/17/2012	22:30	0.8	83	3326	3250
7/17/2012	23:00	0.87	83	3250	3258
7/18/2012	0:00	0.88	83	3318	3243
7/18/2012	1:00	N/A	83	N/A	3234
7/18/2012	2:00	0.83	83	N/A	3231
7/18/2012	3:00	0.85	83	N/A	3227
7/18/2012	4:00	0.9	83	N/A	3221
7/18/2012	5:00	1.01	83	N/A	3224
7/18/2012	6:00	1.1	83	N/A	3232
7/18/2012	7:00	N/A	83	N/A	3237
7/18/2012	8:00	N/A	83	N/A	3238
7/18/2012	9:00	0.99	83	N/A	3241

4.3.2 Field Measurements During "Step Up"

Field measurements were taken at each sampling location. All grab samples were returned to City Hall where a field lab was stationed to test a portion of the sample using the field fluoride colorimeters. These field measurements were utilized to keep track of where the fluoride was moving and help to determine if more sampling was needed or if a particular site no longer needed to be tested. Once samples were tested in the field they were all placed in coolers and transported back to the ERTL lab located at the University of Kentucky. Once the samples were received at the ERTL lab where all of the fluoride concentrations were measured within the next couple of days. Table 8 and 9 shown below display the results from the analysis performed at the ERTL lab.

Table 8 Results of Field Measurements

Date	Actual Time	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9	WQ10	WQ11	WQ12
7/17/2012	8:30	0.77	0.22	0.67	0.62		0.74						
7/17/2012	9:00	0.75	0.19	0.70	0.70	0.25	0.75						0.24
7/17/2012	9:30	0.71	0.20	0.69	0.70		0.77	0.63	0.23				
7/17/2012	10:00	0.75	0.18	0.71	0.70	0.46	0.80	0.62	0.22			0.23	
7/17/2012	10:30	0.77	0.18	0.65	0.71		0.80			0.16	0.14		
7/17/2012	11:00	0.77	0.18	0.64	0.71	0.61	0.80	0.65	0.23				
7/17/2012	11:30	0.78	0.18	0.64	0.72		0.79			0.15	0.14		0.22
7/17/2012	12:00	0.79	0.18	0.67	0.73	0.67	0.79	0.64	0.28				
7/17/2012	12:30	0.79	0.17	0.66	0.73	0.65	0.77	0.71		0.16	0.23		
7/17/2012	13:00	0.81	0.18	0.66	0.75	0.70	0.74	0.69	0.31				0.23
7/17/2012	13:30	0.80	0.18	0.65	0.75	0.70	0.77	0.69		0.13	0.44		
7/17/2012	14:00	0.82	0.17	0.73	0.76	0.69		0.72	0.35			0.21	
7/17/2012	14:30		0.17	0.70	0.76	0.71		0.76	0.34				
7/17/2012	15:00		0.17	0.67	0.77	0.71		0.75	0.39		0.61		
7/17/2012	15:30		0.16	0.72	0.76	0.72		0.76	0.42	0.13	0.63		0.21
7/17/2012	16:00		0.18	0.75	0.77	0.71		0.75	0.44		0.65	0.26	
7/17/2012	16:30		0.18	0.69	0.78	0.73		0.76	0.47		0.64		
7/17/2012	17:00		0.17	0.66	0.77	0.73			0.50	0.13	0.60		
7/17/2012	17:30		0.20	0.62	0.75	0.74			0.51		0.63		
7/17/2012	18:00		0.25						0.51		0.62		
7/17/2012	18:30								0.54		0.64		
7/17/2012	19:00								0.59	0.27	0.62		
7/17/2012	19:30								0.60		0.66		0.21
7/17/2012	20:00								0.58	0.33	0.70	0.28	
7/17/2012	20:30								0.64	0.40	0.73		
7/17/2012	21:00								0.65	0.45			
7/17/2012	21:30									0.50			
7/17/2012	22:00									0.56		0.36	
7/17/2012	22:30									0.55			
7/17/2012	23:00									0.59			
7/17/2012	23:30									0.64			
7/18/2012	0:00									0.64			

Table 9 Results of Field Measurements - Continued

Date	Actual Time	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9	WQ10	WQ11	WQ12
7/18/2012	0:30											0.42	
7/18/2012	1:00												
7/18/2012	1:30												
7/18/2012	2:00												
7/18/2012	2:30												
7/18/2012	3:00												
7/18/2012	3:30												
7/18/2012	4:00												
7/18/2012	4:30												
7/18/2012	5:00												
7/18/2012	5:30												
7/18/2012	6:00												
7/18/2012	6:30									0.74		0.46	
7/18/2012	7:00												0.33
7/18/2012	7:30												
7/18/2012	8:00											0.47	0.39
7/18/2012	8:30												
7/18/2012	9:00												0.45
7/18/2012	9:30												0.46
7/18/2012	10:00											0.52	0.47
7/18/2012	10:30												
7/18/2012	11:00												
7/18/2012	11:30												
7/18/2012	12:00												
7/18/2012	12:30											0.55	0.50
7/18/2012	13:00											0.56	
7/18/2012	13:30												
7/18/2012	14:00												
7/18/2012	14:30											0.57	
7/18/2012	15:00												0.52
7/18/2012	15:30											0.58	0.53
7/18/2012	16:00												
7/18/2012	16:30												
7/18/2012	17:00												0.55

5.0 Results

To verify the results of the water quality model, an extended period simulation of the entire tracer study was run and compared to SCADA data from the WTP. Additionally a continuous pressure recorder's measurements were compared with modeled results to check the hydraulics of the system. Once the hydraulics of the system was verified, a water quality simulation was performed. Results were then analyzed to compare the field measurements of fluoride concentrations to those measured using the model. The results were analyzed and a refinement of the model parameters was performed. Sections 5.1 through 5.3 contain the results and some of the calibration techniques of the calibrated water quality model.

5.1 Extended Period Simulation

An extended period simulation of the water quality model was run first to check to see if the model was hydraulically accurate. This was performed by comparing the tank levels of the model to the SCADA data collected at the WTP. The results are shown in Figure 7. All tank levels of the model were within ± 3 feet of the SCADA data which was deemed acceptable based on the sensitivity of the SCADA system and approximations in the geometry of the modeled tanks.

