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**ESTIMATED COMPLIANCE WITH THE PROPOSED STAGE 2
DISINFECTION BY-PRODUCTS RULE FOR ELEVEN WATER UTILITIES IN
NORTH CAROLINA**

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ABSTRACT

Estimated Compliance with the Proposed Stage 2 Disinfection By-Products Rule for Eleven Water Utilities in North Carolina

Eleven water utilities in North Carolina were examined to assess their potential compliance with the impending Stage 2 Disinfection By-Products (DBP) Rule. The Stage 2 Rule will require that all utilities meet the 80 µg/L maximum contaminant level (MCL) for four trihalomethanes (THM4) and the 60 µg/L MCL for five haloacetic acids (HAA5) on a locational running annual average (LRAA) basis. This represents a major departure from past DBP regulation for which compliance was based on a system-wide running annual average (RAA). Additionally, while compliance has previously been based on DBP levels for samples collected primarily at locations with average distribution system residence times, the Stage 2 Rule will base compliance on DBP levels collected at locations with maximum THM4 and HAA5 concentrations.

To assess potential compliance with the proposed Rule, it was necessary to estimate maximum THM4 and HAA5 concentrations in the distribution systems for each utility using historical quarterly THM4 and HAA5 values. The approach taken was to use the USEPA Water Treatment Plant (WTP) Model and available data to extrapolate to the most remote locations in the distribution system to estimate DBP levels at these locations from which maximum LRAAs could be calculated. In addition, because historic quarterly THM4 and HAA5 measurements are taken as much as five months apart, the WTP Model was utilized to predict monthly DBP values from which LRAAs were calculated.

The results show that several of the utilities may have difficulties complying with the new Rule with regard to one or both of the MCLs for THM4 and HAA5. In addition, significant variations in LRAA concentrations were observed for the eleven utilities evaluated. These variations could be due to a number of factors (e.g. changes in source water quality, changes in treatment practices). A site-by-site analysis of raw water quality and treatment process trains was beyond the scope of this study but should be conducted by the individual utilities to better prepare them for the forthcoming Stage 2 DBP Rule.

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TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES.....	v
LIST OF FIGURES.....	vii
CHAPTER 1 – INTRODUCTION.....	1
CHAPTER 2 – LITERATURE REVIEW.....	4
2.1 The 1979 Interim Trihalomethane Rule.....	4
2.2 The Stage 1 DBP Rule.....	6
2.3 The Information Collection Rule (ICR).....	6
2.4 The Proposed Stage 2 DBP Rule.....	8
2.5 DBP Formation in the Distribution System.....	10
2.6 Estimating DBP Concentrations in the Distribution System.....	13
2.6.1 EPA WTP Model.....	16
CHAPTER 3 - METHODS.....	19
3.1 General Approach.....	19
3.2 Procedures.....	21
3.2.1 Information Collected.....	21
3.2.2 DBP Predictions for Systems Using a Combined Chlorine Residual.....	22
3.2.3 DBP Predictions for Systems Using a Free Chlorine Residual.....	24
CHAPTER 4 - RESULTS.....	27
4.1 Systems Using a Combined Chlorine Residual.....	27
4.1.1 Raleigh.....	27
4.1.2 Durham.....	33
4.1.3 Fayetteville.....	37
4.1.4 Greenville.....	40
4.1.5 High Point.....	43
4.1.6 OWASA.....	47
4.2 Systems Using a Free Chlorine Residual.....	50
4.2.1 Wilmington.....	50
4.2.2 Winston-Salem.....	60
4.2.4 Charlotte.....	81
4.2.4 Burlington.....	92
CHAPTER 5 - DISCUSSION OF RESULTS.....	102
CHAPTER 6 - CONCLUSIONS.....	110
6.1 Conclusions.....	110
6.2 Recommendations.....	111
REFERENCES.....	114
Appendix A - Wilmington.....	118
Appendix B - Winston-Salem.....	126
Appendix C - Greensboro.....	134
Appendix D - Charlotte.....	141
Appendix E - Burlington.....	162

LIST OF TABLES

Table 3.1 Description of utilities.	21
Table 4.1 DBP monitoring results for all Raleigh sampling locations (n = 9)	28
Table 4.2 Measured and Predicted THM4 and HAA5 Concentrations (Raleigh).....	29
Table 4.3 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Raleigh)	31
Table 4.4 DBP monitoring results for all Durham sampling locations (n = 10)	33
Table 4.5 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Durham)	35
Table 4.6 DBP monitoring results for all Fayetteville sampling locations (n = 8).....	37
Table 4.7 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Fayetteville).....	38
Table 4.8 DBP monitoring results for all Greenville sampling locations (n = 8)	40
Table 4.9 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Greenville).....	41
Table 4.10 DBP monitoring results for all High Point sampling locations (n = 9)	43
Table 4.11 Predicted Monthly Average DBP and LRAA Concentrations System-wide (High Point).....	45
Table 4.12 DBP monitoring results for all OWASA sampling locations (n = 5).....	47
Table 4.13 Predicted Monthly Average DBP and LRAA Concentrations System-wide (OWASA).....	48
Table 4.14 Description of distribution system monitoring locations (Wilmington).....	51
Table 4.15 Measured and Predicted THM4 and HAA5 Concentrations for Location 7, t = 96 hours (Wilmington).....	53
Table 4.16 Predicted Monthly Average DBP and LRAA Concentrations for Location 7, t = 96 hours (Wilmington).....	54

Table 4.17 Predicted DBP concentration for a hypothetical maximum residence time, t = 10 days (Wilmington)	57
Table 4.18 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Wilmington)	58
Table 4.19 Description of Distribution System Monitoring Stations (Winston-Salem).....	62
Table 4.20 Measured THM4 and HAA5 Concentrations for Location 3, t = 24 hours (Winston-Salem).....	62
Table 4.21 Predicted DBP and LRAA Concentrations for Location 3, t = 24 hours (Winston-Salem)	63
Table 4.22 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Winston-Salem).....	66
Table 4.23 Predicted maximum DBP and LRAA concentrations for a hypothetical maximum residence time, t = 10 days (Winston-Salem).....	68
Table 4.24 Description of distribution system monitoring locations (Greensboro)	72
Table 4.25 Measured THM4 and HAA5 Concentrations for Location 1, t = 13 hours (Greensboro).....	72
Table 4.26 Predicted Average Monthly DBP and LRAA concentrations for Location 1, t = 13 hours (Greensboro).....	73
Table 4.27 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Greensboro).....	77
Table 4.28 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Greensboro).....	79
Table 4.29 Description of distribution system monitoring locations (Charlotte).....	82
Table 4.30 Measured THM4 and HAA5 Concentrations for Location 3, t = 48 hours (Charlotte).....	82
Table 4.31 Predicted Monthly Average DBP and LRAA Concentrations for Location 3, t = 48 hours (Charlotte).....	83
Table 4.32 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Charlotte).....	87
Table 4.33 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Charlotte)	89
Table 4.34 Description of Distribution System Monitoring Stations (Burlington)	92

Table 4.35 Measured THM4 and HAA5 Concentrations for Location 4, t = 8 hours (Burlington)	93
Table 4.36 26 Predicted Average Monthly DBP and LRAA concentrations for Location 4, t = 8 hours (Burlington)	94
Table 4.37 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Burlington)	97
Table 4.38 Predicted maximum DBP and LRAA concentrations for hypothetical maximum residence time, t = 10 days (Burlington)	99

LIST OF FIGURES

Figure 2.1 Illustration Comparing Highest THM4 concentration and THM4 RAA Concentration (USEPA, 2003).	7
Figure 2.2 Illustration Comparing Highest HAA5 concentration and HAA5 RAA Concentration (USEPA, 2003)	7
Figure 2.3 Comparison of RAA and LRAA calculations (USEPA, 2003).....	9
Figure 3.1 Location of Utilities of the Urban Water Consortium.....	19
Figure 4.1 Comparison between measured and predicted THM4 concentrations in Raleigh	30
Figure 4.2 Comparison between measured and predicted HAA5 concentrations in Raleigh	30
Figure 4.3 Predicted and Measured DBP Concentrations System-wide (Raleigh)	32
Figure 4.4 Predicted System-wide Monthly LRAA Concentrations (Raleigh)	32
Figure 4.5 Predicted and Measured DBP Concentrations System-wide (Durham).....	36
Figure 4.6 Predicted System-wide Monthly LRAA Concentrations (Durham)	36
Figure 4.7 Predicted and Measured DBP Concentrations System-wide (Fayetteville).....	37
Figure 4.8 Predicted System-wide Monthly LRAA Concentrations (Fayetteville).....	37
Figure 4.9 Predicted and Measured DBP Concentrations System-wide (Greenville).....	42
Figure 4.10 Predicted System-wide Monthly LRAA Concentrations (Greenville).....	42
Figure 4.11 Predicted and Measured DBP Concentrations System-wide (High Point).	46
Figure 4.12 Predicted System-wide Monthly LRAA Concentrations (High Point)	46
Figure 4.13 Predicted and Measured DBP Concentrations System-wide (OWASA).	49
Figure 4.14 Predicted System-wide Monthly LRAA Concentrations (OWASA).....	49
Figure 4.15 Comparison between measured and predicted THM4 concentrations (Wilmington)	52

Figure 4.16 Comparison between measured and predicted HAA5 concentrations (Wilmington)	52
Figure 4.17 Predicted and Measured DBP Concentrations for Location 7, t = 96 hours (Wilmington)	55
Figure 4.18 Predicted Monthly LRAA Concentrations for Location 7, t = 96 hours (Wilmington)	55
Figure 4.19 Monthly THM4 LRAA concentrations for all existing monitoring locations (Wilmington)	56
Figure 4.20 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Wilmington)	56
Figure 4.21 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Wilmington)	59
Figure 4.22 Predicted LRAAs for THM4 for various maximum residence times (Wilmington)	59
Figure 4.23 Predicted LRAAs for HAA5 for various maximum residence times (Wilmington)	60
Figure 4.24 Predicted and Measured DBP Concentrations for Location 3, t = 24 hrs (Winston-Salem)	64
Figure 4.25 Predicted Monthly LRAA Concentrations for Location 3, t = 24 hrs (Winston-Salem)	64
Figure 4.26 Monthly THM4 LRAA concentrations for all existing monitoring locations (Winston-Salem)	65
Figure 4.27 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Winston-Salem)	65
Figure 4.28 Comparison between measured and predicted THM4 concentrations (Winston-Salem)	67
Figure 4.29 Comparison between measured and predicted HAA5 concentrations (Winston-Salem)	67
Figure 4.30 Predicted maximum DBP concentrations for a hypothetical maximum residence time, t = 10 days (Winston-Salem)	70
Figure 4.31 Predicted LRAAs for THM4 for various maximum residence (Winston-Salem)	70
Figure 4.32 Predicted LRAAs for HAA5 for various maximum residence times (Winston-Salem)	70

Figure 4.33 Predicted and Measured DBP Concentrations for Location 1, t = 13 hrs (Greensboro)	74
Figure 4.34 Predicted Monthly LRAA Concentrations for Location 1, t = 13 hrs (Greensboro)	74
Figure 4.26 Monthly THM4 LRAA concentrations for all existing monitoring locations (Greensboro)	76
Figure 4.27 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Greensboro)	76
Figure 4.37 Comparison between measured and predicted THM4 concentrations (Greensboro)	78
Figure 4.38 Comparison between measured and predicted HAA5 concentrations (Greensboro)	78
Figure 4.39 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Greensboro)	80
Figure 4.40 Predicted LRAAs for THM4 for various maximum residence times (Greensboro)	80
Figure 4.41 Predicted LRAAs for THM4 for various maximum residence times (Greensboro)	81
Figure 4.42 Predicted and Measured DBP Concentrations for Location 3, t = 48 hrs (Charlotte)	84
Figure 4.43 Predicted Monthly LRAA Concentrations for Location 3, t = 48 hrs (Charlotte) ..	84
Figure 4.44 Monthly THM4 LRAA concentrations for selected existing monitoring locations (Charlotte)	86
Figure 4.45 Monthly HAA5 LRAA concentrations for selected existing monitoring locations (Charlotte)	86
Figure 4.46 Comparison between measured and predicted THM4 concentrations (Charlotte) ..	88
Figure 4.47 Comparison between measured and predicted HAA5 concentrations (Charlotte) ..	88
Figure 4.48 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Charlotte)	90
Figure 4.49 Predicted LRAAs for THM4 for various maximum residence times (Charlotte) ...	90
Figure 4.50 Predicted LRAAs for HAA5 for various maximum residence times (Charlotte) ...	91
Figure 4.51 Predicted and Measured DBP Concentrations for Location 4, t = 8 hrs (Burlington)	95
Figure 4.52 Predicted Monthly LRAA Concentrations for Location 4, t = 8 hrs (Burlington) ..	95

Figure 4.53 Monthly THM4 LRAA concentrations for all existing monitoring locations (Burlington).....	96
Figure 4.54 Monthly THM4 LRAA concentrations for all existing monitoring locations (Burlington).....	96
Figure 4.55 Comparison between measured and predicted THM4 concentrations.....	98
Figure 4.56 Comparison between measured and predicted HAA5 concentrations.....	98
Figure 4.57 Predicted maximum DBP concentrations for a hypothetical maximum residence time, t = 10 days (Burlington).....	100
Figure 4.58 Predicted LRAAs for THM4 for various maximum residence times (Burlington).....	100
Figure 4.59 Predicted LRAAs for HAA5 for various maximum residence times (Burlington).....	101
Figure 5.1 Predicted monthly THM4 LRAA concentrations system-wide for systems using a combined chlorine residual.....	103
Figure 5.2 Predicted monthly HAA5 LRAA concentrations system-wide for systems using a combined chlorine residual.....	103
Figure 5.3 Predicted maximum THM4 LRAA concentrations for maximum residence time, t = 10 days, for systems using a free chlorine residual.....	105
Figure 5.4 Predicted maximum HAA5 LRAA concentrations for maximum residence time, t = 10 days, for systems using a free chlorine residual.....	105
Figure A.1 Predicted and Measured DBP Concentrations for Location 2, t = 24 hours.....	120
Figure A.2 Predicted Monthly LRAA Concentrations for Location 2, t = 24 hrs.....	121
Figure A.3 Predicted and Measured DBP Concentrations for Location 3, t = 48 hours.....	122
Figure A.4 Predicted Monthly LRAA Concentrations for Location 3, t = 48 hrs.....	122
Figure A.5 Predicted and Measured DBP Concentrations for Location 4, t = 48 hours.....	123
Figure A.6 Predicted Monthly LRAA Concentrations for Location 4, t = 48 hrs.....	123
Figure A.7 Predicted and Measured DBP Concentrations for Location 5, t = 120 hours.....	124
Figure A.8 Predicted Monthly LRAA Concentrations for Location 5, t = 120 hrs.....	124

Figure A.9 Predicted and Measured DBP Concentrations for Location 6, t = 24 hours	125
Figure A.10 Predicted Monthly LRAA Concentrations for Location 6, t = 24 hrs	125
Figure A.11 Predicted and Measured DBP Concentrations for Location 8, t = 48 hours	126
Figure A.12 Predicted Monthly LRAA Concentrations for Location 8, t = 48 hrs	126
Figure A.13 Predicted and Measured DBP Concentrations for Location 9, t = 120 hours	127
Figure A.14 Predicted Monthly LRAA Concentrations for Location 9, t = 120 hrs	127
Figure B.1 Predicted and Measured DBP Concentrations for Location 2, t = 12 hours.....	128
Figure B.2 Predicted Monthly LRAA Concentrations for Location 2, t = 12 hrs	128
Figure B.3 Predicted and Measured DBP Concentrations for Location 4, t = 24 or 36 hours .	129
Figure B.4 Predicted Monthly LRAA Concentrations for Location 4, t = 24 or 36 hrs	129
Figure B.5 Predicted and Measured DBP Concentrations for Location 5, t = 36 or 48 hours .	130
Figure B.6 Predicted Monthly LRAA Concentrations for Location 5, t = 36 or 48 hrs	130
Figure B.7 Predicted and Measured DBP Concentrations for Location 7, t = 12 hours.....	131
Figure B.8 Predicted Monthly LRAA Concentrations for Location 7, t = 12 hrs	131
Figure B.9 Predicted and Measured DBP Concentrations for Location 8, t = 24 hours.....	132
Figure B.10 Predicted Monthly LRAA Concentrations for Location 8, t = 24 hrs	132
Figure B.11 Predicted and Measured DBP Concentrations for Location 9, t = 24 or 36 hrs ...	133
Figure B.12 Predicted Monthly LRAA Concentrations for Location 9, t = 24 or 36 hrs	133
Figure B.13 Predicted and Measured DBP Concentrations for Location 10, t = 36 or 48 hrs .	134
Figure B.14 Predicted Monthly LRAA Concentrations for Location 10, t = 36 or 48 hrs	134
Figure B.15 Predicted and Measured DBP Concentrations for Location 11, t = 72 hours.....	135
Figure B.16 Predicted Monthly LRAA Concentrations for Location 11, t = 72 hrs	135
Figure C.1 Predicted and Measured DBP Concentrations for Location 2, t = 11 hours.....	136

Figure C.2 Predicted Monthly LRAA Concentrations for Location 2, t = 11 hrs	136
Figure C.3 Predicted and Measured DBP Concentrations for Location 3, t = 30 hours.....	137
Figure C.4 Predicted Monthly LRAA Concentrations for Location 3, t = 30 hrs	137
Figure C.5 Predicted and Measured DBP Concentrations for Location 4, t = 20 hours.....	138
Figure C.6 Predicted Monthly LRAA Concentrations for Location 4, t = 20 hrs	138
Figure C.7 Predicted and Measured DBP Concentrations for Location 5, t = 50 hours.....	139
Figure C.8 Predicted Monthly LRAA Concentrations for Location 5, t = 50 hrs	139
Figure C.9 Predicted and Measured DBP Concentrations for Location 6, t = 24 hours.....	140
Figure C.10 Predicted Monthly LRAA Concentrations for Location 6, t = 24 hrs	140
Figure C.11 Predicted and Measured DBP Concentrations for Location 7, t = 36 hours.....	141
Figure C.12 Predicted Monthly LRAA Concentrations for Location 7, t = 36 hrs	141
Figure C.13 Predicted and Measured DBP Concentrations for Location 8, t = 6.5 hours.....	142
Figure C.14 Predicted Monthly LRAA Concentrations for Location 8, t = 6.5 hrs	142
Figure D.1 Predicted and Measured DBP Concentrations for Location 1, t = 60 hours	143
Figure D.2 Predicted Monthly LRAA Concentrations for Location 1, t = 60 hrs	143
Figure D.3 Predicted and Measured DBP Concentrations for Location 2, t = 84 hours	144
Figure D.4 Predicted Monthly LRAA Concentrations for Location 2, t = 84 hrs	144
Figure D.5 Predicted and Measured DBP Concentrations for Location 4, t = 36 hours	145
Figure D.6 Predicted Monthly LRAA Concentrations for Location 4, t = 36 hrs	145
Figure D.7 Predicted and Measured DBP Concentrations for Location 5, t = 24 hours	146
Figure D.8 Predicted Monthly LRAA Concentrations for Location 5, t = 24 hrs	146
Figure D.9 Predicted and Measured DBP Concentrations for Location 6, t = 48 hours	147
Figure D.10 Predicted Monthly LRAA Concentrations for Location 6, t = 48 hrs	147
Figure D.11 Predicted and Measured DBP Concentrations for Location 7, t = 36 hours	148
Figure D.12 Predicted Monthly LRAA Concentrations for Location 7, t = 36 hrs	148

Figure D.13	Predicted and Measured DBP Concentrations for Location 8, t = 72 hours	149
Figure D.14	Predicted Monthly LRAA Concentrations for Location 8, t = 72 hrs	149
Figure D.15	Predicted and Measured DBP Concentrations for Location 9, t = 60 hours	150
Figure D.16	Predicted Monthly LRAA Concentrations for Location 9, t = 60 hrs	150
Figure D.17	Predicted and Measured DBP Concentrations for Location 10, t = 60 hours	151
Figure D.18	Predicted Monthly LRAA Concentrations for Location 10, t = 60 hrs	151
Figure D.19	Predicted and Measured DBP Concentrations for Location 11, t = 72 hours	152
Figure D.20	Predicted Monthly LRAA Concentrations for Location 11, t = 72 hrs	152
Figure D.21	Predicted and Measured DBP Concentrations for Location 12, t = 60 hours	153
Figure D.22	Predicted Monthly LRAA Concentrations for Location 12, t = 60 hrs	153
Figure D.23	Predicted and Measured DBP Concentrations for Location 13, t = 48 hours	154
Figure D.24	Predicted Monthly LRAA Concentrations for Location 13, t = 48 hrs	154
Figure D.25	Predicted and Measured DBP Concentrations for Location 14, t = 36 hours	155
Figure D.26	Predicted Monthly LRAA Concentrations for Location 14, t = 36 hrs	155
Figure D.27	Predicted and Measured DBP Concentrations for Location 15, t = 72 hours	156
Figure D.28	Predicted Monthly LRAA Concentrations for Location 15, t = 72 hrs	156
Figure D.29	Predicted and Measured DBP Concentrations for Location 16, t = 84 hours	157
Figure D.30	Predicted Monthly LRAA Concentrations for Location 16, t = 84 hrs	157
Figure D.31	Predicted and Measured DBP Concentrations for Location 17, t = 96 hours	158
Figure D.32	Predicted Monthly LRAA Concentrations for Location 17, t = 96 hrs	158
Figure D.33	Predicted and Measured DBP Concentrations for Location 18, t = 96 hours	159
Figure D.34	Predicted Monthly LRAA Concentrations for Location 18, t = 96 hrs	159
Figure D.35	Predicted and Measured DBP Concentrations for Location 19, t = 48 hours	160
Figure D.36	Predicted Monthly LRAA Concentrations for Location 19, t = 48 hrs	160
Figure D.37	Predicted and Measured DBP Concentrations for Location 20, t = 96 hours	161

Figure D.38 Predicted Monthly LRAA Concentrations for Location 20, t = 96 hrs	161
Figure D.39 Predicted and Measured DBP Concentrations for Location 21, t = 48 hours	162
Figure D.40 Predicted Monthly LRAA Concentrations for Location 21, t = 48 hrs	162
Figure D.41 Predicted and Measured DBP Concentrations for Location 22, t = 36 hours	163
Figure D.42 Predicted Monthly LRAA Concentrations for Location 22, t = 36 hrs	163
Figure E.1 Predicted and Measured DBP Concentrations for Location 1, t = 3 hours.....	164
Figure E.2 Predicted Monthly LRAA Concentrations for Location 1, t = 3 hrs	164
Figure E.3 Predicted and Measured DBP Concentrations for Location 2, t = 20 hours.....	165
Figure E.4 Predicted Monthly LRAA Concentrations for Location 2, t = 20 hrs.....	165
Figure E.5 Predicted and Measured DBP Concentrations for Location 3, t = 16 hours.....	166
Figure E.6 Predicted Monthly LRAA Concentrations for Location 3, t = 16 hrs.....	166
Figure E.7 Predicted and Measured DBP Concentrations for Location 5, t = 24 hours.....	167
Figure E.8 Predicted Monthly LRAA Concentrations for Location 5, t = 24 hrs.....	167
Figure E.9 Predicted and Measured DBP Concentrations for Location 6, t = 48 or 85 hrs.....	168
Figure E.10 Predicted Monthly LRAA Concentrations for Location 6, t = 48 or 85 hrs	168
Figure E.11 Predicted and Measured DBP Concentrations for Location 7, t = 4 hours.....	169
Figure E.12 Predicted Monthly LRAA Concentrations for Location 7, t = 4 hrs.....	169
Figure E.13 Predicted and Measured DBP Concentrations for Location 8, t = 24 or 68 hrs....	170
Figure E.14 Predicted Monthly LRAA Concentrations for Location 7, t = 24 or 68 hrs	170

CHAPTER 1 – INTRODUCTION

Disinfection is an established water treatment process for the inactivation of pathogenic microorganisms and has been used widely in the United States since the early 1900s. Since the discovery of disinfection by-products (DBPs) in the 1970s and their association with adverse health effects, the United States Environmental Protection Agency (USEPA) and water utilities have become concerned about human exposure to DBPs, particularly DBP levels in the distribution system and at the consumer's tap.

Prior to the point of entry to the distribution system, there are a variety of water quality and treatment factors that affect the formation of DBPs. They include the concentration and chemical properties of the natural organic matter (NOM) in the source water, the concentration of bromide, pH, temperature, disinfectant type, dose, and residual concentration, contact time, and the treatment processes used by the utility. However, DBP concentrations in a water distribution system can differ significantly from concentrations at the point of entry into that system from the water treatment plant. Continuing formation and decay of DBPs in distribution systems depends upon the disinfectant used and its residual concentration, pH, temperature, contact time (i.e. water residence time or water age), and characteristics of the distribution system. Numerous models have attempted to capture and describe the formation of DBPs in the distribution system based on these water quality, treatment, and distribution system characteristics.

Currently, the Stage 1 Disinfectants and Disinfection By-Products (D/DBP) Rule regulates two principal classes of DBPs, the trihalomethanes (THMs) and the haloacetic acids (HAAs), to a maximum contaminant level (MCL) of 80 and 60 µg/L, respectively, for total THMs (THM4) and five HAAs (HAA5). Compliance is based on a systemwide running annual average (RAA) of four quarterly samples collected at four locations in the distribution system for each treatment plant. Three of the samples are collected at locations with average distribution system residence times, and one sample is collected from a remote location.

Recently the Stage 2 DBP Rule has been proposed which will require that utilities meet the 80 µg/L MCL for THM4 and the 60 µg/L MCL for HAA5 on a locational running annual average (LRAA) basis. This represents a profound shift in compliance approach for DBPs. Additionally, the Rule will require systems to conduct an Initial Distribution System Evaluation (IDSE) to identify new compliance monitoring sites that represent high THM4 and HAA5 levels.

The new Rule will significantly affect many utilities in the United States. The changes in distribution system monitoring locations and the method of calculation for compliance may bring a number of utilities that presently comply with the Stage 1 DBP Rule out of compliance for the Stage 2 Rule. The objective of this study was to assess the degree to which the eleven utilities in the North Carolina Urban Consortium would be able to comply with the impending Stage 2 DBP Rule.

In order to meet this objective, it was necessary to estimate THM4 and HAA5 levels in remote parts of the utilities' distribution systems based on available historical data consisting of

quarterly DBP measurements, three from average locations and one presumably distal location. The approach taken was to use the USEPA's Water Treatment Plant model, which is an empirically-based regression model for predicting DBP formation, and available data to extrapolate to locations with the highest residence time (water age) to estimate quarterly DBP levels at these locations from which LRAAs could be calculated. In addition, quarterly samples of THM4 and HAA5 have historically been taken as much as five months apart; therefore, the WTP model was utilized to create a record of monthly DBP concentrations estimated from quarterly DBP measurements.

In Chapter 2 of this report, a more complete discussion on the history of DBP regulation, the factors that affect DBP formation, and the methods that have been developed to estimate DBP formation are given. A detailed explanation of the methods used to meet the objective of this project are described in Chapter 3. In Chapter 4, the results for each of the eleven utilities are discussed individually, and the composite results are discussed as a whole in Chapter 5. Finally, the conclusions of the report and recommendations for additional work are given in Chapter 6.

CHAPTER 2 – LITERATURE REVIEW

2.1 The 1979 Interim Trihalomethane Rule

Public health concern about DBPs was first raised with the discovery of chloroform and other THMs in drinking water in the 1970s and their subsequent identification as possible human carcinogens. In 1979, the USEPA promulgated the Interim Trihalomethane Rule establishing an MCL of 0.10 mg/L (100 µg/L) for THM₄, making it the first class of DBPs to be regulated in the United States (USEPA, 1979). The four THMs are chloroform (CHCl₃), bromodichloromethane (CHBrCl₂), dibromochloromethane (CHBr₂Cl), and bromoform (CHBr₃). Compliance was based on a running annual average (RAA) of four quarterly samples collected at four locations in the distribution system for each treatment plant. Three of the samples per treatment plant were to be collected at locations with average distribution system residence times, and one sample was to be collected from a remote location. In addition, the Rule applied only to community water systems that served 10,000 people or more because of concerns regarding the possible compromising of disinfection practices for smaller systems attempting to comply with this Rule (Singer, 1994; Pontius, 1999)

The 100 µg/L MCL was selected as a feasible level, achievable with the best water treatment technology available at the time, without compromising protection from pathogenic microorganisms (USEPA, 1979). However, it was understood to be an interim position and a more comprehensive rule was to be promulgated as more information regarding the health effects of individual THM₄ species became available and the economic and technological feasibility of controlling THM₄ levels was demonstrated on a practical level (Pontius, 1999).

The widespread occurrence of DBPs led to numerous studies in the 1970s and 1980s designed to explore the association between cancer and chlorinated drinking water supplies.

Epidemiological studies showed statistically significant associations of chlorinated drinking water with lung cancer (Bean et al. 1982), colon cancer (Young et al. 1981), bladder cancer (Cantor et al. 1978), breast cancer (Gottlieb et al. 1982) and brain cancer (Cantor et al. 1978), but the majority of these studies were based on limited exposure information and the specific DBP(s) responsible for these results could not be identified. Hundreds of DBPs have been found in chlorinated drinking water since the discovery of THMs, including haloacetic acids (HAAs). Among those for which analytical methods exist, THMs and HAAs contribute the highest concentrations (on a weight basis) of DBPs in treated drinking waters (Krasner et al., 1989).

Beginning in 1991, the USEPA was required to set regulations every three years for 25 drinking water contaminants under the Safe Drinking Water Act (SDWA) (Means and Krasner, 1993) and in 1989 the USEPA began to focus on the regulation of DBPs to partially satisfy this requirement (Pontius, 1999). A number of factors complicated the regulation of DBPs. Alternative disinfectants to chlorine, such as ozone and chlorine dioxide, each had limitations in that they formed disinfection by-products of their own which also had adverse health effects (Pontius, 1999). In addition, there still remained a lack of conclusive evidence linking DBPs with adverse health effects. Due to the complexity of the issues faced in the rulemaking, the USEPA utilized a negotiated rule-making process in 1993 which resulted in the creation of a two-stage Disinfectants/Disinfection By-Products (D/DBP) Rule and an Information Collection Rule (ICR) (Pontius, 1999).

2.2 The Stage 1 DBP Rule

The Stage 1 D/DBP Rule was promulgated in November 1998 (USEPA, 1998). This Rule reduced the MCL for THM4 to 0.080 mg/L (80 µg/L) and established an MCL for five HAAs (HAA5) of 0.060 mg/L (60 µg/L). The five HAAs are monochloroacetic acid (ClAA), monobromoacetic acid (BrAA), dichloroacetic acid (Cl₂AA), dibromoacetic acid (Br₂AA), and trichloroacetic acid (Cl₃AA). Compliance with the Stage 1 MCLs for THM4 and HAA5, similar to the 1979 Interim THM Rule, is based on a running annual average of four locations in the distribution system, three with average residence times and one at a remote location. Unlike the 1979 Rule, the Stage 1 DBP Rule applies to all community water systems, including systems serving less than 10,000 people (USEPA, 1998).

The Stage 1 DBP Rule focused on the monitoring and reduction of THM4 and HAA5 concentrations. However, it was assumed that these groups are indicators of other potentially harmful halogenated DBPs and that their control was to be a method of regulating all halogenated DBPs (USEPA, 1998).

2.3 The Information Collection Rule (ICR)

The Information Collection Rule (ICR), which was promulgated in 1996 (USEPA, 1996), provided for the collection of a large array of water quality, treatment, and DBP data, including THM and HAA concentrations within water treatment plants and in their distribution systems. The data from the ICR showed that the RAA compliance calculation allows a significant amount of sampling locations within the distribution system to have DBP levels above, and in some

cases appreciably above, the MCLs (USEPA, 2003). This is illustrated in Figures 2.1 and 2.2 for THM4 and HAA5, respectively.

Figure 2.1 Illustration Comparing Highest THM4 concentration and THM4 RAA Concentration (USEPA, 2003)

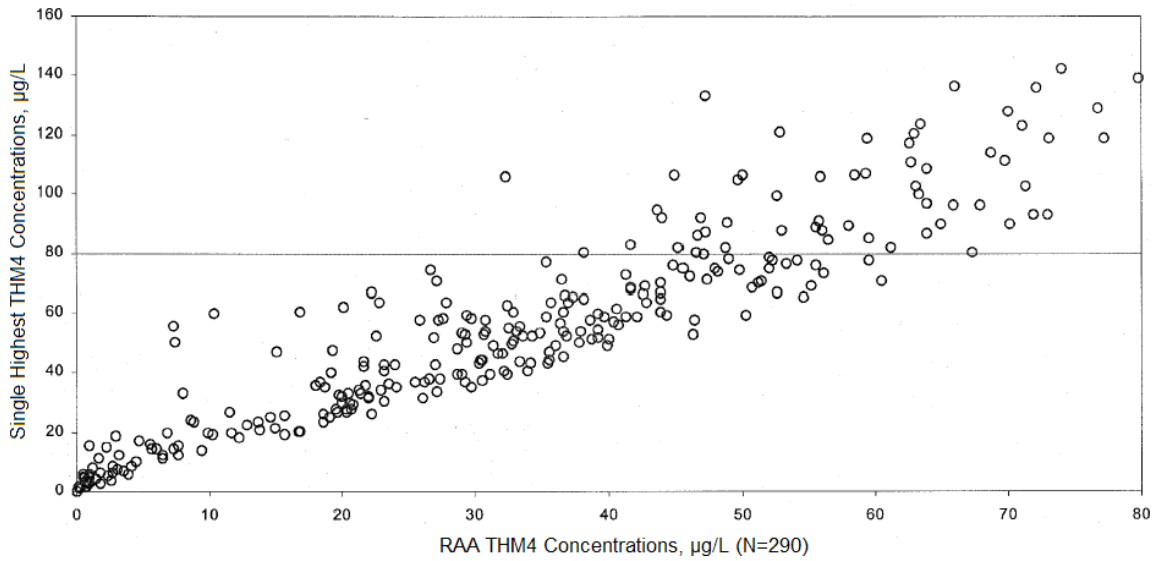
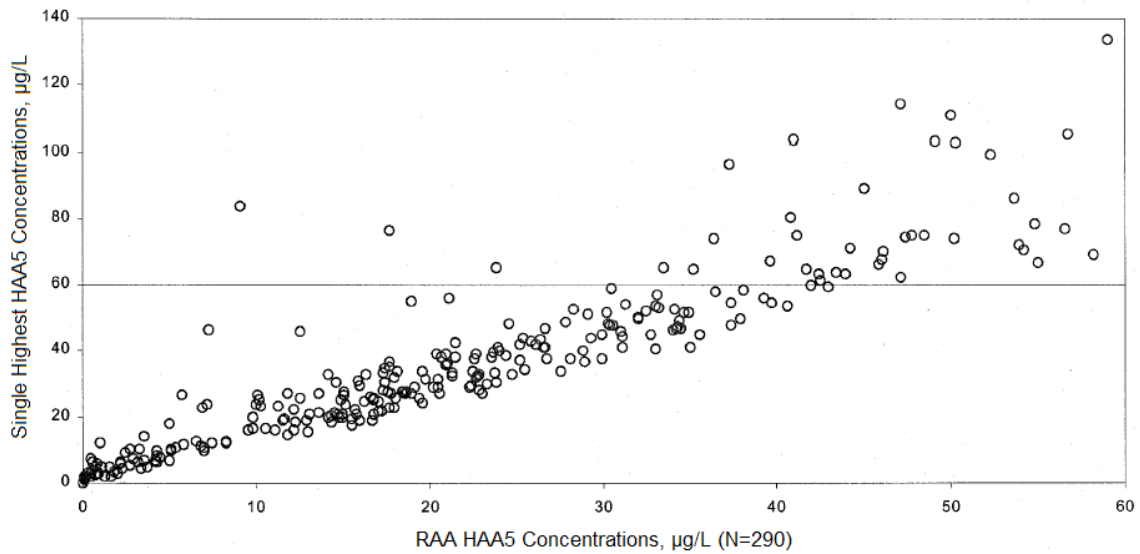


Figure 2.2 Illustration Comparing Highest HAA5 concentration and HAA5 RAA Concentration (USEPA, 2003)



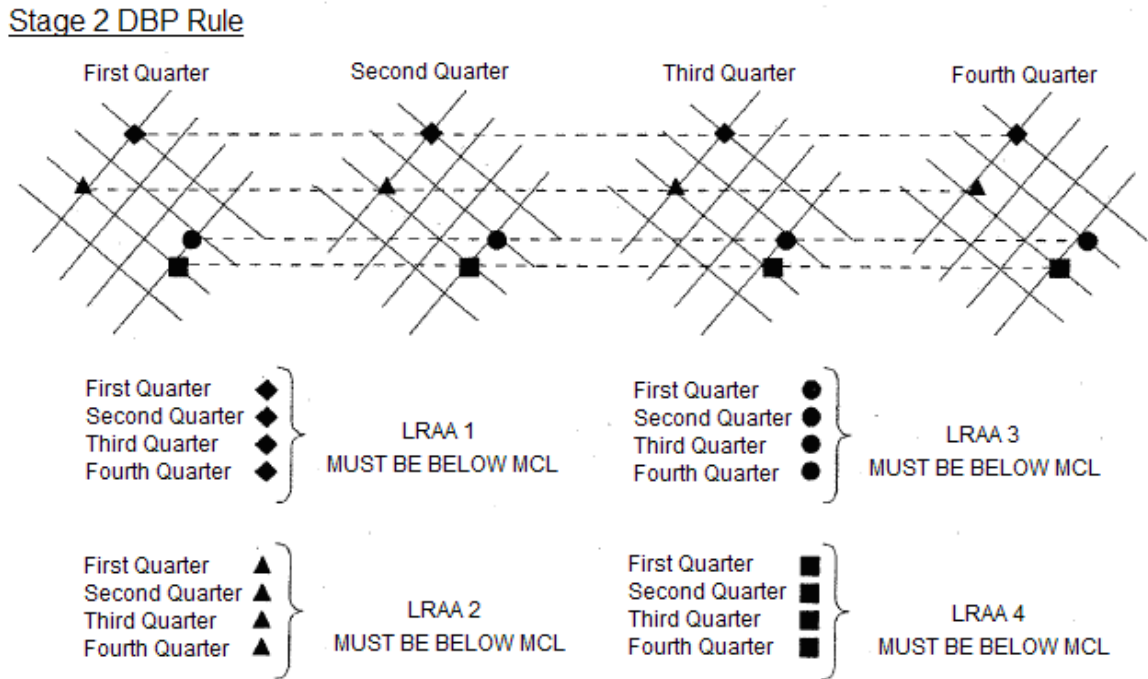
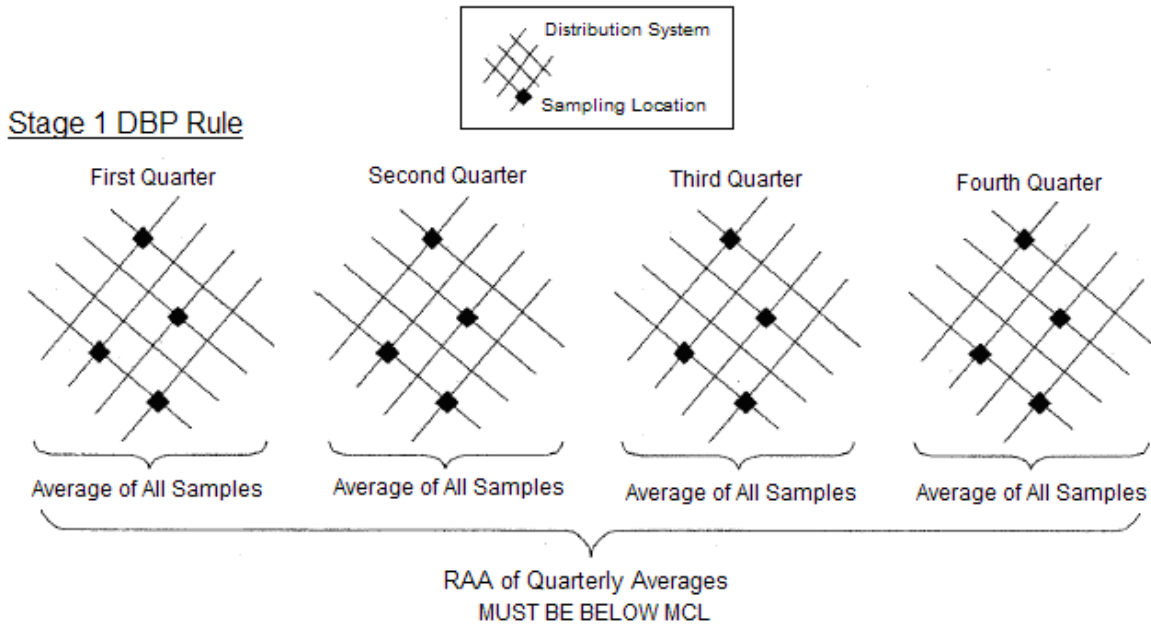
Because these peak DBP occurrences are masked by averaging them with lower distribution system occurrence levels, the Stage 1 DBP Rule did not provide equal consumer protection. In addition, new health studies have become available since the promulgation of the Stage 1 D/DBP Rule which suggest that acute exposures to DBPs are associated with various adverse reproductive and developmental effects (Reif et al., 2000; Bove et al., 2002; Nieuwenhuijsen et al., 2000). In addition, studies continue to support an association between chronic exposures to DBPs and bladder, colon, and rectal cancers (Yang et al., 1998; Koivusalo et al., 1998; and King et al., 2000).

Based on new health studies linking acute DBP exposure to reproductive and developmental health effects, as well as results from the ICR database showing high levels of DBPs in systems complying with the Stage 1 DBP Rule, the Stage 2 DBP Rule was proposed in 2003 (USEPA, 2003).

2.4 The Proposed Stage 2 DBP Rule

Under the Stage 2 D/DBP Rule, the MCLs of 80 µg/L for THM4 and 60 µg/L for HAA5 are retained, but the concentrations will be regulated as a locational running annual average (LRAA) of four remote locations in the distribution system for each treatment plant (USEPA, 2003). This represents a major departure from past DBP regulations in which compliance is based on a system-wide running annual average. A comparison of RAA and LRAA calculations is given in Figure 2.3.

Figure 2.3 Comparison of RAA and LRAA calculations (USEPA, 2003)



Compliance based on the LRAA is expected to provide for more consistent levels of exposure to DBPs across the entire distribution system, equity in terms of DBP exposure, and a reduction in DBP concentration peaks.

In addition, the Stage 2 Rule, if adopted as proposed, will require systems to conduct an Initial Distribution System Evaluation (IDSE) to identify monitoring locations where the highest levels of THM4 and HAA5 levels will be found. Results of the IDSE will be used to select compliance monitoring sites for the Stage 2 Rule. The Stage 2 Rule also will require systems experiencing short term peaks in DBP levels significantly higher than the MCL (“significant excursions”) to perform a significant excursion evaluation to examine distribution system operational practices and to identify opportunities to reduce DBP concentrations in the distribution system. The definition of “significant excursions” has yet to be determined.

The following compliance schedule has been proposed for the new Rule. Systems serving a population greater than 10,000 must submit the results of their IDSE two years after Rule promulgation and must comply with the Stage 2 MCLs six years after promulgation. For systems serving a population less than 10,000, IDSE reports are due four years after promulgation and compliance must be achieved with the Stage 2 MCLs from 7.5 to 8.5 years after promulgation (USEPA, 2003). The Stage 2 DBP Rule is expected to be finalized in December, 2005.

2.5 DBP Formation in the Distribution System

DBP concentrations can be highly variable throughout a distribution system and can also vary over time at the same distribution system location (Singer, 2001; Pereira et al., 2004). In order to understand how DBP levels vary spatially and temporally, it is necessary to understand the factors that influence DBP formation.

Prior to the point of entry to the distribution system, there are a variety of water quality and treatment factors that affect the formation of DBPs. They include the concentration and chemical properties of the NOM in the source water, the concentration of bromide, pH, temperature, disinfectant type, dose and residual concentration, contact time, and the treatment processes used by the utility (Krasner, 1999; Singer 1994). However, DBP concentrations in a water distribution system can differ significantly from concentrations at the point of entry to the distribution system (Obolensky and Frey, 2002). Continuing formation and decay of DBPs in distribution systems depend upon the terminal disinfectant used, contact time (i.e. water residence time or water age), residual disinfectant concentration, pH, temperature, characteristics of the distribution system, and the specific DBP in question (Singer, 2001).

It has been well established that secondary disinfection by combined chlorine results in the formation of lower concentrations of THMs and HAAs compared to free chlorine (Speitel, 1999). In fact, THM and HAA formation essentially cease when a combined chlorine residual is used, and relatively uniform THM and HAA concentrations can be expected throughout the distribution system (Singer, 2001). When a free chlorine residual is used, DBPs continue to form in the distribution system as long as a free chlorine residual exists, and significant spatial variations can be expected.

It is also known that the rate of THM and HAA formation increases with increasing temperature. Disinfectant residuals deplete rapidly when the water temperature is high. Therefore, in order to maintain an adequate level of residual disinfectant in the distribution system, higher disinfectant

doses are applied during the summer, which results in higher DBP concentrations (Chen and Weisel, 1998; Singer, 1994).

Increases in contact time result in increased DBP formation as long as a free chlorine residual persists; therefore significant spatial variations can be expected. In the absence of a disinfectant residual, THMs have been shown to be stable in water distribution systems while some species of HAAs have been shown to degrade (Williams et al., 1995, Baribeau et al., 2000, Schlesinger, 2004). Contact time or water age in a distribution system is a complex function of water demand patterns in the system, design of the network, and storage volume and operation of storage tanks (Singer, 2001). Appreciable diurnal variations in water quality, such as chlorine residual and DBP levels, can be encountered as a result of these factors (Pereira et al, 2004; Speight and Singer, 2005).

pH is also an important factor in the formation of DBPs. Elevated pH values tend to favor enhanced formation of THMs, trihaloacetic acid formation is favored at lower pH values, while dihaloacetic acid formation is relatively insensitive to pH (Singer, 2001).

The physical and biological characteristics of the distribution system can affect DBP concentrations. Material on the pipe wall, such as biofilms and corrosion by-products, provide a reservoir of organic material which exerts a disinfectant demand and can result in increased DBP concentrations in the distribution system (Rossman et al., 2001).

Furthermore, HAAs have faster kinetics of formation than THMs. Therefore, more HAAs form in the water treatment plant and less tend to be formed in the distribution system (Singer, 2001). As a result, HAA5 concentrations have been shown to vary less than THM4 concentrations across distribution systems (Obolensky and Frey, 2002). It is important to note that peak concentrations of DBPs are likely to occur at different sites within a given distribution system, considering the different formation kinetics of different DBPs, and the potential degradation of some DBPs (e.g. HAAs) in the distribution system.

2.6 Estimating DBP Concentrations in the Distribution System

Due to logistical difficulties and the cost of characterizing DBP concentrations by extensive system-wide sampling, several methods have been developed to attempt to capture and describe the formation and occurrence of THMs and HAAs in the distribution system based on the water quality and treatment characteristics described above.

Efforts to estimate DBP formation were started upon the discovery of chloroform in treated drinking water (Rook, 1974; Bellar and Linchtenberg, 1974). These efforts have been developed primarily to assess consumer exposure to health risk from drinking water and to design appropriate regulatory programs.

Mathematical models for quantification of DBPs have largely been developed using empirical approaches. These modeling approaches involve statistical analysis of data derived from controlled laboratory or field experiments to develop regression equations that predict central tendencies of DBP formation as a power function of water quality and reaction conditions.

Several statistical equations used to model DBP formation have the generalized form shown in the following equation (Amy et al., 1987; Harrington et al., 1992; Chowdhury and Amy, 1999)

$$DBP_i = k(DOC * UVA)^a (Br)^b (T)^c (Cl_2)^d (pH)^e (t)^f \quad (1)$$

where the independent parameters DOC, UVA, Br, T, Cl₂, pH, and t correspond to dissolved organic carbon concentration (mg/L), UV absorbance at 254 nm (1/cm), bromide concentration (µg/L), temperature (°C), chlorine dose (mg/L), chlorination pH, and reaction time (hr), respectively, and k, a, b, c, d, e, and f are empirical constants. Most often, the type and concentration of NOM is represented by the DOC concentration and UV absorbance of the water. If these water quality and treatment variables are known, the concentrations of specific DBP species of concern or groups of DBPs can be estimated.

A more mechanistic model has also been developed by McClellan (2000) which attempts to capture the underlying chemistry of DBP formation to the greatest extent possible. The mathematical form of the model is a system of differential rate equations based on conceptual reaction mechanisms and elementary chemical kinetic principles. The results obtained using the model were comparable to or better than the results obtained using empirical models (McClellan, 2000). The primary advantage of the model is its flexibility in that it can handle more complex situations such as booster chlorination. However, mechanistic models of this type are extremely difficult to calibrate.

The simulated distribution system (SDS) method was developed as a surrogate for field sampling to determine DBP concentrations in the distribution system (Koch et al., 1991). It involves the incubation of a sample of water from the point of entry to the distribution system in sealed headspace-free glass bottles under system-specific conditions that mimic water in the distribution system (time, temperature, pH, and secondary disinfectant concentration). The sample is then analyzed at various disinfectant contact times for THMs and HAAs. The results from the SDS method can then be used to develop kinetic curves which tend to follow a first-order saturation growth model of the form shown in Equation 2:

$$C_t = C_o + C_u(1 - e^{-kt}) \quad (2)$$

where C_t is the DBP concentration at any time (t), C_o is the DBP concentration at the point of entry to the distribution system ($t = 0$), C_u is the ultimate DBP concentration (where the DBP concentration tends to plateau at long residence times), and k is the DBP formation constant for that particular water (Rossman, 2000). This method allows for the prediction of DBP concentrations at distribution system locations with known water ages (hydraulic residence times). However, research has shown that this may not necessarily reflect the actual reaction conditions in a distribution system due to reactions between residual chlorine in the treated water and organic material on the pipe wall (Rossman et al., 2001). Furthermore, this model assumes that all of the water reaching any given point in the distribution system comes directly from the point of entry to the system, which is often not the case. This method has been linked with hydraulic models of distribution systems to predict DBP formation (Rossman, 2000). However, this approach requires significant effort to calibrate and verify the hydraulic model.

Another kinetic-based DBP formation model has been developed based on chlorine demand (Gang et al., 2002; Sohn et al., 2004). This method involves fitting chlorine decay data to a two-phase chlorine decay model (i.e. fast reaction followed by slow reaction). The model coefficients are then used to predict DBP concentration assuming that DBP formation is a direct result of chlorine consumption. These models have then been combined with empirical-based models using regression equations to predict reaction coefficients (Clark et al., 2001, Sohn et al., 2004). Evaluations of this method have shown it to be a good predictor of the central tendency of DBP formation; however, no significant improvements were observed with this approach compared to the empirical regression models.

Due to the model's flexibility and adaptability, and the comprehensiveness of the database from which it was developed, the regression equations developed by Amy et al. (1998) have been incorporated into EPA's Water Treatment Plant (WTP) model (CDWO, 2001) which is currently the most widely used model for predicting DBP concentrations in treated drinking water. The WTP model is described in greater detail below.

2.6.1 EPA WTP Model

Empirically-based regression models for predicting DBP formation were first developed by Amy and coworkers (Amy et al., 1987). These models were verified (Harrington et al., 1992) and incorporated into the USEPA WTP model in 1992 (Malcolm Pirnie Inc., 1992) which was used to support the D/DBP negotiated rule-making process in 1993-1994. More recently, the USEPA WTP Model has been modified to reflect increased data availability and new treatment processes since 1992 (CDWO, 2001). In particular, the newest version of the WTP Model contains DBP

formation equations for treated water (CDWO, 2001) which are based on the work of Amy et al (1998). These models have since been verified by Solarik et al. (2000) and are given below:

$$THM4 = 23.9(DOC * UVA)^{0.403} (Cl_2)^{0.225} (Br)^{0.141} (1.1560)^{(pH-7.5)} (1.0263)^{(T-20)} (t)^{0.264} \quad (3)$$

$$HAA5 = 30.7(DOC * UVA)^{0.302} (Cl_2)^{0.541} (Br)^{-0.012} (0.932)^{(pH-7.5)} (1.021)^{(T-20)} (t)^{0.161} \quad (4)$$

where DOC = dissolved organic carbon concentration (mg/L) for $1.00 \leq DOC \leq 7.77$, UVA = UV absorbance at 254 nm (1/cm) for $0.016 \leq UVA \leq 0.215$, Cl_2 = applied chlorine dose (mg/L) for $1.11 \leq Cl_2 \leq 24.75$, Br = bromide concentration ($\mu\text{g/L}$) for $23 \leq Br \leq 308$, Temperature = 20 °C, pH = 7.5, and t = reaction time (hours) for $2 \leq t \leq 168$.

In the WTP model, these equations are applied to the chlorination of coagulated water, as well as water that is softened, treated by granular activated carbon (GAC), treated by membranes, or ozonated and biotreated (Solarik et al. 2000). However, insufficient pH and temperature data were available to develop DBP formation equations for these treated waters. Instead, temperature and pH factors that were developed from raw water data were applied to the treated water equations. These factors are only valid in the 15 to 25°C temperature range and the 6.5-8.5 pH range (Solarik, 2000). One of the major limitations of this model are the boundary conditions from which it was developed.

Predictive equations for DBP formation in the distribution system do not exist at this time. The most common approach employed to predict DBP concentrations in water distribution systems is to consider the distribution system to be merely an extension of the treatment plant, and to

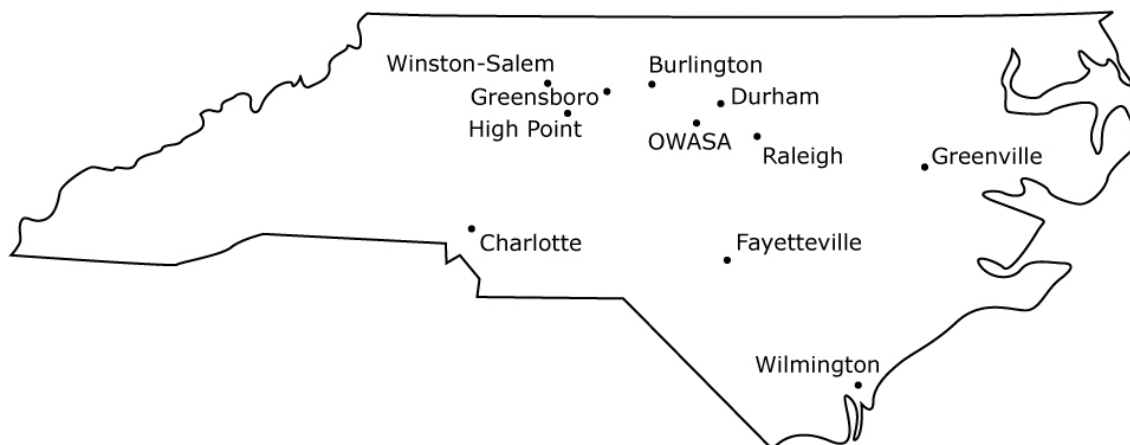
assume DBP formation to follow the same formation rates as given in Equations 3 and 4 (Solarik et al., 2000).

CHAPTER 3 - METHODS

3.1 General Approach

Drinking water treatment utilities located in eleven cities across North Carolina were studied to assess the degree to which they would be able to comply with the impending Stage 2 Disinfection By-Products Rule. The eleven utilities studied belong to the North Carolina Urban Water Consortium. They were: Burlington, Charlotte, Durham, Fayetteville, Greensboro, Greenville, High Point, Orange Water and Sewer Authority (OWASA), Raleigh, Wilmington, and Winston-Salem (see Figure 3.1).

Figure 3.1 Location of Utilities of the Urban Water Consortium



In order to assess the degree to which these utilities would be able to comply with the impending Stage 2 DBP Rule, it was necessary to estimate THM4 and HAA5 levels in remote parts of their distribution systems based on available historical data which included only quarterly DBP data, three from average locations and one from a presumably distal location. Several approaches were available to estimate maximum DBP levels in the distribution systems, such as the SDS

method, modeling of each of the distribution systems, or intensive sampling of the systems. However, these methods could not be employed due to limitations in available resources and logistical difficulties associated with implementing these methods. Instead, the approach taken was to use the WTP model and available data to extrapolate to the most remote locations and estimate monthly DBP levels at these locations from which LRAAs could then be calculated. This method required minimal resources and utilized data that were readily available from the utilities. In addition, because quarterly samples of THM4 and HAA5 could be taken as much as five months apart, the WTP model was used to create a record of monthly DBP values estimated from quarterly DBP measurements.

To begin the study, the participating utilities were contacted and relevant historical DBP data were obtained for the previous 3-4 years. These data were then analyzed using one of two approaches depending upon the residual disinfectant used in the distribution system. These analyses were performed for each of the eleven systems to the extent that the required information was available. The two approaches employed are described in detail in the following section of this report.

Table 3.1 summarizes the characteristics of the eleven utilities. Several of the utilities using free chlorine as the residual disinfectant in the distribution system switched to combined chlorine during the period from 2001 to 2004. These utilities were Durham, Fayetteville, Greenville and OWASA. For the purpose of this study, the DBP data collected while the system was on free chlorine were not used in this analysis.

Table 3.1 Description of utilities

Utility	Residual Disinfectant in Distribution System	Date Switched from Free to Combined Chlorine	Number of Water Treatment Plants	Number of Distribution System Monitoring Locations ^a	Total Population Served	Method of Estimating Water Age at Monitoring Locations
Burlington	Free Cl ₂	--	2	8	46,000	Hydraulic Model
Charlotte	Free Cl ₂	--	3	25	700,000	Estimate
Durham	Combined Cl ₂	1/29/2002	2	10	183,000	Not Required ^b
Fayetteville	Combined Cl ₂	3/4/2003	2	8	170,000	Not Required ^b
Greensboro	Free Cl ₂	--	2	8	225,000	Hydraulic Model
Greenville	Combined Cl ₂	12/12/2002	1	8	76,000	Not Required ^b
High Point	Combined Cl ₂	prior to 2001	1	9	91,000	Not Required ^b
OWASA	Combined Cl ₂	2/1/2002	1	5	80,000	Not Required ^b
Raleigh	Combined Cl ₂	prior to 2001	1	9	344,000	Not Required ^b
Wilmington	Free Cl ₂	--	1	9	102,000	Tracer Study
Winston-Salem	Free Cl ₂	--	2	11	277,000	Hydraulic Model

a) Includes sample taken at the point of entry

b) Residence times for monitoring locations for systems using combined chlorine were not required

3.2 Procedures

3.2.1 Information Collected

The required data were obtained from the eleven participating utilities and transferred into Excel files. The data included quarterly THM4 and HAA5 concentrations at each of the compliance monitoring stations in the utility's distribution system from 2001 to 2004, corresponding water temperatures, average monthly water temperatures, mean hydraulic residence time (water age) associated with each of the monitoring stations, and the type of residual disinfectant used (free or combined chlorine). The mean hydraulic residence times reported by the utilities were determined from tracer studies or hydraulic models of the distribution system, or were estimates provided by utility personnel.

3.2.2 DBP Predictions for Systems Using a Combined Chlorine Residual

For systems using a combined chlorine residual, it was assumed that, for each sampling date, the DBP concentrations are essentially the same system-wide, i.e. at all points in the distribution system. This was verified by observing that the standard deviations of the measured THM4 and HAA5 concentrations on any sampling date for systems with a combined chlorine residual were very small relative to the standard deviations for systems using free chlorine. Hence, it was assumed that there is no spatial variation in THM4 and HAA5 concentrations in chloraminated distribution systems and that the LRAAs will be the same for all sampling sites, even for new remote sampling stations that might be incorporated into the monitoring program.

Because chlorine dose and corresponding THM4 and HAA5 formation are highly temperature dependent, a record of monthly system-wide THM4 and HAA5 concentrations was developed from the measured quarterly values using the predictive models given by Equations 3 and 4. Monthly TOC, UV, and Br concentrations were not available at the POE on the date of DBP sample collection. Therefore, in order to use the WTP model equations, it was assumed that TOC, UV, Br, and pH do not change appreciably during any given quarter and were treated as constants in Equations 3 and 4. This is probably not absolutely correct, but there was little recourse if the WTP modeling approach was to be used. Accordingly, Equations 5 and 6 were derived from the WTP Model, treating temperature as the only variable.

$$THM4_2 = THM4_1(1.0263)^{T_2-T_1} \quad (5)$$

$$HAA5_2 = HAA5_1(1.021)^{T_2-T_1} \quad (6)$$

Since it was assumed that DBP concentrations do not vary system-wide, the average THM4, HAA5, and temperature values on any given sampling date ($THM4_1$, $HAA5_1$, and T_1 , respectively) were used to predict average monthly system-wide $THM4_2$ and $HAA5_2$ concentrations for any other month with a monthly average temperature of T_2 . This assumes, as noted above, that all other factors that influence THM and HAA formation, e.g. raw water quality, treatment conditions, treatment plant residence times, and water quality characteristics of the finished water, are the same from month to month in any given quarter. The predicted THM4 and HAA5 values for months between sampling events were calculated as an average of the predicted values obtained using the measured concentrations which bracketed that month. For months in which sampling events occurred, average DBP concentrations on each sampling date were temperature-adjusted to represent the average monthly DBP concentration using the monthly average water temperature. The resulting monthly predicted DBP concentrations were then used to calculate LRAAs for each month using the values for the preceding 12 months. Many utilities did not measure temperature at the time of DBP sample collection. For these utilities, the raw or finished water temperature on the day of sampling was used for utilities with only one treatment plant, or an average of the raw or finished water temperature for all plants on the day of sampling was used for those utilities with more than one treatment plant.

This approach takes into account the fact that the historical quarterly THM4 and HAA5 measurements have not always been taken every three months and have not always been taken during the times of peak THM4 and HAA5 formation (hottest months with greatest chlorine usage). Again, these are system-wide LRAAs because of the assumption that there is no spatial variation in THM4 or HAA5 concentrations in systems using a combined chlorine residual.

Many chloraminated systems switch to a free chlorine residual in the distribution system one month each year (typically in March) in an attempt to control biofilm development. Utilities usually do not sample during this period, as high DBP levels are expected. Therefore, the modeling approach used in this analysis does not consider the impact of the switchover to free chlorine on DBP levels.

3.2.3 DBP Predictions for Systems Using a Free Chlorine Residual

For systems using a free chlorine residual, it was expected that there would be significant spatial as well as temporal variations in DBP levels in the distribution system. Accordingly, a two-step approach was used for estimating LRAAs for these systems.

First, measured THM₄, HAA₅ and temperature values for each monitoring location (THM_{4,1}, HAA_{5,1}, and T₁, respectively) were used to calculate monthly average THM₄ and HAA₅ concentrations (THM_{4,2} and HAA_{5,2}, respectively) for that location for any other month with an average temperature of T₂ using Equations 5 and 6. The predicted THM₄ and HAA₅ values for months between sampling events are an average of the predicted values obtained using the measured concentrations which bracketed that month. The resulting monthly DBP concentrations were then used to calculate monthly LRAA concentrations for each monitoring location using the values for the preceding 12 months.

Again, many utilities did not measure temperature at the time of DBP sample collection. For those utilities, the raw or finished water temperature on the day of sampling was used. If the utility had more than one treatment plant, the temperature on the day of sampling for the plant

which served the sampling site of interest was used. If it was not known which plant served a given sampling site, an average of the temperatures at all the treatment plants on the day of sampling was used.

Second, to predict the maximum formation of THM4 and HAA5, measured DBP concentrations and their corresponding residence times were used to estimate DBP levels at remote locations using the predictive models given by Equation 7 and 8 which were derived from the WTP model, assuming that TOC, UV, Br, and pH do not change from location to location.

$$THM4_2 = THM4_1 \left(\frac{t_2}{t_1} \right)^{0.264} \quad (7)$$

$$HAA5_2 = HAA5_1 \left(\frac{t_2}{t_1} \right)^{0.161} \quad (8)$$

THM4 and HAA5 concentrations (THM4₂ and HAA5₂, respectively) for a maximum residence time t_2 were predicted from measured THM4 and HAA5 concentrations (THM4₁ and HAA5₁, respectively) at residence time t_1 for each quarterly sampling date to create a record of quarterly maximum DBP values. A 95 percentile maximum water age value of 10 days was used based on an informal survey conducted among several water distribution system experts, including Walter Grayman (Consultant, Cincinnati, OH), James Uber (University of Cincinnati), Vanessa Speight (Malcolm Pirnie Inc.), Alexa Obolensky (Philadelphia Water Department), Charlotte Smith (Consultant, Oakland, CA), and Melissa Friedman (Environmental Engineering Services Inc.). It is important to note that a residence time of 10 days is beyond the experimental conditions (2 hrs $\leq t \leq$ 168 hrs or 7 days) used to develop Equations 3 and 4 from which Equations 7 and 8 were derived. Nevertheless, it was assumed that such an extrapolation could be made.

The quarterly maximum values were then used to predict the maximum monthly THM4 and HAA5 concentrations using Equations 5 and 6. These predicted monthly DBP concentrations were employed to calculate the maximum LRAA for each month using the values for the preceding 12 months. It should be noted that this approach does not allow for a determination of the location at which these maximum values occur on any day or for any month. Still, it is an indication of the worst case situation and the degree to which the utility will be impacted by the Stage 2 DBP Rule.

Since there is uncertainty with regard to the assumption of the maximum residence time being 10 days, assumed maximum residence times of 2, 4, 7, and 14 days were also examined in order to test the sensitivity of the predicted LRAA concentrations to the maximum residence time assumed.

CHAPTER 4 - RESULTS

4.1 Systems Using a Combined Chlorine Residual

4.1.1 Raleigh

Table 4.1 shows a summary of DBP monitoring results for the Raleigh utility. It includes average THM4 and HAA5 concentrations for all nine sampling locations. As shown, the standard deviation and coefficients of variation of the measured THM4 and HAA5 concentrations for the Raleigh sampling stations are relatively low, with a few exceptions. The coefficients of variation are higher for HAA5 compared to THM4, which may be a reflection of the greater analytical difficulty associated with this DBP. This supports the assumption that THM4 and HAA5 concentrations are essentially the same system-wide, and that there is little spatial variation on any given sampling date.

Because the Raleigh system sampled monthly for THM4 and HAA5 for some parts of the year, this allowed us to test the validity of Equations 5 and 6 in Chapter 3 to predict monthly THM4 and HAA5 concentrations at different temperatures from measured THM4 and HAA5 values at known temperatures. Samples were selected to represent quarterly DBP values (these samples are denoted by an asterisk in Table 4.1) and the methodology described in Chapter 3 was employed to predict monthly average DBP concentrations between sampling dates. The measured THM4 and HAA5 values and the predicted concentrations using Equations 5 and 6 are given in Table 4.2.

Table 4.1 DBP monitoring results for all Raleigh sampling locations (n = 9)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
1/29/01	12	20	5	24	14	5	34
6/19/01	26	61	13	21	58	24	41
9/24/01	27	69	6	8	49	11	22
12/17/01*	19	39	7	19	25	15	62
2/15/02	15	49	7	14	19	6	30
3/24/02*	17	59	18	30	42	13	32
4/23/02	22	73	8	11	35	8	24
5/28/02	24	86	9	11	35	4	12
6/3/02*	26	91	9	10	43	7	16
6/5/02	27	75	27	36	22	12	54
6/20/02	27	76	10	14	40	11	26
8/14/02	29	69	7	10	37	6	16
9/19/02*	27	89	8	9	35	9	25
11/13/02*	19	53	6	12	43	10	22
2/20/03	10	38	2	6	29	8	27
3/24/03*	15	42	17	41	44	13	29
4/24/03	20	48	2	5	48	15	32
5/12/03	22	53	4	8	64	14	22
6/23/03*	26	56	6	11	48	10	20
7/17/03	28	55	9	16	52	6	11
8/15/03	29	60	4	6	32	10	32
9/30/03*	26	53	7	13	29	5	16
10/27/03	23	40	5	12	22	6	28
11/18/03*	20	37	3	7	15	6	39
2/16/04	15	36	5	13	29	8	29
3/29/04*	17	53	7	13	52	16	30
4/23/04	17	49	3	5	36	13	37
5/11/04	21	49	3	6	40	6	16
6/29/04*	25	40	4	10	50	8	15
7/21/04	27	58	9	16	48	4	9
8/31/04	27	51	7	14	28	11	40

a) Average of water temperatures at all sampling locations on the day of sampling

* Sampling dates which were selected to represent quarterly DBP values

Figures 4.1 and 4.2 show a comparison between the measured and predicted THM4 and HAA5 concentrations, respectively. The line shown in each figure is a 1:1 line which represents perfect agreement. In general, the models were able to predict DBP concentrations relatively well, implying that the assumptions used in applying Equations 5 and 6 were reasonable.

Table 4.2 Measured and Predicted THM4 and HAA5 Concentrations (Raleigh)

Sampling Date	Measured THM4 (µg/L)	Predicted THM4 (µg/L)	Measured HAA5 (µg/L)	Predicted HAA5 (µg/L)
2/15/02	49	45	19	31
4/23/02	73	66	35	38
5/28/02	86	72	35	40
8/14/02	69	91	37	37
2/20/03	38	41	29	39
4/24/03	48	44	48	43
5/12/03	53	49	64	46
7/17/03	55	58	52	41
8/15/03	60	59	32	41
10/27/03	40	44	22	21
2/16/04	36	36	29	29
4/23/04	49	42	36	47
5/11/04	49	51	40	54
7/21/04	58	50	48	42

Hence, a complete record of monthly system-wide THM4 and HAA5 concentrations and monthly system-wide LRAA concentrations were developed employing the temperature-adjusted modeling approach using Equations 5 and 6, as described in Chapter 3. The record is shown in Table 4.3. Figure 4.3 shows predicted monthly average THM4 and HAA5 concentrations along with the corresponding measured values. Peak THM4 concentrations in 2002 exceed the MCL of 80 µg/L but appear to be unusually high compared to peak THM4 concentrations in other years. In addition, HAA5 concentrations in 2002 appear to be unusually low compared to HAA5 concentrations in other years where peak HAA5 concentrations either approach or exceed the MCL of 60 µg/L. The reason for this pattern is not known, but is most likely related to variations in raw water quality or treatment.

Presented in Figure 4.4 are the monthly predicted LRAA concentrations for THM4 and HAA5. The LRAAs are below the 80 µg/L MCL for THM4 and the 60 µg/L MCL for HAA5 throughout

Figure 4.1 Comparison between measured and predicted THM4 concentrations in Raleigh

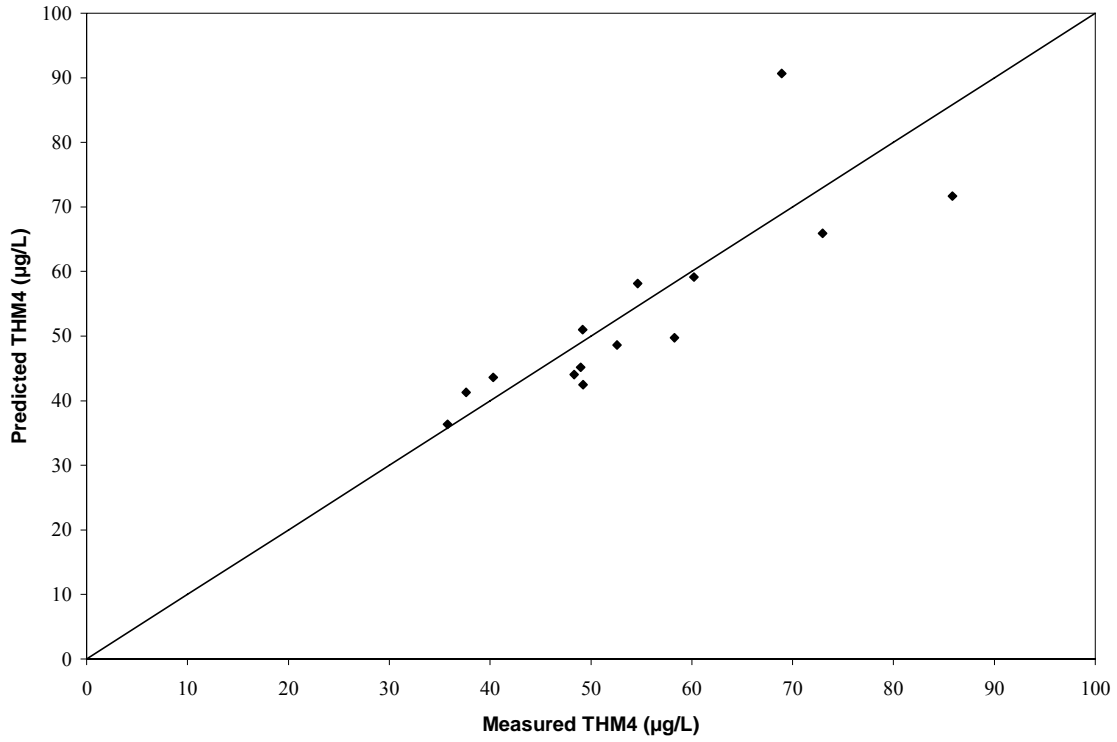


Figure 4.2 Comparison between measured and predicted HAA5 concentrations in Raleigh

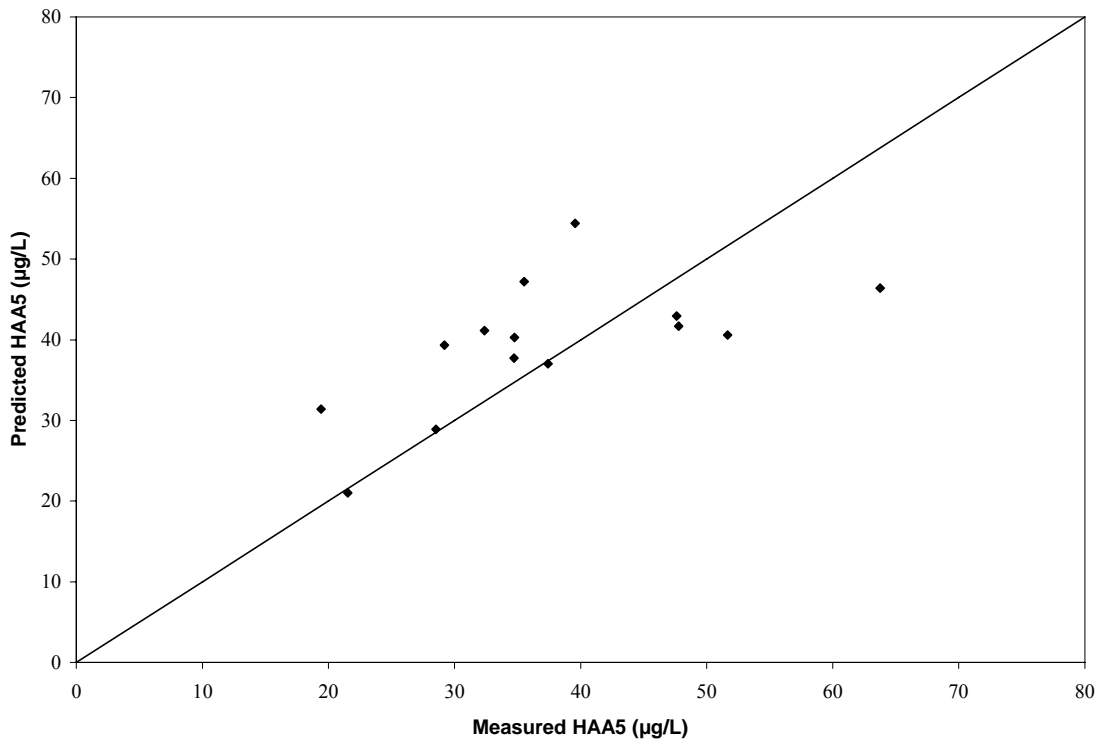


Table 4.3 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Raleigh)

Month	Avg. Monthly Temp. (°C)	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
1/01	8	18		13	
2/01	12	31		29	
3/01	12	31		29	
4/01	16	35		32	
5/01	21	40		35	
6/01	25	59		57	
7/01	27	66		54	
8/01	27	66		54	
9/01	26	67		47	
10/01	22	52		35	
11/01	18	47		33	
12/01	16	37	46	24	37
1/02	12	39	47	20	37
2/02	15	49	49	19	36
3/02	14	54	51	39	37
4/02	20	69	54	33	38
5/02	23	84	57	34	37
6/02	26	80	59	35	36
7/02	28	76	60	36	34
8/02	29	68	60	37	33
9/02	27	90	62	36	32
10/02	24	72	64	41	32
11/02	20	54	64	44	33
12/02	17	48	65	38	34
1/03	13	44	66	35	36
2/03	12	40	65	31	37
3/03	14	40	64	43	37
4/03	17	45	62	45	38
5/03	21	50	59	61	40
6/03	25	55	57	48	41
7/03	28	55	55	52	43
8/03	29	60	55	32	42
9/03	26	54	52	29	42
10/03	22	40	49	21	40
11/03	19	36	47	14	37
12/03	15	34	46	21	36
1/04	12	31	45	20	35
2/04	10	32	44	26	34
3/04	13	48	45	48	35
4/04	17	49	45	36	34
5/04	24	53	46	42	32
6/04	28	43	44	52	33
7/04	30	62	45	50	33
8/04	27	52	44	28	32

Figure 4.3 Predicted and Measured DBP Concentrations System-wide (Raleigh)

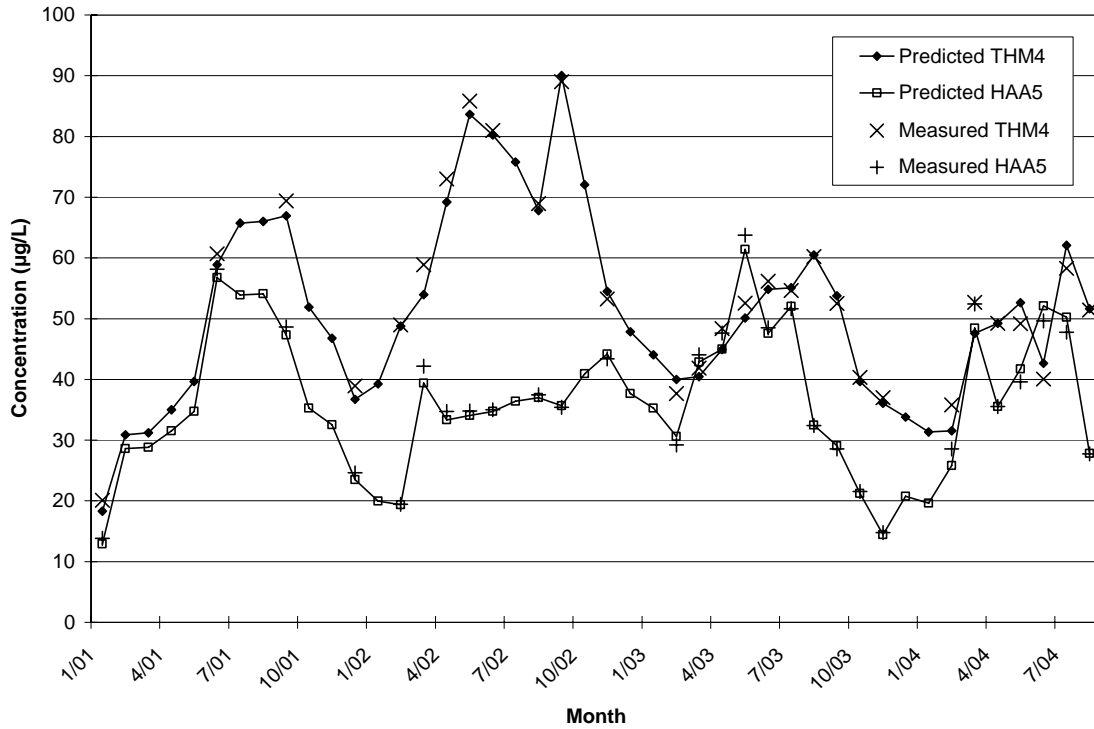
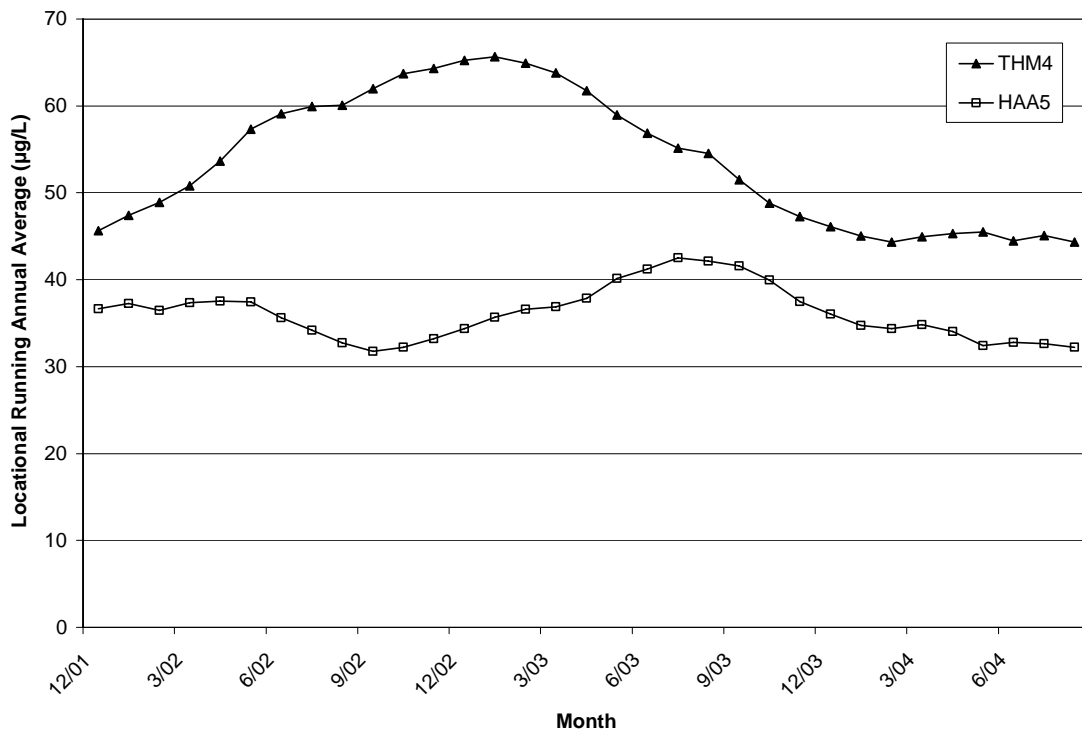


Figure 4.4 Predicted System-wide Monthly LRAA Concentrations (Raleigh)



the entire period studied. Therefore, if the model is valid and appreciable changes in raw water quality or treatment do not occur, and if the utility continues the use of combined chlorine as the residual disinfectant, the Raleigh utility should be able to comply with the impending Stage 2 DBP Rule.

4.1.2 Durham

Table 4.4 presents a summary of DBP monitoring results for Durham’s ten monitoring locations, which includes the average THM4 and HAA5 concentrations on the day of sampling. As shown, the standard deviations and coefficients of variation of the measured THM4 and HAA5 concentrations for the Durham distribution system sampling points has become relatively small, with a few exceptions, since the residual disinfectant in the distribution system was switched from free to combined chlorine on 1/29/02. This supports the assumption that there is little

Table 4.4 DBP monitoring results for all Durham sampling locations (n = 10)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
1/24/01	7	37	11	31	36	8	22
4/19/01	17	92	34	37	55	12	21
9/25/01	24	85	33	38	42	14	34
12/12/01	14	96	30	32	49	18	37
3/1/02 ^b	9	44	7	16	45	9	21
5/1/02	18	56	8	15	40	7	18
9/26/02	22	112	23	21	39	8	19
12/4/02	11	82	26	32	56	9	16
2/12/03	7	40	7	18	43	4	10
5/7/03	17	58	9	15	55	4	8
9/17/03	22	96	14	15	75	21	28
12/18/03	9	46	5	11	53	7	14
2/19/04	7	39	7	17	27	3	10
5/12/04	19	54	5	9	36	5	14
9/14/04	24	62	20	31	69	21	31

a) Average raw water temperatures of Brown and Williams WTPs on day of sampling

b) Switched residual disinfectant in distribution system from free to combined chlorine on 1/29/2002

spatial variation in DBP concentrations for systems using a combined chlorine residual.