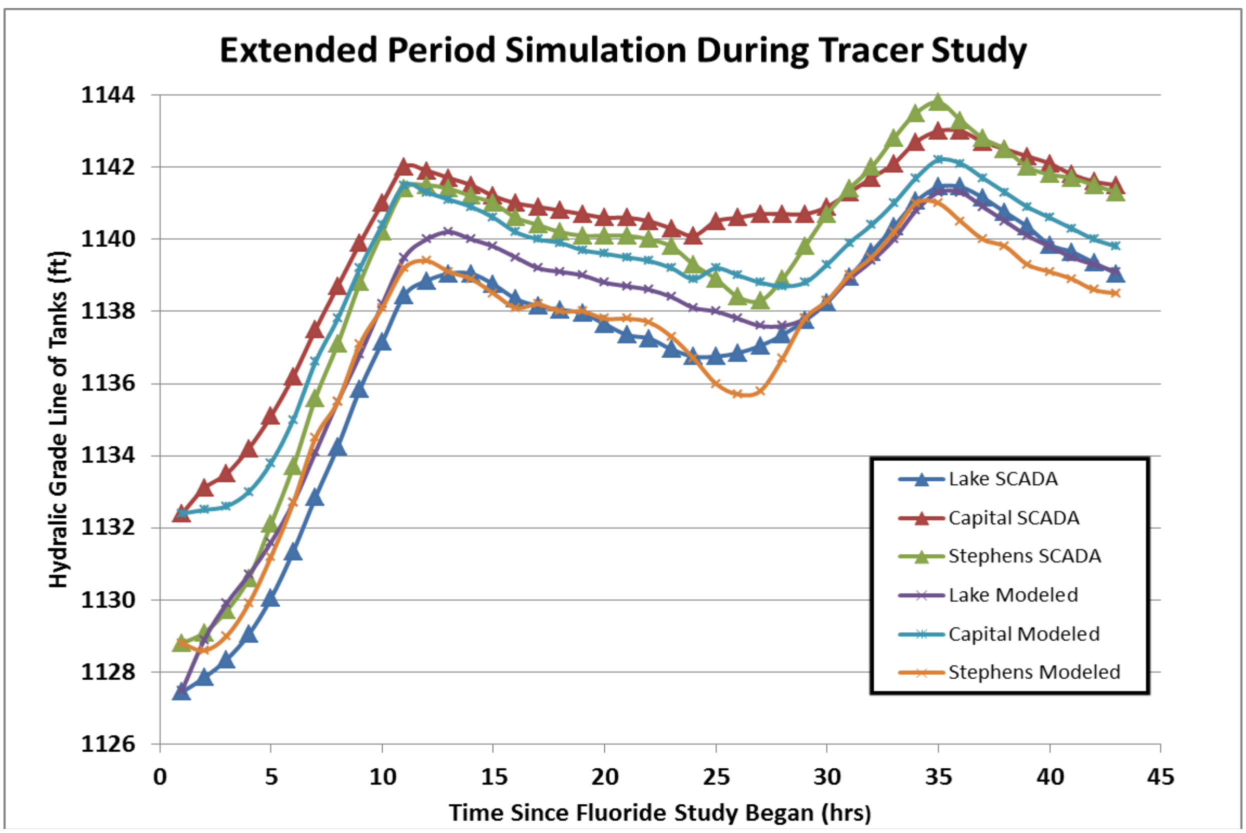

Figure 7 Extended Period Simulation During Tracer Study

5.2 Continuous Digital Pressure Gauge

To further improve model calibration, data from a continuous digital pressure gauge was placed in a key area in the distribution system. This gauge was placed directly off a 20 inch transmission line. The corresponding field pressure measurements were compared with the modeled pressure data. The total variation from the digital pressure gauge and the modeled pressure was approximately 2 psi. This difference is within the error of the digital pressure gauge. Previous calibration work performed on this particular gauge showed that it under predicted pressures by ~1 psi. The results are shown in Figure 8.

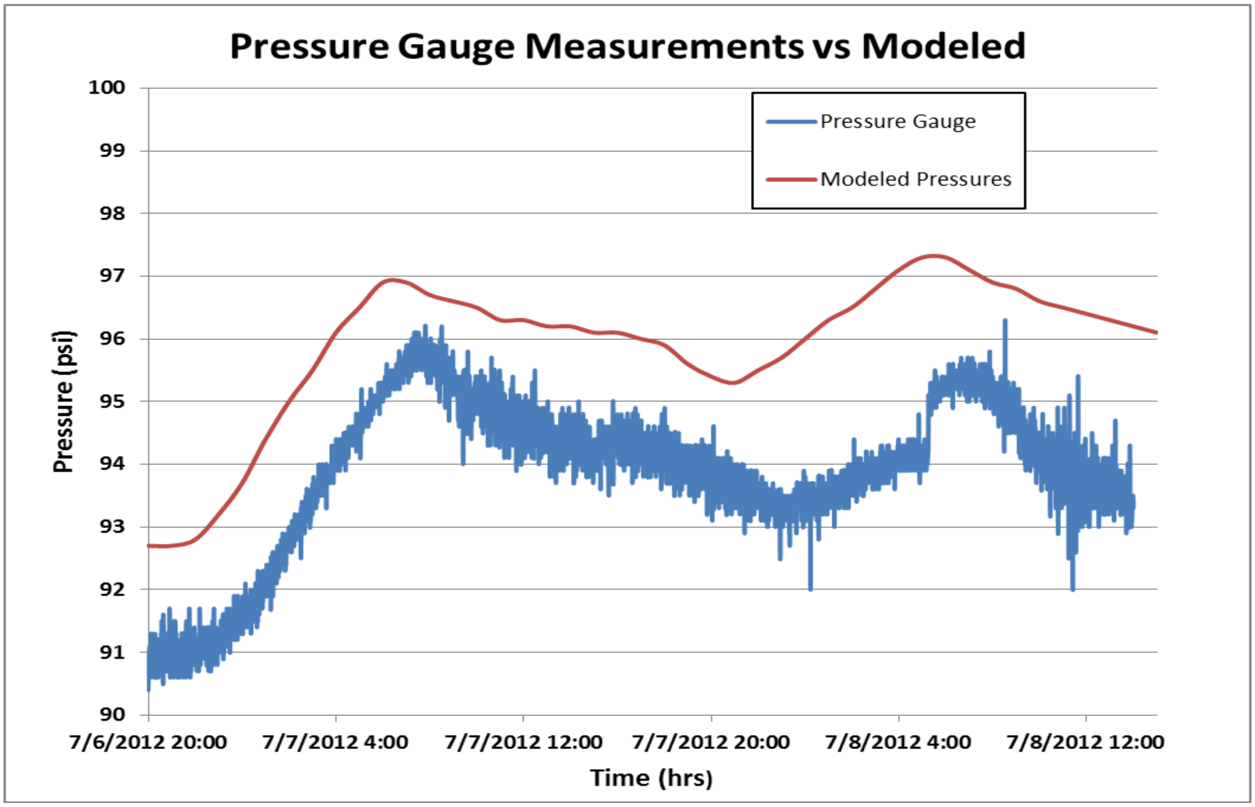

Figure 8 Pressure Gauge Measurements vs. Modeled

5.3 Discussion of Results: Field Measurements vs Modeled Results

Overall the original hydraulic model did an adequate job of predicting the modeled fluoride concentrations throughout the system. Some of the changes to the model are described below as well as some explanations for variations in site 2, 8, 11 and 12.

One of the main aspects of the calibration was adjusting the C-Factor of a large 20 inch ductile iron transmission line. This line had originally been given a Hazen Williams C-Factor of approximately 115. This C-factor was assigned to the entire 20 inch line. Upon further investigation this line has undergone three different construction phases beginning in 1991, 1994 and in 2005. For the new areas of the 20 inch line a C-Factor of approximately 140 was assigned. This change in the C-factor was verified by measuring tank levels and comparing the data with the pressure collected from the digital pressure gauge.

During the calibration of the water quality model it was discovered that several of the pipes in the system were disconnected. These discrepancies were easily spotted by following the fluoride concentration throughout the model and locating where the concentrations would stop. These disconnections had previously gone unnoticed during the hydraulic calibration because they did not have a significant impact on the hydraulics of the system.