Using the methodology described in Chapter 3, a record of monthly predicted DBP and LRAA concentrations were calculated using Equations 5 and 6. The record is shown in Table 4.5 and is illustrated in Figures 4.5 and 4.6. Figure 4.5 shows that peak concentrations of THM4 and HAA5 occur in September, with the exception of HAA5 concentrations in 2002 which remained relatively stable throughout the year. From 2002 to 2004, peak concentrations for THM4 decreased from 120 $\mu\text{g/L}$ to around 60 $\mu\text{g/L}$. The reason for these differences from year to year is unknown but is most likely related to variations in raw water quality or treatment.

As shown in Figure 4.6, the LRAA for THM4 tends to decrease from 80 $\mu\text{g/L}$ to below 60 $\mu\text{g/L}$ over the period from 2/03 to 9/04, whereas the LRAA concentration for HAA5 increases from 45 $\mu\text{g/L}$ to 60 $\mu\text{g/L}$, then decreases again to below 50 $\mu\text{g/L}$ over the same time period. Although the LRAAs for both THM4 and HAA5 do not exceed the MCLs of 80 $\mu\text{g/L}$ and 60 $\mu\text{g/L}$, respectively, THM4 and HAA5 levels are above 80 percent of the MCLs for the majority of the time period studied, and approach the MCLs at various times. Accordingly, the Durham utility may have periodic difficulties complying with the Stage 2 DBP Rule unless additional treatment changes are made.

Table 4.5 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Durham)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
3/02	12	47		47	
4/02	16	54		46	
5/02	19	58		41	
6/02	25	94		44	
7/02	27	101		46	
8/02	26	97		45	
9/02	25	121		42	
10/02	20	106		53	
11/02	14	90		46	
12/02	9	78		54	
1/03	7	58		48	
2/03	7	40	79	43	46
3/03	11	47	79	48	46
4/03	14	51	78	51	47
5/03	16	58	78	55	48
6/03	21	80	77	67	50
7/03	24	85	76	71	52
8/03	25	89	75	73	54
9/03	24	100	74	78	57
10/03	20	76	71	69	59
11/03	16	69	69	64	60
12/03	10	47	67	54	60
1/04	8	42	66	39	59
2/04	7	40	66	27	58
3/04	12	45	65	30	57
4/04	15	49	65	32	55
5/04	19	54	65	36	53
6/04	23	60	63	53	52
7/04	25	64	61	56	51
8/04	25	64	59	55	50
9/04	24	63	56	69	49

a) Average of monthly raw water temperatures of Brown and Williams WTPs

Figure 4.5 Predicted and Measured DBP Concentrations System-wide (Durham)

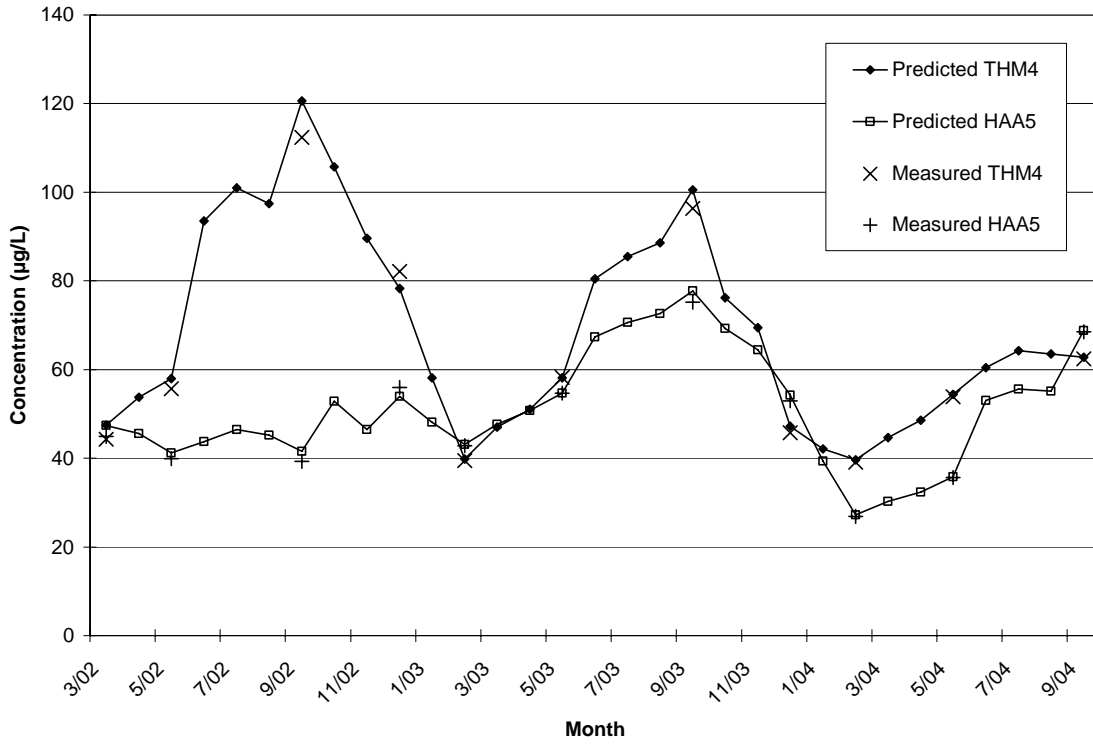
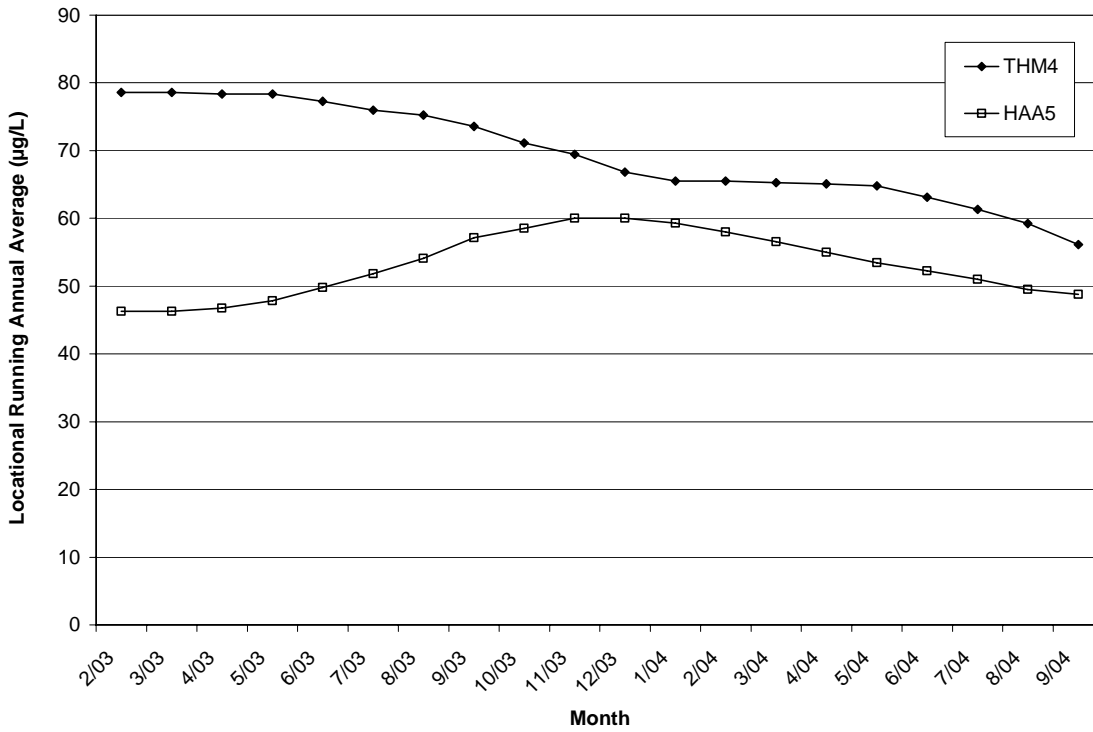


Figure 4.6 Predicted System-wide Monthly LRAA Concentrations (Durham)



4.1.3 Fayetteville

Table 4.6 shows the monthly average THM4 and HAA5 concentrations for Fayetteville. In order to verify that there is little spatial variation of DBP concentrations in the distribution system while using a combined chlorine residual, the standard deviations and the coefficients of variation of the eight measured THM4 and HAA5 concentrations were calculated, and are presented in Table 4.6. The standard deviations have become relatively small since the residual disinfectant in the distribution system was switched from a free to a combined chlorine residual on 3/4/03. Accordingly, all DBP concentrations are expected to be relatively uniform in the distribution system for any given date.

Table 4.6 DBP monitoring results for all Fayetteville sampling locations (n = 8)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
1/18/01	12	42	13	31	32	10	31
4/17/01	23	75	10	14	42	16	37
9/24/01	28	111	22	19	67	19	28
12/18/01	19	62	16	26	35	15	42
2/14/02	15	50	15	30	58	14	23
4/3/02	23	68	22	32	52	11	22
9/12/02	30	152	30	20	60	32	53
12/5/02	12	52	21	39	40	7	16
3/18/03 ^b	21 ^c	46	8	17	37	4	11
4/2/03	23 ^c	48	7	15	51	9	17
8/26/03	28	66	7	11	52	8	15
11/25/03	16	60	7	12	33	2	7
1/15/04	8	27	4	14	23	6	26
2/27/04	9	31	3	10	19	3	17
4/29/04	22	66	12	18	32	8	24
8/30/04	26	75	9	12	49	11	22

a) Average temperature of Glenville and Hoffer WTPs at POE on day of sampling

b) Switched residual disinfectant in distribution system from free to combined chlorine on 3/4/03

c) Temperature at Hoffer WTP only; Glenville WTP out of service

In Table 4.7, a record of monthly predicted DBP and LRAA concentrations for the entire system are given, as calculated applying the methodology described in Chapter 3, using Equations 5 and 6. The record is illustrated in Figures 4.7 and 4.8. As shown in Figure 4.7, system-wide DBP concentrations remain below 80 µg/L and 60 µg/L for THM4 and HAA5, respectively, from 4/03 to 8/04, with only one exception in 7/04 where the THM4 concentration was 80 µg/L. A strong seasonal effect is apparent.

Table 4.7 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Fayetteville)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
4/03	24	49		53	
5/03	26	58		53	
6/03	29	63		56	
7/03	26	58		53	
8/03	27	65		51	
9/03	25	68		44	
10/03	20	60		40	
11/03	16	60		34	
12/03	9	39		26	
1/04	9	27		23	
2/04	9	32		20	
3/04	14	45	52	24	40
4/04	19	61	53	30	38
5/04	24	71	54	41	37
6/04	27	77	55	43	36
7/04	29	80	57	45	35
8/04	26	75	58	49	35

a) Average of monthly temperatures of Glenville and Hoffer WTPs

Figure 4.8 shows that the range of LRAAs during the time period from 3/04 to 8/04 are 50 - 60 µg/L and 35 - 40 µg/L for THM4 and HAA5, respectively. Due to this utility's recent switch to combined chlorine, predicted LRAA information under these conditions are limited. However, all LRAA concentrations calculated during this limited time period are below 80 percent of the 80 µg/L MCL for THM4 and the 60 µg/L MCL for HAA5. Therefore, the Fayetteville utility

Figure 4.7 Predicted and Measured DBP Concentrations System-wide (Fayetteville)

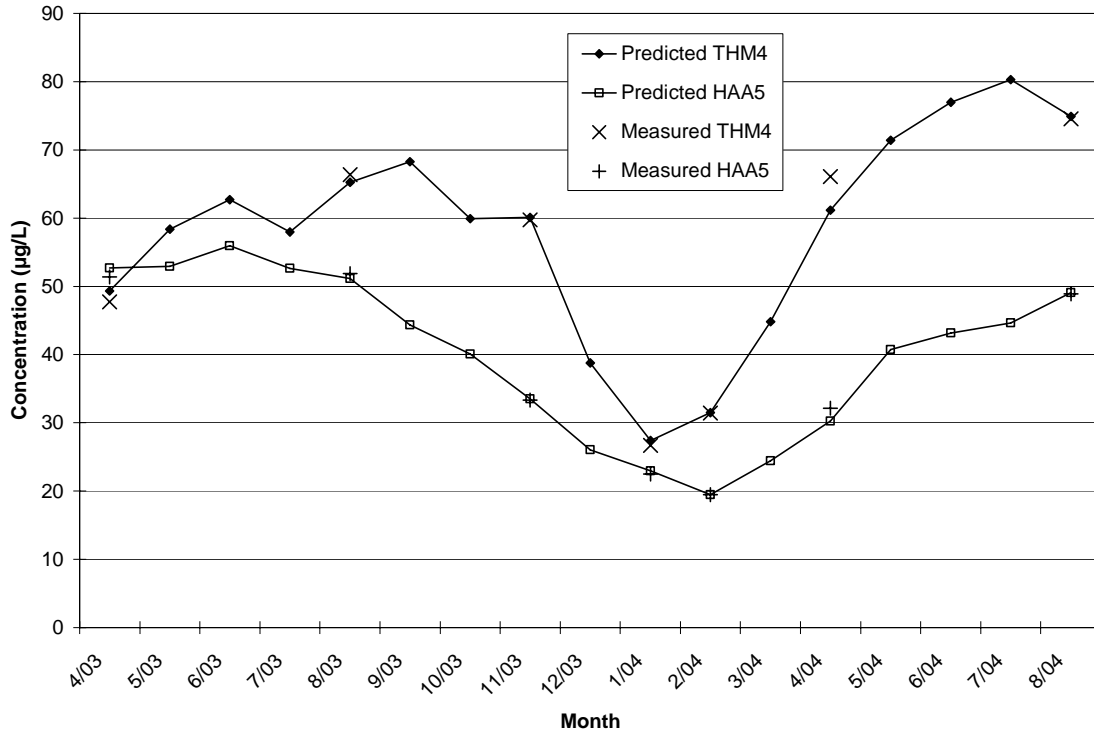
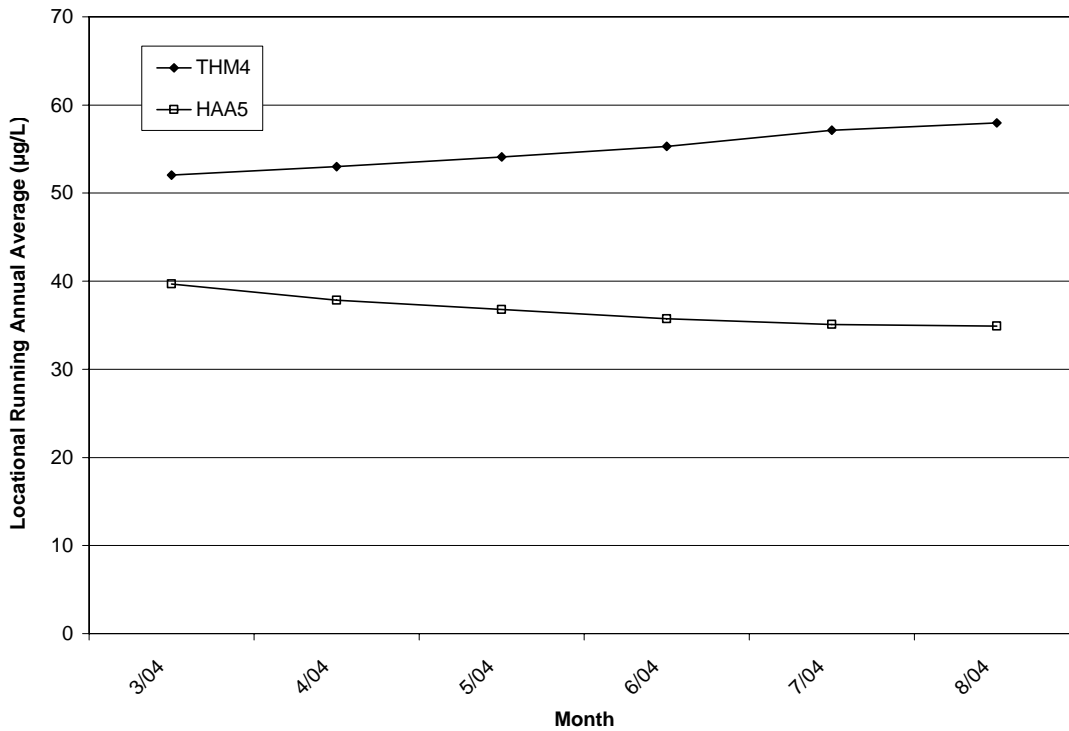


Figure 4.8 Predicted System-wide Monthly LRAA Concentrations (Fayetteville)



should be able to comply with the impending Stage 2 DBP Rule if the water quality conditions do not change significantly and if the utility continues to use combined chlorine as the residual disinfectant in the distribution system.

4.1.4 Greenville

A summary of the DBP monitoring results for the eight Greenville distribution system monitoring locations is given in Table 4.8. HAA5 sampling was not required on 2/25/02 and 5/21/02 due to an expansion project that was occurring at the time; permission to skip this reporting requirement was granted by the State. As shown in Table 4.8, the standard deviations and coefficients of variation of DBP concentrations measured at the eight distribution system sampling locations for Greenville have become relatively small since the utility switched from free chlorine to a combined chlorine residual in the distribution system on 12/12/02. This

Table 4.8 DBP monitoring results for all Greenville sampling locations (n = 8)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
2/21/01	15	47	25	55	40	22	54
5/9/01	21	82	39	48	74	25	33
8/21/01	27	109	36	33	85	35	41
11/19/01	19	40	12	29	45	13	29
2/25/02	13	36	8	23	(d)	(d)	(d)
5/21/02	22	138	23	17	(d)	(d)	(d)
9/25/02	26	170	30	17	150	24	16
12/19/02 ^b	9 ^c	38	5	14	34	4	12
2/5/03	12	23	3	13	20	3	13
6/9/03	23	83	8	10	63	4	7
9/11/03	26	66	7	10	38	3	9
12/1/03	13	26	3	11	30	4	13
3/4/04	15	18	4	24	24	2	10
6/4/04	26	66	20	30	41	16	40

a) Average of temperature values at all sampling stations on day of sampling

b) Switched residual disinfectant in the distribution system from free to combined chlorine on 12/12/02

c) Finished water temperature on day of sampling; no temperature values at sampling locations

d) Collection of HAA5 data waived by State due to expansion project

supports our assumption that DBP values are essentially the same system-wide, and that there is little spatial variation in THM4 and HAA5 concentrations on any given sampling date.

A record of monthly system-wide THM4 and HAA5 concentrations, developed using the approach given in the previous chapter, is given in Table 4.9 and is illustrated in Figures 4.9 and 4.10. As shown in Figure 4.9, DBP concentrations peak in the summer of 2003 at levels higher than the MCLs of 80 µg/L and 60 µg/L for THM4 and HAA5, respectively, but decrease to levels below the MCLs in 2004. Given that Greenville switched to a combined chlorine residual in late 2002, the amount of data that was available only allowed calculations of LRAAs from 11/03 to 6/04. However, Figure 4.10 shows that predicted LRAAs during that time period are

Table 4.9 Predicted Monthly Average DBP and LRAA Concentrations System-wide (Greenville)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
12/02	10	39		34	
1/03	9	30		26	
2/03	7	21		18	
3/03	13	43		35	
4/03	16	48		38	
5/03	21	54		42	
6/03	24	84		64	
7/03	27	80		53	
8/03	27	80		53	
9/03	25	65		37	
10/03	20	44		34	
11/03	18	41	52	32	39
12/03	10	24	51	28	38
1/04	8	19	50	24	38
2/04	8	19	50	24	39
3/04	14	17	48	23	38
4/04	18	37	47	30	37
5/04	24	43	46	34	36
6/04	28	69	45	42	35

a) Average monthly finished water temperature

Figure 4.9 Predicted and Measured DBP Concentrations System-wide (Greenville)

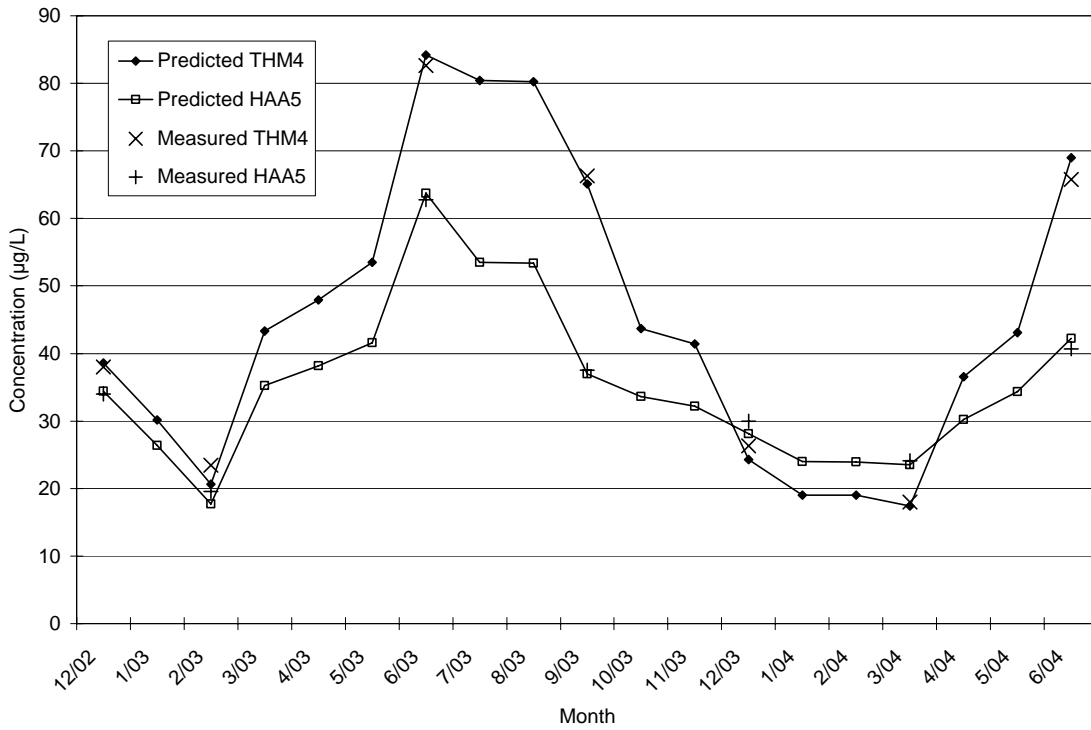
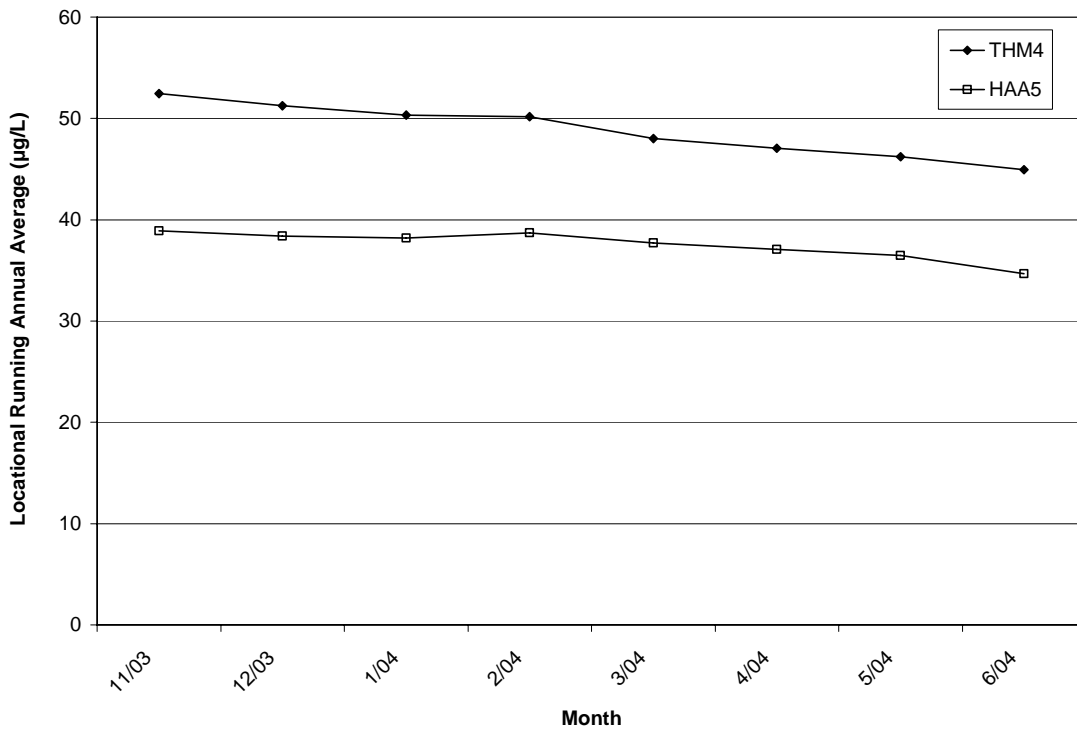


Figure 4.10 Predicted System-wide Monthly LRAA Concentrations (Greenville)



well below 80 percent of the MCLs for both THM4 and HAA5. Therefore, if the model is valid, the Greenville utility should be able to comply with the Stage 2 DBP Rule if raw water quality does not change appreciably and if the utility continues to use a combined chlorine residual in the distribution system.

4.1.5 High Point

Table 4.10 presents a summary of the DBP monitoring results for the nine distribution system monitoring locations for High Point. It shows that the standard deviations and the coefficients of variation calculated for the measured DBP concentrations at the distribution system sampling points are relatively low with a few exceptions. This supports the assumption that THM4 and HAA5 concentrations are essentially the same system-wide, and that there is little spatial variation in THM4 and HAA5 concentrations on any given sampling date. The last four reported

Table 4.10 DBP monitoring results for all High Point sampling locations (n = 9)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
3/27/01	15	45	4	9	43	6	13
6/20/01	28	98	25	25	56	11	20
8/8/01	29	75	7	9	48	4	8
12/5/01	16	46	8	18	28	5	19
2/25/02	13	40	4	9	36	3	9
4/25/02	22	45	3	8	39	5	13
7/11/02	29	57	8	15	58	9	15
12/4/02	12	39	10	26	49	9	18
3/24/03	15	29	7	23	36	4	11
6/24/03	25	84	19	23	66	4	7
9/15/03	25	76	13	17	24	19	77
12/3/03	14	55	9	17	1 ^b		
3/3/04	12	42	5	12	1 ^b		
6/10/04	26	82	9	11	21 ^b		
9/15/04	25	64	8	12	20 ^b		

a) Raw water temperature at the Ward Water Filtration Plant on the day of sampling

b) These values are inconsistent with the other HAA results and therefore are not included in this analysis

concentrations for HAA5 appear to be erroneous as they are inconsistent with the other monitoring results. Accordingly, they have not been included in the LRAA analysis.

Table 4.11 presents the record of monthly DBP and LRAA concentrations as calculated using the approach described in Chapter 3. Figures 4.11 and 4.12 show monthly predicted DBP and LRAA concentrations, respectively. Due to the questionable HAA5 samples taken after 9/03, the HAA5 analysis is limited to that date. Peak THM4 concentrations exceed 80 µg/L in the summer of 2003 and in 6/04, and peak HAA5 concentrations exceed 60 µg/L in 8/02 and 6/03 (Figure 4.11). Predicted LRAA concentrations for High Point never exceed the MCLs of 80 µg/L and 60 µg/L as proposed by the Stage 2 DBP Rule, as shown in Figure 4.12. Accordingly, the High Point utility should be able to comply with the Stage 2 DBP Rule assuming that the utility continues to use a combined chlorine residual in the distribution system and that raw water quality does not change appreciably.

Table 4.11 Predicted Monthly Average DBP and LRAA Concentrations System-wide (High Point)

Month	Avg. Monthly Temp. (°C)	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
3/01	14	44		43	
4/01	18	53		46	
5/01	23	60		51	
6/01	26	66		54	
7/01	28	69		52	
8/01	29	74		48	
9/01	26	64		40	
10/01	21	56		36	
11/01	17	50		33	
12/01	15	44		27	
1/02	11	39		30	
2/02	12	40	55	36	41
3/02	14	40	55	35	41
4/02	20	45	54	37	40
5/02	23	50	53	45	39
6/02	27	56	52	49	39
7/02	29	61	52	57	39
8/02	29	61	51	64	41
9/02	26	56	50	59	42
10/02	22	51	49	55	44
11/02	15	43	49	48	45
12/02	12	38	48	49	47
1/03	10	31	48	39	48
2/03	10	31	47	40	48
3/03	14	28	46	35	48
4/03	16	48	46	46	49
5/03	21	55	47	50	49
6/03	24	82	49	64	50
7/03	27	85	51	(a)	(a)
8/03	27	85	53	(a)	(a)
9/03	25	77	54	(a)	(a)
10/03	21	67	56	(a)	(a)
11/03	18	61	57	(a)	(a)
12/03	11	51	58	(a)	(a)
1/04	10	45	60	(a)	(a)
2/04	10	45	61	(a)	(a)
3/04	14	44	62	(a)	(a)
4/04	17	56	63	(a)	(a)
5/04	24	67	64	(a)	(a)
6/04	27	84	64	(a)	(a)
7/04	28	78	63	(a)	(a)
8/04	27	76	62	(a)	(a)
9/04	25	64	61	(a)	(a)

a) These values could not be calculated due to questionable HAA5 data for 12/03-9/04

Figure 4.11 Predicted and Measured DBP Concentrations System-wide (High Point)

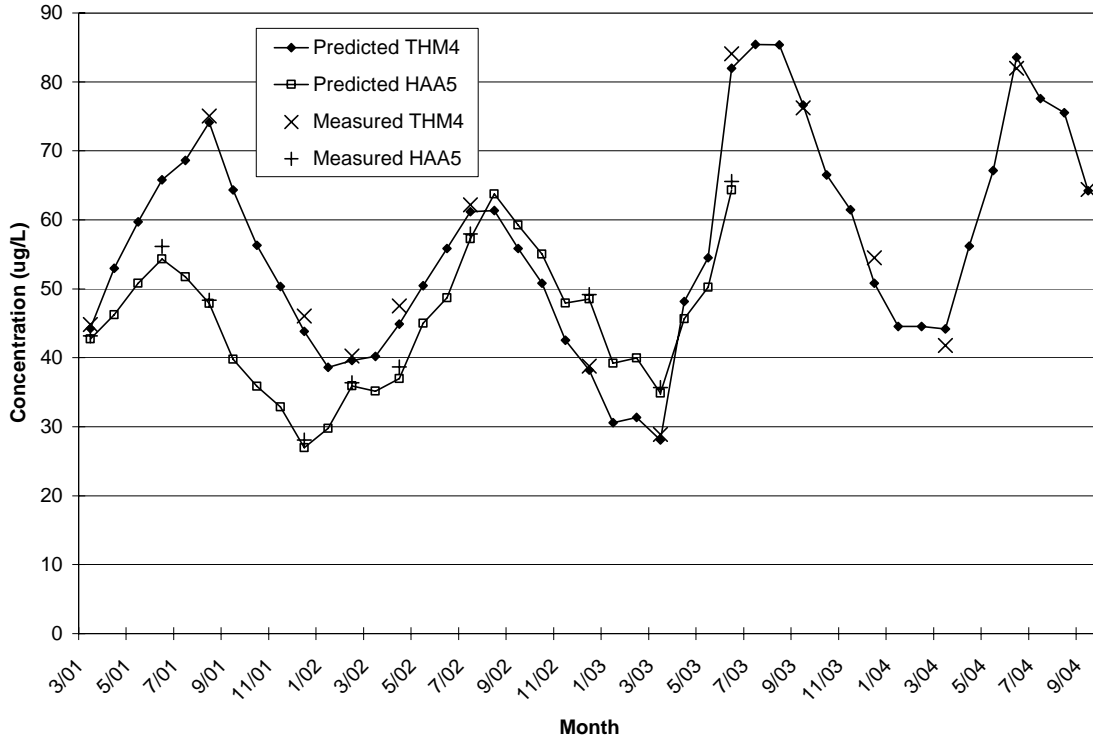
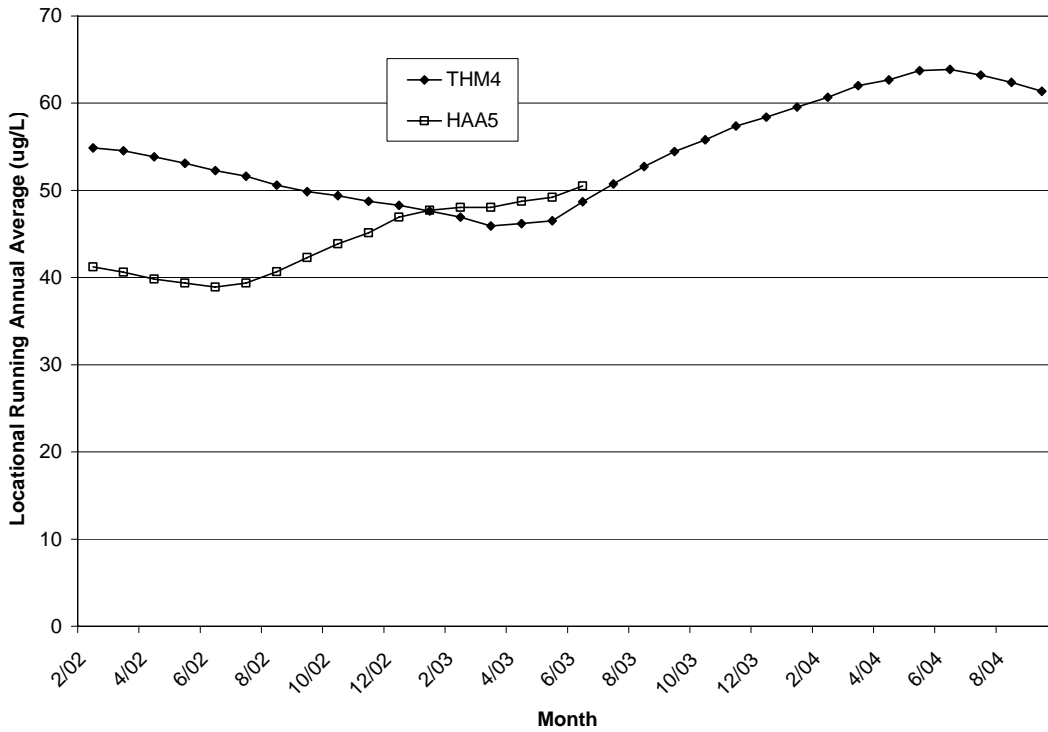


Figure 4.12 Predicted System-wide Monthly LRAA Concentrations (High Point)



4.1.6 OWASA

Table 4.12 presents a summary of DPB monitoring results for the five OWASA monitoring locations. It shows that the standard deviations and coefficients of variation of the measured THM4 and HAA5 concentrations at the OWASA sampling stations are relatively low, even during the time the system was using a free chlorine residual. This verifies the assumption that DBP concentrations do not vary spatially in the distribution system on any given sampling date for systems on combined chlorine.

Table 4.12 DBP monitoring results for all OWASA sampling locations (n = 5)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Average THM4 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)	Average HAA5 on Day of Sampling (µg/L)	Standard Deviation (µg/L)	Coefficient of Variation (%)
2/13/01	11	47	5	10	48	8	16
4/24/01	19	58	8	13	68	2	3
8/21/01	26	53	18	34	44	9	21
11/7/01	17	27	8	28	31	5	17
2/13/02 ^b	11	26	10	37	30	2	6
5/14/02	20	29	6	21	26	2	7
8/19/02	26	41	4	9	30	1	4
11/12/02	17	42	7	16	52	4	9
2/24/03	10	37	6	17	42	3	7
5/20/03	19	72	6	8	74	5	7
6/24/03	21	71	9	12	77	2	2
9/11/03	23	53	7	13	51	3	5
11/10/03	17	51	8	16	45	2	4
2/9/04	8	30	6	20	37	1	4
5/17/04	22	35	3	9	35	2	6

a) Average temperatures at all sampling stations on day of sampling

b) Switched residual disinfectant in distribution system from free to combined chlorine on 2/1/02

Monthly predicted DBP and LRAA concentrations system-wide are presented in Table 4.13

Table 4.13 and are illustrated in Figures 4.13 and 4.14. Figure 4.13 shows that THM4 and HAA5 concentrations appear to be higher in 2003 than in other years. The reason for this is unclear without a closer examination of OWASA's raw water quality and treatment records. As

shown in Figure 4.14, LRAA concentrations for THM4 and HAA5 follow the same trend from 1/03 to 5/04, with the LRAAs for HAA5 being slightly higher than those for THM4. LRAAs for both THM4 and HAA5 increase from 35 to 60 µg/L, then decrease to approximately 48 µg/L over the period of this analysis. LRAAs for HAA5 never exceed the 60 µg/L MCL, but peak very close to it at 56 µg/L during the late summer and early fall of 2003. Based on the predicted LRAAs calculated from 1/03 to 5/04, it appears that OWASA will be able to comply with the 80

Table 4.13 Predicted Monthly Average DBP and LRAA Concentrations System-wide (OWASA)

Month	Avg. Monthly Temp. (°C)	Predicted Monthly Average THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Monthly Average HAA5 (µg/L)	HAA5 LRAA (µg/L)
2/02	13	27		32	
3/02	16	28		29	
4/02	20	31		31	
5/02	19	29		26	
6/02	21	33		27	
7/02	24	36		29	
8/02	26	41		30	
9/02	24	44		44	
10/02	21	41		42	
11/02	15	40		50	
12/02	12	38		45	
1/03	12	38	35	45	36
2/03	13	40	36	45	37
3/03	13	51	38	55	39
4/03	15	54	40	57	41
5/03	18	71	44	73	45
6/03	20	69	47	75	49
7/03	22	62	49	64	52
8/03	26	70	51	70	55
9/03	23	53	52	50	56
10/03	19	51	53	47	56
11/03	16	50	54	44	56
12/03	10	37	54	39	55
1/04	10	36	54	38	55
2/04	9	31	53	37	54
3/04	13	31	51	35	52
4/04	18	35	50	38	51
5/04	21	35	47	35	48

Figure 4.13 Predicted and Measured DBP Concentrations System-wide (OWASA)

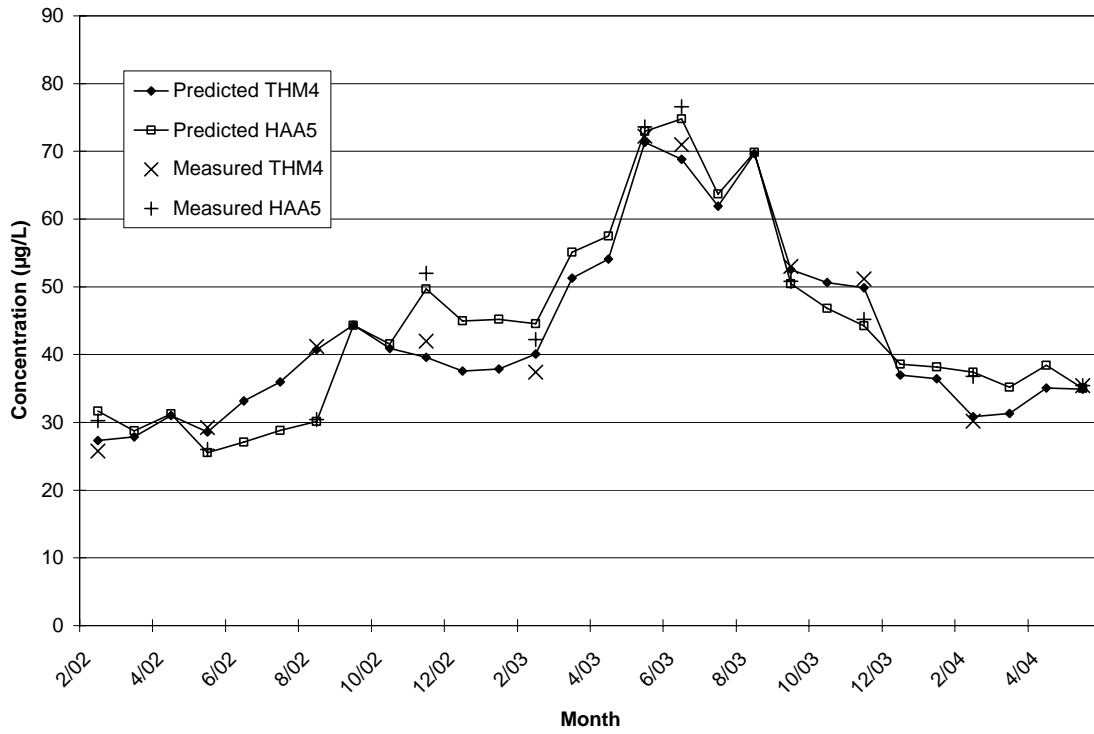
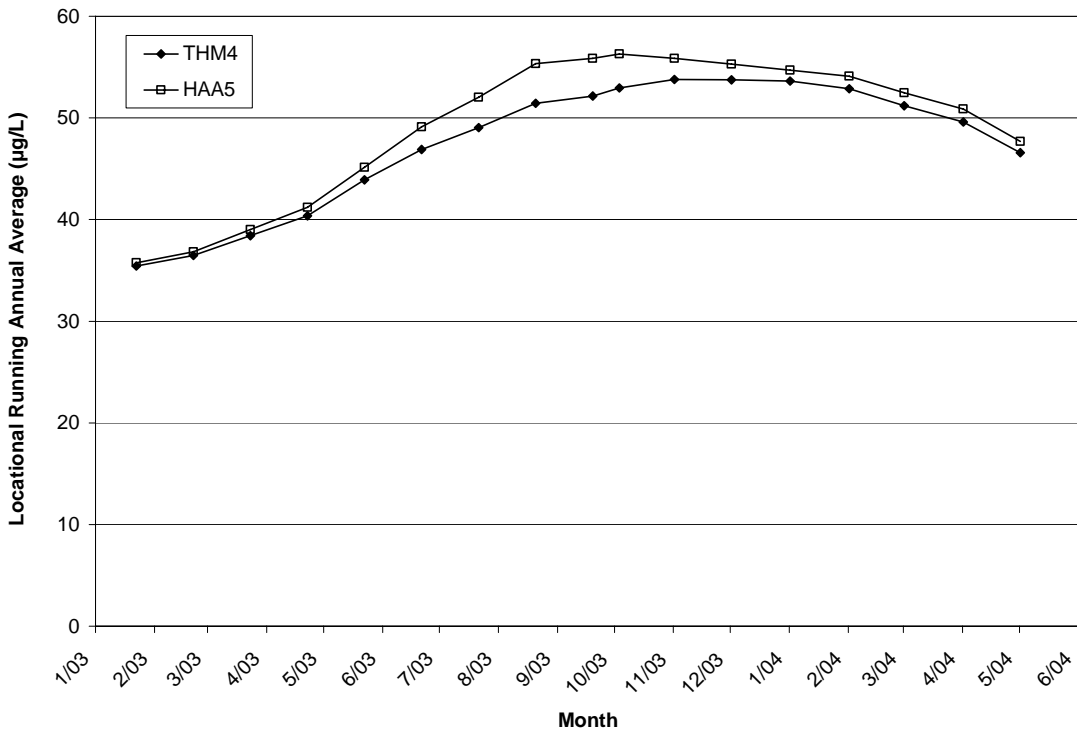


Figure 4.14 Predicted System-wide Monthly LRAA Concentrations (OWASA)



$\mu\text{g/L}$ MCL for THM4, but may have difficulty complying with the 60 $\mu\text{g/L}$ MCL for HAA5.

The cause of the elevated DBP concentrations in the summer of 2003 needs to be determined.

4.2 Systems Using a Free Chlorine Residual

4.2.1 Wilmington

For systems using a free chlorine residual as the terminal disinfectant, LRAA values were first calculated for each monitoring location using the same temperature-adjusted approach as for the chloraminating systems, i.e. Equations 5 and 6. Then the monitoring data were used to predict maximum DBP and LRAA concentrations in the distribution system using the time-adjustment model given by Equations 7 and 8 in Chapter 3.

In order to evaluate the predictive reliability of the time-adjustment model, measured DBP values from one of the distribution system monitoring locations in Wilmington, with a known residence time (water age) were used to predict DBP values at the residence times of the remaining monitoring locations. Wilmington's nine monitoring locations are listed in Table 4.14 along with their corresponding residence times, which were determined by a tracer study. The results of using measured DBP concentrations at Location 2 ($t = 24$ hrs) as a basis for predicting DBP concentrations at the other eight locations, employing Equations 7 and 8, are illustrated in Figures 4.15 and 4.16 which compare the measured and predicted values for THM4 and HAA5, respectively. The 1:1 lighter line shown in the two figures represents the line of perfect agreement, while the second darker line is the line of best fit from a linear regression analysis. The equation shown on each of the figures is the equation for the regression line, along with the corresponding R^2 value for the regression. The results demonstrate a good correlation between the predicted and measured concentrations, with R^2 values of 0.894 and 0.863 for THM 4 and

Table 4.14 Description of distribution system monitoring locations (Wilmington)

Location	Description	Residence Time ^a (Hrs)
1	Entry	0
2	001 - City Hall	24
3	002 - Health Dept.	48
4	003 - NSWWTP	48
5	004 - Echo Farms	120
6	031 - Walnut St.	24
7	032 - 17 St.	96
8	033 - Market St.	48
9	035 - Landfall Arb.	120

a) Residence times determined by a tracer study

HAA5, respectively, although the models tended to over-predict the concentrations in both cases. The reason for the over-prediction is probably associated with uncertainty in the residence times for each of the sampling locations. Therefore, the THM4 and HAA5 concentrations predicted using the time-adjustment model given by Equations 7 and 8 for Wilmington were adjusted using the regression equations given in Figures 4.15 and 4.16.

A record of monthly DBP and LRAA concentrations for all existing distribution system monitoring locations was developed for Wilmington using the quarterly DBP measurements and Equations 5 and 6 in Chapter 3. Illustrative results for Location 7 (t = 96 hrs) are given in Table 4.15 and 4.16. The results for each of the other monitoring locations are included in Appendix A.

As shown in Figure 4.17, DBP concentrations at Location 7 peak at levels slightly above the MCLs of 80 µg/L and 60 µg/L for THM4 and HAA5, respectively, in the summer of 2002. However, Figure 4.18 shows that the LRAA concentrations for both THM4 and HAA5 for the period 12/01 to 7/04 are well below the MCLs at Location 7 (t = 96 hrs). Therefore, this existing

Figure 4.15 Comparison between measured and predicted THM4 concentrations (Wilmington)

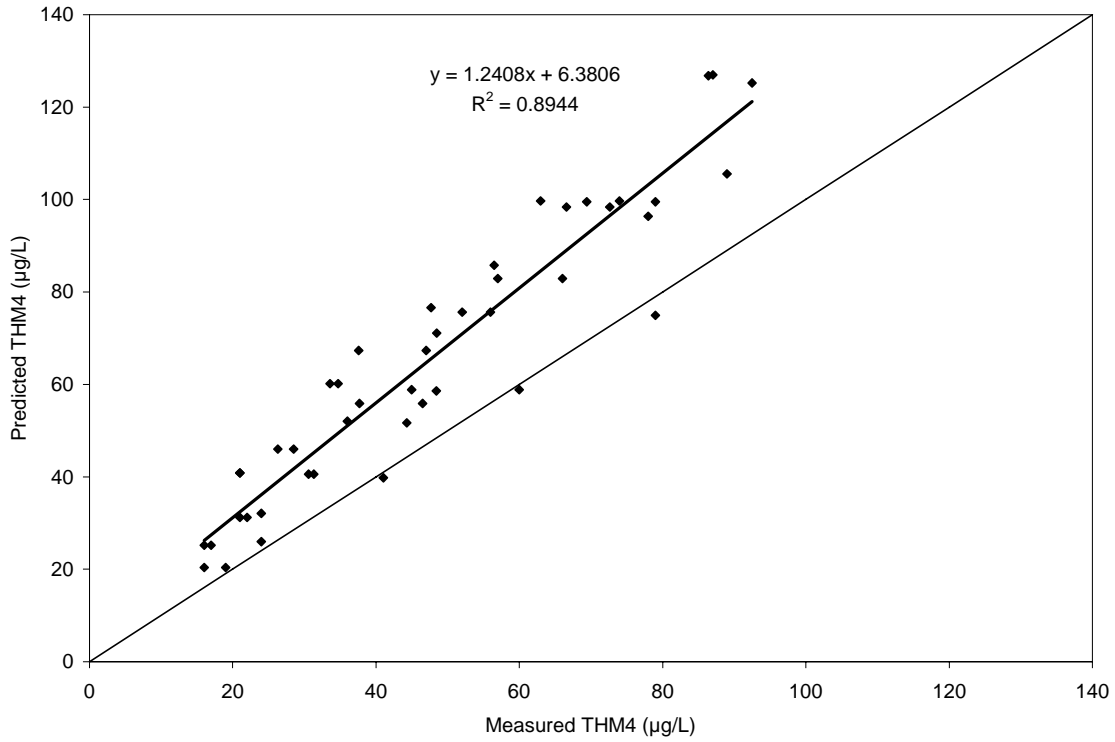


Figure 4.16 Comparison between measured and predicted HAA5 concentrations (Wilmington)

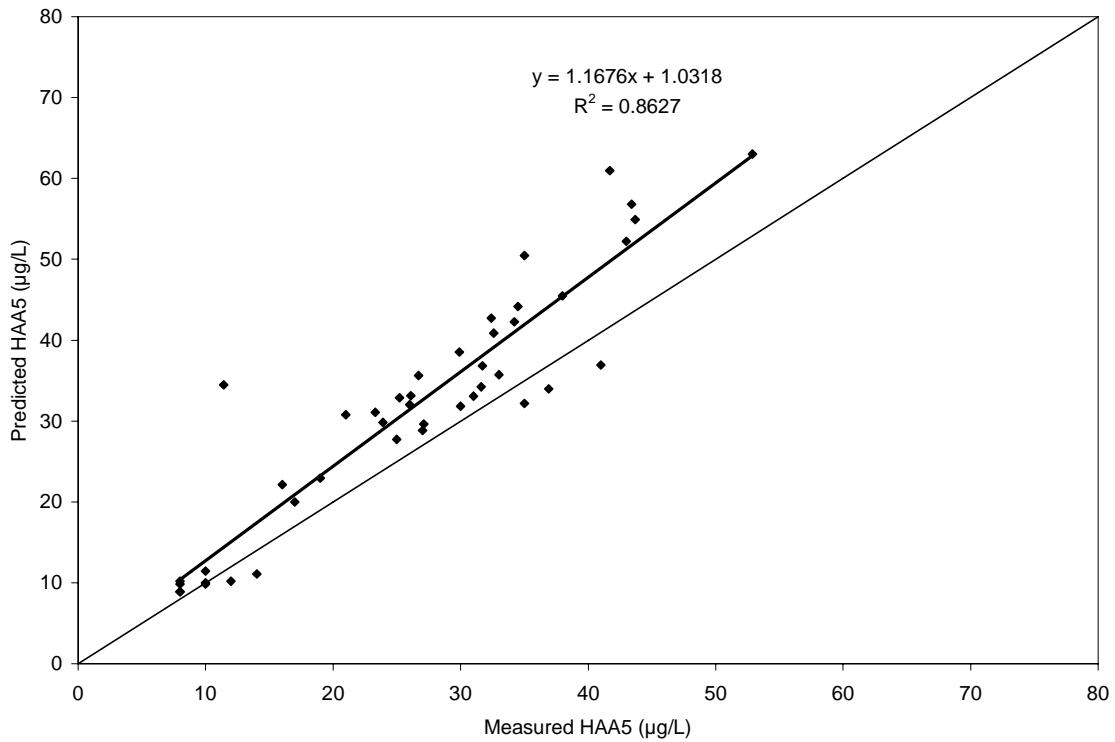


Table 4.15 Measured THM4 and HAA5 Concentrations for Location 7, t = 96 hours (Wilmington)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4 (µg/L)	Measured HAA5 (µg/L)
1/23/01	10	31	25
4/3/01	16	33	42
7/10/01	27	71	33
11/19/01	16	49	11
1/9/02	11	33	26
4/3/02	15	38	32
8/1/02	30	65	63
9/11/02	28	88	28
10/2/02	27	58	33
1/7/03	11	21	14
4/2/03	19	22	16
7/2/03	27	50	35
10/1/03	24	37	21
1/7/04	13	16	10
4/7/04	20	21	8
7/7/04	28	62	26

a) Temperature at sampling location on the day of sampling

sampling location, and all other existing monitoring stations in Wilmington (see Figures 4.19 and 4.20) are currently in compliance with the proposed Stage 2 DBP Rule, although they do experience significant seasonal variations, with some showing THM4 concentrations in excess of the 80 µg/L MCL on several occasions during the period of analysis (see Appendix A).

To determine the maximum THM4 and HAA5 concentrations that can be expected in the Wilmington distribution system, measured quarterly values at Location 2 (t = 24 hrs) were used to predict DBP levels for a maximum residence time of 10 days, using Equations 7 and 8. As shown in Table 4.17, these predicted values were then adjusted by the regression equations given in Figures 4.15 and 4.16. The record of maximum quarterly DBP concentrations in Table 4.17 was then used to predict maximum monthly DBP concentrations using Equations 5 and 6, from

Table 4.16 Predicted Average Monthly DBP and LRAA concentrations for Location 7, t = 96 hrs (Wilmington)

Month	Avg. Monthly Temp. (°C)	Predicted Average Monthly THM4 (µg/L)	Predicted THM4 LRAA (µg/L)	Predicted Average Monthly HAA5 (µg/L)	Predicted HAA5 LRAA (µg/L)
1/01	11	32		26	
2/01	12	31		32	
3/01	15	34		35	
4/01	21	38		46	
5/01	23	52		39	
6/01	27	57		42	
7/01	28	73		34	
8/01	29	72		24	
9/01	26	67		23	
10/01	22	59		21	
11/01	19	53		12	
12/01	18	46	51	21	30
1/02	12	34	51	27	30
2/02	14	36	52	29	30
3/02	16	38	52	31	29
4/02	21	44	52	37	28
5/02	24	51	52	47	29
6/02	27	56	52	50	30
7/02	29	59	51	53	31
8/02	29	64	51	62	34
9/02	26	84	52	27	35
10/02	24	55	52	31	36
11/02	17	35	50	22	36
12/02	11	30	49	19	36
1/03	11	21	48	14	35
2/03	11	19	46	14	34
3/03	14	21	45	15	33
4/03	16	20	43	15	31
5/03	20	33	41	24	29
6/03	24	36	40	26	27
7/03	27	50	39	35	25
8/03	27	46	37	29	22
9/03	26	44	34	28	23
10/03	21	34	32	20	22
11/03	19	25	32	15	21
12/03	14	22	31	14	21
1/04	11	15	31	10	20
2/04	12	16	30	8	20
3/04	15	18	30	9	19
4/04	19	21	30	8	19
5/04	24	40	31	16	18
6/04	27	43	31	18	17
7/04	28	63	32	26	17

Figure 4.17 Predicted and Measured DBP Concentrations for Location 7, t = 96 hrs (Wilmington)

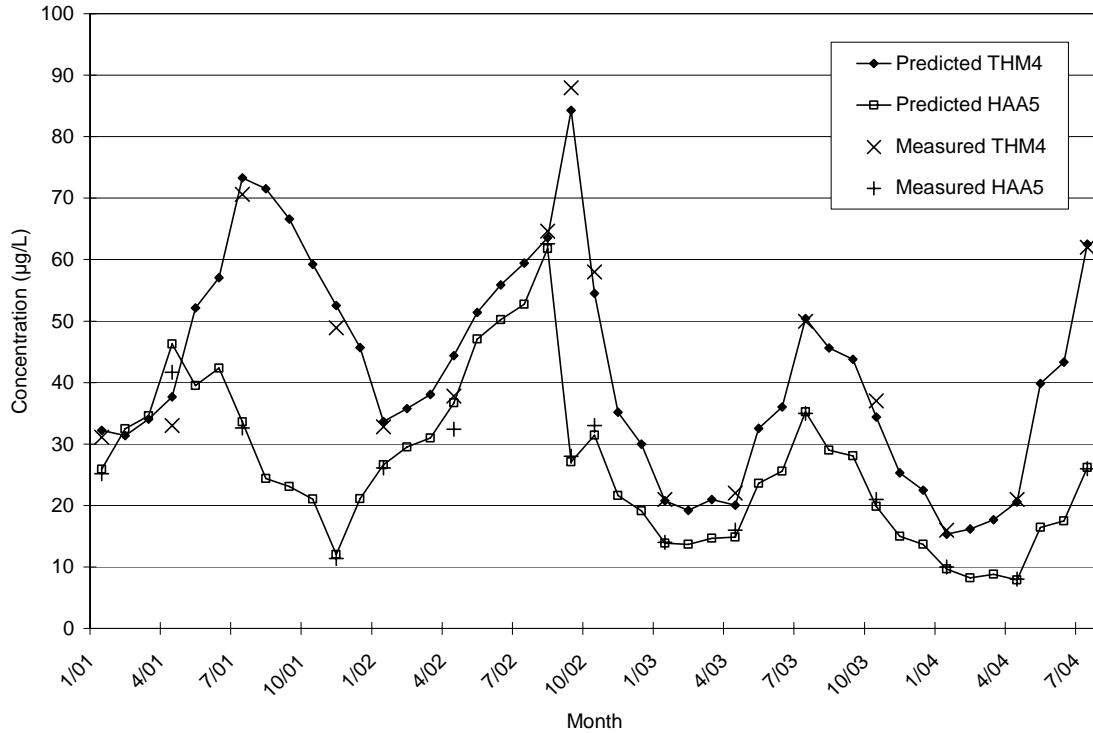


Figure 4.18 Predicted Monthly LRAA Concentrations for Location 7, t = 96 hrs (Wilmington)

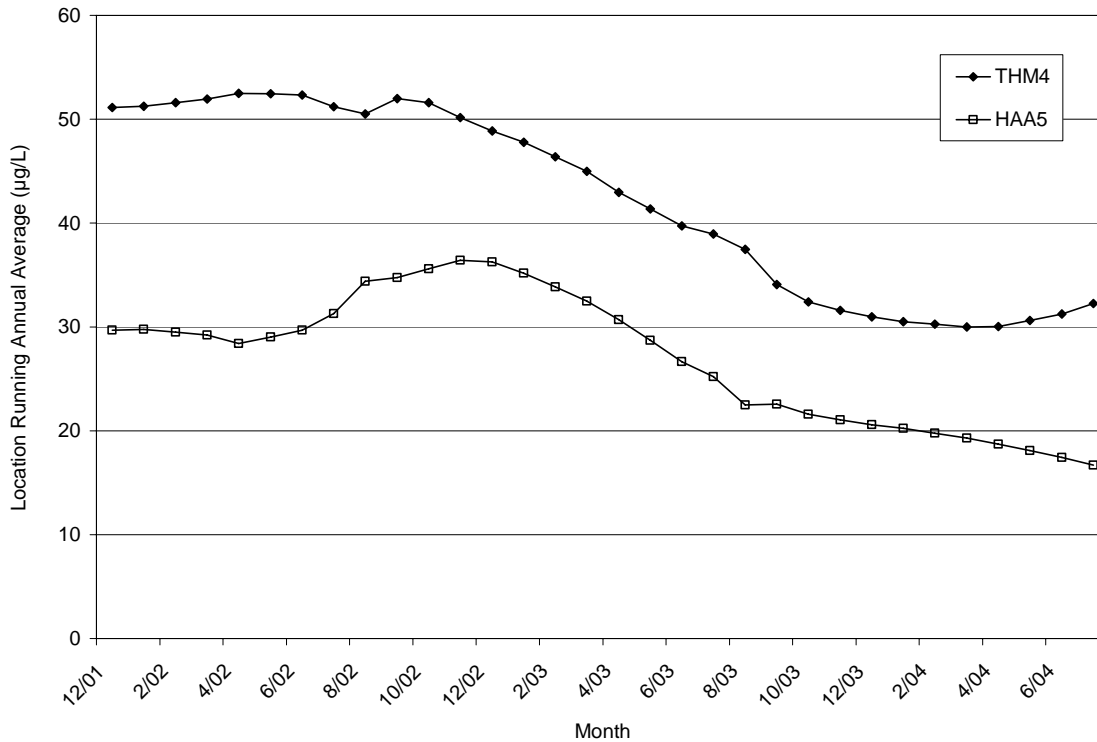


Figure 4.19 Monthly THM4 LRAA concentrations for all existing monitoring locations (Wilmington)

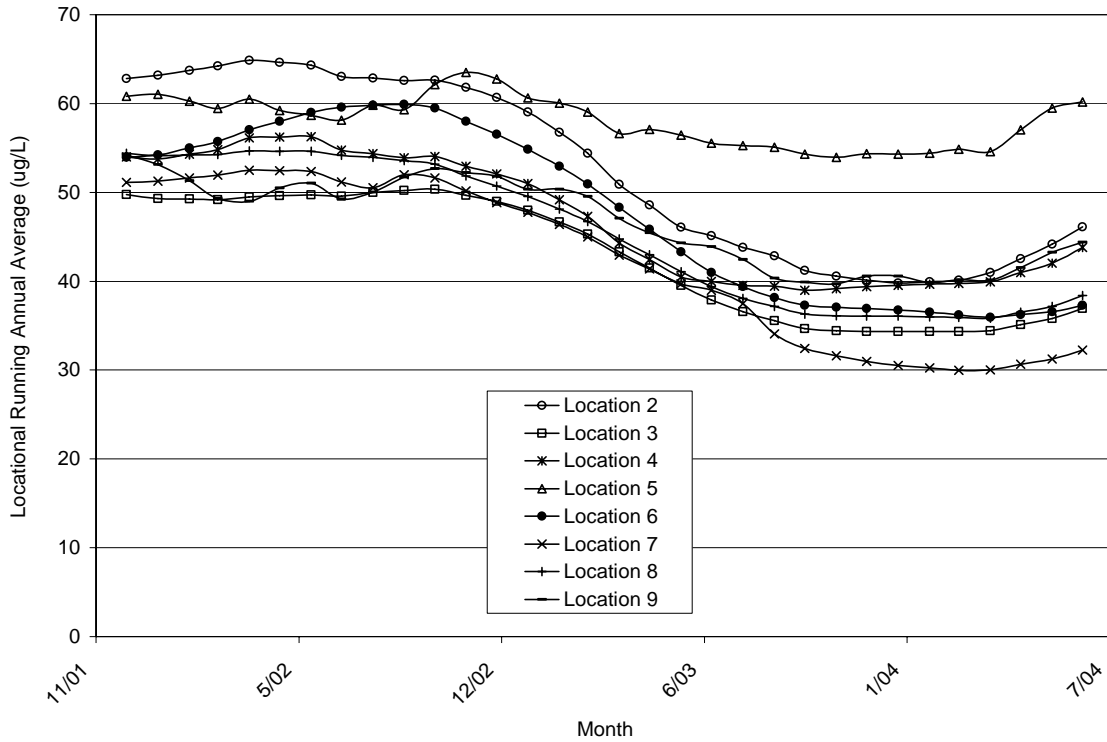


Figure 4.20 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Wilmington)

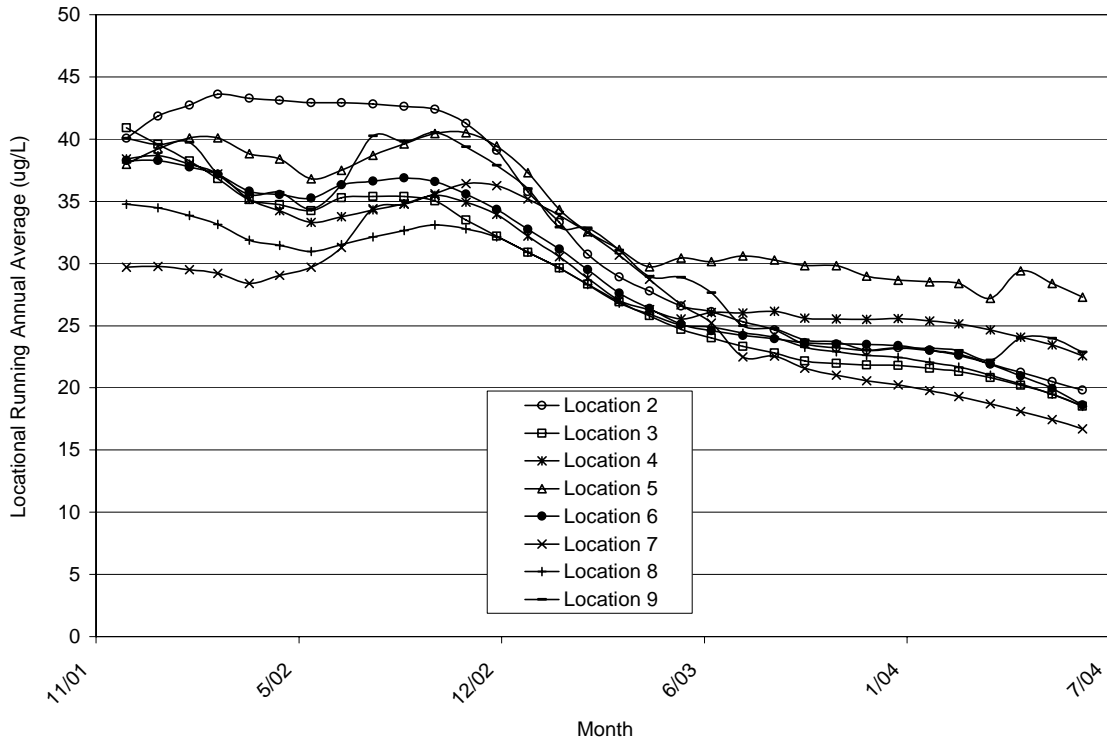


Table 4.17 Predicted DBP concentration for a hypothetical maximum residence time, t = 10 days (Wilmington)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4, t = 1 day (µg/L)	Predicted Max THM4, t = 10 days (µg/L)	Adjusted Predicted THM4, t = 10 days (µg/L)	Measured HAA5, t = 1 day (µg/L)	Predicted Max HAA5, t = 10 days (µg/L)	Adjusted Predicted HAA5, t = 10 days (µg/L)
1/23/01	10	34	62	45	27	39	32
4/3/01	16	50	92	69	50	72	61
7/10/01	27	82	150	116	33	48	40
11/19/01	16	47	85	64	28	41	34
1/9/02	11	38	70	52	27	39	32
4/3/02	16	56	103	78	35	50	42
7/3/02	29	83	152	118	51	74	63
10/2/02	26	69	127	97	29	42	35
1/7/03	13	21	39	26	9	13	10
4/2/03	19	26	48	33	18	26	21
7/2/03	26	63	116	88	41	59	50
10/1/03	24	49	90	67	25	36	30
1/7/04	15	17	31	20	8	12	9
4/7/04	20	34	62	45	8	12	9
7/7/04	27	83	152	118	26	38	31

a) Temperature at sampling location on day of sampling

which the LRAA concentrations for THM4 and HAA5 were calculated. The results are shown in Table 4.18.

Predicted maximum DBP concentrations for a hypothetical location with a residence time of 10 days is illustrated in Figure 4.21. THM4 concentrations can reach peak values as high as 140 µg/L at a residence time of 10 days, which could require a significant excursion evaluation. HAA5 concentrations, however, only slightly exceed the MCL of 60 µg/L on two occasions. Figures 4.22 and 4.23 show the predicted LRAAs for a maximum residence time of 10 days, and for residence times up to 14 days. From 11/01 to about 3/03, Wilmington would exceed the LRAA for THM4 at residence times greater than 7 days. Beyond 4/03, all LRAA values fall

Table 4.18 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Wilmington)

Month	Avg. Monthly Temp. (°C)	Maximum Monthly THM4 (µg/L)	Maximum THM4 LRAA (µg/L)	Maximum Monthly HAA5 (µg/L)	Maximum HAA5 LRAA (µg/L)
1/01	11	47		33	
2/01	12	56		45	
3/01	15	60		48	
4/01	21	80		68	
5/01	23	103		57	
6/01	27	113		61	
7/01	28	138		46	
8/01	29	115		45	
9/01	26	107		43	
10/01	22	95		39	
11/01	19	68		36	
12/01	18	65	87	37	47
1/02	12	53	88	33	47
2/02	14	65	88	38	46
3/02	16	69	89	40	45
4/02	21	91	90	48	43
5/02	24	99	90	53	43
6/02	27	108	89	57	43
7/02	29	116	88	62	44
8/02	29	113	87	50	45
9/02	26	103	87	47	45
10/02	24	96	87	35	44
11/02	17	55	86	21	43
12/02	11	47	85	18	42
1/03	11	24	82	10	40
2/03	11	26	79	14	38
3/03	14	28	75	15	36
4/03	16	30	70	20	33
5/03	20	58	67	35	32
6/03	24	64	63	37	30
7/03	27	98	62	54	30
8/03	27	89	60	44	29
9/03	26	85	58	43	29
10/03	21	67	56	30	28
11/03	19	43	55	19	28
12/03	14	38	54	18	28
1/04	11	19	54	9	28
2/04	12	28	54	8	28
3/04	15	31	54	9	27
4/04	19	46	55	9	26
5/04	24	85	58	21	25
6/04	27	93	60	22	24
7/04	28	132	63	34	22

Figure 4.21 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, $t = 10$ days (Wilmington)

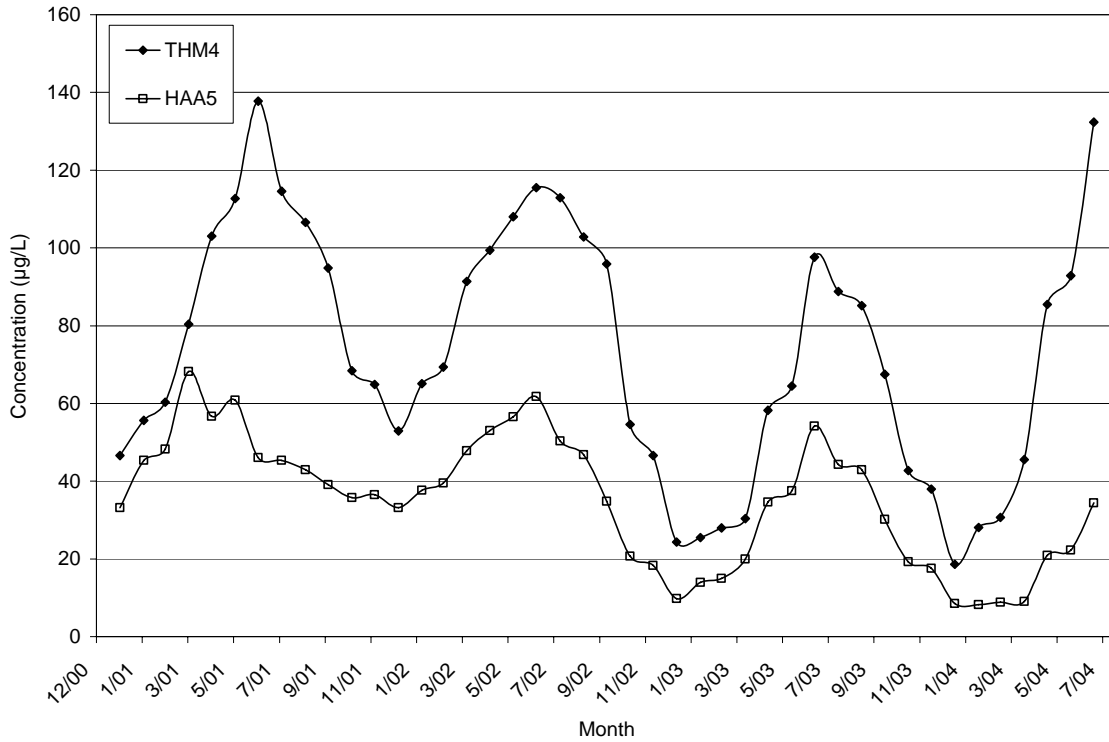


Figure 4.22 Predicted LRAAs for THM4 for various maximum residence times (Wilmington)

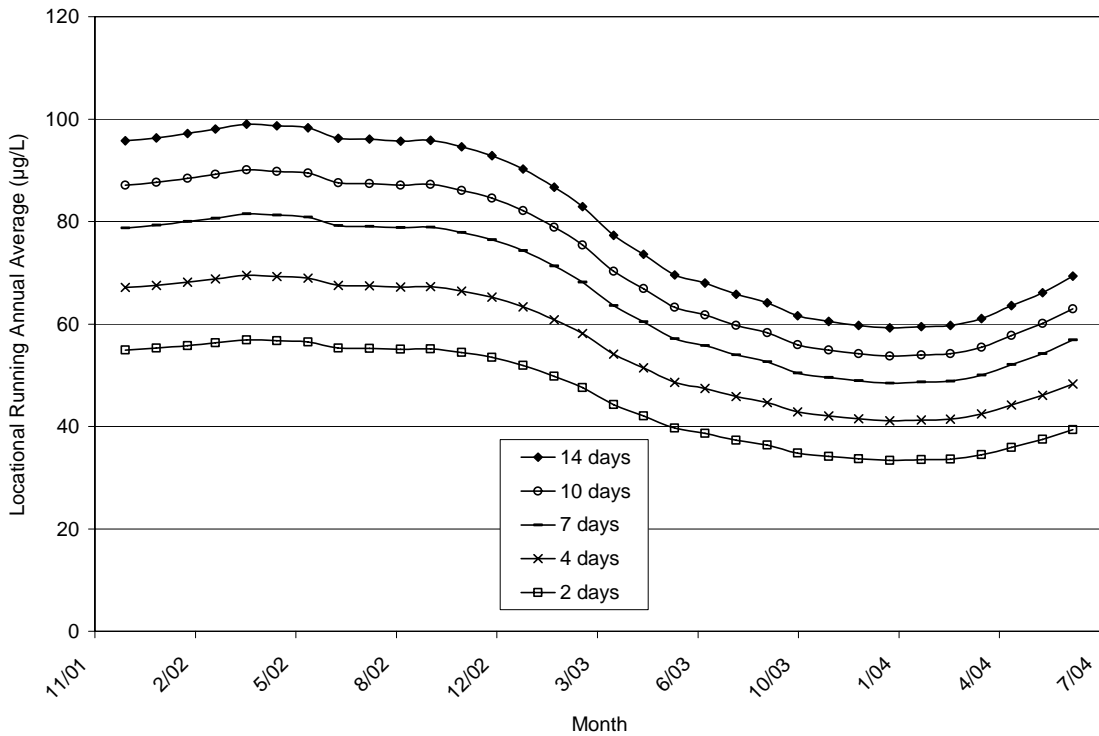
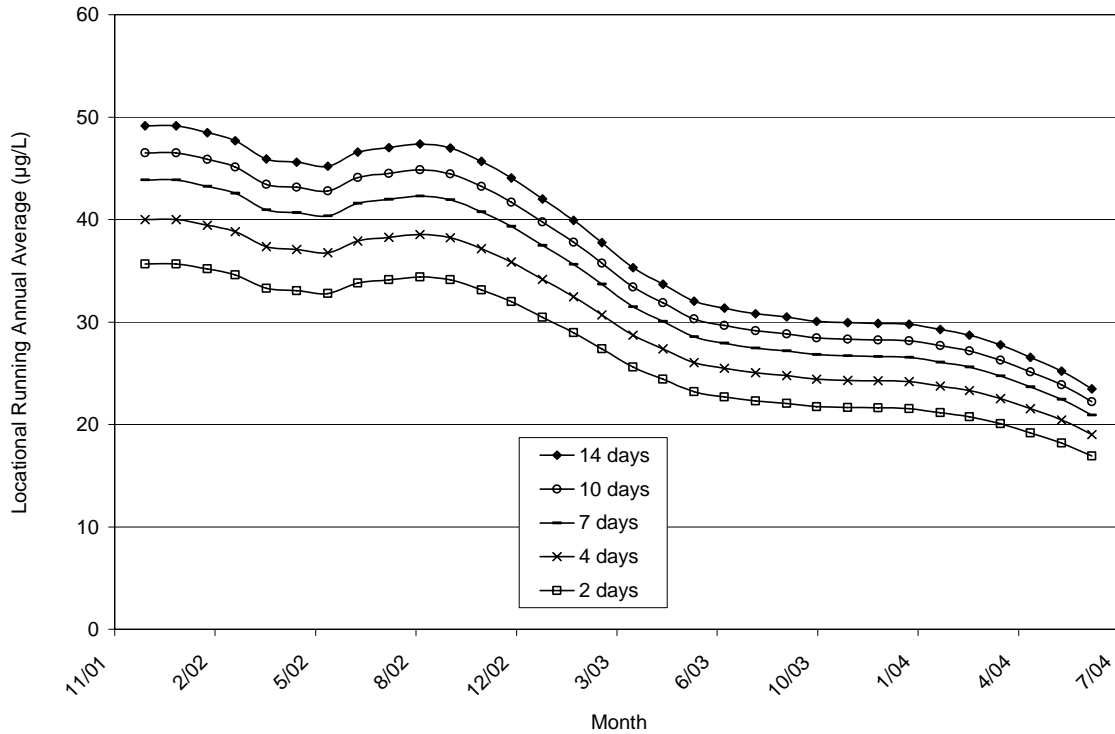


Figure 4.23 Predicted LRAAs for HAA5 for various maximum residence times (Wilmington)



below the 80 µg/L MCL for THM4, even for residence times up to 14 days. The predicted LRAAs for HAA5 all fall below the 60 µg/L MCL for HAA5 as proposed by the Stage 2 DBP Rule, even for residence times up to 14 days. Therefore, assuming that raw water quality does not change appreciably, the Wilmington utility should be able to continue to use free chlorine as its terminal disinfectant and should have no difficulty complying with the Stage 2 DBP Rule for a maximum residence time up to 7 days.

4.2.2 Winston-Salem

A record of monthly THM4 and HAA5 concentrations was developed for each of the existing sampling locations using the approach described in Chapter 3 (Equations 5 and 6). Winston-Salem’s monitoring locations are listed in Table 4.19, along with their corresponding residence times which were determined by a hydraulic model. An illustrative record of THM4 and HAA5

concentrations for Location 3 ($t = 24$ hrs) is shown in Tables 4.20 and 4.21. The corresponding records for the other existing monitoring locations are presented in Appendix B. Some sampling locations had residence times which varied by season. For these locations, residence times were assigned to sampling dates depending upon the month of sampling; sampling events which occurred between April and September were given summer residence time values, and winter residence time values were assigned for the remaining sampling events.

Figures 4.24 and 4.25 show predicted DBP and LRAA concentrations for Location 3. As shown in Figure 4.24, THM4 and HAA5 concentrations are similar throughout the time period studied and follow the same pattern. THM4 and HAA5 concentrations peak during the summer to values as high as 100 $\mu\text{g/L}$ in 2001 to significantly lower levels in 2003. The cause of this variation is not known but is most likely due to changes in raw water quality. In the proposed Stage 2 DBP Rule, peak DBP concentrations such as those found in 2001 could require significant excursion evaluations.

Figure 4.25 shows that the LRAA concentrations for Location 3 significantly decrease from 2/02 to 8/03, after which they remain relatively steady at around 33 $\mu\text{g/L}$ and 30 $\mu\text{g/L}$ for THM4 and HAA5, respectively. These values are well below the proposed MCLs of 80 $\mu\text{g/L}$ for THM4 and 60 $\mu\text{g/L}$ for HAA5. A similar trend was found for all of Winston Salem's current monitoring locations, as shown in Figures 4.26 and 4.27. Some locations exceeded the LRAA MCL for HAA5 for several months in 2002, but were below the MCL for the remainder of the period of record.