In addition to the connectivity issues, demand reallocation was performed near site 12. This site is located in the rural area of the system and had not been given a great deal of detail when demand was previously placed in this area. All the demand for this area had been clumped into a few locations instead of distributed evenly throughout the area. Further investigation showed that the metering information for this area was underrepresented and that a greater water demand existed in this area than had been previously modeled.

Site 10 was also a location where demand reallocation occurred. This situation was unique. Demand allocation occurring near site 12 was changed in the model, whereas site 10 presented a onetime situation. Site 10 is also near the edge of the system. In this area there was a line break and one large customer had used an exceptionally high amount of water during the tracer study. After confirming with billing records, a large demand was placed in this area to aid with the calibration of the water quality model. Since this situation was unique, its affects were only changed during the calibration and not in the final water quality model presented to the City of Nicholasville.

Site 2 offered its own set of problems. This site was placed off of a large 12 inch line near the Stephen’s Drive Tank. During field testing there wasn’t any notable increase in fluoride concentrations. Due to these observations during the actual field testing, spur of the moment testing was conducted on nearby hydrants. These hydrants were located on parallel lines and on downstream lines. The results from these hydrants indicate that the fluoride was increasing near the tank. This data led investigators to suspect that the water in the distribution system was passing through a parallel 20 inch line instead of the 12 inch line, making site 2 basically a dead zone. Other issues that were associated with this site were flow reversals. The model indicated that this site had several flow reversals throughout the study which may have prevented fluoride mixing.

Other errors that existed in the model occurred at sampling sites that were located in low demand or primarily residential areas. Sites 11 and 12 were low demand residential areas and sites 8, 9 were primarily located in the heart of residential areas.

These sites appear to have a more gradual increase in fluoride concentration than what the model predicted. This error in the modeling could be a result of the demand patterns. Unique demand patterns were not given to distinguish between industrial, commercial and residential areas; there was only a single demand pattern for the entire system. It is possible that the demand pattern for residential areas was smaller/larger at times compared to the system demand pattern. This would account for the gradual increase in fluoride as opposed to a sudden spike in the concentration. Sites located near industrial and commercial areas had fewer errors between the field sampling and what the model predicted.

Site 1 was located near the capital court tank and the modeled results are fairly accurate at this location. Site 3 and 4 were located near the Lake Street tank. There was a little bit of fluctuation within the tank but for the most part the model results resemble the field results. Site 5, 6 and 7 were located close to the large 20 inch transmission mains. These sites provide the greatest correlation between the modeled results and the measured results. To view the comparison of modeled versus measured results see Figures 9 - 20.