Table 4.19 Description of Distribution System Monitoring Stations (Winston-Salem)

Location	Description	Residence Time ^a (hrs)		Water Treatment Plant Serving This Location:
		Summer	Winter	
1	EP1 - Thomas WTP	0	0	
2	T15 - 15th St. Tank	12	12	Thomas
3	609 - Reidco Highway 158	24	24	Thomas
4	622 - One Stop West Mt. St.	24	36	Thomas
5	648 - Highway 66 Shell Station	36	48	Thomas
6	EP2 - Neilson WTP	0	0	
7	T02 - Sides Rd. Tank	12	12	Neilson
8	860 - Texas Robinhood Rd.	24	24	Neilson
9	857 - Mt. Tabor Animal Hospital	24	36	Neilson
10	840 - Neighbor's Food Shop	36	48	Neilson
11	961 - Allegacy Credit Union	72	72	Thomas

a) Residence times determined by a hydraulic model

Table 4.20 Measured THM4 and HAA5 Concentrations for Location 3, t = 24 hours (Winston-Salem)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4 (µg/L)	Measured HAA5 (µg/L)
3/13/01	10	39	47
5/30/01	21	92	92
9/26/01	22	83	93
12/10/01	13	42	60
2/6/02	7	17	18
5/8/02	20	31	33
8/26/02	28	74	82
12/4/02	7	17	15
2/5/03	7	22	22
5/7/03	17	26	29
8/27/03	25	47	36
11/12/03	15	40	36
2/4/04	5	13	13
5/11/04	21	32	31

a) Water temperature for Thomas WTP on day of sampling

Table 4.21 Predicted DBP and LRAA Concentrations for Location 3, t = 24 hrs (Winston-Salem)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Average Monthly THM4 (µg/L)	Predicted THM4 LRAA (µg/L)	Predicted Average Monthly HAA5 (µg/L)	Predicted HAA5 LRAA (µg/L)
3/01	10	39		47	
4/01	15	61		66	
5/01	20	89		90	
6/01	24	94		98	
7/01	26	98		101	
8/01	26	99		102	
9/01	23	86		96	
10/01	17	60		75	
11/01	13	53		68	
12/01	11	40		57	
1/02	6	26		35	
2/02	8	17	64	18	71
3/02	11	22	62	23	69
4/02	18	26	59	27	66
5/02	21	32	54	33	61
6/02	26	53	51	57	58
7/02	27	54	47	59	54
8/02	28	73	45	81	52
9/02	24	46	42	48	48
10/02	20	42	40	44	46
11/02	14	35	39	39	43
12/02	7	17	37	15	40
1/03	9	21	36	19	39
2/03	9	23	37	23	39
3/03	12	24	37	25	39
4/03	15	26	37	27	39
5/03	21	29	37	31	39
6/03	23	38	36	33	37
7/03	26	40	34	35	35
8/03	25	47	32	36	31
9/03	23	48	32	39	30
10/03	19	42	32	35	30
11/03	14	39	33	35	29
12/03	10	25	33	24	30
1/04	9	24	34	23	30
2/04	9	14	33	14	30
3/04	14	22	33	22	29
4/04	16	23	32	22	29
5/04	23	34	33	33	29

a) Average monthly water temperature for Thomas WTP

Figure 4.24 Predicted and Measured DBP Concentrations for Location 3, t = 24 hrs (Winston-Salem)

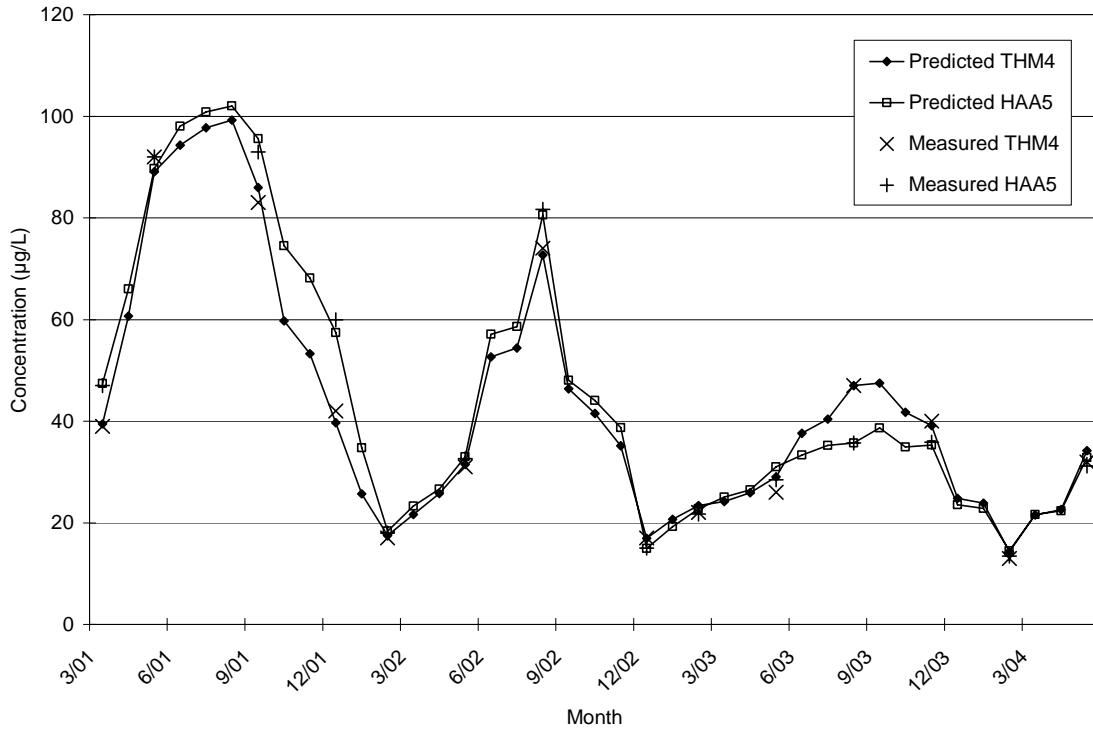


Figure 4.25 Predicted Monthly LRAA Concentrations for Location 3, t = 24 hrs (Winston-Salem)

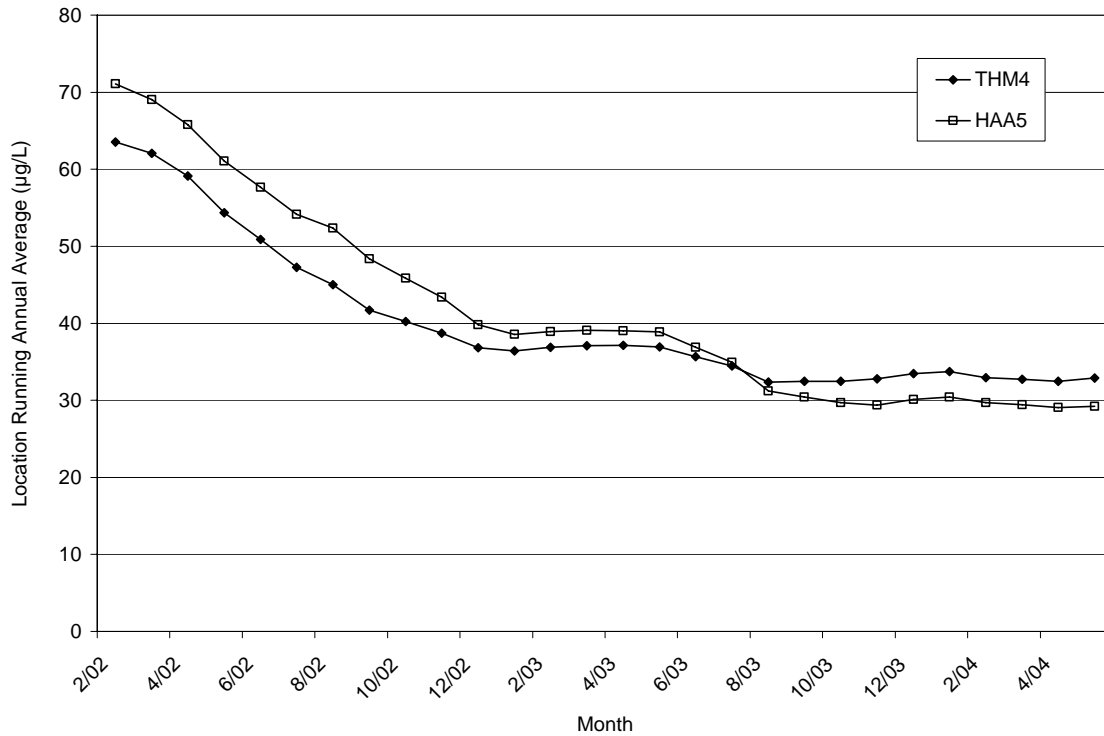


Figure 4.26 Monthly THM4 LRAA concentrations for all existing monitoring locations (Winston-Salem)

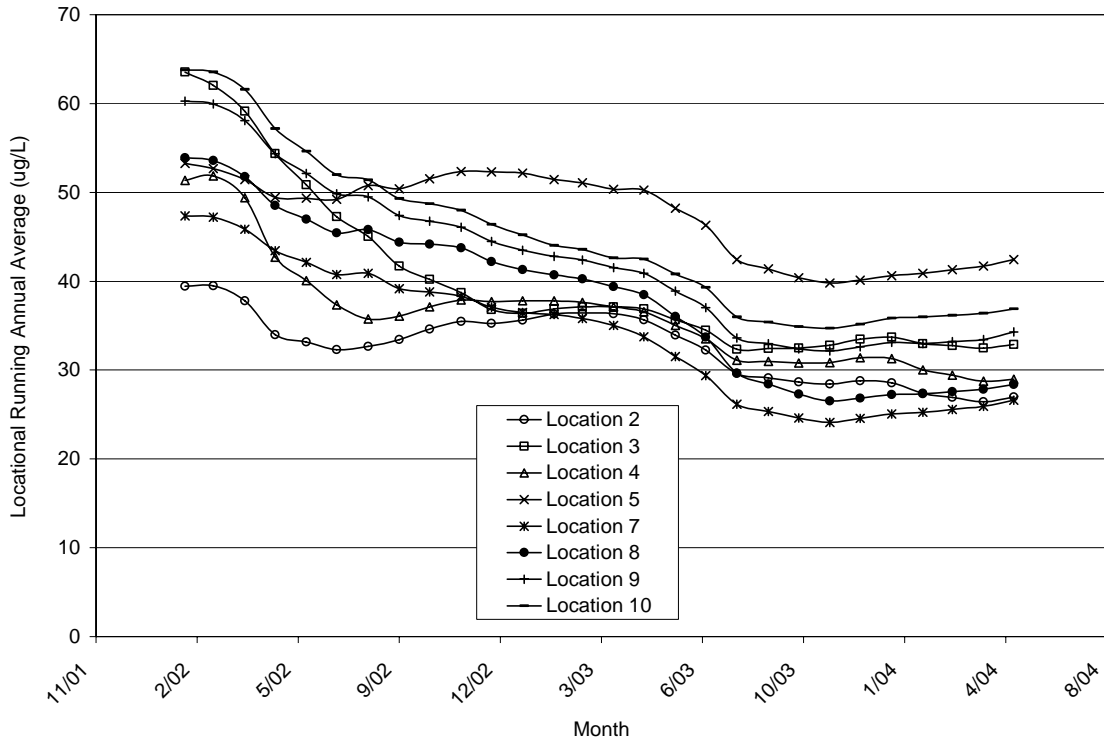
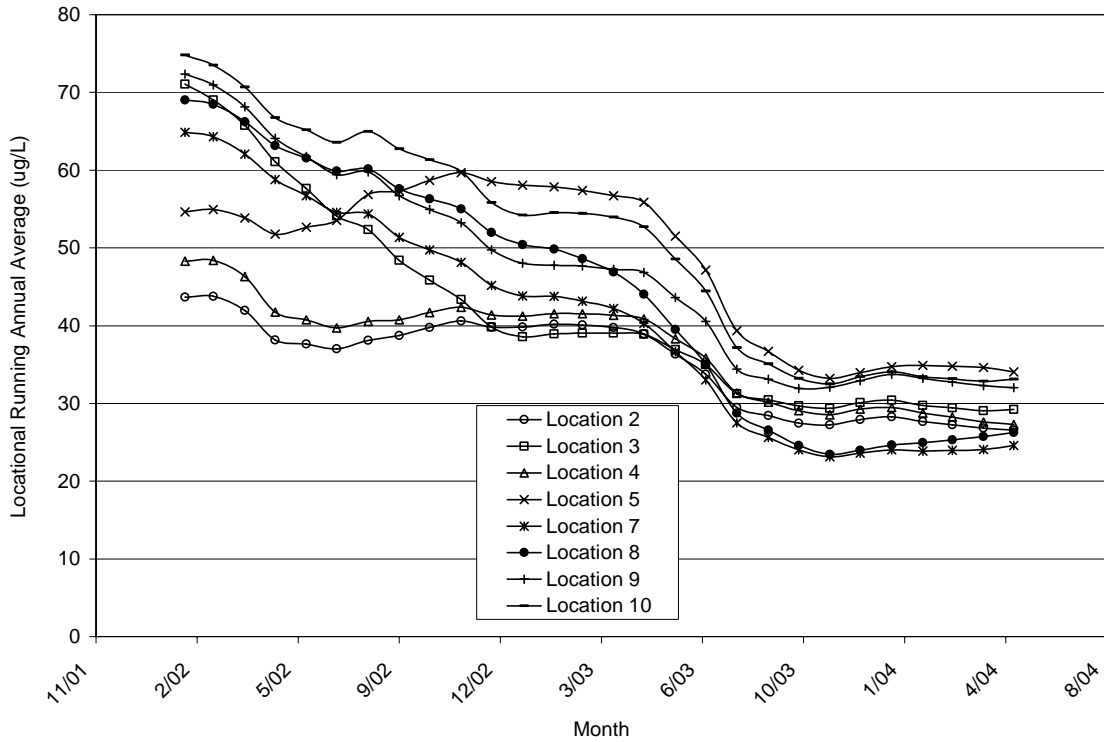


Figure 4.27 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Winston-Salem)



Equations 7 and 8, using Location 2 (t = 12 hrs) as a basis, were used to predict THM4 and HAA5 concentrations for each sampling date for a hypothetical location with a maximum residence time of 10 days. Table 4.22 shows the maximum predicted DBP concentration for each sampling date. The predicted values from Equations 7 and 8 were adjusted using the

Table 4.22 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Winston-Salem)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4, t = 12 hrs (µg/L)	Predicted Max THM4, t = 10 days (µg/L)	Adjusted Predicted THM4, t = 10 days (µg/L)	Measured HAA5, t = 12 hrs (µg/L)	Predicted Max HAA5, t = 10 days (µg/L)	Adjusted Predicted HAA5, t = 10 days (µg/L)
3/13/01	10	22	49	38	22	36	32
5/30/01	21	82	181	145	84	136	123
9/26/01	22	33	73	58	41	66	60
12/10/01	13	19	42	33	27	44	39
2/6/02	8	17	37	29	16	26	23
5/8/02	21	33	73	58	36	58	52
8/26/02	29	71	157	126	83	135	122
12/4/02	7	15	33	26	17	27	24
2/5/03	8	24	53	42	20	33	29
5/7/03	17	23	51	40	24	39	34
8/27/03	26	38	84	67	31	50	45
11/12/03	14	31	68	54	38	62	55
2/4/04	5	10	22	17	13	21	18
5/11/04	22	30	66	53	22	36	32

a) Water temperature for Thomas WTP on day of sampling

regression equations given in Figures 4.28 and 4.29. It should be noted that, in the case of Winston-Salem, the predicted THM4 and HAA5 concentrations using Equations 7 and 8 with the measured values at Location 2 as a basis, were reasonably consistent with the corresponding measured values ($R^2 = 0.880$ and 0.922 for THM4 and HAA5, respectively), although there was a slight tendency for the model to over-predict the actual concentrations. The predicted maximum quarterly DBP concentrations in Table 4.22 were used to create a record of monthly maximum DBP values using Equations 5 and 6 in the same manner as was done for the systems using a combined chlorine residual. The results are shown in Table 4.23.

Figure 4.28 Comparison between measured and predicted THM4 concentrations (Winston-Salem)

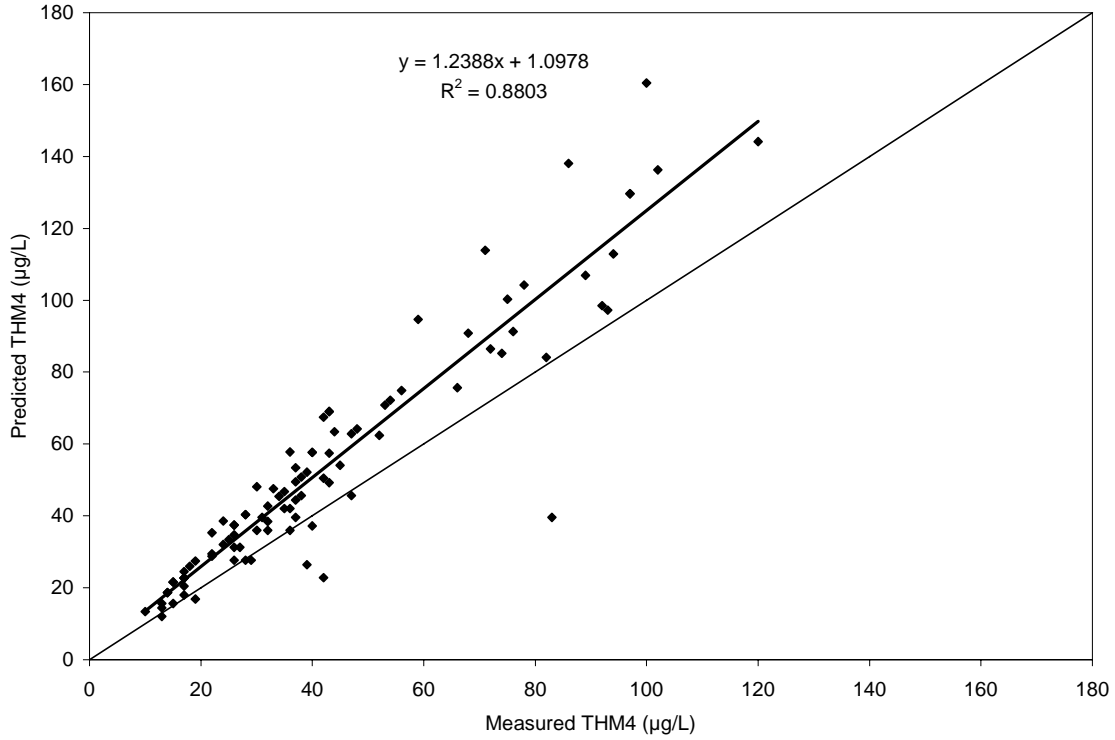


Figure 4.29 Comparison between measured and predicted HAA5 concentrations (Winston-Salem)

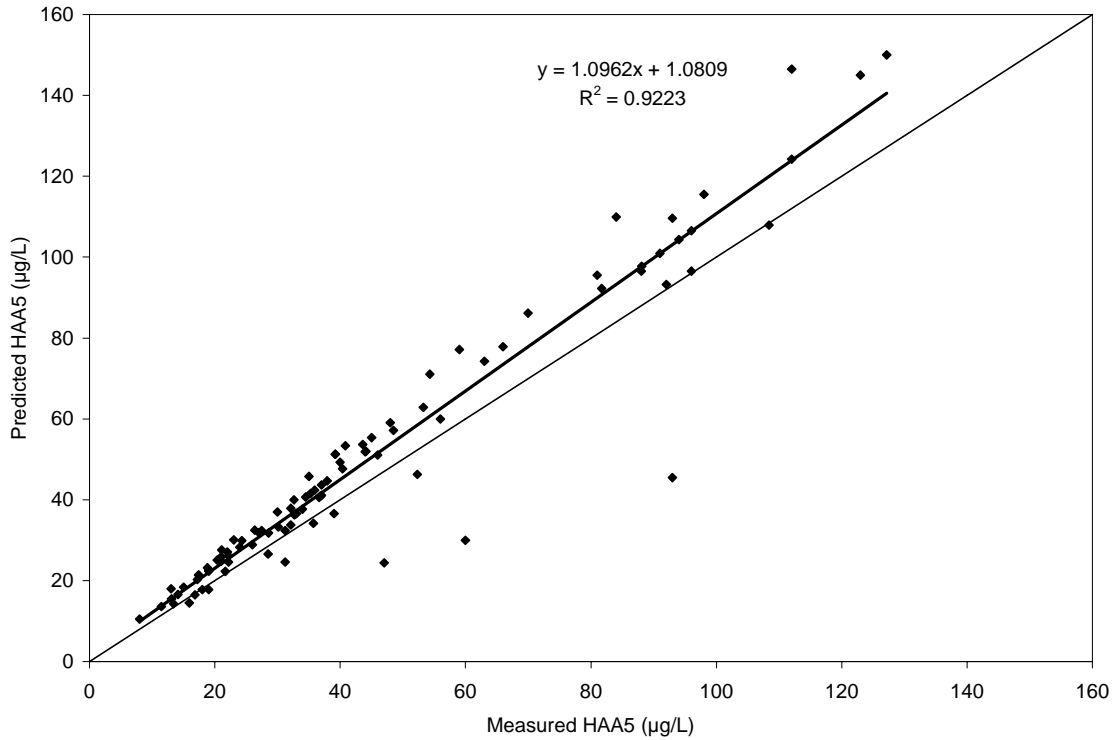


Table 4.23 Predicted maximum DBP and LRAA concentrations for a hypothetical maximum residence time, t = 10 days (Winston-Salem)

Month	Avg. Monthly Temp. (°C) ^a	Maximum Monthly THM4 (µg/L)	Maximum THM4 LRAA (µg/L)	Maximum Monthly HAA5 (µg/L)	Maximum HAA5 LRAA (µg/L)
3/01	10	38		32	
4/01	15	86		72	
5/01	20	141		120	
6/01	25	162		98	
7/01	26	167		100	
8/01	27	170		102	
9/01	23	60		61	
10/01	17	52		48	
11/01	12	45		43	
12/01	11	31		37	
1/02	6	27		28	
2/02	9	30	84	23	64
3/02	12	39	84	34	64
4/02	19	49	81	40	61
5/02	23	62	74	55	56
6/02	26	107	70	87	55
7/02	27	110	65	89	54
8/02	28	122	61	119	55
9/02	24	125	66	72	56
10/02	19	108	71	65	58
11/02	13	88	75	56	59
12/02	7	25	74	23	58
1/03	7	32	75	26	57
2/03	8	42	76	29	58
3/03	12	42	76	31	58
4/03	15	46	76	33	57
5/03	20	43	74	37	56
6/03	22	59	70	40	52
7/03	25	63	66	42	48
8/03	25	65	62	44	41
9/03	23	83	58	54	40
10/03	17	70	55	49	39
11/03	14	54	52	55	39
12/03	8	36	53	34	40
1/04	7	35	53	33	40
2/04	8	18	51	19	39
3/04	13	30	50	24	39
4/04	16	33	49	25	38
5/04	23	54	50	32	38

a) Average of monthly temperatures for Neilson and Thomas WTP

Figure 4.30 shows the predicted maximum THM4 and HAA5 concentrations at a hypothetical location with a maximum residence time of 10 days. Peak THM4 concentrations range from 170 µg/L down to 80 µg/L during the summers of 2001 and 2003, respectively, and peak HAA5 concentrations range from 120 µg/L down to 60 µg/L over the same time period. Some of the predicted values are twice the MCLs of 80 µg/L and 60 µg/L for THM4 and HAA5, respectively, and may require significant excursion evaluations under the proposed Stage 2 DBP Rule.

Figures 4.31 and 4.32 show the LRAAs for THM4 and HAA5, respectively, for the hypothetical location with a maximum residence time of 10 days, and also show how the predicted maximum LRAA concentrations would change with different maximum residence times. As shown Figure 4.31, the predicted LRAA concentrations for THM4 range from 52 µg/L to 92 µg/L in January 2002 for residence times of 2-14 days, decreasing to a range of 30 to 60 µg/L starting 10/03. Figure 4.32 shows a similar trend for the predicted maximum LRAA concentrations for HAA5, which show a range of 50 to 70 µg/L in January 2002 and then decreasing to a range of 30 to 40 µg/L starting 10/03. The cause of these very pronounced differences from year to year are not known, but the difference are critical to Winston-Salem's posture with respect to DBP compliance.

Therefore, if Winston-Salem continues to use free chlorine as its terminal disinfectant, the ability of Winston-Salem to comply with the proposed Stage 2 DBP Rule depends significantly on raw water quality and the maximum residence time in the Winston-Salem system. For water quality and treatment conditions such as those encountered since 10/03, Winston-Salem should be able to meet the LRAA MCLs for residence times up to 2 weeks (14 days). For water quality and

Figure 4.30 Predicted maximum DBP concentrations for a hypothetical maximum residence time, $t = 10$ days (Winston-Salem)

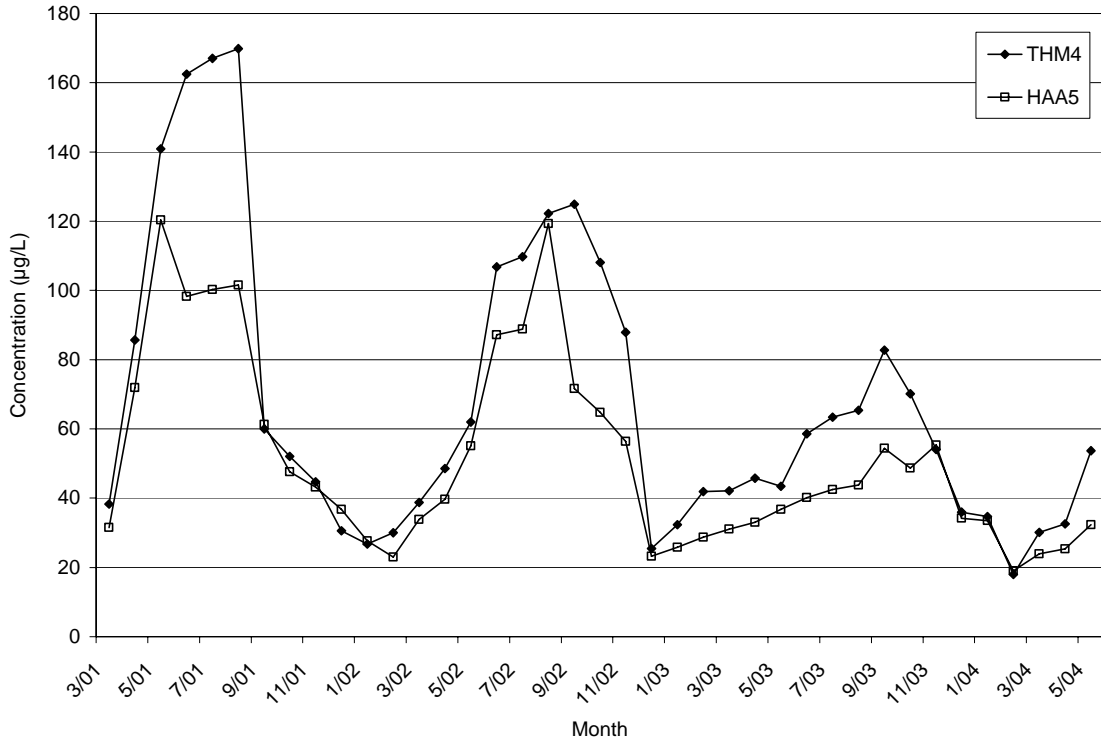


Figure 4.31 Predicted LRAAs for THM4 for various maximum residence (Winston-Salem)

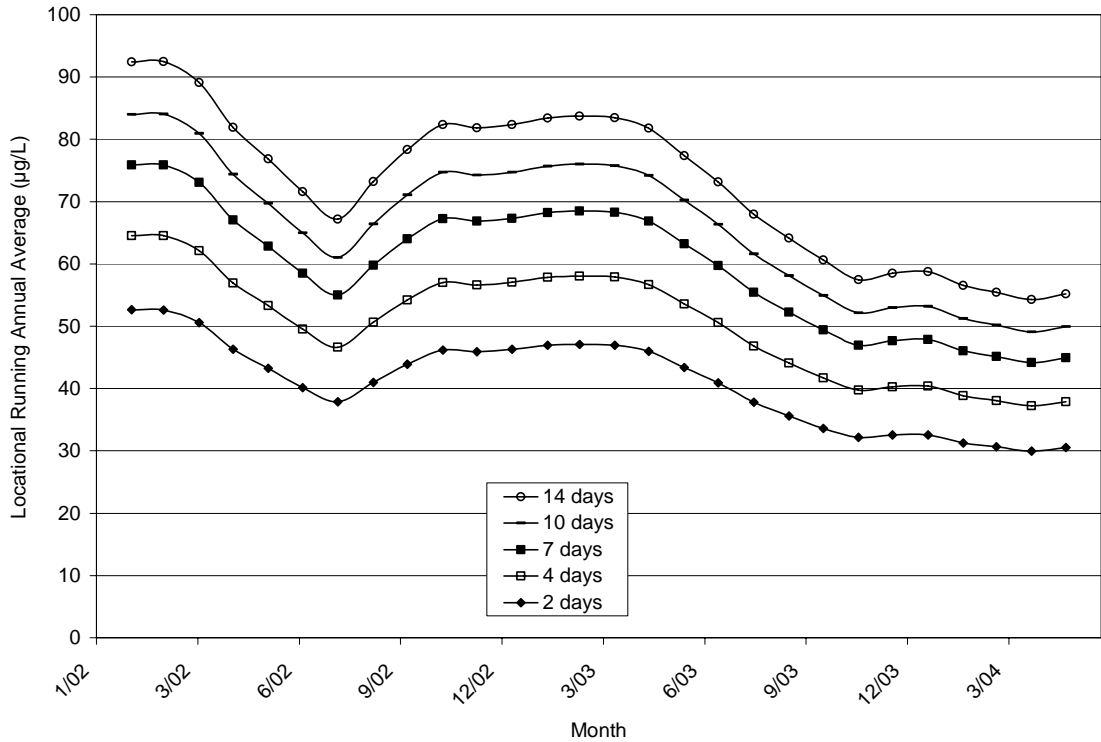
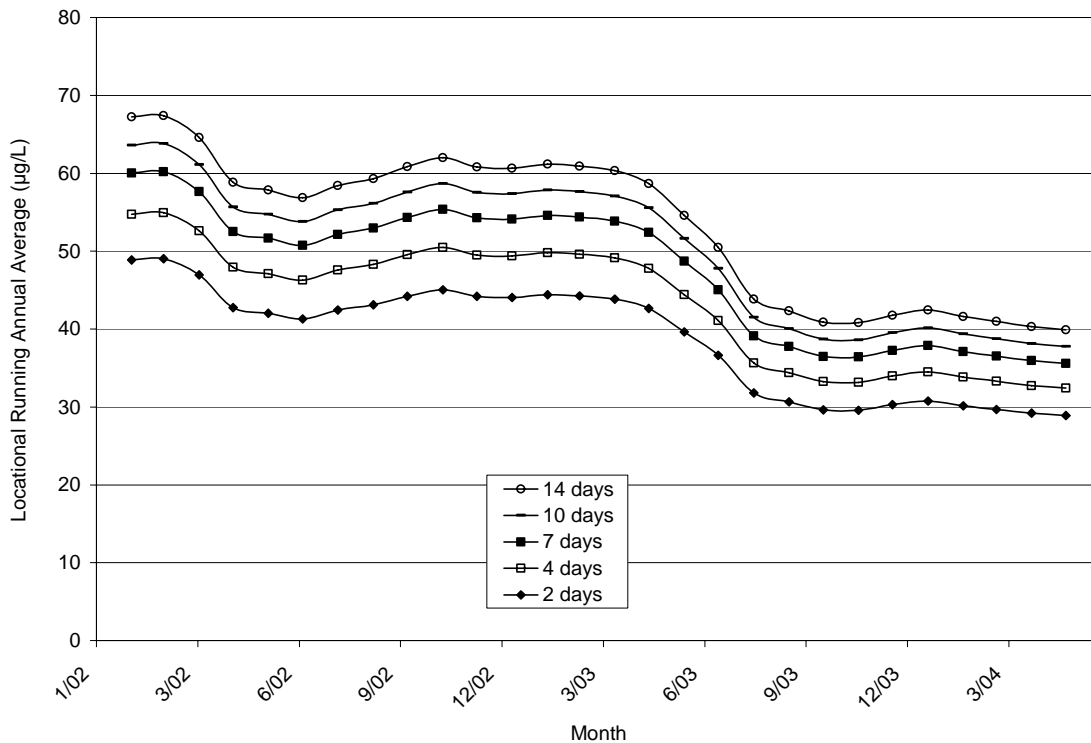


Figure 4.32 Predicted LRAAs for HAA5 for various maximum residence times (Winston-Salem)



treatment conditions such as those encountered in 2001, Winston-Salem would be expected to meet the LRAA MCL for THM4 only at residence times of about 2 days and would not be expected to meet the LRAA MCL for HAA5 at residence times of 2 days or more.

4.2.3 Greensboro

Monthly DBP and LRAA concentrations were predicted from quarterly THM4 and HAA5 values using Equations 5 and 6 for all eight distribution system monitoring locations in Greensboro, as listed in Table 4.24. Measured quarterly THM4 and HAA5 values for Location 1 (t = 13 hrs) are given in Table 4.25, and predicted monthly values are given in Table 4.26. Figures 4.33 and 4.34 illustrate the record of predicted monthly DBP and LRAA concentrations for Location 1. The corresponding predictions for the other monitoring locations are presented in Appendix C.

Table 4.24 Description of distribution system monitoring locations (Greensboro)

Location	Description	Residence Time ^a (hrs)	Water Treatment Plant Serving This Location
1	005 - Church St./Cornwallis Fire Station	13	Townsend
2	006 - Bessemer Village Laundry - Bessemer/ Huffine Mill	11	Townsend
3	009 - Citco Pop Shop - W. Market/Stagecoach Trail	30	Mitchell
4	010 - McDonald's - Battleground/Westridge	20	Townsend
5	012 - McDonald's - Adam's Farm Shopping Center	50	Townsend
6	013 - Southeast Launderette-Pleasant Garden/US 421	24	Mitchell
7	014 - Wilco/Wendy's - Mt. Hope Church/Interstate 85	36	Townsend
8	015 - Coliseum - High Point Road/Patterson St.	6.5	Mitchell

a) Residence times determined by a hydraulic model

Table 4.25 Measured THM4 and HAA5 Concentrations for Location 1, t = 13 hours (Greensboro)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4 (µg/L)	Measured HAA5 (µg/L)
3/15/01	14	47	27
6/21/01	26	42	23
9/26/01	24	49	31
12/13/01	12	24	25
3/20/02	15	13	9
6/21/02	26	44	34
9/24/02	24	92	77
12/18/02	11	34	27
3/17/03	12	35	27
6/11/03	23	83	65
9/4/03	28	89	48
12/3/03	15	34	35
3/2/04	10	29	26
6/9/04	26	55	29

a) Raw water temperature at Townsend WTP on day of sampling

Table 4.26 Predicted Average Monthly DBP and LRAA concentrations for Location 1, t = 13 hrs (Greensboro)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Average Monthly THM4 (µg/L)	Predicted THM4 LRAA (µg/L)	Predicted Average Monthly HAA5 (µg/L)	Predicted HAA5 LRAA (µg/L)
3/01	14	46		27	
4/01	18	43		24	
5/01	22	48		26	
6/01	26	43		23	
7/01	27	49		28	
8/01	27	49		28	
9/01	25	50		31	
10/01	20	37		29	
11/01	17	34		27	
12/01	15	26		27	
1/02	11	17		16	
2/02	12	18	38	17	25
3/02	14	13	36	9	24
4/02	20	26	34	20	24
5/02	22	28	32	21	23
6/02	27	44	33	34	24
7/02	27	73	35	59	27
8/02	27	73	37	59	29
9/02	24	92	40	77	33
10/02	22	66	42	54	35
11/02	16	57	44	48	37
12/02	12	35	45	28	37
1/03	9	32	46	26	38
2/03	4	28	47	23	38
3/03	13	36	49	27	40
4/03	16	54	51	43	41
5/03	21	62	54	47	44
6/03	24	85	58	66	46
7/03	27	90	59	59	46
8/03	27	91	61	59	46
9/03	25	83	60	45	44
10/03	21	57	59	41	43
11/03	18	52	59	38	42
12/03	11	30	58	33	42
1/04	9	28	58	28	42
2/04	8	28	58	28	43
3/04	13	32	58	27	43
4/04	18	40	56	27	42
5/04	25	48	55	32	40
6/04	27	56	53	29	37

a) Average monthly raw water temperature for Townsend WTP

Figure 4.33 Predicted and Measured DBP Concentrations for Location 1, t = 13 hrs (Greensboro)

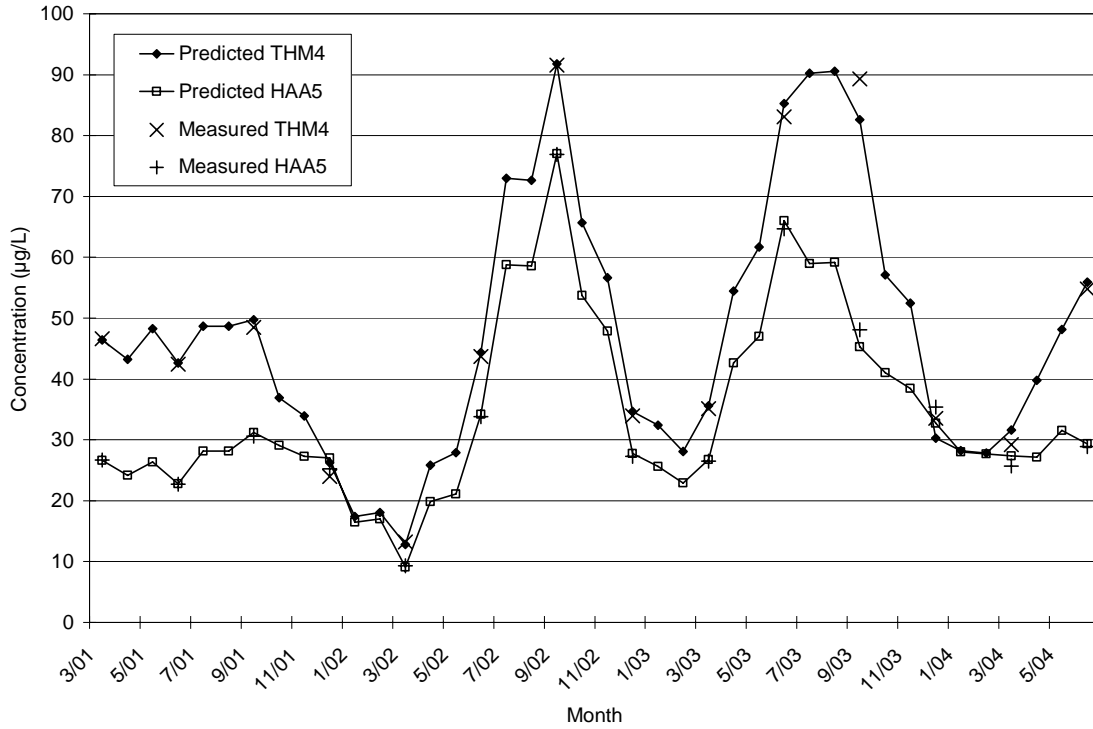
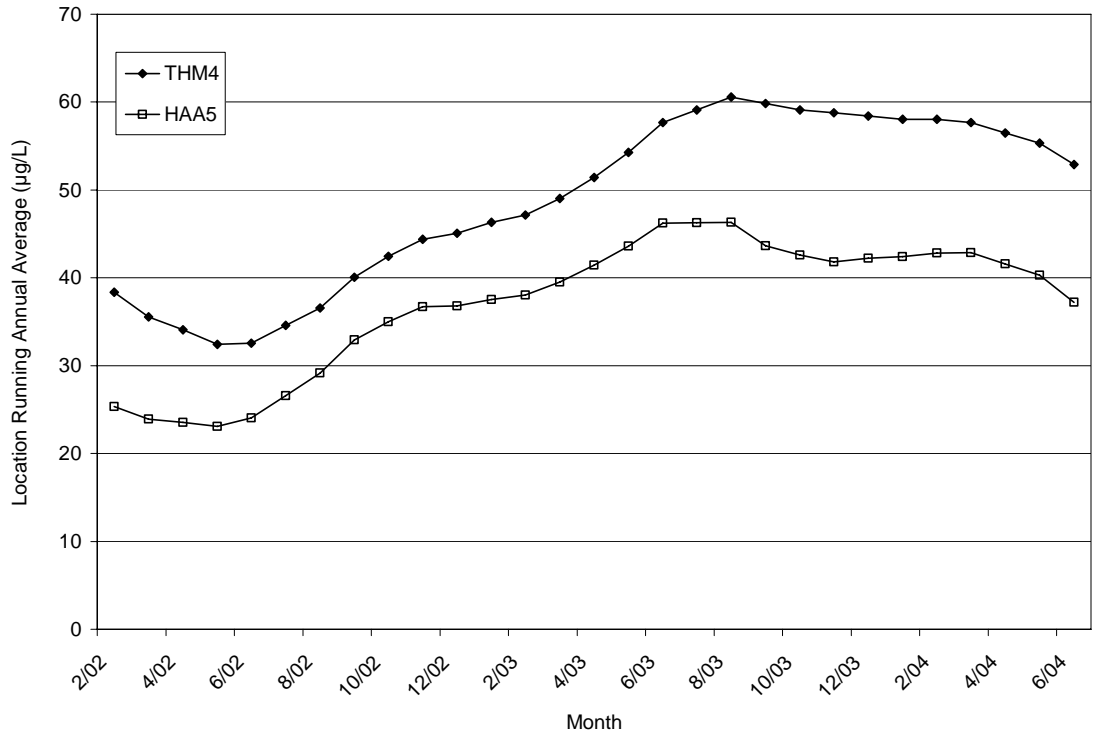


Figure 4.34 Predicted Monthly LRAA concentrations for Location 1, t = 13 hrs (Greensboro)



THM4 and HAA5 concentrations at Location 1 peak at levels higher than the 80 µg/L and 60 µg/L MCLs, respectively, in the summer of 2002 and 2003, whereas DBP concentrations in 2001 were well below the MCLs for both THM4 and HAA5. Figure 4.34 shows that the LRAAs for THM4 and HAA5 at Location 1 increase significantly from 6/02 to 8/03, but all values remain below the LRAA MCLs. Therefore, Location 1 (t = 13 hrs) should be in compliance with the Stage 2 DBP Rule.

Figure 4.35 and 4.36 show predicted monthly THM4 and HAA5 LRAA concentrations for all of Greensboro's existing monitoring locations. Location 7 (t = 36 hrs) exceeded the LRAA MCL for THM4 through most of 2003, and Location 3 (t = 30 hrs) came close to the LRAA MCL for THM4 in 2004. The other locations, even Location 5 with a reported residence time of 50 hrs, do not appear to be in danger of exceeding the LRAA MCLs.

In order to determine the maximum THM4 and HAA5 concentrations that could be expected in the distribution system, the time-adjustment model represented by Equations 7 and 8 were used as described in Chapter 3, utilizing Location 8 (t = 6.5 hrs) as a reference point. Table 4. shows predicted THM4 and HAA5 concentrations for a hypothetical maximum residence time of 10 days based on the measurements at Location 8 for each sampling date. These predicted values were then adjusted using the regression equations given in Figures 4.37 and 4.38. Again these regression equations were developed from a comparison of the predicted THM4 and HAA5 concentrations for the other seven existing monitoring locations using Equations 7 and 8 with Location 8 as a basis and the measured THM4 and HAA5 concentrations at these same locations. These adjusted values were then used to develop a record of maximum monthly DBP

Figure 4.35 Monthly THM4 LRAA concentrations for all existing monitoring locations (Greensboro)

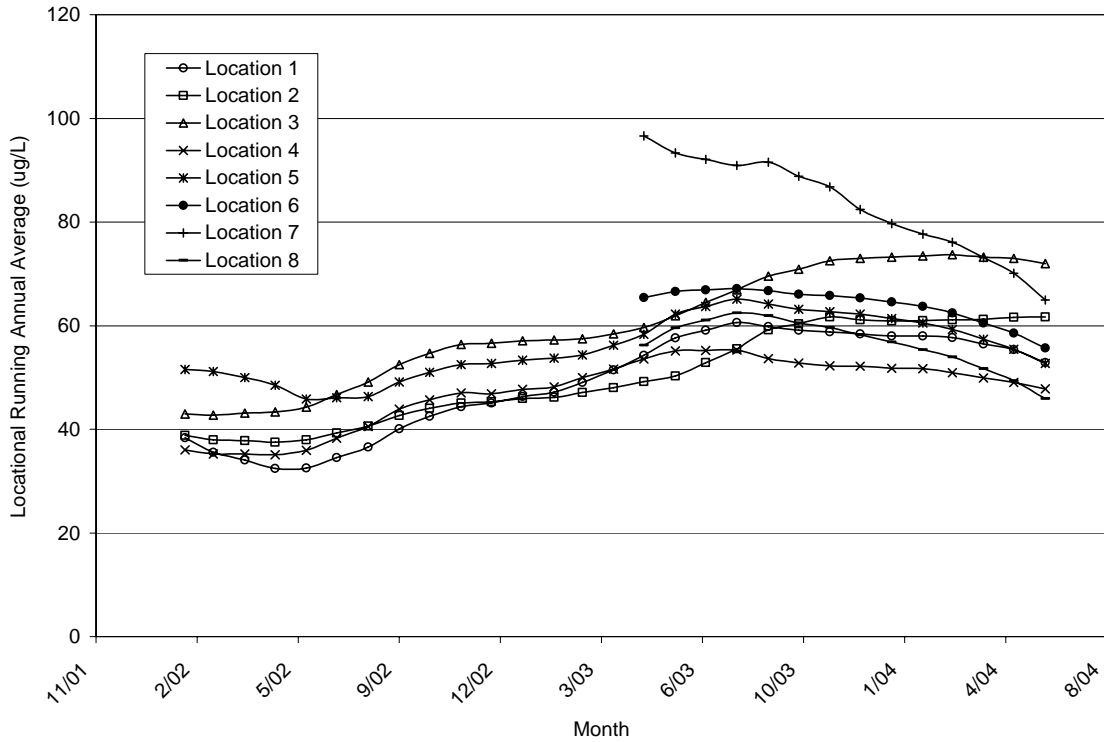


Figure 4.36 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Greensboro)

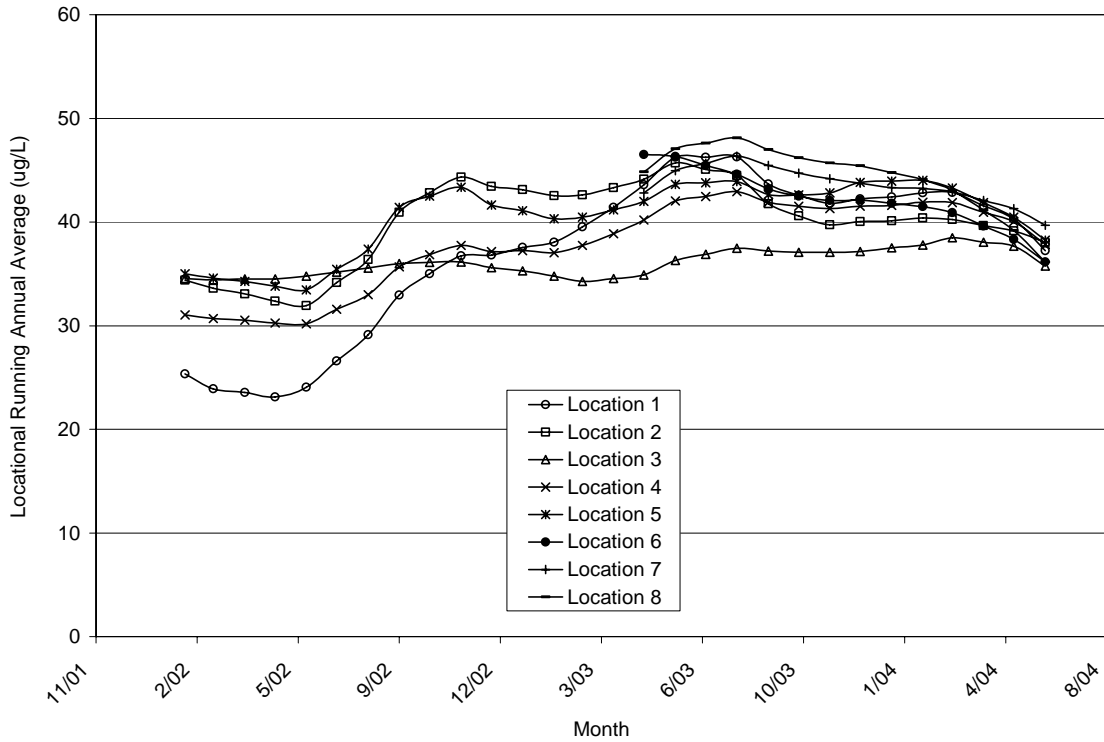


Table 4.27 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Greensboro)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4, t = 6.5 hrs (µg/L)	Predicted Max THM4, t = 10 days (µg/L)	Adjusted Predicted THM4, t = 10 days (µg/L)	Measured HAA5, t = 6.5 hrs (µg/L)	Predicted Max HAA5, t = 10 days (µg/L)	Adjusted Predicted HAA5, t = 10 days (µg/L)
6/21/02	26	40	102	94	31	55	46
9/24/02	25	91	236	242	68	122	109
12/18/02	8	42	108	101	34	61	51
3/17/03	13	41	106	97	39	69	59
6/11/03	23	79	206	208	57	102	90
9/4/03	27	88	229	234	57	101	89
12/3/03	13	28	74	62	34	60	51
3/2/04	11	21	53	39	24	42	34
6/9/04	25	39	101	92	21	37	29

b) Average raw water temperature at Mitchell plant on day of sample

concentrations using Equations 5 and 6 as described in Chapter 3. The result is shown in Table 4.28.

Figure 4.39 shows the predicted THM4 and HAA5 concentrations for a hypothetical location with a maximum residence time of 10 days. Peak values greater than twice the MCL of 80 µg/L for THM4 are predicted in the summer months of 2002 and 2003. Predicted HAA5 concentrations also exceed the MCL of 60 µg/L for the same time periods. Under the proposed Stage 2 DBP Rule, these values could represent significant excursions and require further evaluation.

Figures 4.40 and 4.41 show the LRAAs for THM4 and HAA5, respectively, for a hypothetical location with a maximum residence time of 10 days and for other potential maximum residence times from 2-14 days. For THM4, locations with residence times as low as 2 days would appear to have difficulty complying with the new Rule (see for example Locations 3 and 7 in Figure

Figure 4.37 Comparison between measured and predicted THM4 concentrations (Greensboro)

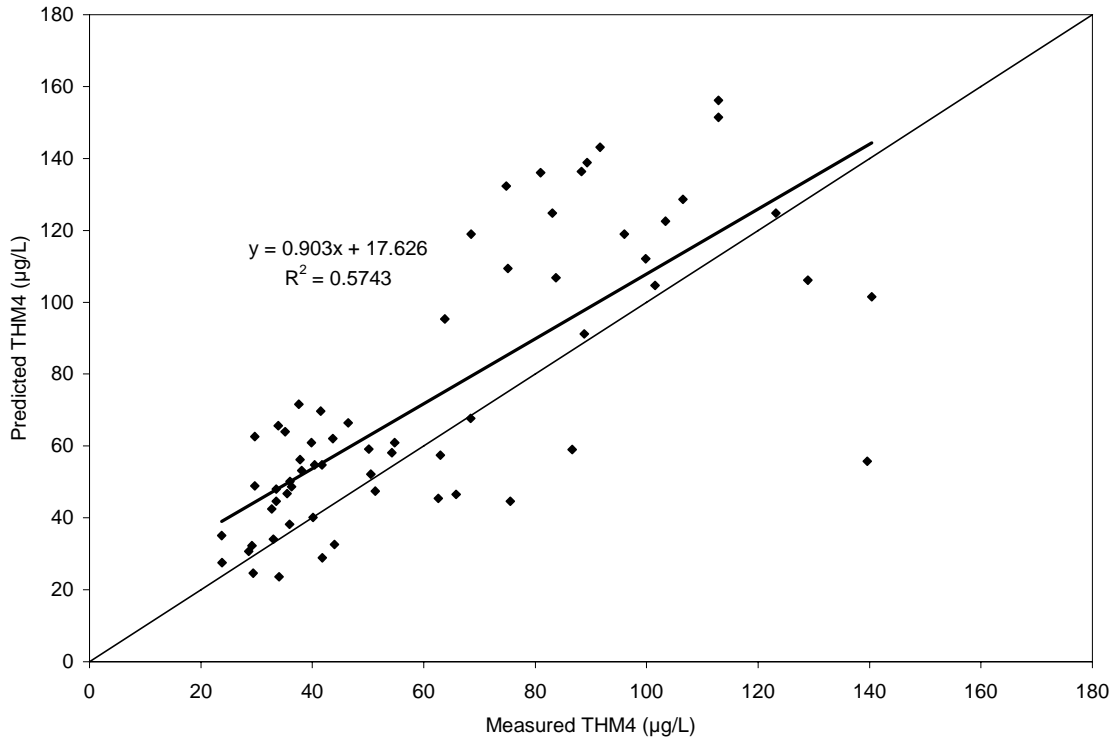


Figure 4.38 Comparison between measured and predicted HAA5 concentrations (Greensboro)

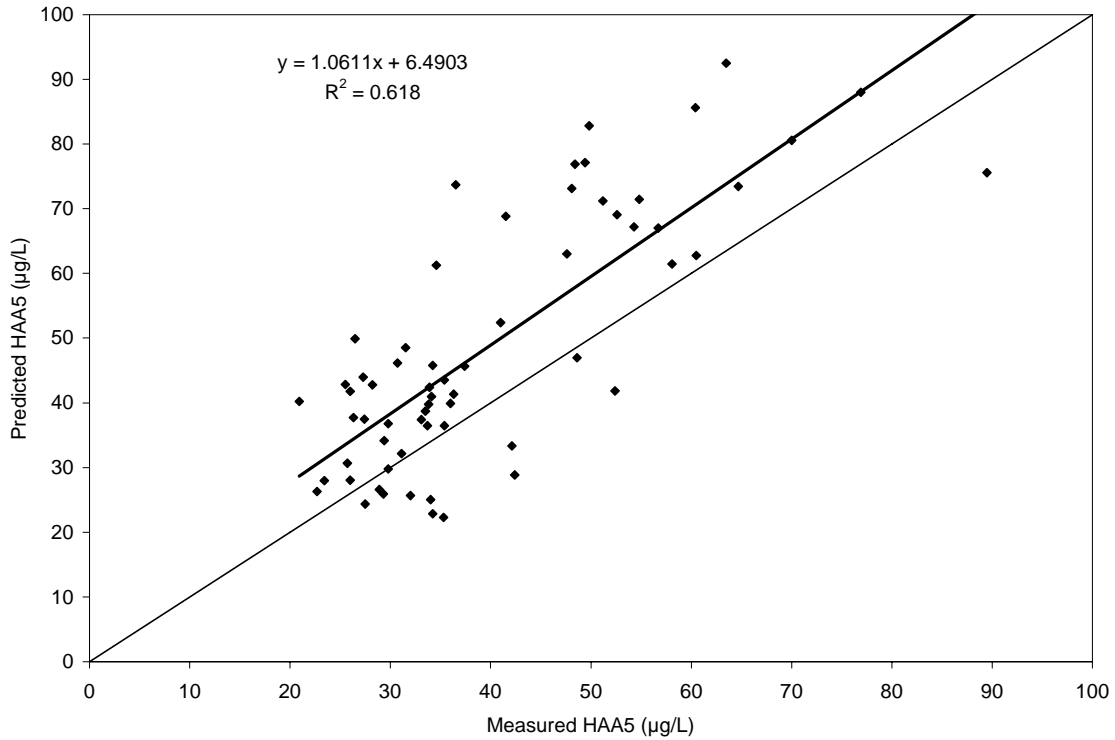


Table 4.28 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Greensboro)

Month	Avg. Monthly Temp. (°C) ^a	Maximum Monthly THM4 (µg/L)	Maximum THM4 LRAA (µg/L)	Maximum Monthly HAA5 (µg/L)	Maximum HAA5 LRAA (µg/L)
6/02	26	94		46	
7/02	27	179		81	
8/02	27	179		81	
9/02	24	240		108	
10/02	21	181		84	
11/02	16	155		74	
12/02	11	104		52	
1/03	9	93		52	
2/03	6	87		50	
3/03	12	97		59	
4/03	16	140		70	
5/03	21	158	142	77	70
6/03	24	212	152	91	73
7/03	27	229	156	92	74
8/03	27	229	160	92	75
9/03	25	218	159	84	73
10/03	21	135	155	68	72
11/03	18	124	152	64	71
12/03	11	57	148	47	71
1/04	9	46	144	39	69
2/04	8	45	141	39	69
3/04	13	43	136	36	67
4/04	17	61	130	32	63
5/04	24	72	123	36	60
6/04	26	93	113	29	55

a) Average of monthly temperatures of Mitchell and Townsend WTPs

4.35), whereas for HAA5, locations with a residence time less than 2 days should be able to comply with the Rule. Accordingly, Greensboro will have difficulty complying with the proposed Stage 2 Rule using free chlorine as a terminal disinfectant.

Figure 4.39 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, $t = 10$ days (Greensboro)



Figure 4.40 Predicted LRAAs for THM4 for various maximum residence times (Greensboro)

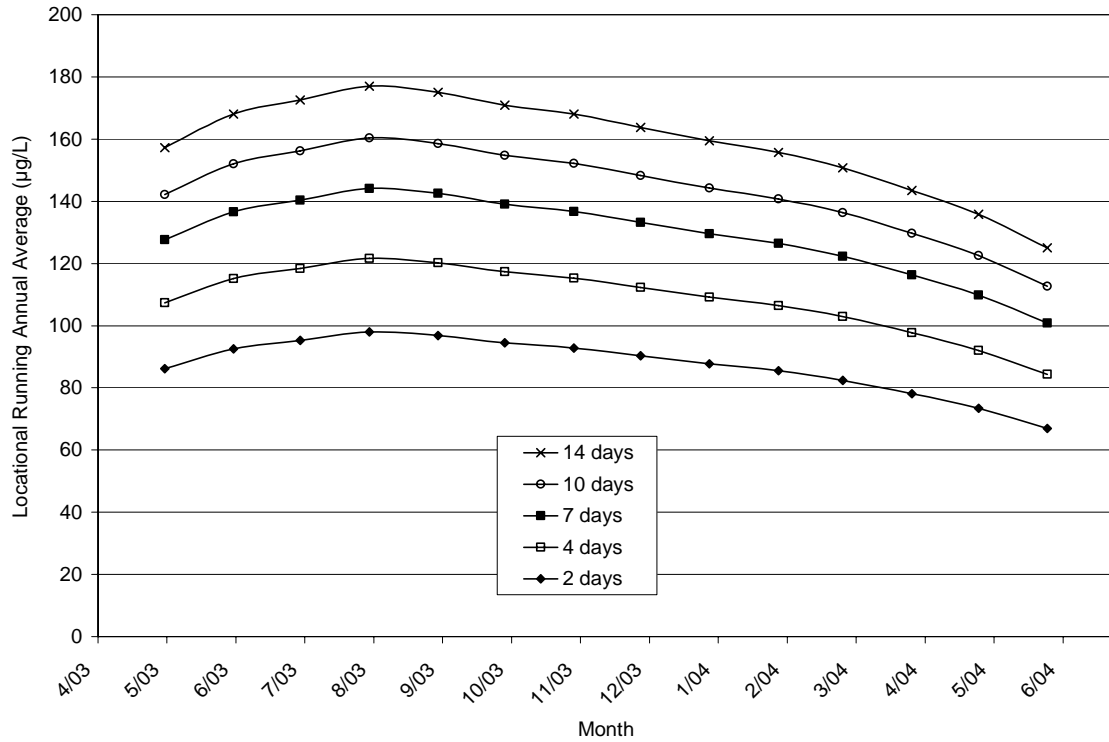
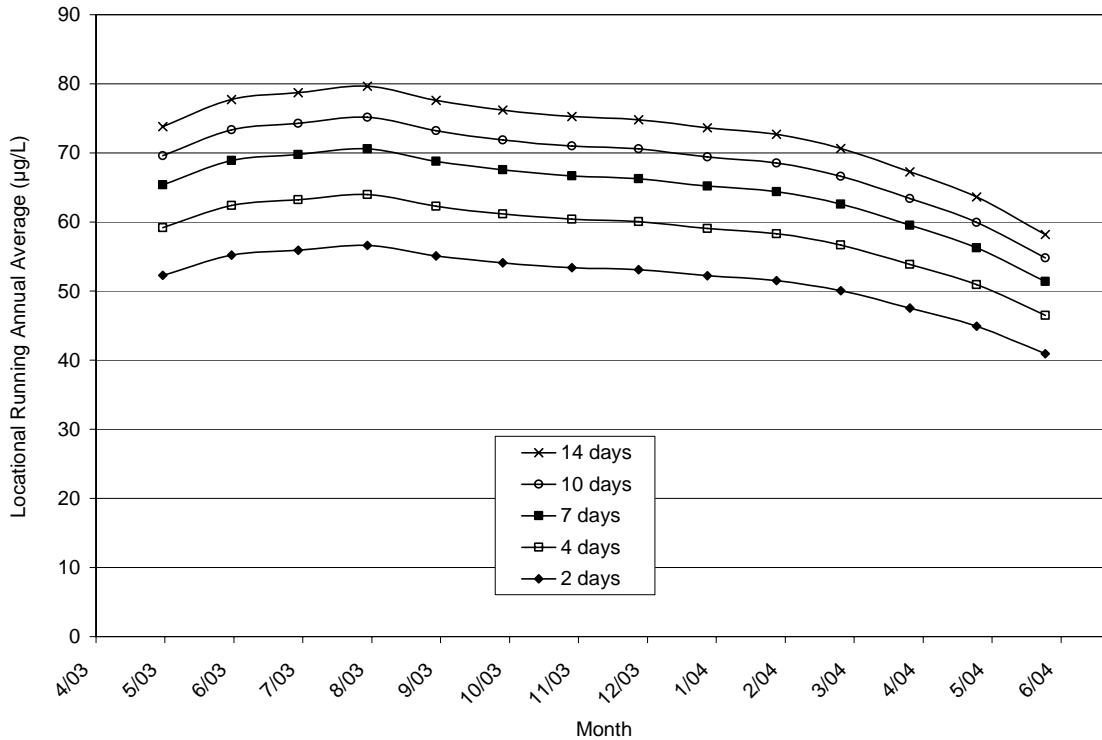


Figure 4.41 Predicted LRAAs for HAA5 for various maximum residence times (Greensboro)



4.2.4 Charlotte

Table 4.29 presents a list of Charlotte’s monitoring locations with their corresponding residence times, which are estimates provided by utility personnel. A record of monthly DBP concentrations for each location was created from the quarterly measured DBP concentrations and the temperature-adjustment model given by Equations 5 and 6 in Chapter 3. An illustrative example for Location 3 is given in Tables 4.30 and 4.31. A corresponding record for each monitoring location is included as Appendix D. Electronic files of HAA5 monitoring data were only available since 2/03 and for THM4 since 2/02.

Figures 4.42 and 4.43 show predicted monthly DBP and LRAA concentrations, respectively, for Location 3. Figure 4.42 shows that THM4 and HAA5 concentrations at Location 3 peak during the summer months. In addition, the THM4 concentration for 8/03 is very close to the 80 µg/L

Table 4.29 Description of distribution system monitoring locations (Charlotte)

Location	Location Code	Residence Time ^a (hrs)
1	A11	60
2	A14	84
3	A37	48
4	B12	36
5	B35	24
6	C12	48
7	C55	36
8	C63	72
9	C67	60
10	D41	60
11	E54	72
12	E74	60
13	E76	48
14	G25	36
15	G40	72
16	H40	84
17	H44	96
18	H55	96
19	I01	48
20	I14	96
21	I21	48
22	I23	36

a) Residence times are estimates provided by utility personnel

Table 4.30 Measured THM4 and HAA5 Concentrations for Location 3, t = 48 hours (Charlotte)

Sampling Date	Temp. on Day of Sampling (°C)	Measured THM4 (µg/L)	Measured HAA5 (µg/L)
2/12/02	11	38	
6/3/02	28	69	
9/3/02	27	54	
10/24/02	21	53	
2/20/03	11	36	25
6/5/03	23	48	39
8/20/03	29	78	47
11/13/03	20	41	26
2/4/04	13	23	20
5/5/04	21	45	23

Table 4.31 Predicted Monthly Average DBP and LRAA Concentrations for Location 3, t = 48 hrs (Charlotte)

Month	Avg. Monthly Temp. (°C)	Predicted Average Monthly THM4 (µg/L)	Predicted THM4 LRAA (µg/L)	Predicted Average Monthly HAA5 (µg/L)	Predicted HAA5 LRAA (µg/L)
2/02	12	39			
3/02	14	44			
4/02	16	47			
5/02	22	54			
6/02	28	68			
7/02	29	63			
8/02	30	65			
9/02	28	55			
10/02	21	53			
11/02	19	47			
12/02	16	44			
1/03	13	40	51		
2/03	11	36	51	25	
3/03	14	38	51	29	
4/03	16	41	50	31	
5/03	20	44	49	33	
6/03	22	46	48	38	
7/03	29	68	48	46	
8/03	29	78	49	47	
9/03	27	62	50	38	
10/03	24	57	50	35	
11/03	20	41	49	26	
12/03	20	34	49	25	
1/04	17	32	48	23	33
2/04	13	23	47	20	33
3/04	19	35	47	22	32
4/04	22	38	46	24	31
5/04	22	46	47	23	31

MCL for THM4. However, as shown in Figure 4.43, the LRAAs for THM4 at Location 3 are approximately 50 µg/L over the time period studied. The HAA5 record is limited, but the LRAA for the limited dataset shows an average of about 30 µg/L. Therefore, this monitoring location with a residence time of 48 hrs would be in compliance with the Stage 2 DBP Rule.

Figure 4.42 Predicted and Measured DBP Concentrations for Location 3, t = 48 hrs (Charlotte)

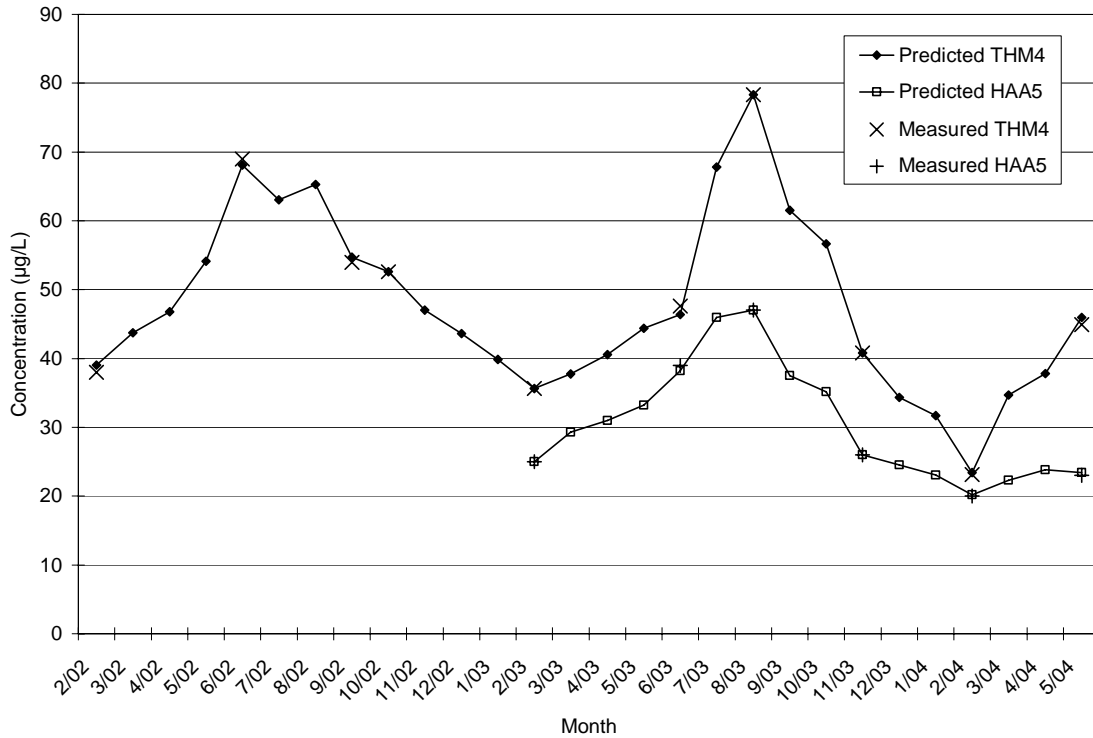
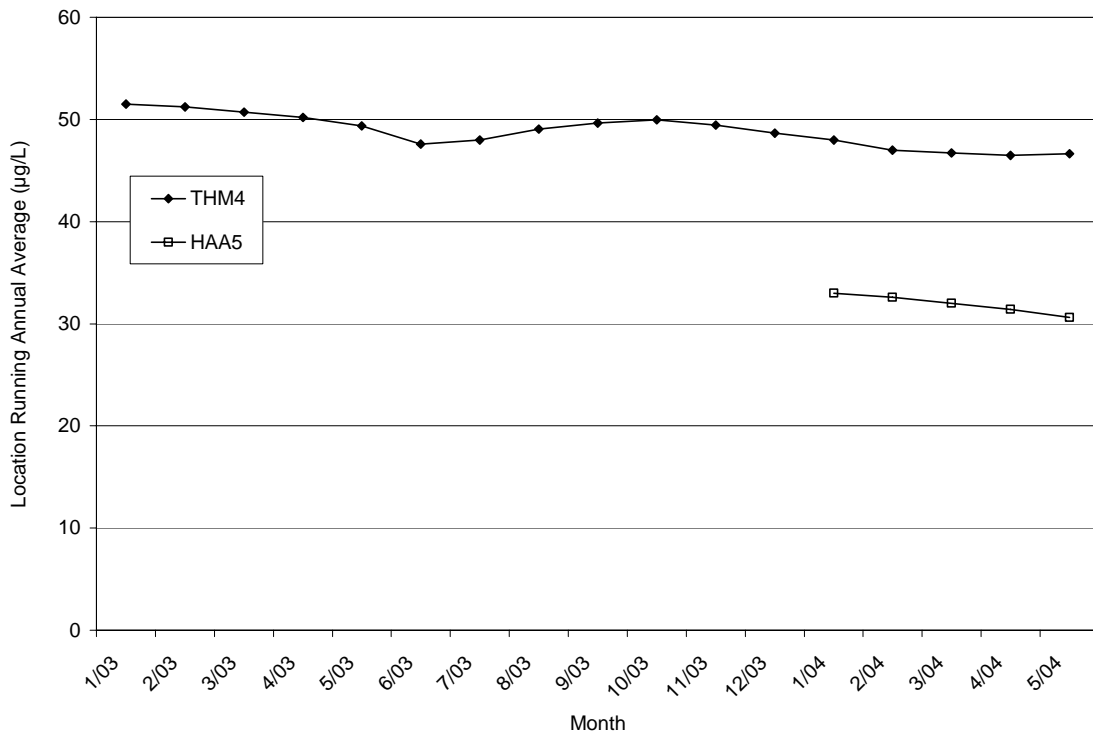


Figure 4.43 Predicted Monthly LRAA Concentrations for Location 3, t = 48 hrs (Charlotte)



Figures 4.44 and 4.45 show predicted monthly THM4 and HAA5 LRAA concentrations, respectively, for several of the existing monitoring locations representing a range of residence times from 24 to 96 hrs. Figure 4.44 shows that Location 17, which has a residence time of 96 hrs, would be in compliance with the new LRAA MCL for THM4. A parallel analysis for the other Charlotte monitoring locations indicates that all of the other existing monitoring locations, with residence times up to 96 hrs, would also be compliant with the MCLs, although Locations 2 (t = 84 hrs) and 17 (t = 96 hrs) exceed 80 percent of the MCL for THM4 for extended periods of time (see Appendix D). Many of Charlotte's monitoring locations that are included in Appendix D have incomplete databases for THM4 and HAA5 due to the lack of availability of these values in electronic files.

Equations 7 and 8 were used to predict THM4 and HAA5 concentrations for each sampling date for a hypothetical location with a maximum residence time of 10 days. The measured values at Location 7 (t = 36 hrs) were used in the model to predict the concentrations at 10 days. Table 4.32 shows maximum quarterly DBP concentrations predicted using the measured DBP values from Location 7 which were then adjusted using the regression equations given in Figures 4.46 and 4.47. The regression equations in Figures 4.46 and 4.47 were developed by comparing the predicted DBP concentrations for the other monitoring locations using Equations 7 and 8 and the measured values at Location 7 with the actual measured concentrations at these other monitoring locations. The predicted maximum quarterly DBP concentrations were used to create a record of monthly maximum DBP values using Equations 5 and 6. The results are shown in Table 4.33.

Figure 4.44 Monthly THM4 LRAA concentrations for selected existing monitoring locations (Charlotte)

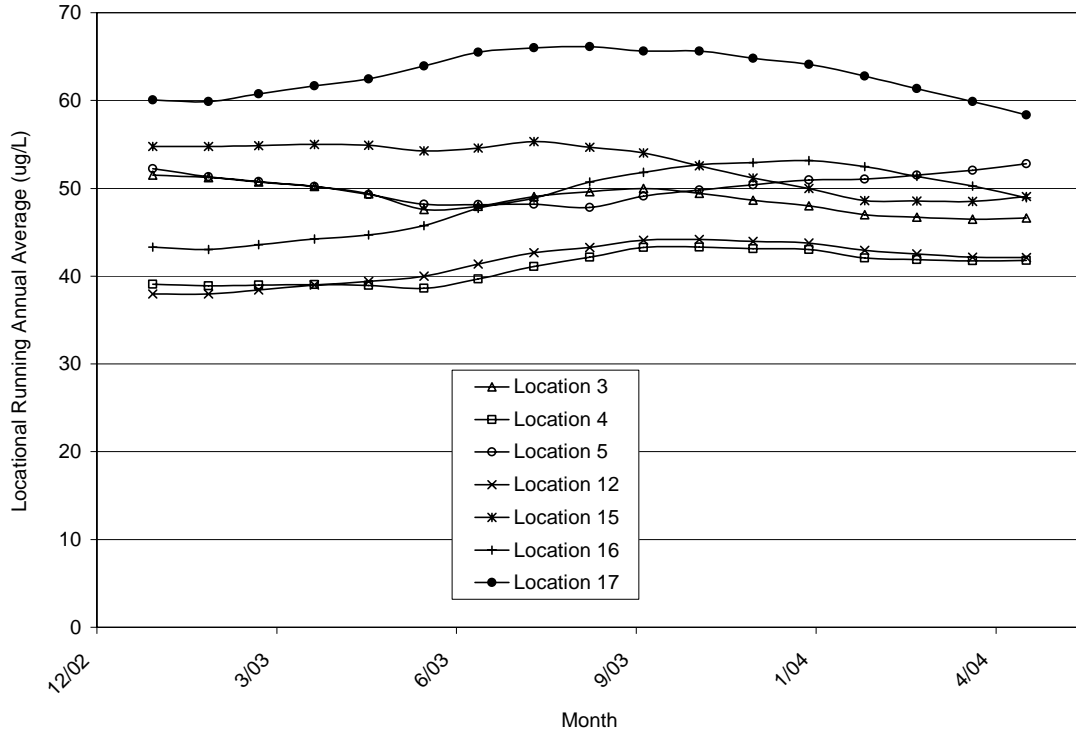


Figure 4.45 Monthly HAA5 LRAA concentrations for selected existing monitoring locations (Charlotte)

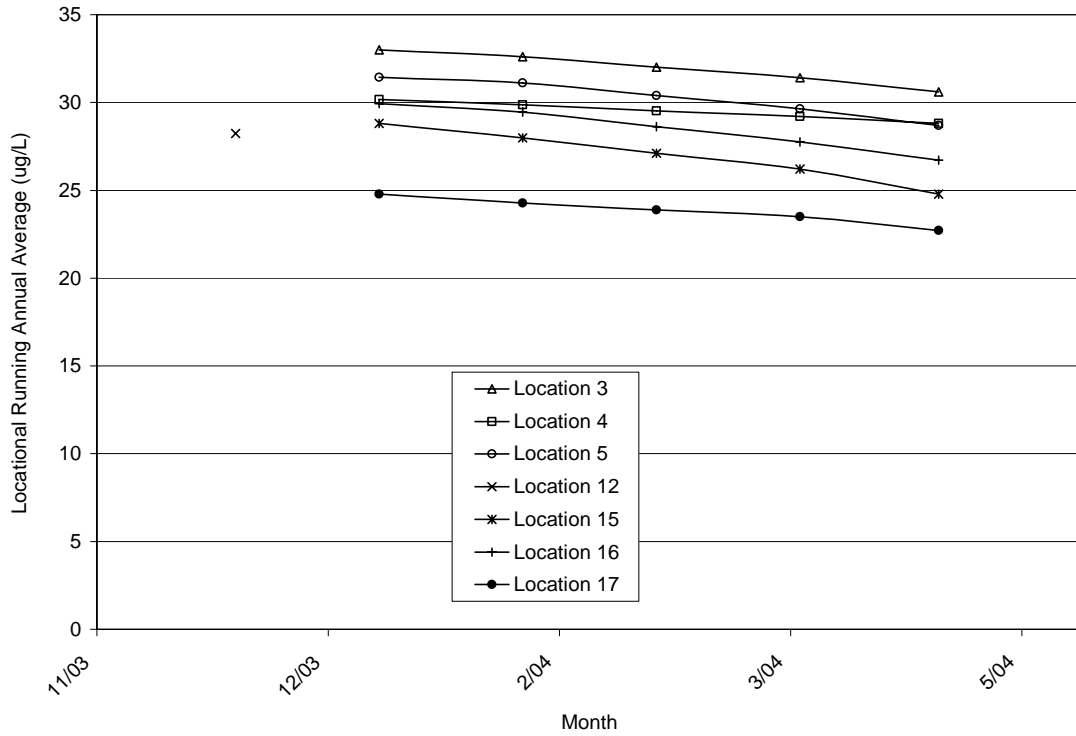


Table 4.32 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Charlotte)

Sampling Date	Temp. on Day of Sampling (°C)	Measured THM4, t = 36 hrs (µg/L)	Predicted Max THM4, t = 10 days (µg/L)	Adjusted Predicted THM4, t = 10 days (µg/L)	Measured HAA5, t = 36 hrs (µg/L)	Predicted Max HAA5, t = 10 days (µg/L)	Adjusted Predicted HAA5, t = 10 days (µg/L)
2/12/02	11	35	58	47			
6/3/02	28	56	92	81			
9/3/02	27	65	106	95			
10/24/02	21	60	99	88			
2/20/03	11	37	61	51	24	33	40
6/5/03	23	60	98	87	30	41	54
8/20/03	29	83	138	126	32	43	59
11/13/03	20	45	74	63	18	24	25
2/4/04	13	26	43	33	14	19	16
5/5/04	21	55	90	79	21	29	32

The predicted monthly maximum THM4 and HAA5 concentrations at a hypothetical location with a maximum residence time of 10 days is presented in Figure 4.48. The figure shows that THM4 concentrations can peak at levels higher than the 80 µg/L MCL for THM4 during the summer months, whereas HAA5 concentrations remain at or below the 60 µg/L MCL for HAA5, although the HAA5 record is limited. Depending upon the criterion set by the EPA and by the State, peak concentrations such as those predicted for THM4 may require a significant excursion evaluation.

Figures 4.49 and 4.50 show the predicted LRAAs for THM4 and HAA5, respectively, for a hypothetical location with a maximum residence time of 10 days, and for residence times up to 14 days. Figure 4.49 shows that the LRAAs for THM4 range from about 45 to 90 µg/L, depending upon the maximum residence time. If the maximum residence time in the distribution system is 14 days, the Charlotte utility could have been out of compliance with the Stage 2 DBP Rule for most of the year. If the maximum residence time in the distribution system is 10 days,

Figure 4.46 Comparison between measured and predicted THM4 concentrations (Charlotte)

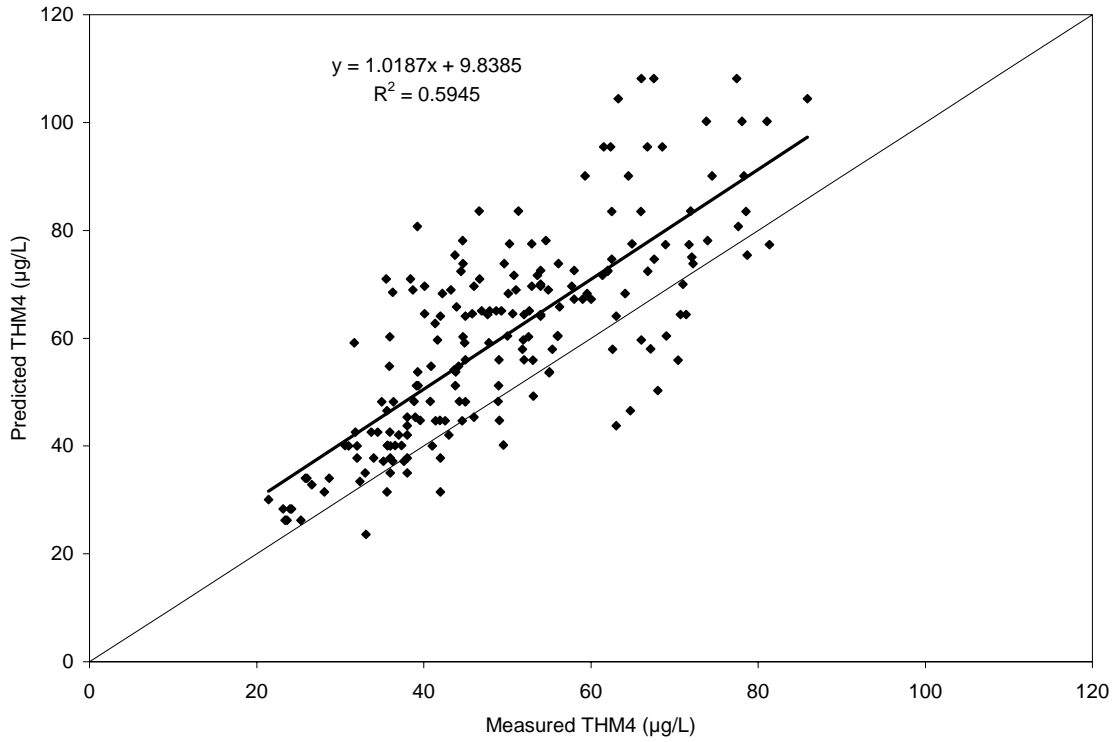


Figure 4.47 Comparison between measured and predicted HAA5 concentrations (Charlotte)

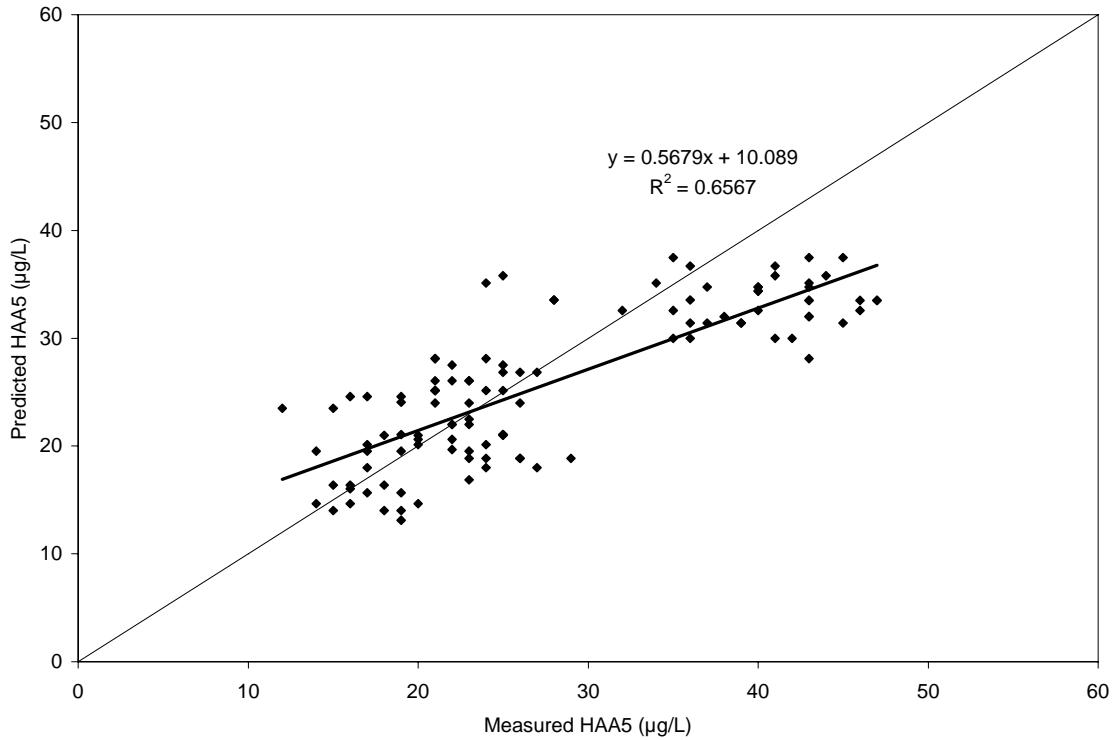


Table 4.33 Predicted maximum DBP and LRAA concentrations for maximum residence time, t = 10 days (Charlotte)

Month	Avg. Monthly Temp. (°C)	Maximum Monthly THM4 (µg/L)	Maximum THM4 LRAA (µg/L)	Maximum Monthly HAA5 (µg/L)	Maximum HAA5 LRAA (µg/L)
2/02	12	48			
3/02	14	53			
4/02	16	56			
5/02	22	65			
6/02	28	80			
7/02	29	90			
8/02	30	94			
9/02	28	96			
10/02	21	88			
11/02	19	73			
12/02	16	68			
1/03	13	62	73		
2/03	11	51	73	40	
3/03	14	61	74	43	
4/03	16	66	74	46	
5/03	20	72	75	49	
6/03	22	85	75	53	
7/03	29	115	77	60	
8/03	29	126	80	59	
9/03	27	97	80	43	
10/03	24	89	80	40	
11/03	20	63	79	25	
12/03	20	51	78	22	
1/04	17	47	77	20	42
2/04	13	33	75	16	40
3/04	19	56	75	24	38
4/04	22	61	75	26	36
5/04	22	81	75	33	35

the Charlotte utility could have been out of compliance with the Stage 2 DBP Rule for the latter part of 2003. However, if the maximum residence time is 7 days or less, Charlotte should be able to meet the MCL for THM4 at all locations provided that raw water quality does not change appreciably. For HAA5, the LRAAs do not exceed the 60 µg/L MCL from 1/04 to 5/04 for

Figure 4.48 Predicted maximum monthly DBP concentrations for a hypothetical maximum residence time, $t = 10$ days (Charlotte)