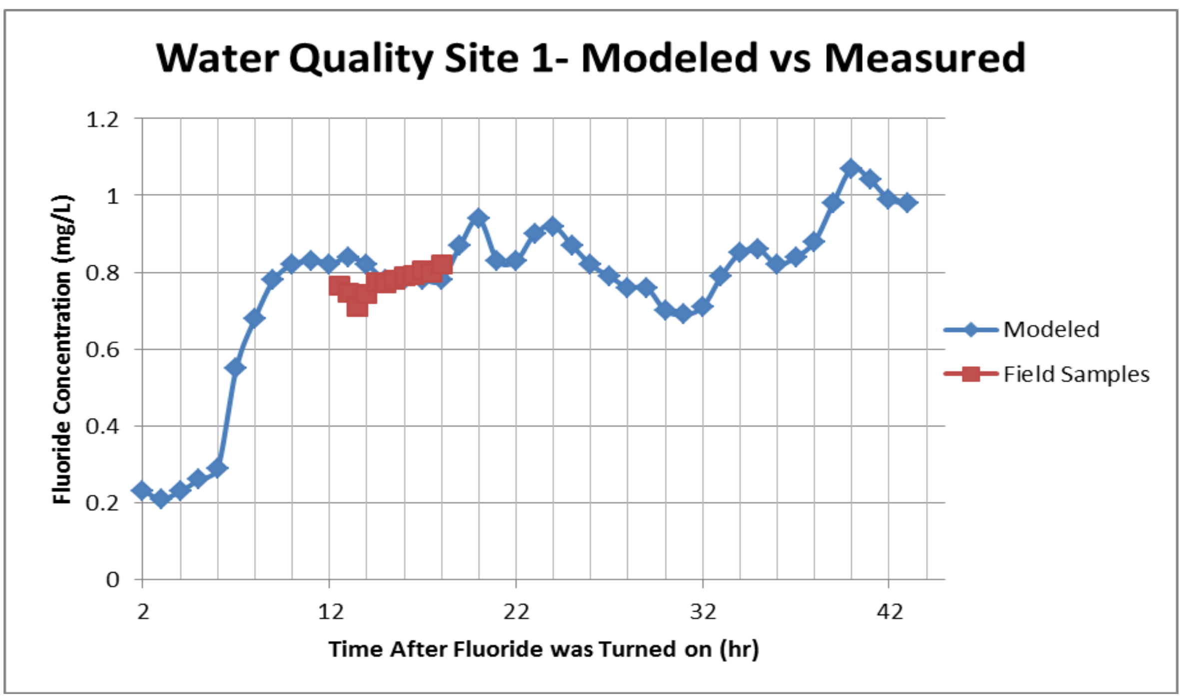

Figure 9 Water Quality Site 1 - Modeled vs Measured

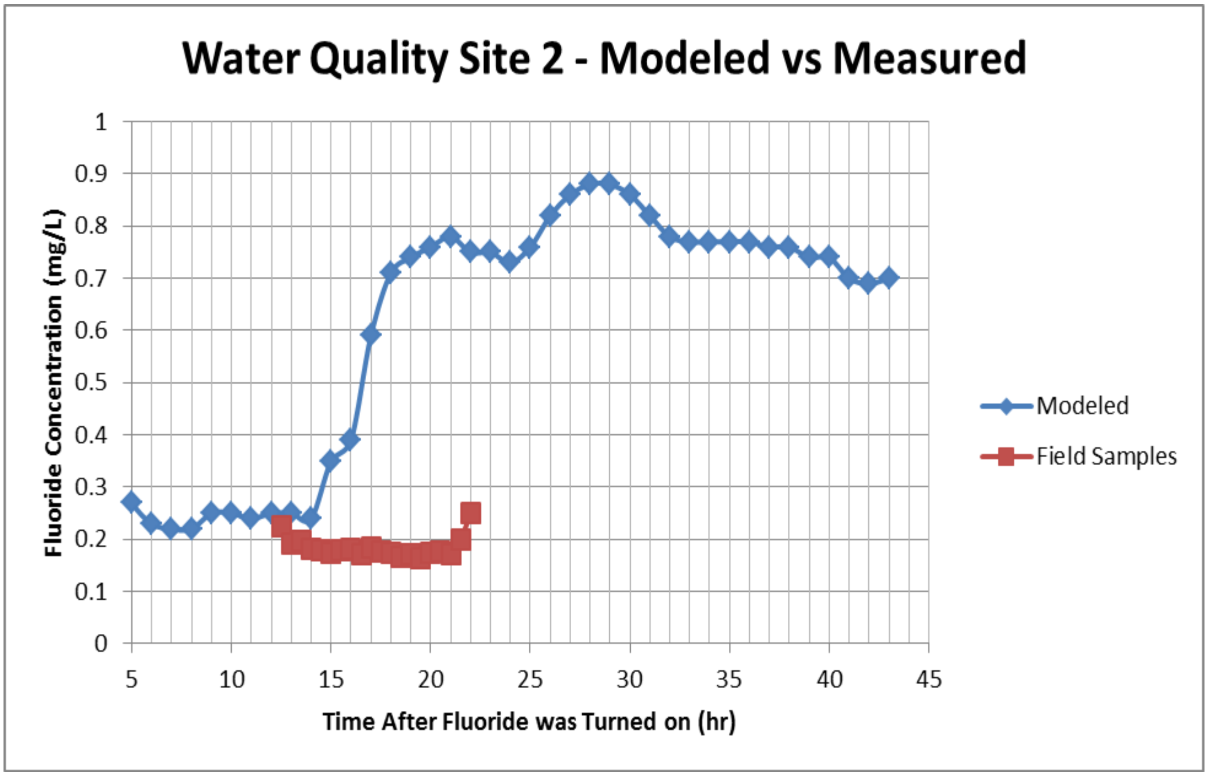

Figure 10 Water Quality Site 2 - Modeled vs Measured

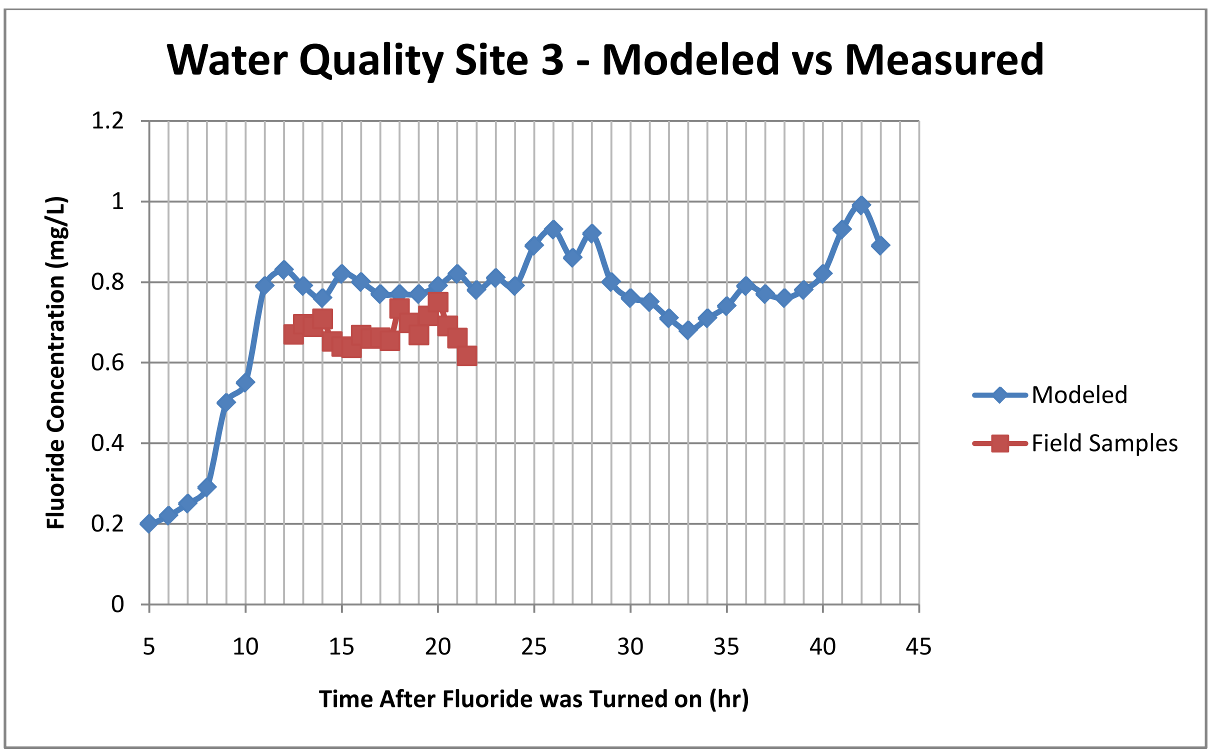

Figure 11 Water Quality Site 3 - Modeled vs Measured

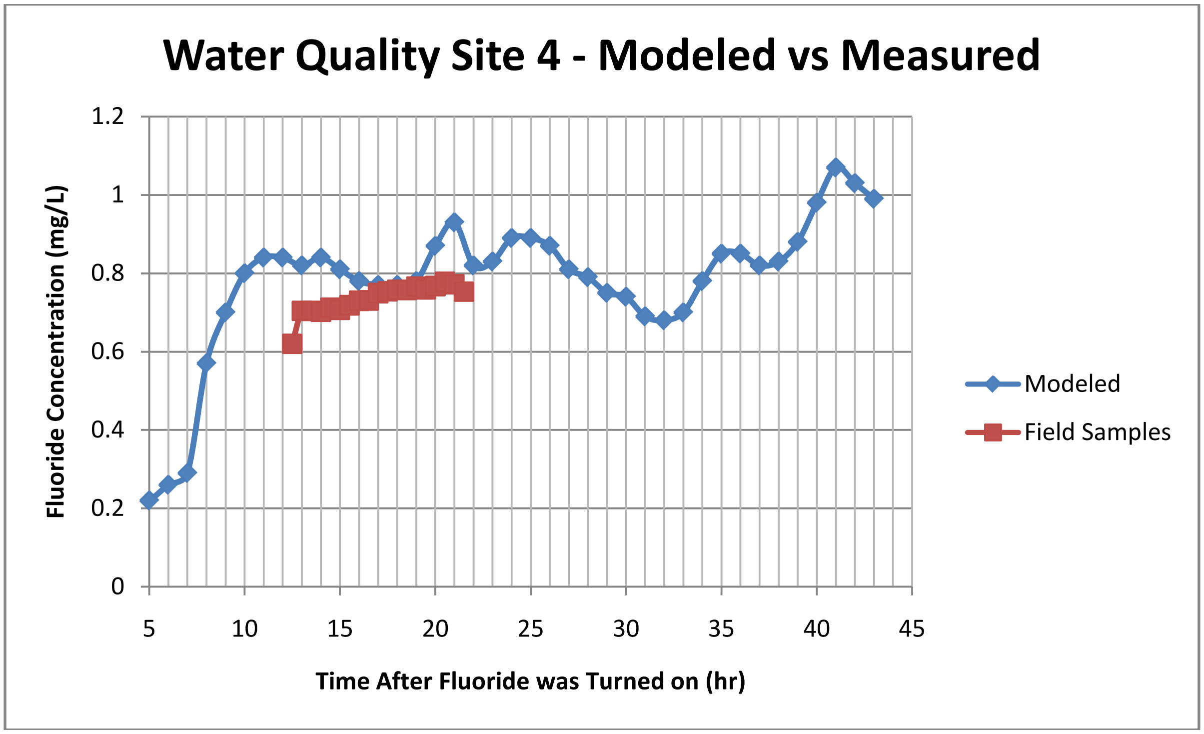

Figure 12 Water Quality Site 4 - Modeled vs Measured

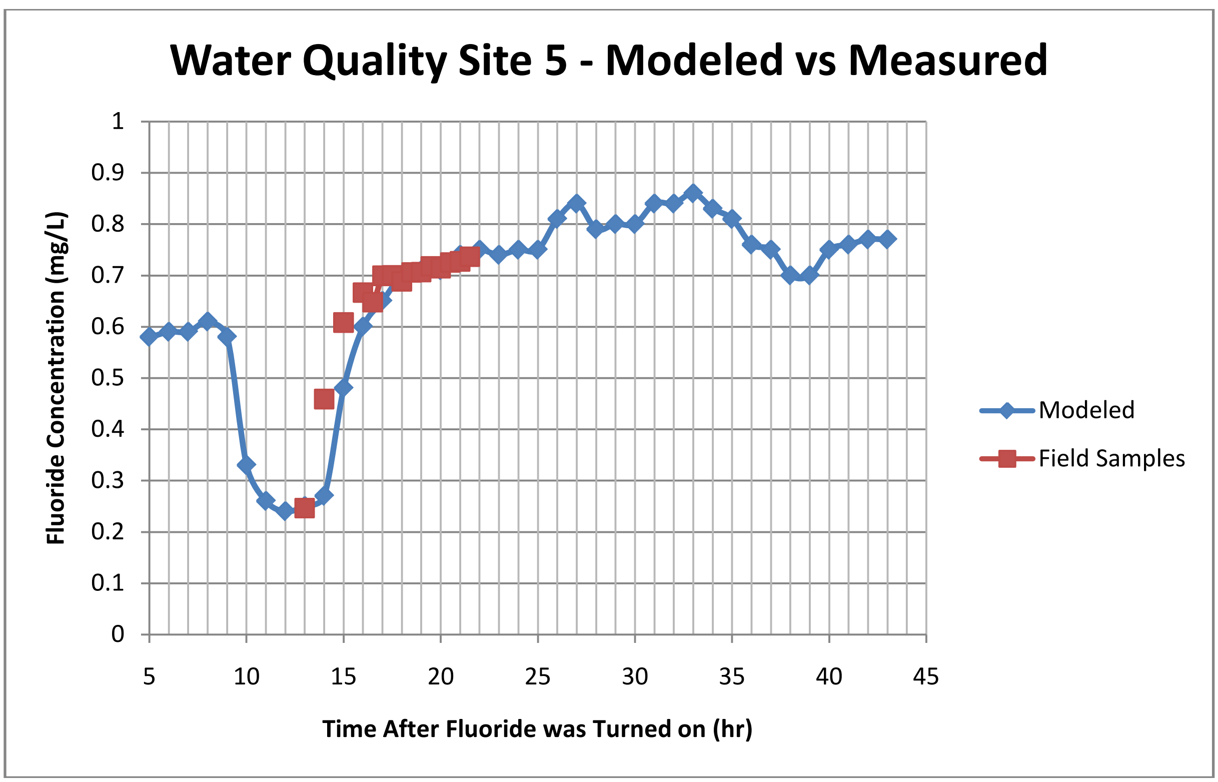

Figure 13 Water Quality Site 5 - Modeled vs Measured

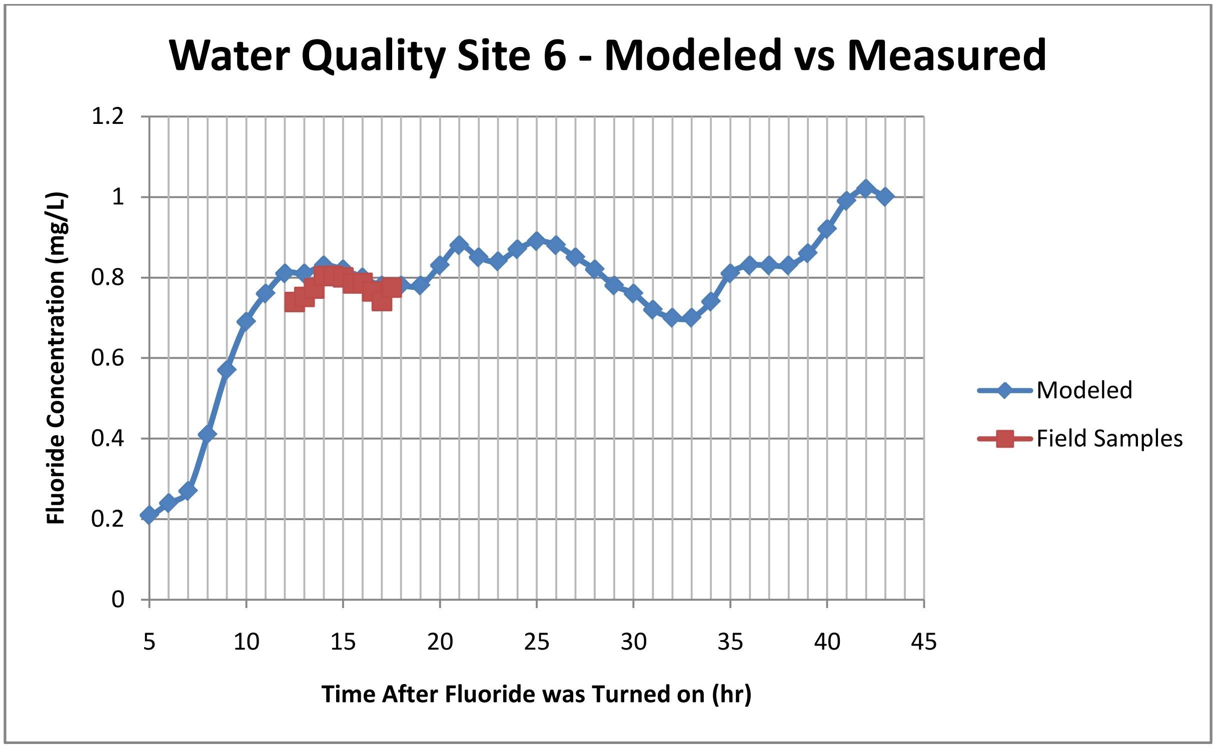

Figure 14 Water Quality Site 6 - Modeled vs Measured

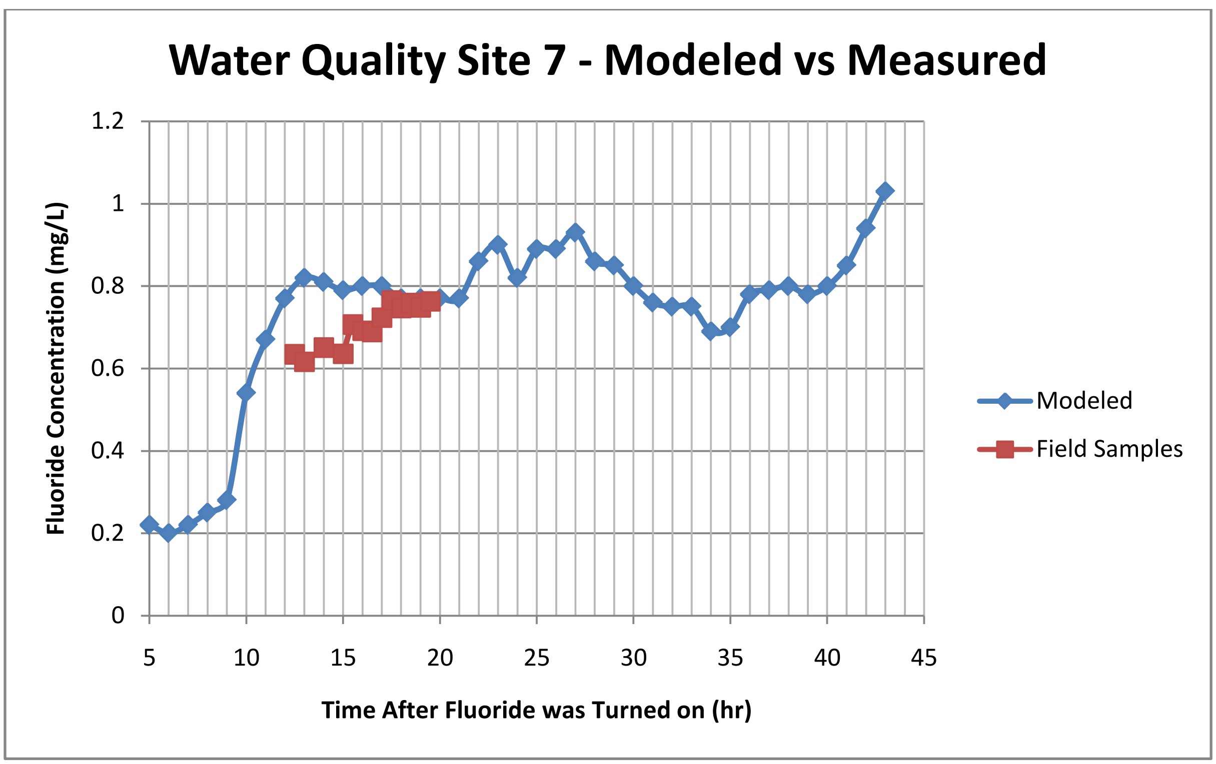

Figure 15 Water Quality Site 7 - Modeled vs Measured

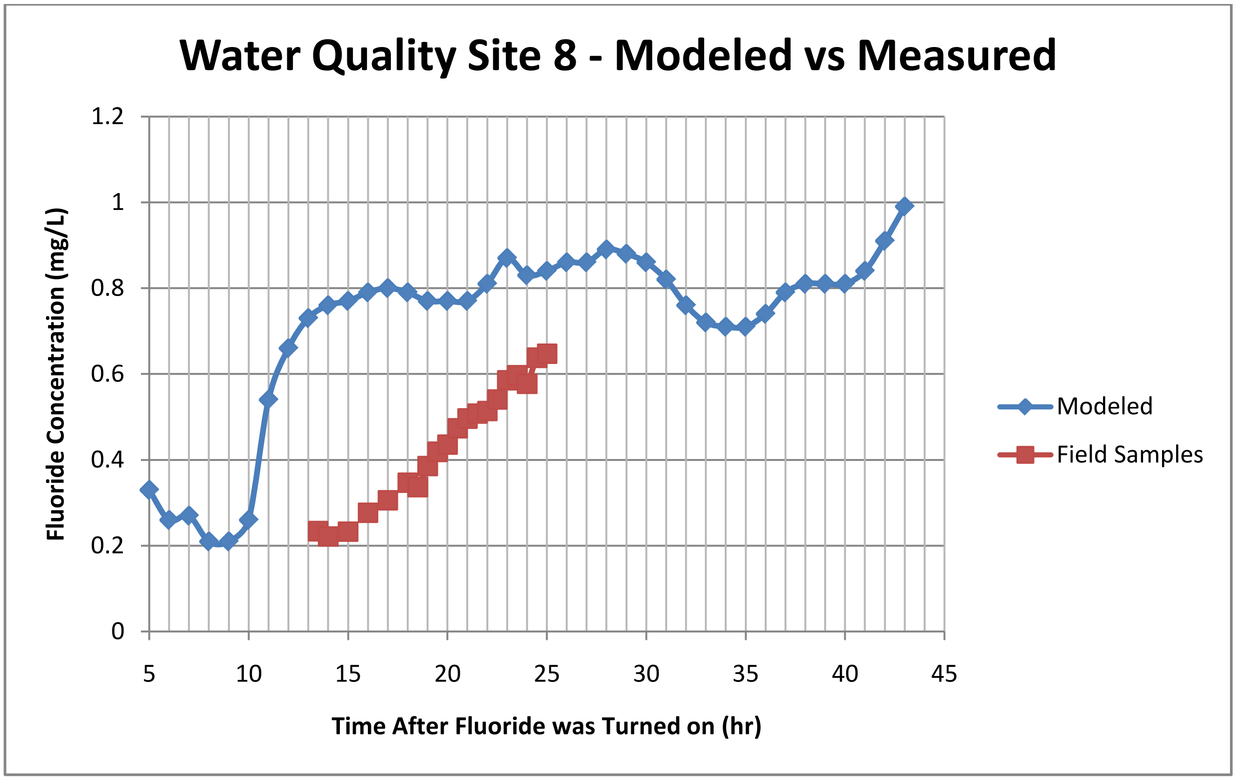

Figure 16 Water Quality Site 8 - Modeled vs Measured

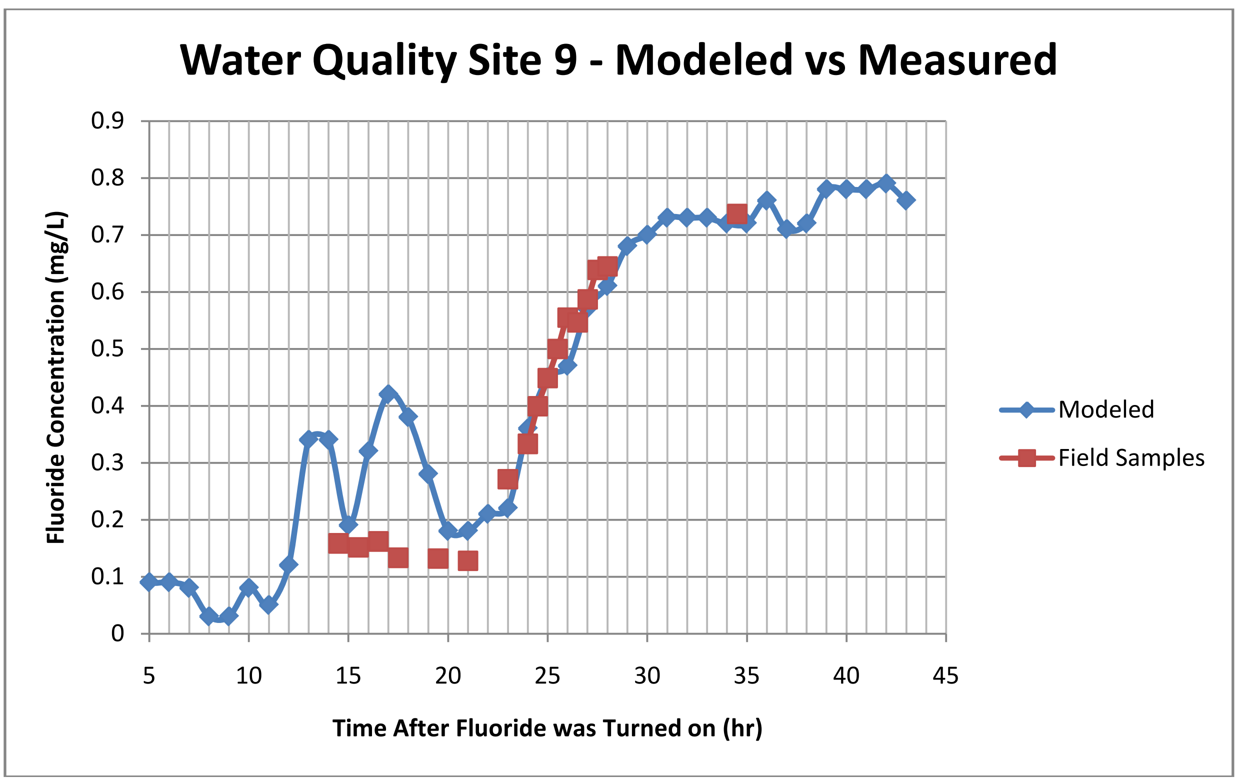

Figure 17 Water Quality Site 9 - Modeled vs Measured

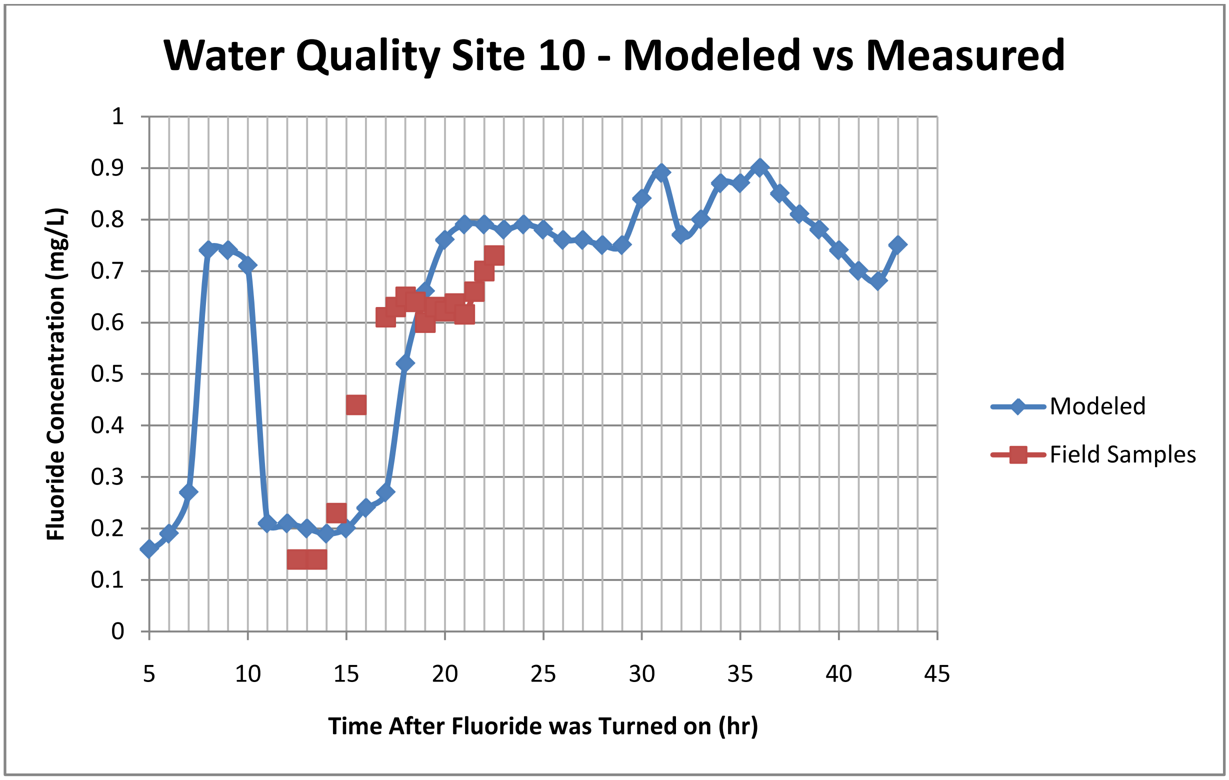

Figure 18 Water Quality Site 10 - Modeled vs Measured

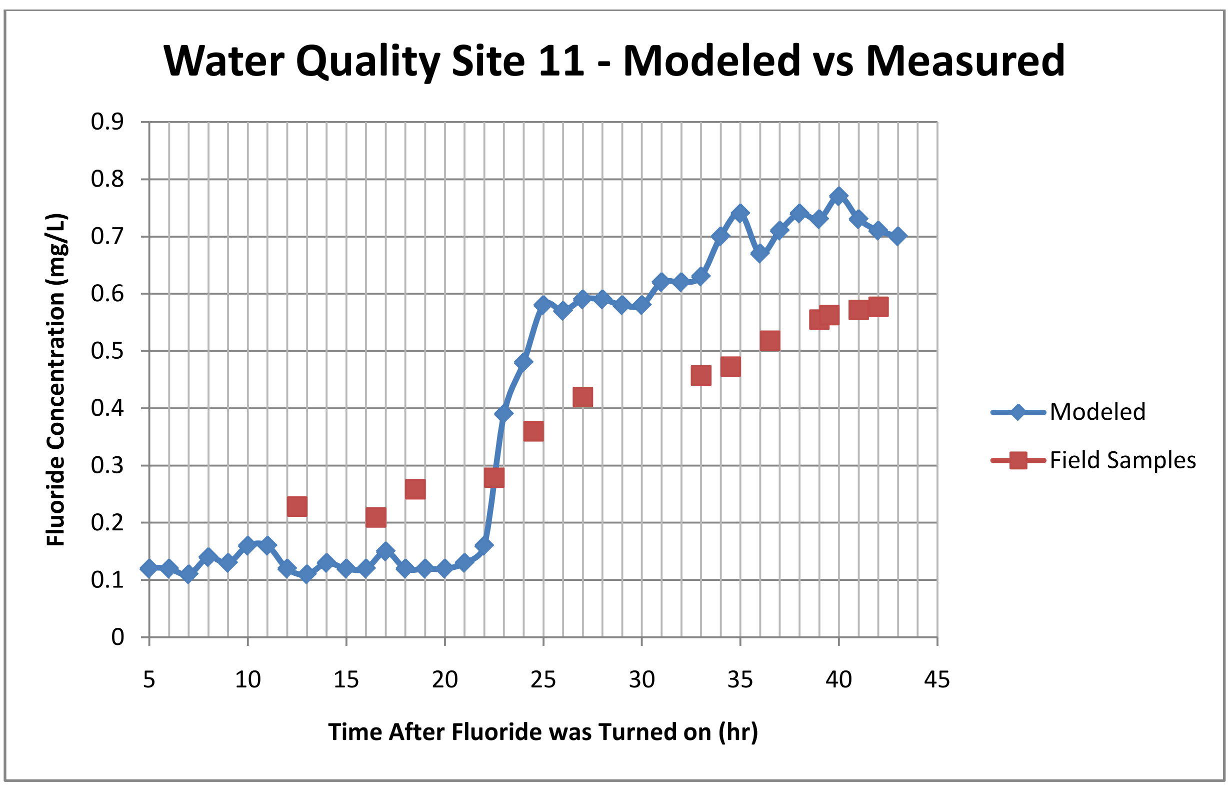

Figure 19 Water Quality Site 11 - Modeled vs Measured

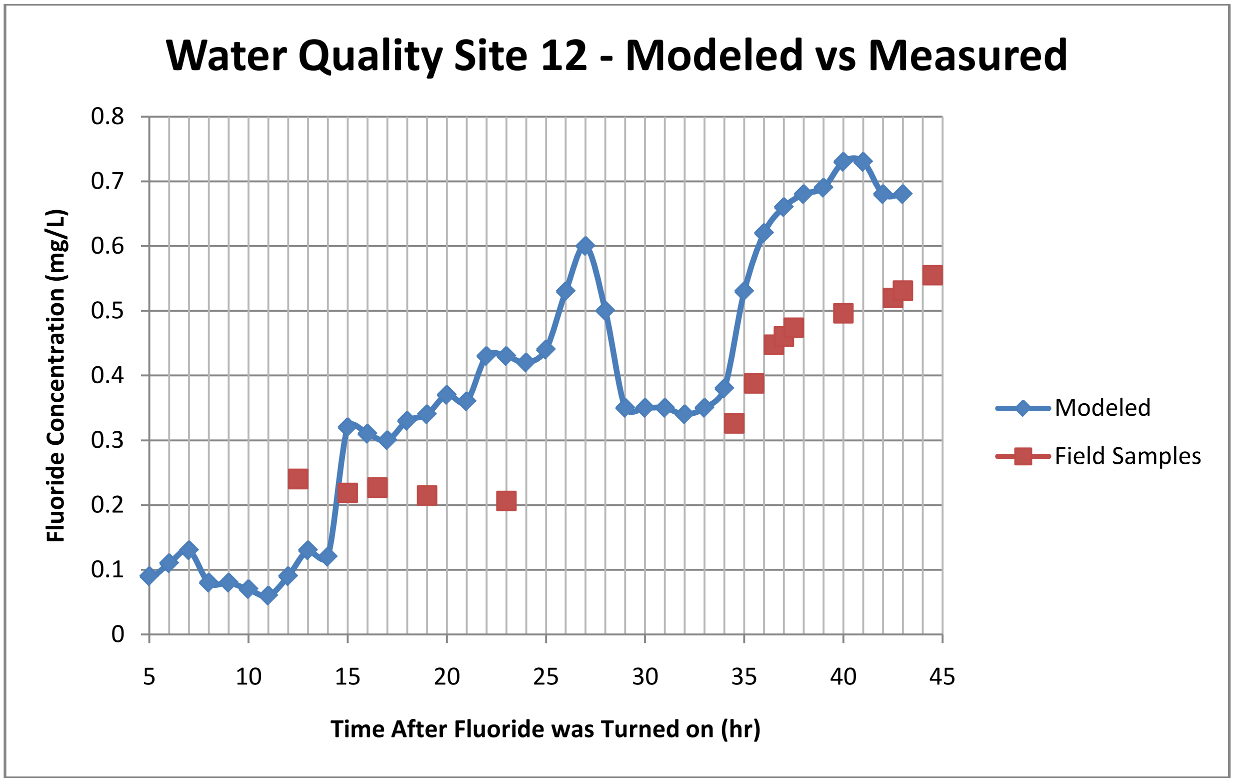

Figure 20 Water Quality Site 12 - Modeled vs Measured

5.4 Recommendations for Further Fluoride Tracer Studies

With any study there are both good and bad aspects. This section will identify lessons learned as well as suggests improvement for future fluoride tracer studies.