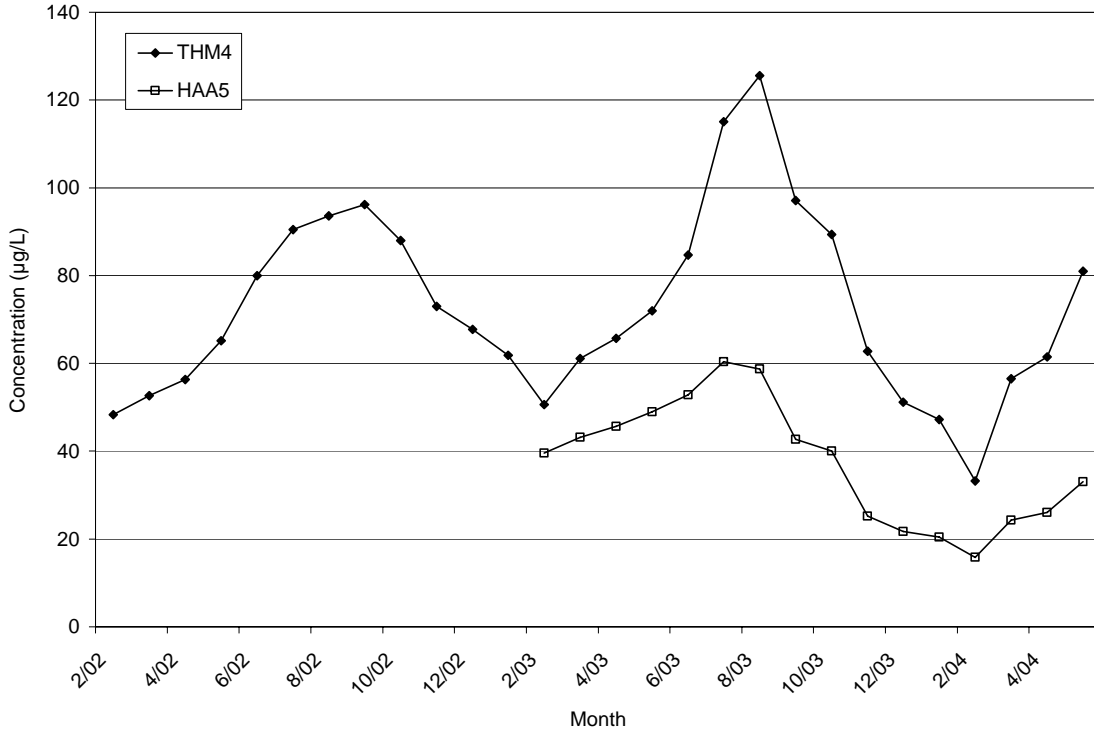


Figure 4.49 Predicted LRAAs for THM4 for various maximum residence times (Charlotte)

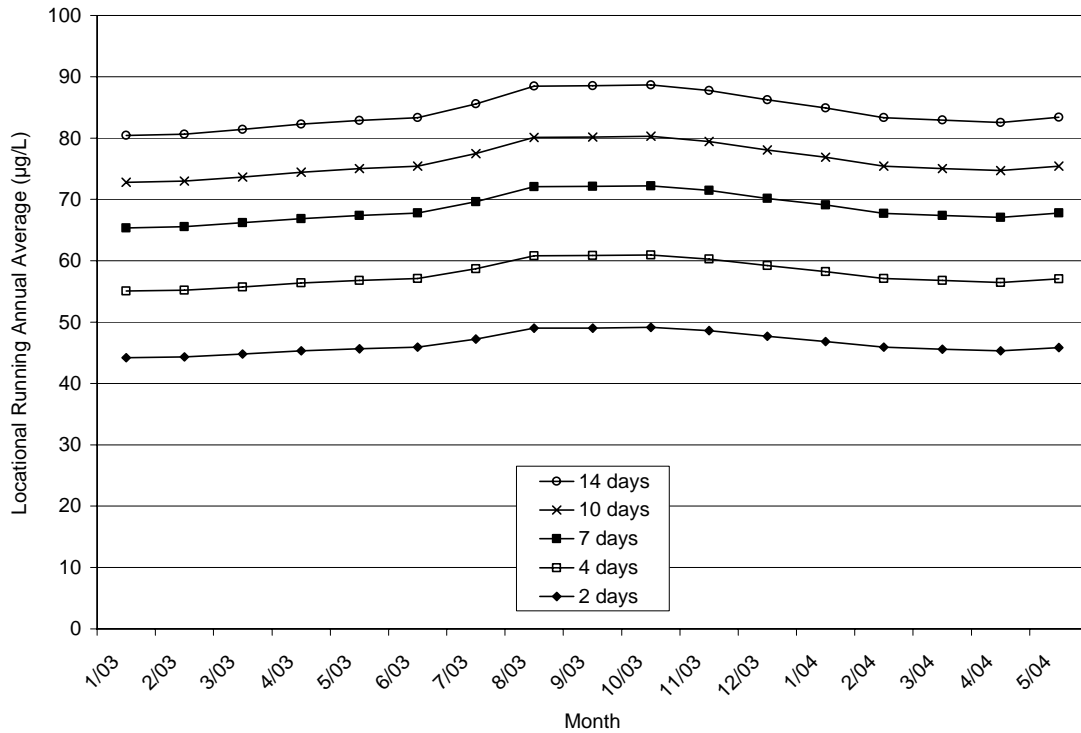
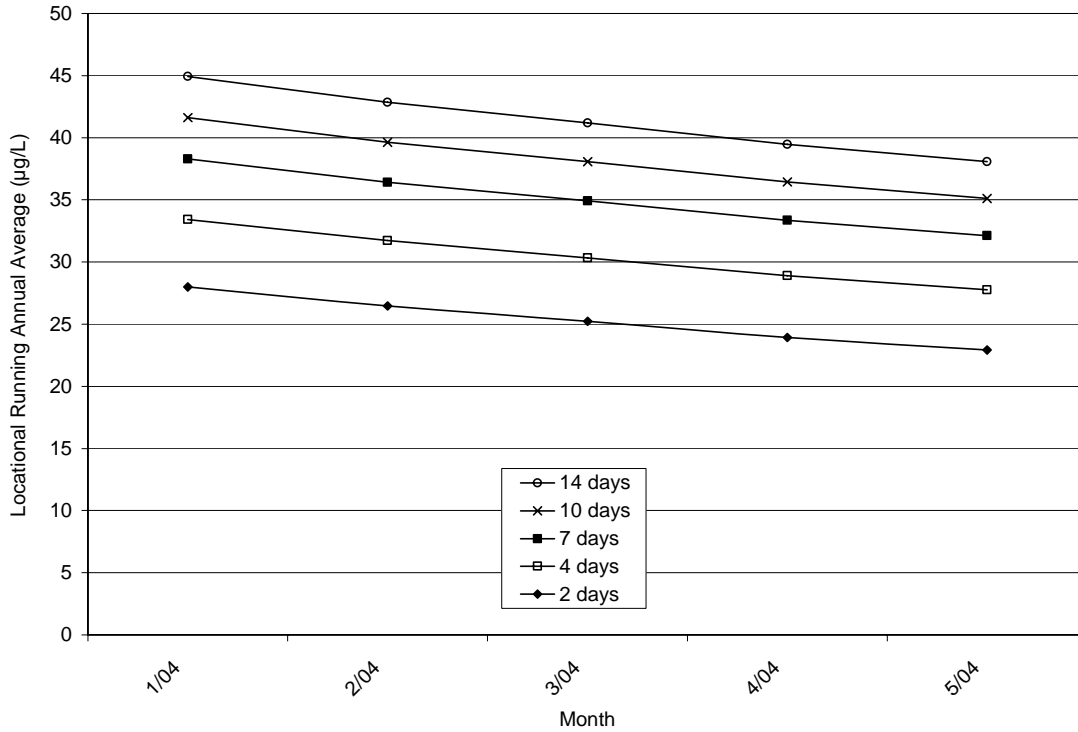


Figure 4.50 Predicted LRAAs for HAA5 for various maximum residence times (Charlotte)



maximum residence times up to 14 days (Figure 4.49). Therefore, this utility may have difficulties complying with the Stage 2 DBP Rule for THM4 if the maximum residence time in the distribution system is 10 days or more, but should not have difficulty complying with the 60 µg/L MCL for HAA5, although the database for this conclusion is limited. If the maximum residence time in the Charlotte system is 7 days or less, Charlotte should be able to comply with the 80 µg/L MCL for THM4, assuming that the modeling results are valid.

4.2.4 Burlington

Burlington’s eight monitoring locations are listed in Table 4.34 along with their corresponding residence times, which were determined by a hydraulic model. A record of monthly THM4 and HAA5 concentrations was developed for each monitoring location employing the approach described in the previous chapter, using the temperature-adjustment model given by Equations 5 and 6,. For purposes of illustration, measured THM4 and HAA5 values for Location 4 (t = 8 hrs) are given in Table 4.35Table 4. and the record of monthly predicted THM4 and HAA5 values is shown in Table 4.36. Figures 4.51 shows the predicted and measured DBP concentrations for Location 4, and the resulting LRAA concentrations are shown in Figure 4.52. The corresponding record for each of the other monitoring locations for Burlington is given in Appendix E.

Table 4.34 Description of Distribution System Monitoring Stations (Burlington)

Location	Description	Residence Time ^a (hrs) - With Thomas WTP in Operation	Residence Time ^a (hrs) - With Mackintosh WTP in Operation
1	089 - 2628 Alamance Rd.	3	3
2	116 - 1334 Overbrook Dr.	20	20
3	001 - 124 Mebane St.	16	16
4	070 - 1807 N. Church St.	8	8
5	151 - 2921 NC Hwy 100	24	24
6	067 - 2112 Wilkin’s St.	48	85
7	055 - NC Hwy 70 West	4	4
8	028 - 225 Stone Quarry Rd.	24	68

a) Residence times determined by a hydraulic model

As shown in Figure 4.51, THM4 concentrations at monitoring Location 4 peak at very high levels in the month of September. In addition, HAA5 concentrations also exceed the 60 µg/L MCL for an extended period of time, from 4/03 to 10/03. Figure 4.52 shows that the LRAAs for THM4 at this monitoring location are in compliance with the 80 µg/L MCL as proposed by the

Table 4.35 Measured THM4 and HAA5 Concentrations for Location 4, t = 8 hours (Burlington)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4 (µg/L)	Measured HAA5 (µg/L)
2/12/02	8	25	37
4/10/02	17	32	57
9/20/02	24	108	45
12/12/02	12	34	50
2/12/03	8	39	33
4/3/03	16	48	66
9/23/03	23	116	76
12/22/03	11	29	43
2/9/04	9	35	56
4/26/04	21	53	35

a) Temperature at the POE on day of sampling

Stage 2 DBP Rule, but are at levels above 80 percent of the MCL for the latter part of 2003 and in 2004. The LRAAs for HAA5 exceed the 60 µg/L MCL at this location, beginning in 9/03. Therefore, this existing monitoring location, with a residence time of 8 hrs, should be able to comply with the MCL for THM4, but may have difficulty complying with the MCL for HAA5 under the existing treatment scheme. Figures 4.53 and 4.54 show monthly LRAA concentrations for all existing monitoring locations for THM4 and HAA5, respectively. The figures indicate that all existing monitoring locations should be able to comply with the 80 µg/L MCL for THM4, but several locations will be non-compliant with the 60 µg/L MCL for HAA5. The fact that some of these non-compliant locations have relatively short residence times whereas other stations with longer residence times (e.g. Location 6) appear to comply with the Stage 2 Rule raises questions about the validity of the reported residence times given in Table 4.34.

Table 4.36 Predicted Average Monthly DBP and LRAA concentrations for Location 4, t = 8 hrs (Burlington)

Month	Avg. Monthly Temp. (°C) ^a	Predicted Average Monthly THM4 (µg/L)	THM4 LRAA (µg/L)	Predicted Average Monthly HAA5 (µg/L)	HAA5 LRAA (µg/L)
2/02	11	28		39	
3/02	13	29		46	
4/02	19	34		60	
5/02	22	69		53	
6/02	27	79		59	
7/02	28	81		60	
8/02	28	82		61	
9/02	23	106		44	
10/02	21	72		51	
11/02	15	61		45	
12/02	11	33		48	
1/03	9	36	59	40	51
2/03	8	40	60	34	50
3/03	12	44	61	48	50
4/03	16	48	63	65	51
5/03	20	80	63	71	52
6/03	23	87	64	76	54
7/03	25	92	65	80	55
8/03	26	93	66	80	57
9/03	24	118	67	77	60
10/03	20	72	67	62	61
11/03	17	66	67	58	62
12/03	11	29	67	43	61
1/04	9	31	67	48	62
2/04	8	34	66	54	64
3/04	13	41	66	45	63
4/04	16	46	66	32	60

a) Average monthly temperature at POE

To determine the maximum THM4 and HAA5 concentrations, Equations 7 and 8 were used as described in Chapter 3 to calculate the maximum DBP concentrations that can be expected at a hypothetical location with a residence time of 10 days using the measured values at Location 4 (t = 8 hrs). As shown in Table 4.37, a record of maximum quarterly DBP concentrations was developed using the time-adjustment model, then the resulting predicted values were adjusted using the regression equations given in Figures 4.55 and 4.56. These maximum quarterly DBP

Figure 4.51 Predicted and Measured DBP concentrations for Location 4, t = 8 hrs (Burlington)

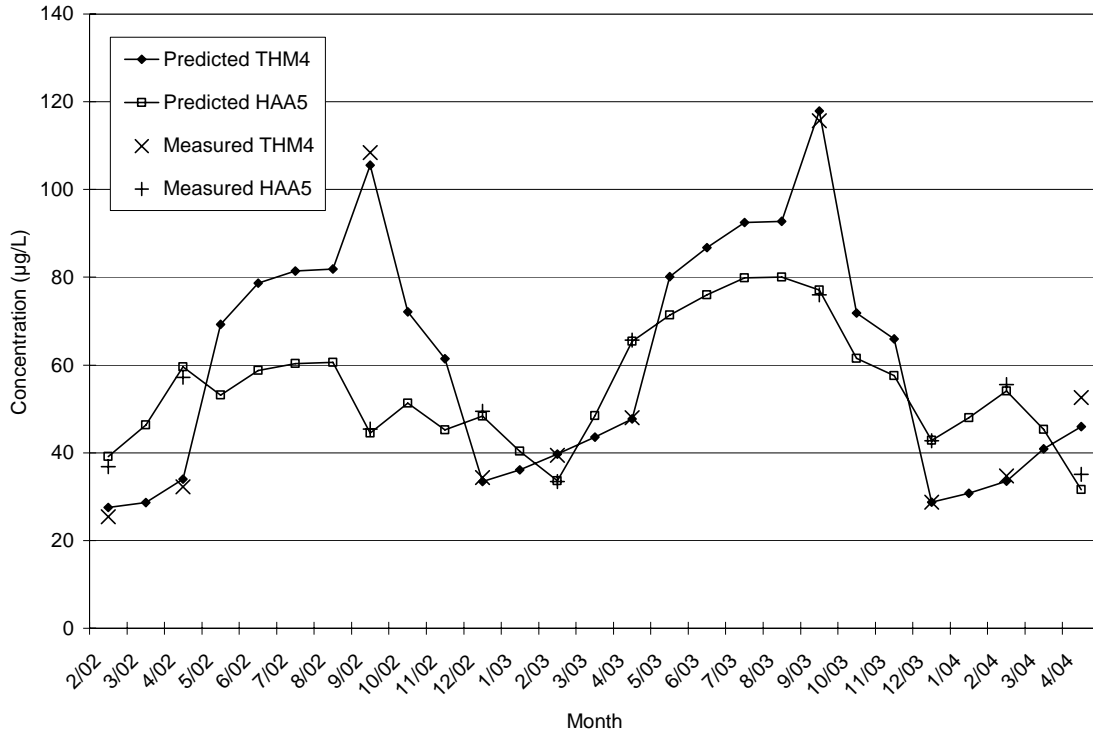


Figure 4.52 Predicted Monthly LRAA Concentrations for Location 4, t = 8 hrs, Burlington

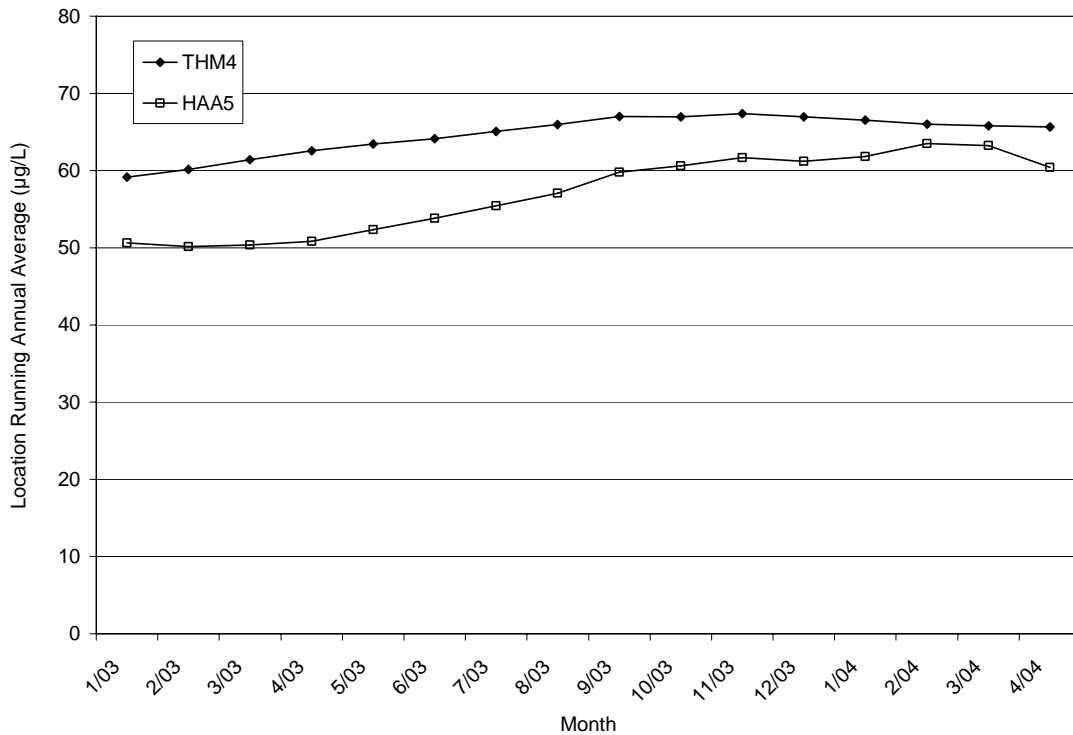


Figure 4.53 Monthly THM4 LRAA concentrations for all existing monitoring locations (Burlington)

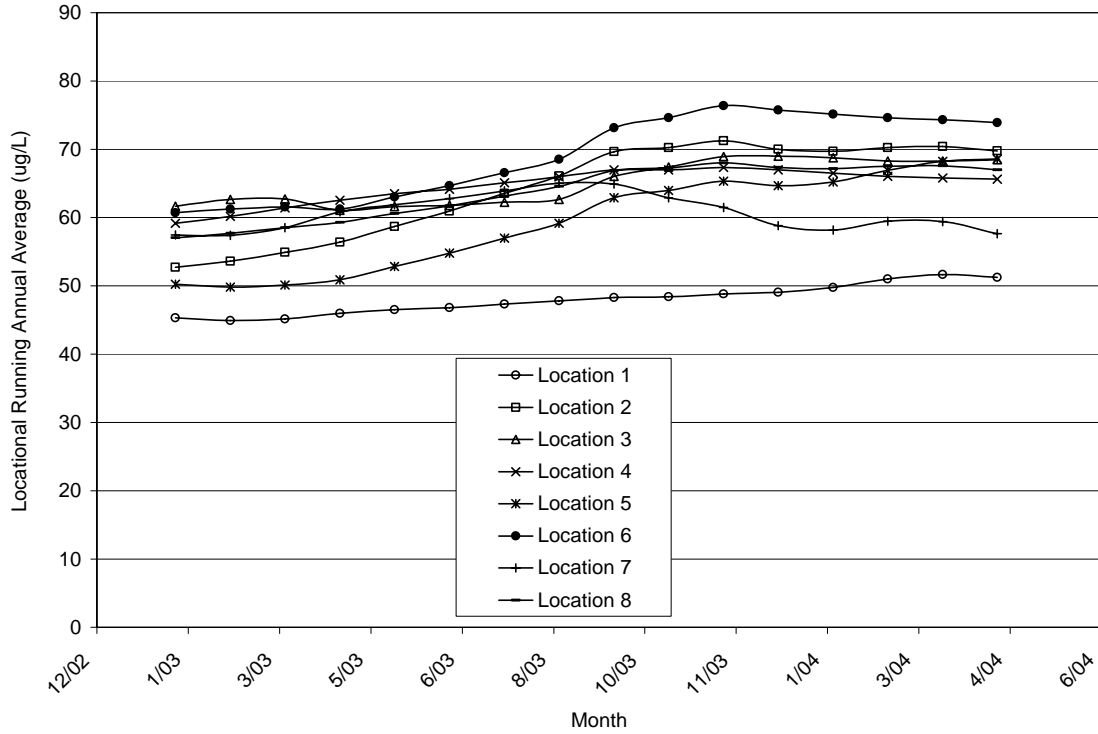


Figure 4.54 Monthly HAA5 LRAA concentrations for all existing monitoring locations (Burlington)

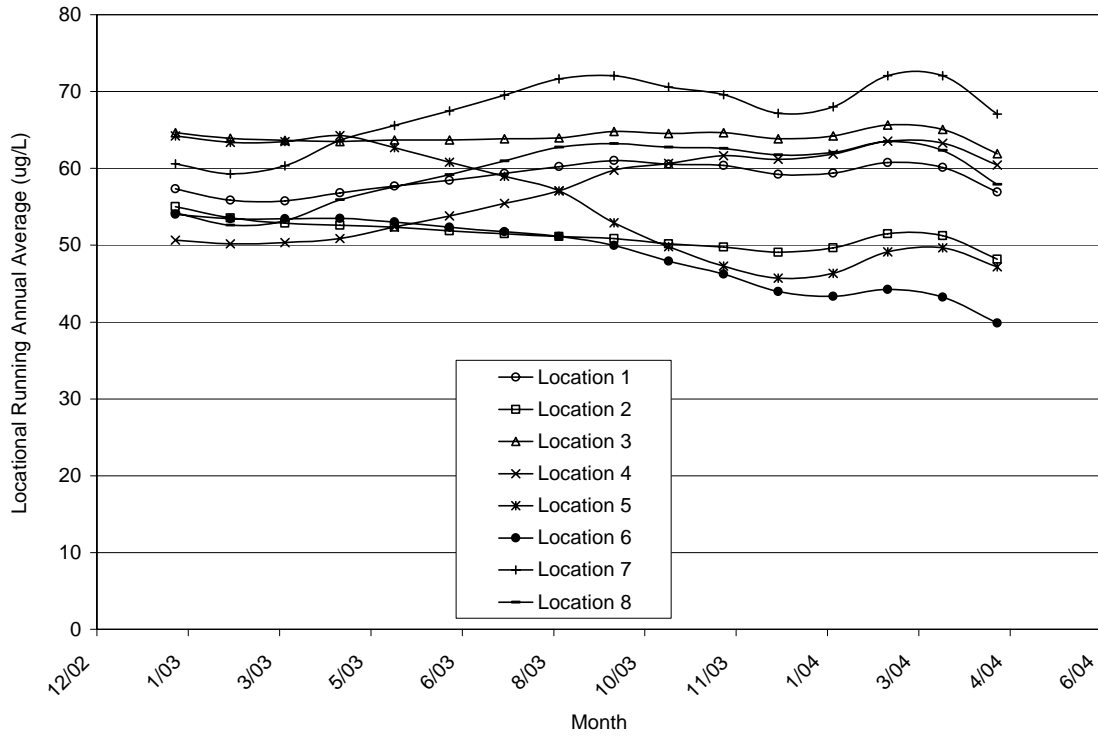


Table 4.37 Predicted maximum quarterly DBP concentrations for a hypothetical maximum residence time, t = 10 days (Burlington)

Sampling Date	Temp. on Day of Sampling (°C) ^a	Measured THM4, t = 8 hrs (µg/L)	Predicted Max THM4, t = 10 days (µg/L)	Adjusted Predicted THM4, t = 10 days (µg/L)	Measured HAA5, t = 8 hrs (µg/L)	Predicted Max HAA5, t = 10 days (µg/L)	Adjusted Predicted HAA5, t = 10 days (µg/L)
2/12/02	8	25	62	49	37	64	62
4/10/02	17	32	79	62	57	99	97
9/20/02	24	108	266	201	45	79	77
12/12/02	12	34	84	66	50	86	84
2/12/03	8	39	97	75	33	58	57
4/3/03	16	48	118	91	66	114	111
9/23/03	23	116	284	214	76	131	129
12/22/03	11	29	70	55	43	74	72
2/9/04	9	35	85	66	56	96	94
4/26/04	21	53	129	99	35	61	59

a) Temperature at the POE on day of sampling

concentrations were used to predict monthly maximum DBP and LRAA concentrations which are given in Table 4.38, using the temperature-adjustment model (Equations 5 and 6).

The predicted maximum monthly THM4 and HAA5 concentrations for a hypothetical location with a maximum residence time of 10 days are presented in Figure 4.57. The results show that this utility will have high DBP concentrations relative to the MCLs, with significant peaks as well. Figures 4.58 and 4.59 show the LRAAs for THM4 and HAA5, respectively, for a maximum residence time of 10 days and for other potential maximum residence times up to 14 days. LRAA concentrations are expected to exceed both the MCLs of 80 µg/L and 60 µg/L for THM4 and HAA5, respectively, for all residence times greater than 2 days. As noted earlier, Locations 3, 4, 7, and 8 are already expected to exceed the proposed LRAA MCL for HAA5 based on existing measurements. Accordingly, the Burlington utility will have difficulties

Figure 4.55 Comparison between measured and predicted THM4 concentrations

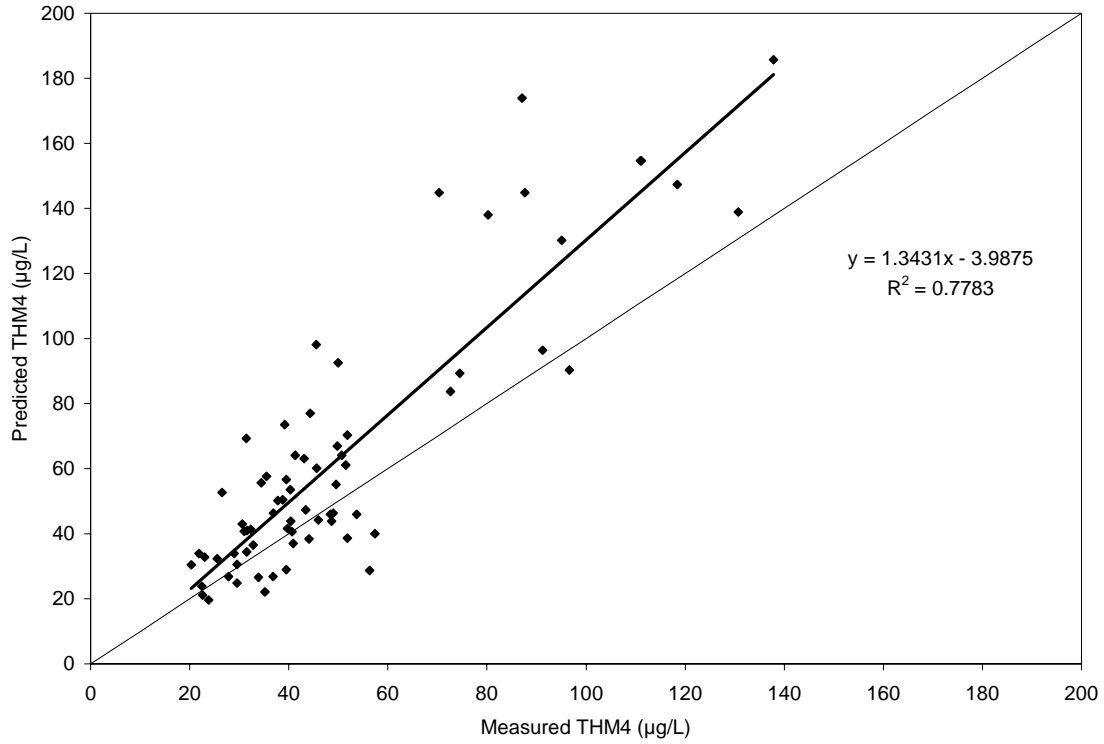


Figure 4.56 Comparison between measured and predicted HAA5 concentrations

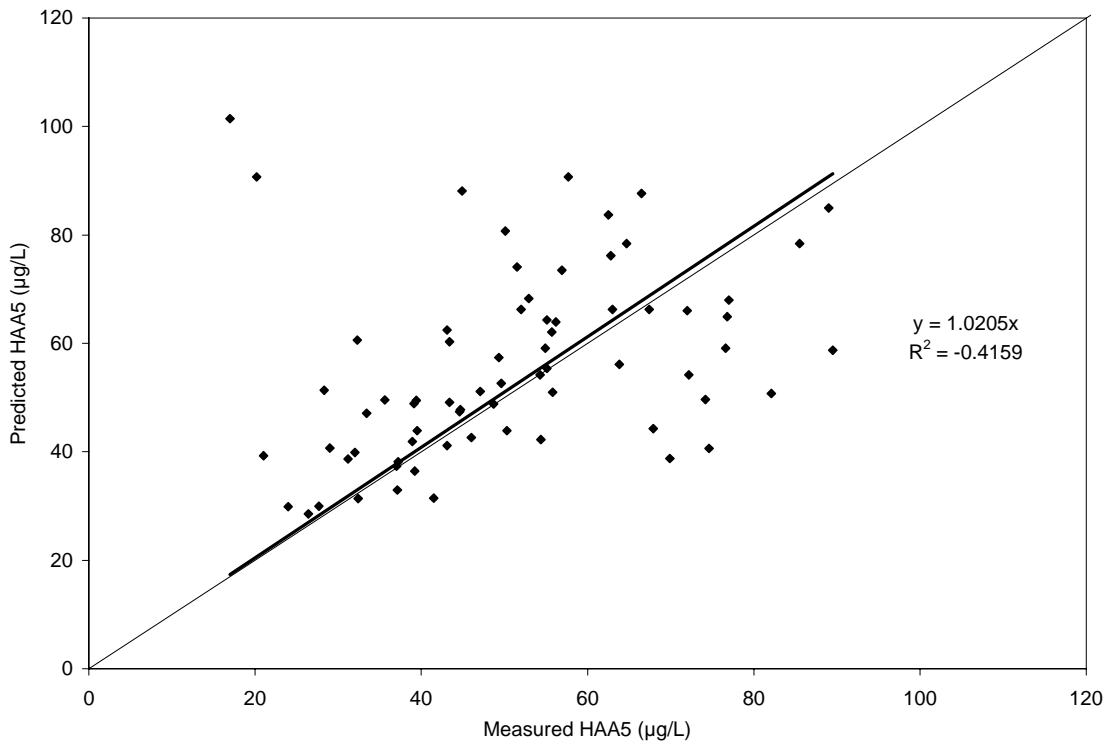


Table 4.38 Predicted maximum DBP and LRAA concentrations for hypothetical maximum residence time, t = 10 days (Burlington)

Month	Avg. Monthly Temp. (°C) ^a	Maximum Monthly THM4 (µg/L)	Maximum THM4 LRAA (µg/L)	Maximum Monthly HAA5 (µg/L)	Maximum HAA5 LRAA (µg/L)
2/02	11	53		66	
3/02	13	55		79	
4/02	19	65		101	
5/02	22	130		90	
6/02	27	147		100	
7/02	28	152		102	
8/02	28	153		103	
9/02	23	196		75	
10/02	21	135		87	
11/02	15	115		77	
12/02	11	64		82	
1/03	9	69	111	68	86
2/03	8	76	113	57	85
3/03	12	83	115	82	85
4/03	16	90	117	111	86
5/03	20	149	119	121	89
6/03	23	162	120	129	91
7/03	25	173	122	135	94
8/03	26	173	124	136	97
9/03	24	218	126	131	101
10/03	20	135	126	104	103
11/03	17	124	126	98	104
12/03	11	56	126	72	104
1/04	9	59	125	81	105
2/04	8	64	124	92	108
3/04	13	78	123	77	107
4/04	16	87	123	53	102

a) Average monthly temperature at POE

complying with the Stage 2 DBP Rule if they continue to use free chlorine as the terminal disinfectant and if they do not modify their treatment to control DBP formation.

Figure 4.57 Predicted maximum DBP concentrations for a hypothetical maximum residence time, $t = 10$ days (Burlington)

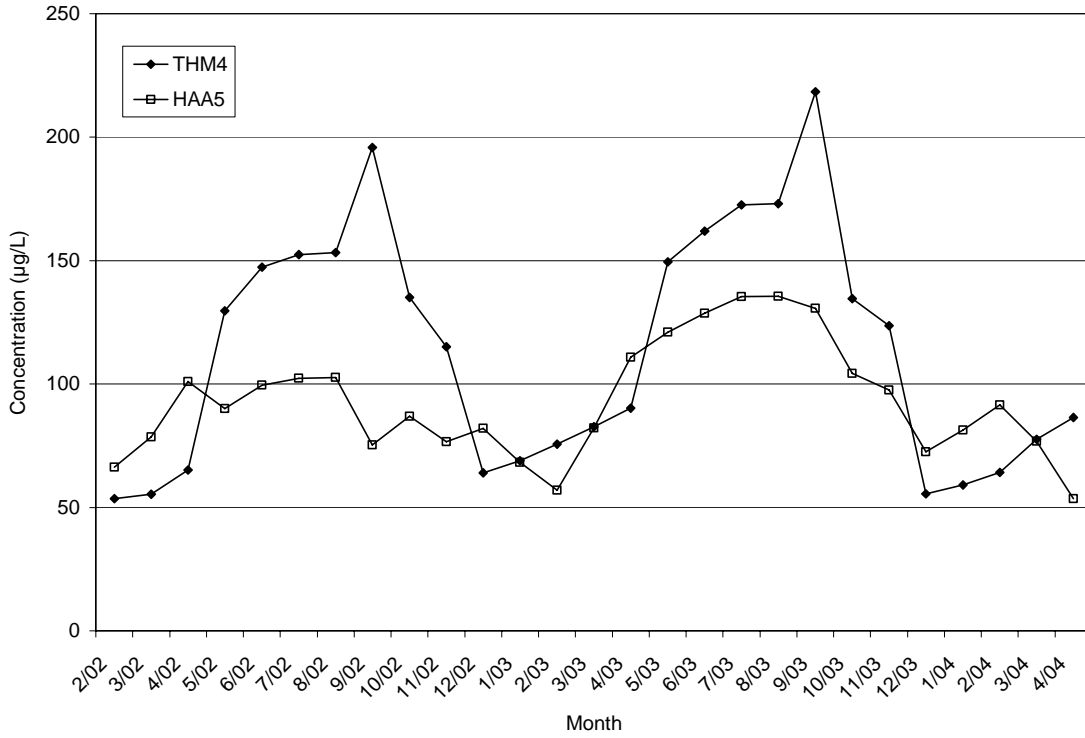


Figure 4.58 Predicted LRAAs for THM4 for various maximum residence times (Burlington)

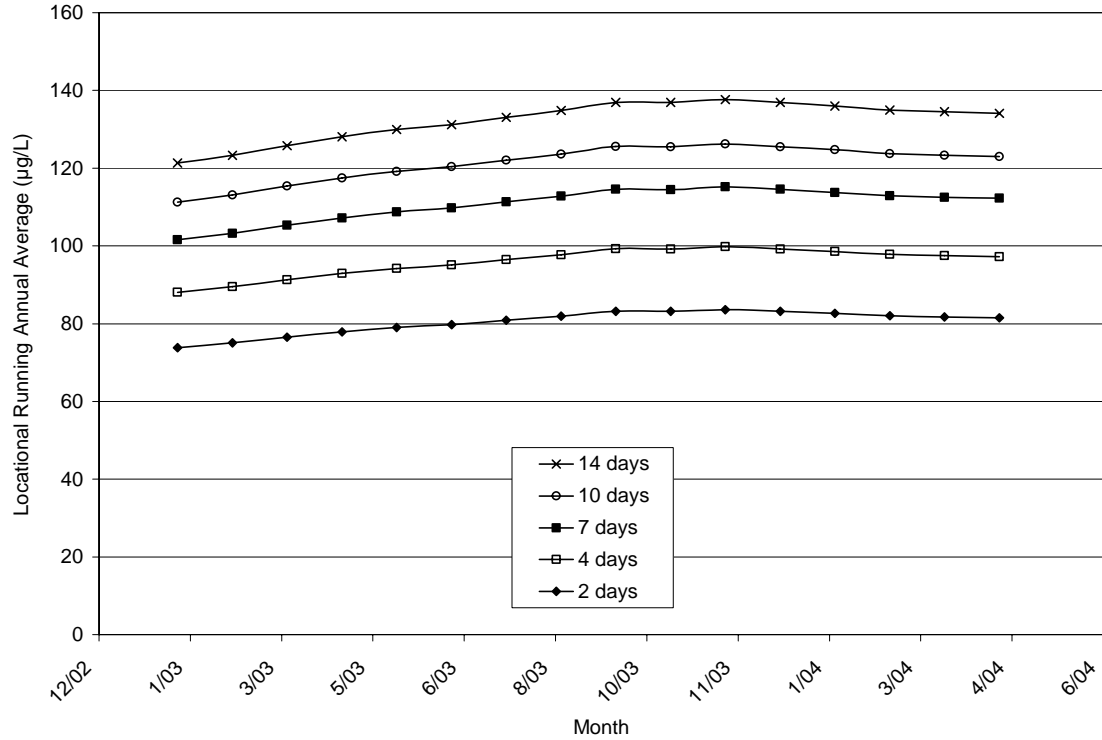
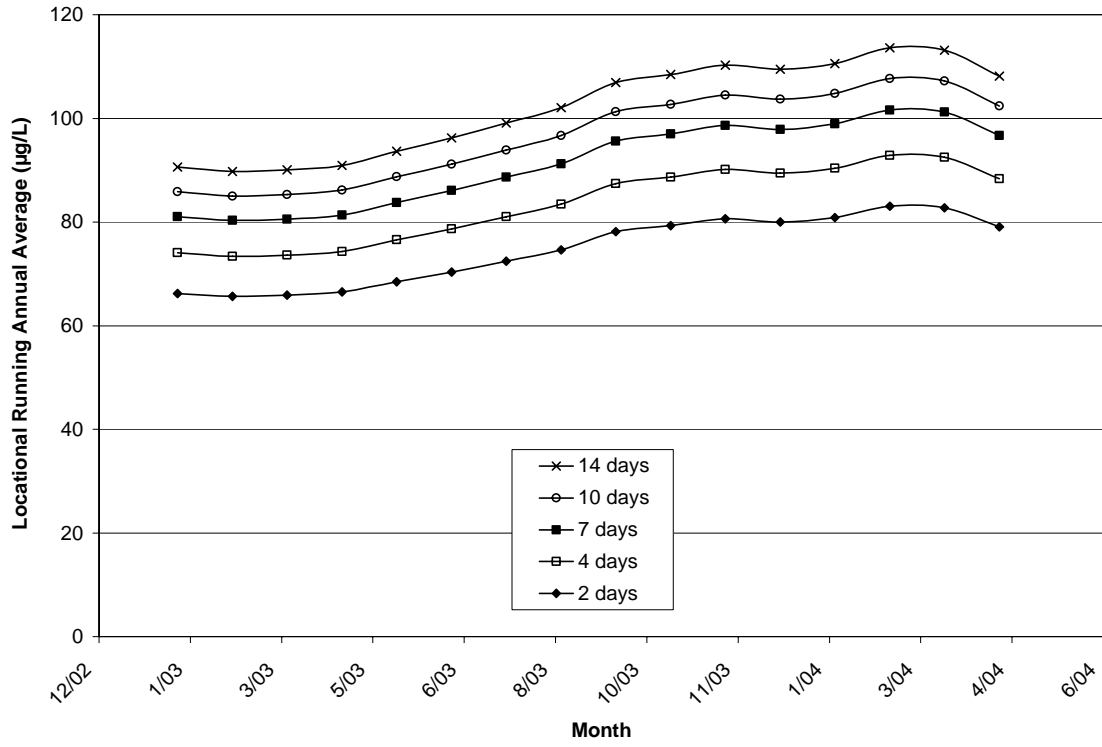


Figure 4.59 Predicted LRAAs for HAA5 for various maximum residence times (Burlington)



CHAPTER 5 - DISCUSSION OF RESULTS

In the previous chapter, the results from each of the eleven utilities were discussed individually. In this chapter, the composite results are discussed as a whole. Figures 5.1 and 5.2 show the predicted monthly maximum LRAA concentrations for THM4 and HAA5, respectively, for systems using a combined chlorine residual, which include Durham, Raleigh, OWASA, Fayetteville, Greenville, and High Point. These monthly maximum LRAAs are assumed to be system-wide values because of the use of combined chlorine. All LRAA concentrations for THM4 for these systems are between 30 µg/L and 80 µg/L and LRAA concentrations for HAA5 are between 30 µg/L and 60 µg/L. These values are at or below the proposed LRAA MCLs of 80 µg/L for THM4 and 60 µg/L for HAA5. Durham came close to exceeding the LRAA MCL for THM4 in early 2003, and both Durham and OWASA came close to exceeding the LRAA MCL for HAA5 in the winter of 2004. All of the other systems on combined chlorine are comfortably below the MCLs.