Some issues in regards to the tracer study could have been avoided with a more thorough analysis of the "Step Down" sampling. One instance is in the case of Site 2. This location provided bad data for the study but this could have been prevented if greater attention had been given to the results of the pre-sampling program. The results of the pre-sampling at this site indicated the fluoride had not dropped as much as expected but this was overlooked when finalizing the test sites. During the final analysis of this site, the model showed flow reversal in this area. Closer attention should have been given to this site to address this issue.

Other obstacles that went undiscovered was the inaccuracy of the field fluoride colorimeter. The field fluoride colorimeter was calibrated using a standard 1.0 mg/L solution. Despite several calibrations of the hand held device, measurements taken by the colorimeter differed greatly from measurements conducted in the lab. Some issues that could cause the fluoride colorimeters to drift were the temperature and the turbidity of the sample. In some instances the field samples were off by as much as 0.3 mg/L. Additional calibration should have been performed to test the accuracy of the field colorimeter against the lab samples as opposed to only calibration by the standard 1.0 mg/L solution. Tank mixing also created a lot of concerns with the modeling. Precise measurements were needed to accurately reflect the tank mixing in the water quality model. For two of the tanks both the inflow and outflow of the tanks were monitored. For one tank there was only one site that was used to monitor the tank. By monitoring the inflow and outflow of every tank, the total cost and time of the study was increased. The additional accuracy you received from the inflow and outflow line was extremely beneficial. The SCADA data for each tank allowed you to estimate the hydraulics of the actual inflow and outflow of each tank. Therefore if you monitored the corresponding concentrations of fluoride at these locations you get an accurate measure of how the tanks were mixing or lack thereof. In this particular study, monitoring the inflow and outflow of the two tanks did not improve the accuracy of the model and only served to verify that the tank mixing was modeled correctly.

It was a also a good idea to perform the “pre” sampling approach when the fluoride was being turned down to help predict what would happen during the actual tracer study. The pre-sampling approach was able to spot anomalies in the system such as the mixing properties of the tanks and clear wells. Since the “pre” sampling occurred a week before the actual tracer study it was a pretty good indication of what could be expected from an operations perspective and demand components of the water treatment plant and the water distribution system as a whole. Originally when the calibration of the model was being performed data had been collected during the months of October, November and some in May. Seasonal changes could have significant effect on the modeling and prediction thus “pre” sampling helped to spot some of these major changes. It also allowed for improvements in organization and the overall tracer study project. During the “pre” sampling you were able to see what works and what didn’t work and had time to brainstorm alternative solution or better practices. For example site 12 was moved down one hydrant to place it on a line with larger demand as opposed to it being placed on a primarily dead line.

6.0 Summary and Conclusions

As part of a contract between the University of Kentucky and the National Institute of Hometown Security (i.e. OTA #HSHQDC-07-3-00005, Subcontract #02-10-UK). As part of this contract, UK researchers have developed and calibrated a hydraulic model of the Nicholasville, Kentucky water distribution system. The calibrated hydraulic and water quality model will assist with the development of an improved understanding about the impact of flow dynamics changes on distribution system water quality, and the potential benefits of using real-time network models to improve operational decisions – including detection and response to potential contamination events. This study presents results for a fluoride tracer study that was used to verify and improve the calibration of the hydraulic model for the Nicholasville system.

The overall calibration of the system is considered a success. From a hydraulics perspective, the modeled tank and pressure measurements are within ± 1.5 psi of what was observed. The variation in the fluoride concentrations between what was modeled and what was measured is fairly accurate for the majority of customers within the system. The error between what was modeled versus measured is relatively small for the sites located within the city limits. The results don't appear to deviate much until you get out into the outer regions in the distribution system which can be attributed to several different factors. The model accurately models tank mixing and can give a good indication of travel times of the fluoride concentration within the distribution system.

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