As shown in Figure 5.1, there are a variety of trends and patterns shown for LRAA concentrations for THM4 for those utilities using a combined chlorine residual in the distribution system. The Durham and Raleigh utilities show a downward trend beginning in early 2003 and continuing through 2004. In contrast, High Point shows a pronounced upward trend over this same time period, but then the LRAA concentrations begin to decrease in the summer of 2004. OWASA shows an upward trend in LRAA values from early 2003 to early 2004, but then the values decline. Fayetteville and Greenville exhibit contrasting patterns in 2004. It was expected

Figure 5.1 Predicted monthly THM4 LRAA concentrations system-wide for systems using a combined chlorine residual

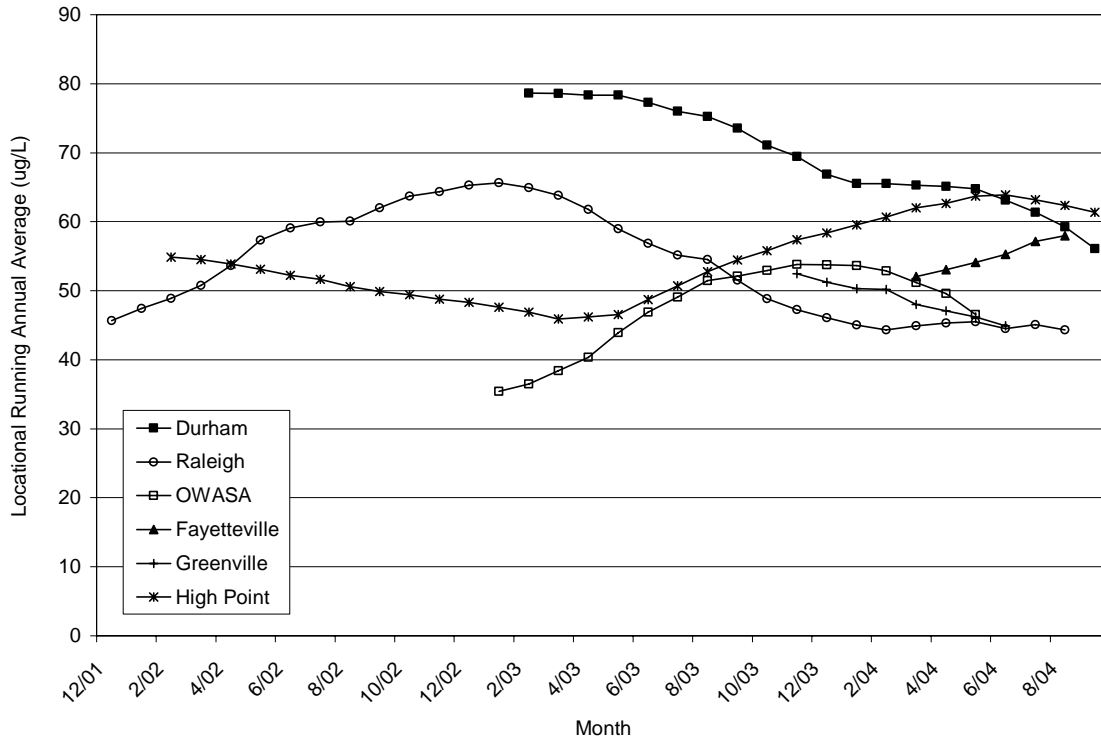
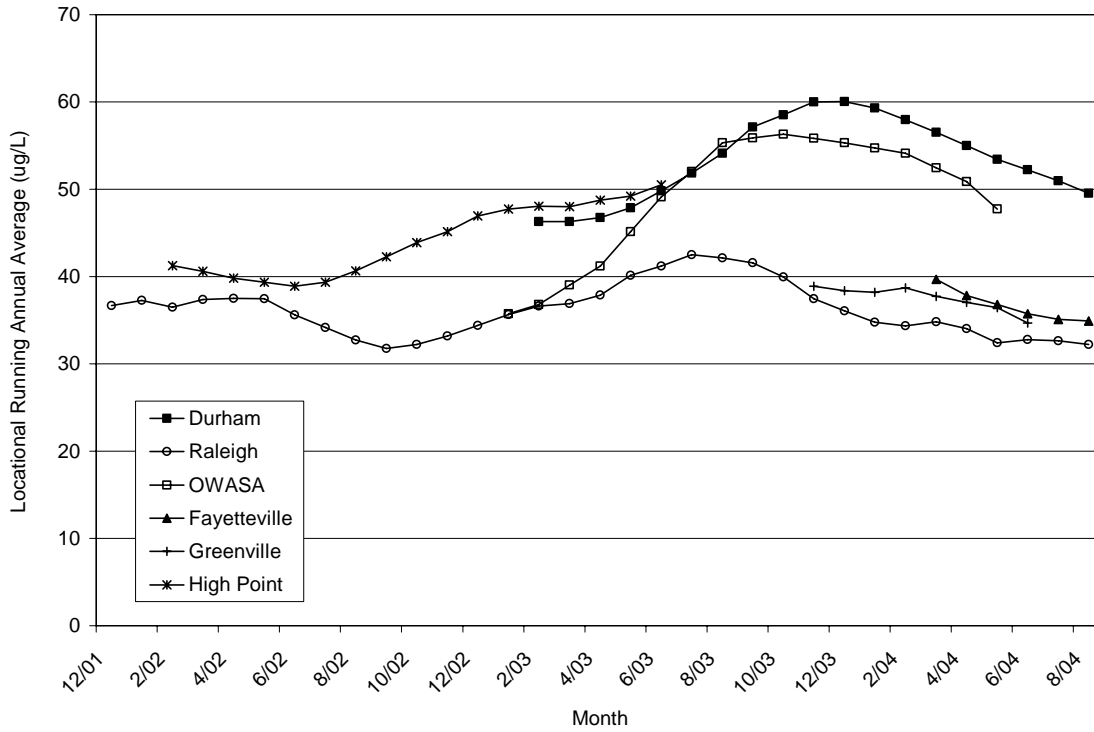


Figure 5.2 Predicted monthly HAA5 LRAA concentrations system-wide for systems using a combined chlorine residual



that there might be similar monthly patterns for all of the utilities because of their geographic proximity in the central Piedmont of North Carolina and the similar temperature and rainfall patterns that are expected to impact DBP precursors in the raw water sources. This is obviously not the case. The variation could be due to the fact that some systems such as Durham, OWASA, Raleigh, and High Point have impoundments for raw water sources, whereas Fayetteville and Greenville have river sources.

Similarly, a variety of trends and patterns are found for the LRAA concentrations for HAA5 for these utilities, as shown in Figure 5.2. There is a greater degree of consistency among the different patterns for HAA5 than there was for THM4. All of the utilities seem to show an upward trend in LRAA concentrations beginning early in 2003, followed by a downward trend through 2004.

Figures 5.3 and 5.4 show the predicted maximum monthly LRAA concentrations for THM4 and HAA5, respectively, for systems using a free chlorine residual, assuming a maximum distribution system residence time of 10 days. These systems include Burlington, Charlotte, Greensboro, Winston-Salem, and Wilmington. LRAA concentrations for THM4 for these systems are between 50 and 150 $\mu\text{g/L}$ and LRAA concentrations for HAA5 are between 20 and 100 $\mu\text{g/L}$. This represents a much broader range of LRAA concentrations for both THM4 and HAA5 compared to those found for systems using a combined chlorine residual. This is expected due to the fact that the use of chloramines in the distribution system has been found to maintain consistent concentrations of HAA5 and THM4 throughout the distribution system, and that these concentrations are essentially the same as in the finished water at the point of entry to

Figure 5.3 Predicted maximum THM4 LRAA concentrations for maximum residence time, $t = 10$ days, for systems using a free chlorine residual

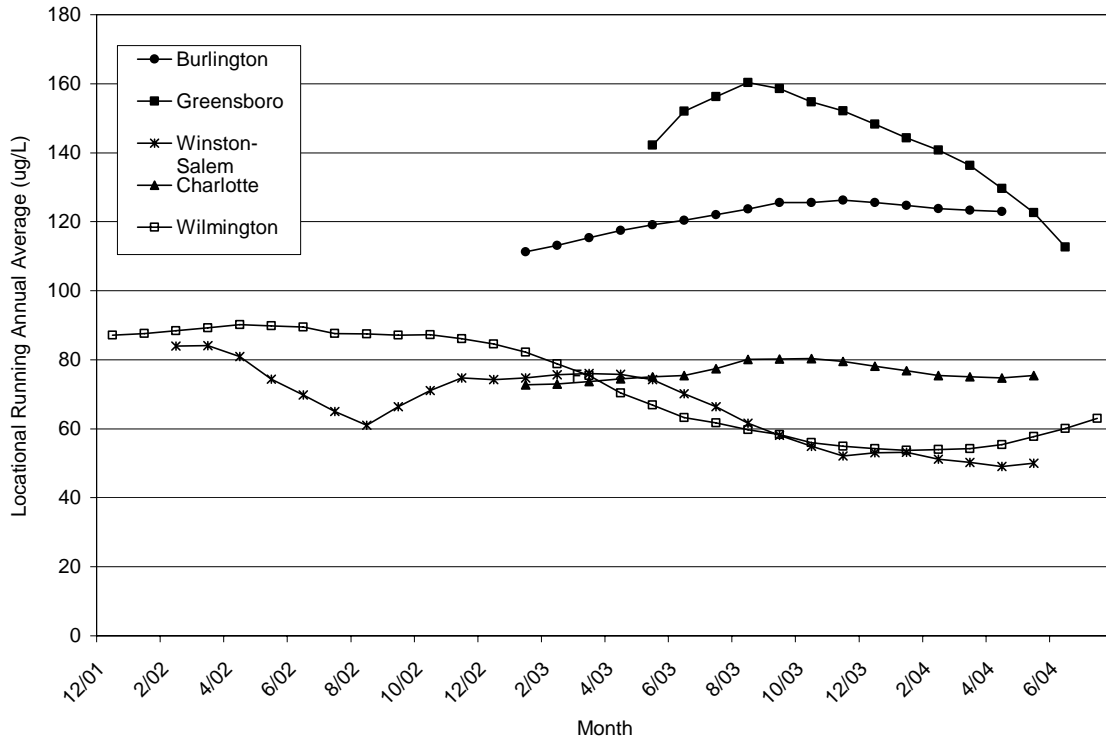
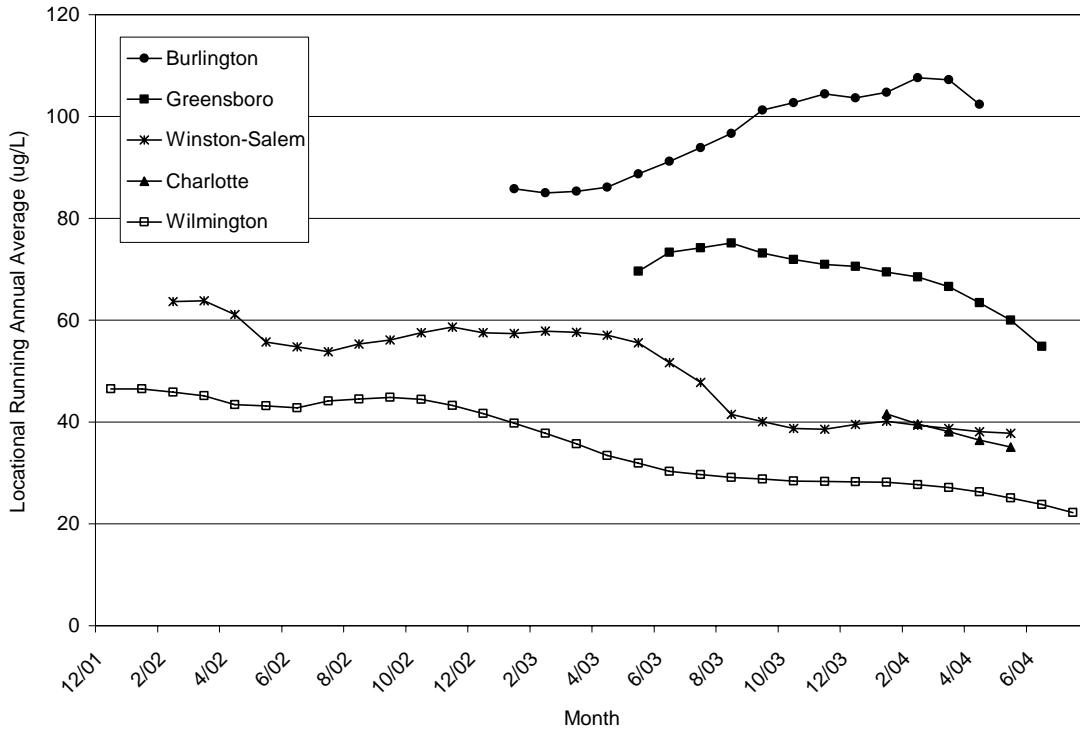


Figure 5.4 Predicted maximum HAA5 LRAA concentrations for maximum residence time, $t = 10$ days, for systems using a free chlorine residual



the distribution system because chloramines essentially stop the formation of additional THM4 and HAA5 (Singer, 2001). The range of THM4 and HAA5 concentrations shown in Figures 5.3 and 5.4 includes a number of instances where the concentrations appear to exceed the LRAA MCLs of 80 µg/L for THM4 and 60 µg/L for HAA5 for a residence time of 10 days. As shown in Figure 5.3, the Burlington and Greensboro utilities would have greatly exceeded the MCL for THM4 for most of the period of study, Winston-Salem and Wilmington would both have exceeded the MCL to a lesser degree in 2002 and a portion of 2003 for Wilmington, but then would have exhibited compliance for the remainder of 2003 and 2004. Charlotte would have been below or at the MCL for THM4 for the entire period for which data are available.

As in the case of the utilities on combined chlorine, there does not appear to be a consistent monthly pattern among these utilities, with Burlington showing increasing THM levels from 2002 through 2003 while Winston-Salem and Wilmington show a decreasing trend over this same time period.

The LRAA concentrations for HAA5, as shown in Figure 5.4, show a similar pattern. Burlington and Greensboro would have significantly exceeded the MCL for HAA5 for a residence time of 10 days over the entire period of study. Winston-Salem would have been out of compliance in early 2002, but would then have been in compliance for the remainder of the period of study. Wilmington and Charlotte would have been in compliance with the MCL for HAA5 throughout the study period. Wilmington, Greensboro, and Winston-Salem show pronounced downward trends in HAA levels, which is different than the pattern seen for Burlington. As noted above, it was expected that there might be similar monthly patterns for all of the utilities because of their

geographic proximity and similar climatology. This is obviously not the case. Again, this variation could be due to the fact that the Greensboro and Charlotte utilities have impoundments for raw water sources, whereas Winston-Salem, Wilmington and Burlington have river sources.

As indicated in the discussion above, significant differences in the LRAA concentrations for THM4 and HAA5, and in their trends, were observed for the eleven utilities evaluated. The ability to understand the basis for these differences and to allow for the development of meaningful conclusions about the different patterns was limited by the water quality information that was available to meet the objectives of this study. An explanation for the trends observed at each utility was beyond the scope of this project, and would require a comprehensive site-by-site analysis.

Many of the trends and patterns found could be due to a number of factors, e.g. variations in source water quality, changes in treatment plant operations and performance. Raw water characteristics, such as the concentration and chemical characteristics of NOM which varies with source water and season, have a profound effect on DBP formation in the treatment plant. Therefore, changes in source water quality can impact the levels of DBPs found in the distribution system (Croue et al., 1999). Seasonal phenomena, such as rainfall and temperature, can also affect DBP formation. For instance, after an extended period of drought, as was the case in North Carolina through early 2003, heavy rainfalls can wash stockpiles of decayed vegetative matter into raw water sources, thereby increasing the concentration of DBP precursors in these raw water sources. Additionally, changes in the treatment process train can affect DBP

formation. For example, the replacement of free chlorine with ozone as the primary disinfectant, as in the case of Wilmington and Raleigh, has been found to decrease the formation of THM4 and HAA5 by reducing the chlorine demand of the water (Reckhow, 1999). Furthermore, geographical considerations could also affect DBP formation. Studies have shown that TOC concentrations increase in the raw waters across North Carolina, from the mountainous west to the coastal east (Young and Singer, 1979; Singer et al., 1982). Therefore, all other factors being equal, it would be expected that DBP formation would be lowest in Charlotte and would increase through the central Piedmont to the coast of North Carolina. The relatively low DBP levels exhibited in Wilmington are most likely a result of the use of ozone as a primary disinfectant at that utility.

An explanation for the trends observed at each utility would require a comprehensive site-by-site analysis. Such an analysis would require:

- A monthly record of TOC concentrations and UV absorbance of the raw water;
- A monthly record of pre-chlorination and post-chlorination doses and detailed information as to where the chlorine is applied;
- A monthly record of TOC and UV removal prior to the application of chlorine;
- Information about the use of alternate oxidants and disinfectants (e.g. ozone, chlorine dioxide) prior to the application of chlorine;
- Information about the point of ammonia addition for those plants using combined chlorine, and the chlorine:ammonia ratio;
- A monthly record of flow rates that could impact free chlorine contact times for DBP formation in the treatment plant;

- A monthly record of pH values in various processes which could impact the distribution of THM and HAA species concentrations.
- Better definition of distribution system residence times associated with the different monitoring locations.

CHAPTER 6 - CONCLUSIONS

6.1 Conclusions

The objective of this study was to assess the degree to which the eleven utilities in North Carolina comprising the Urban Water Consortium would be able to comply with the forthcoming Stage 2 DBP Rule. The conclusions of this study are as follows:

- Use of the USEPA's Water Treatment Plant model represents an effective approach for estimating THM4 and HAA5 concentrations under different sets of conditions. THM4 and HAA5 concentrations measured under one set of conditions can be extrapolated to another set of conditions using this approach.
- The following utilities should not have difficulty complying with the impending Stage 2 DBP Rule provided that their source water and treatment practices do not change appreciably: Raleigh, Fayetteville, Greenville, and High Point. These utilities have predicted LRAA concentrations for THM4 and HAA5 that never exceed the 80 µg/L MCL for THM4 and the 60 µg/L MCL for HAA5, and are below 80 percent of the MCLs for the majority of the time period studied.
- Wilmington should be able to comply with the 60 µg/L MCL for HAA5 but may have difficulty complying with the 80 µg/L MCL for THM4 if the maximum residence time in their distribution system is greater than 7 days.

- Charlotte may have difficulty complying with the Stage 2 DBP Rule for THM4 if the maximum residence time in their distribution system is greater than 10 days but should not have difficulty complying with the 60 µg/L MCL for HAA5. If the maximum residence time in the Charlotte system is 7 days or less, Charlotte should be able to comply with the 80 µg/L MCL for THM4s.
- The remaining utilities, Durham, Burlington, Greensboro, OWASA, and Winston-Salem, may have difficulty complying with the new Rule unless modifications are made in their treatment practices: These utilities have predicted LRAA concentrations which approach or exceed the 80 µg/L MCL for THM4 or the 60 µg/L MCL for HAA5, or both.

These conclusions are predicated on the validity of the modeling approach used in this investigation. Attempts to demonstrate the validity of the modeling approach suggest that the models give predictions that are consistent with observed measurements.

6.2 Recommendations

In order to better characterize DBP concentrations in the distribution system, a more intensive THM and HAA monitoring program should be undertaken by the utilities, such as that recommended by the IDSE which is a part of the Stage 2 DBP Rule. These measurements can be used to test the validity of the models used in this study and the conclusions reached. THM and HAA concentrations in water distribution systems exhibit significant spatial and temporal variations, particularly in systems using free chlorine as the terminal disinfectant. These variations are system-specific and need to be understood by the respective utilities so that their

systems can be effectively managed. Other water quality parameters should be measured at the same time and at the same locations where the DBP samples are collected, such as temperature, pH, and especially residual chlorine concentrations. This will improve understanding of the spatial and temporal variations and the factors contributing to these variations. In addition, all nine HAA species should be measured, as it is likely that they will be regulated in the future. In this manner, the database can be extended so that a more comprehensive assessment of the formation and decay of DBPs in the distribution system can be made. Utilities should also consider the development and use of models to better define and understand what happens in their system. For example, a methodology for developing site-specific DBP formation and chlorine consumption models has been outlined by Westerhoff et al. (2000).

In addition, a site-by-site analysis is needed to better understand the trends and patterns found for each of the utilities studied to better prepare them for the Stage 2 DBP Rule. The analysis should include a review of source water quality and treatment practices, and an identification of potential problem areas and an evaluation of potential solutions, including treatment plant modifications that may be necessary to reduce DBP formation before the water enters the distribution system.

Many utilities in the United States have switched from free to combined chlorine as the residual disinfectant in the distribution system and many others are likely to follow suit as more utilities attempt to lower THM4 and HAA5 levels to comply with the LRAA aspects of the Stage 2 DBP Rule. However, N-nitrosodimethylamine (NDMA) has been identified as an emerging contaminant that has been associated with chloramination (Najm and Trussel, 2001). NDMA

has been classified as a probable human carcinogen by the USEPA, which estimates its 10^{-6} cancer risk level in drinking water at 0.7 ng/L (USEPA, 1997). Although this “DBP” is not currently regulated by the EPA, its potential regulation in the future could significantly impact those systems using chloramines as a terminal disinfectant. Additionally, other adverse water quality issues associated with the use of combined chlorine as a terminal disinfectant have been reported, such as nitrification problems. Therefore, these issues should be taken into consideration before switching from a free to a combined chlorine residual, and alternative approaches for DBP control, such as removing DBP precursors by granular carbon adsorption, membrane filtration, and anion exchange, should be considered.

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Appendix A - Wilmington

Figure A.1 Predicted and Measured DBP Concentrations for Location 2, t = 24 hrs

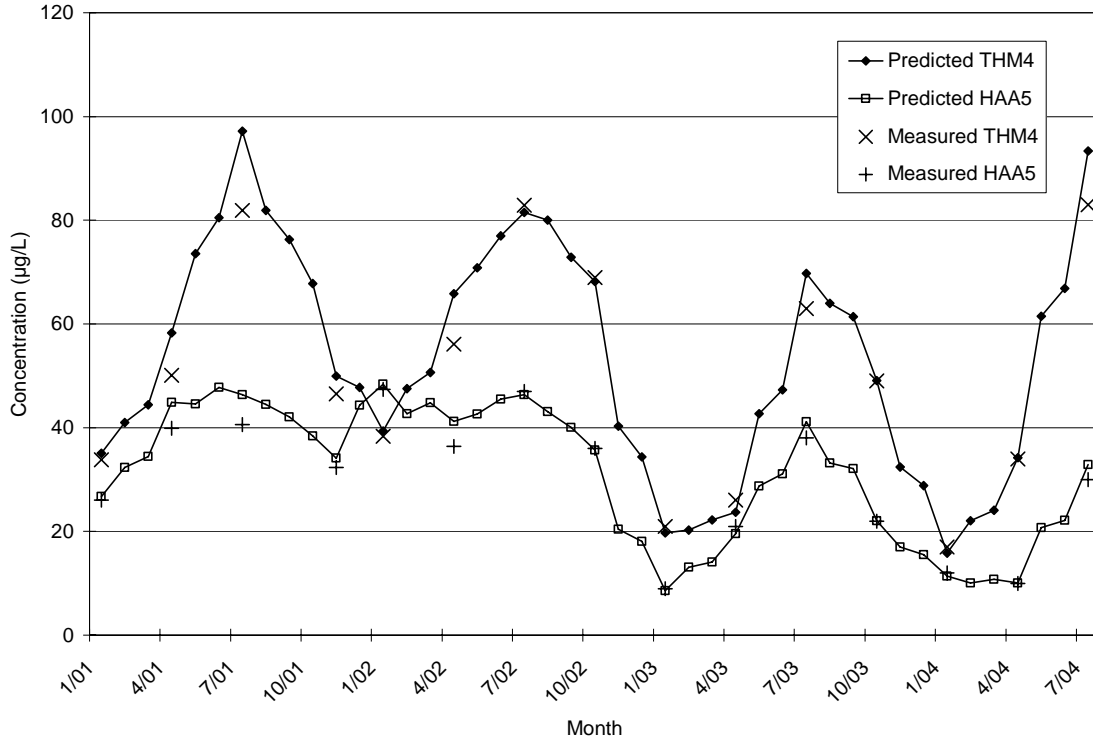


Figure A.2 Predicted Monthly LRAA Concentrations for Location 2, t = 24 hrs

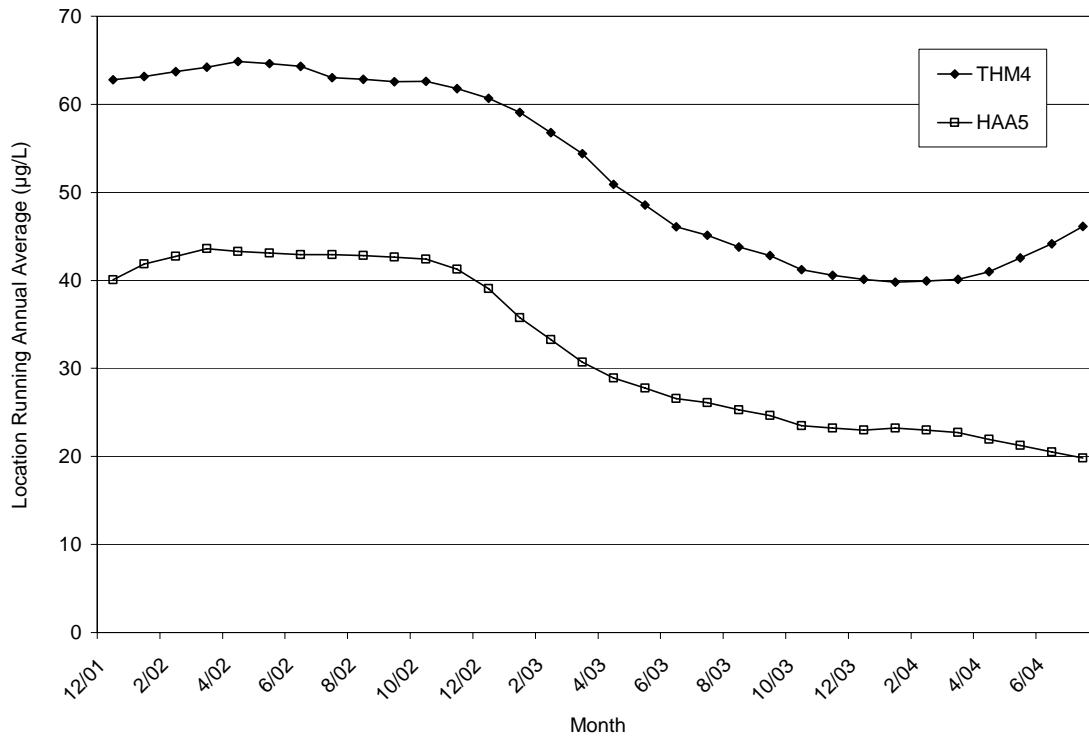


Figure A.3 Predicted and Measured DBP Concentrations for Location 3, t = 48 hrs

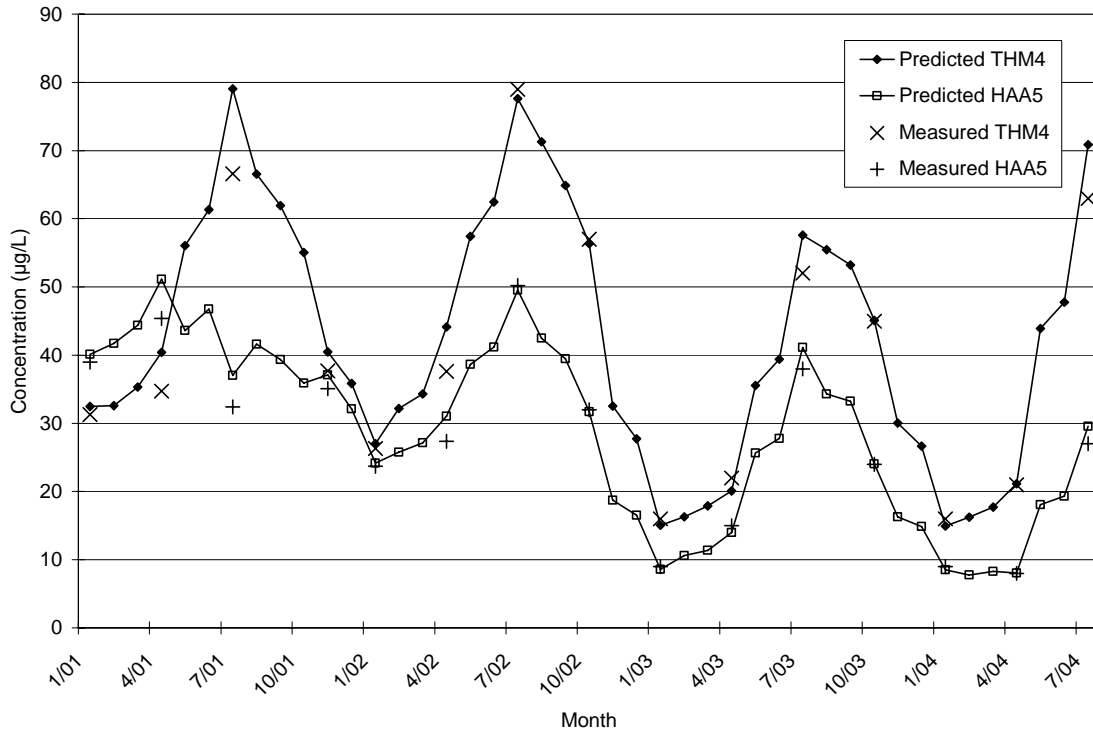


Figure A.4 Predicted Monthly LRAA Concentrations for Location 3, t = 48 hrs

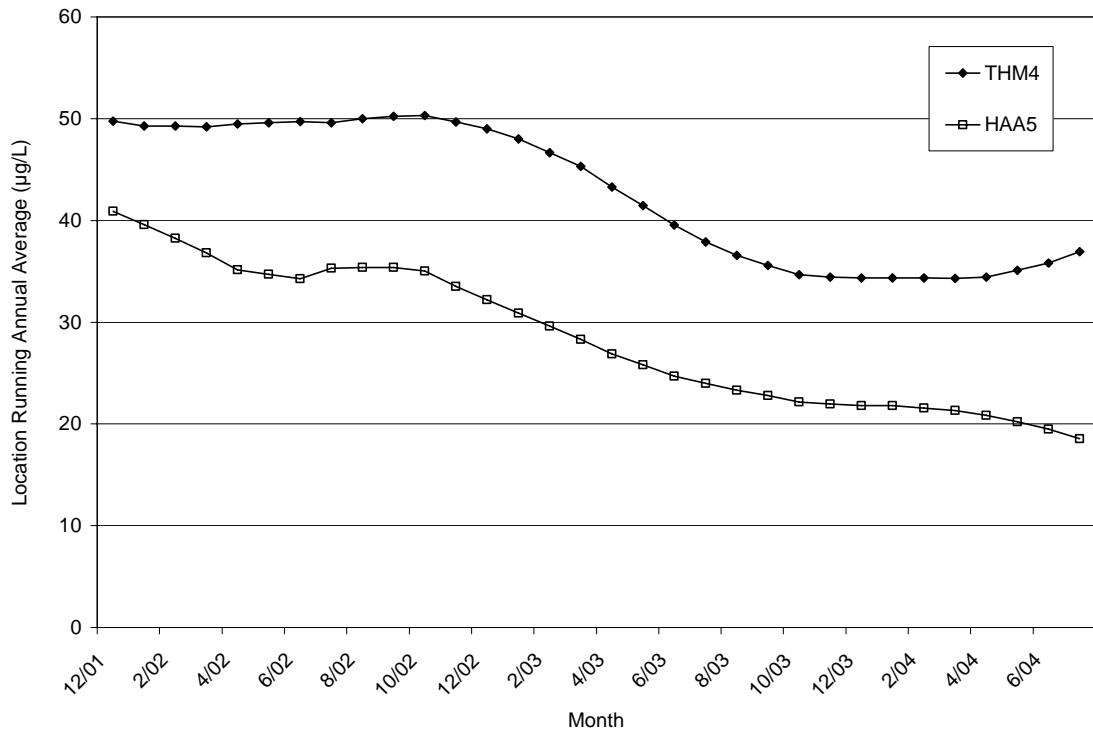


Figure A.5 Predicted and Measured DBP Concentrations for Location 4, t = 48 hrs

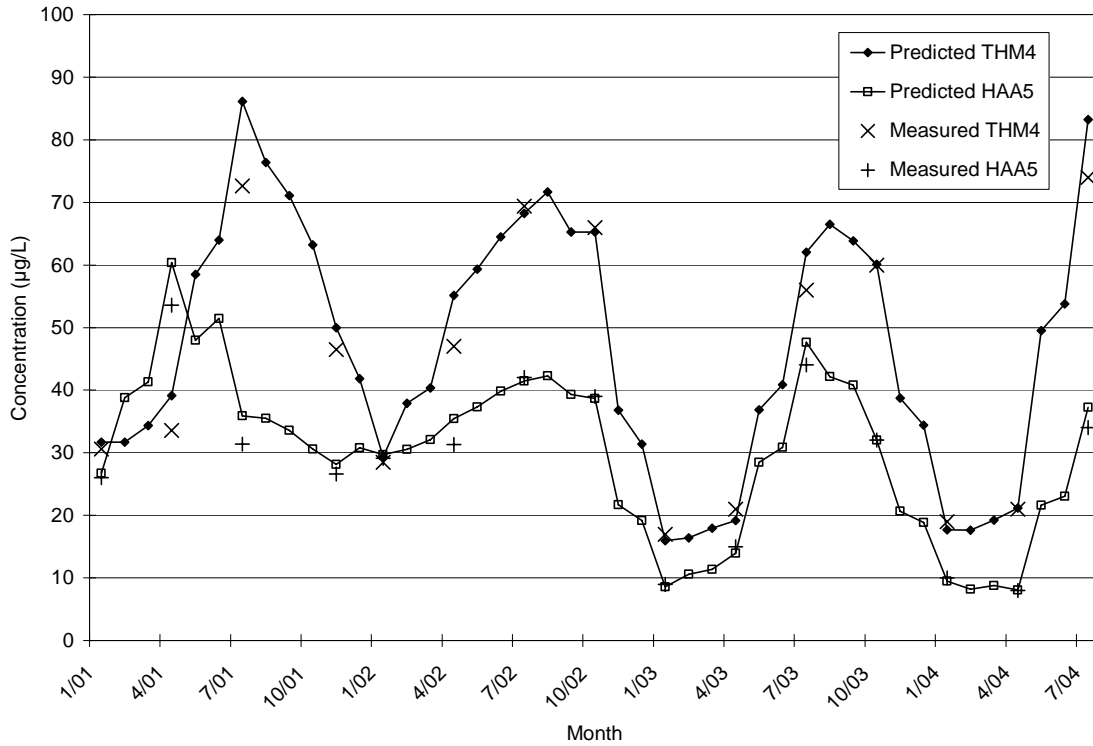


Figure A.6 Predicted Monthly LRAA Concentrations for Location 4, t = 48 hrs

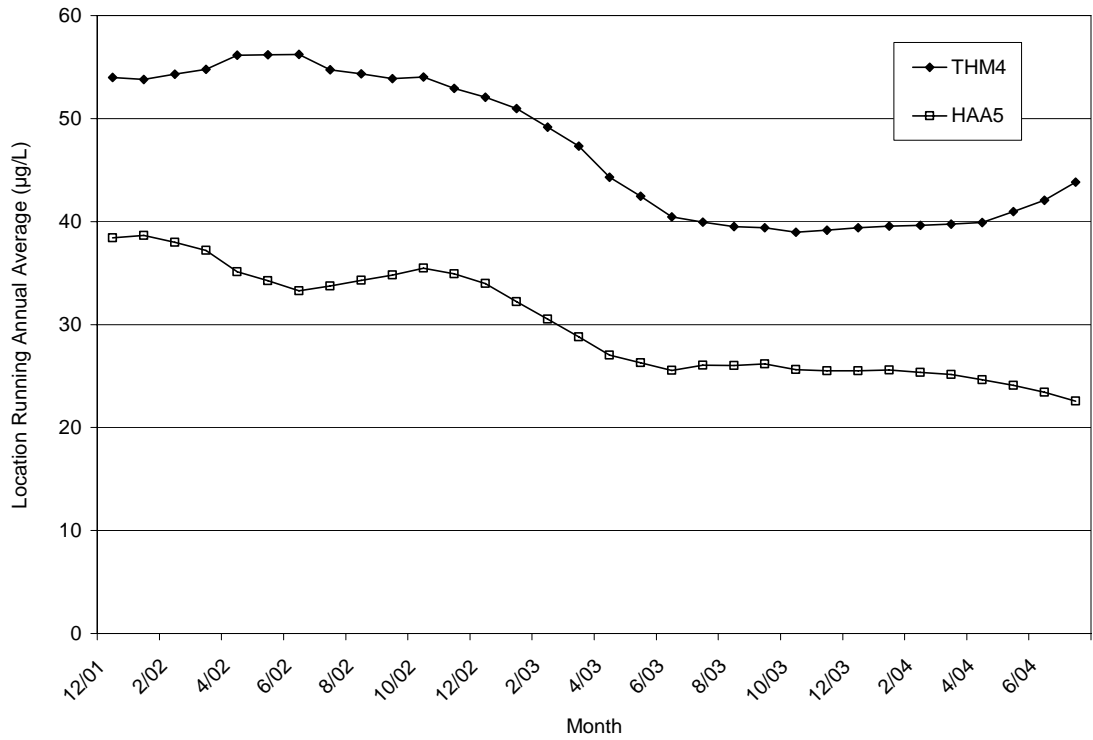


Figure A.7 Predicted and Measured DBP Concentrations for Location 5, t = 120 hrs

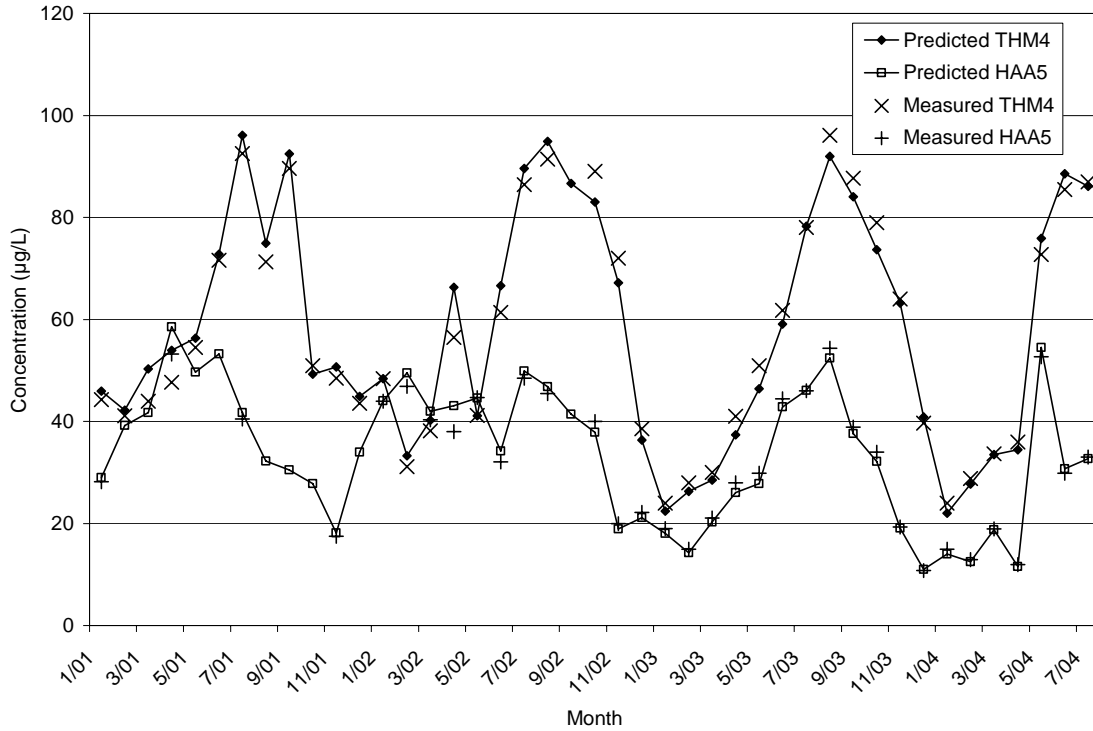


Figure A.8 Predicted Monthly LRAA Concentrations for Location 5, t = 120 hrs

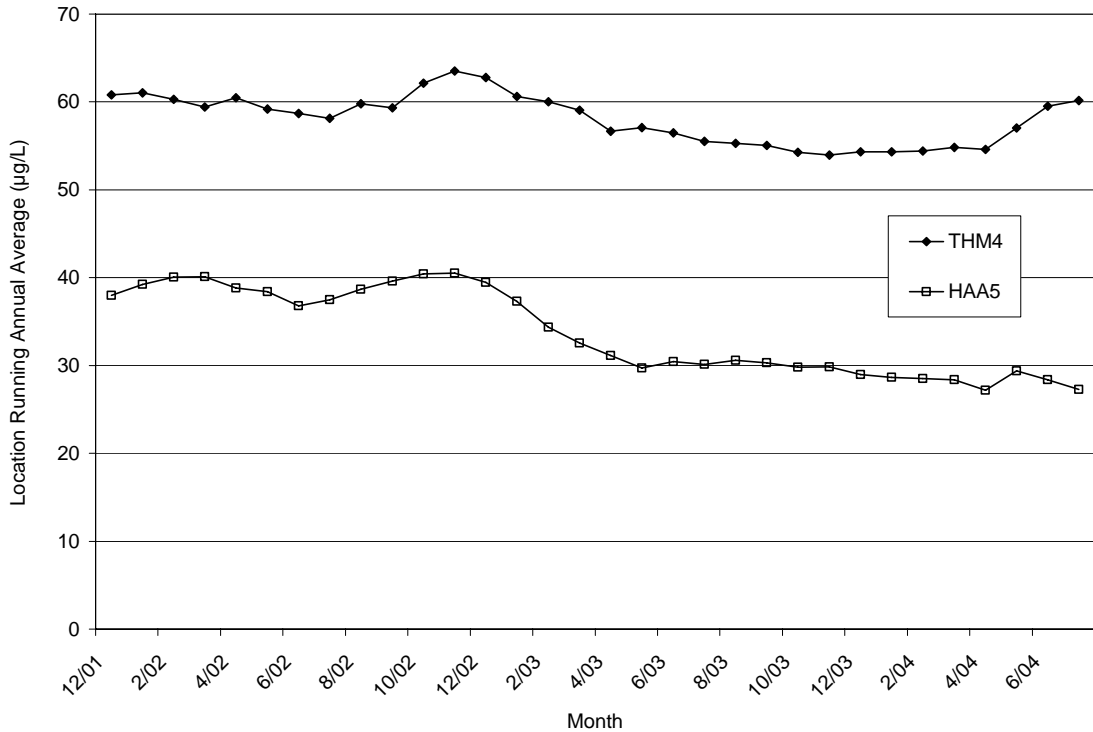


Figure A.9 Predicted and Measured DBP Concentrations for Location 6, t = 24 hrs

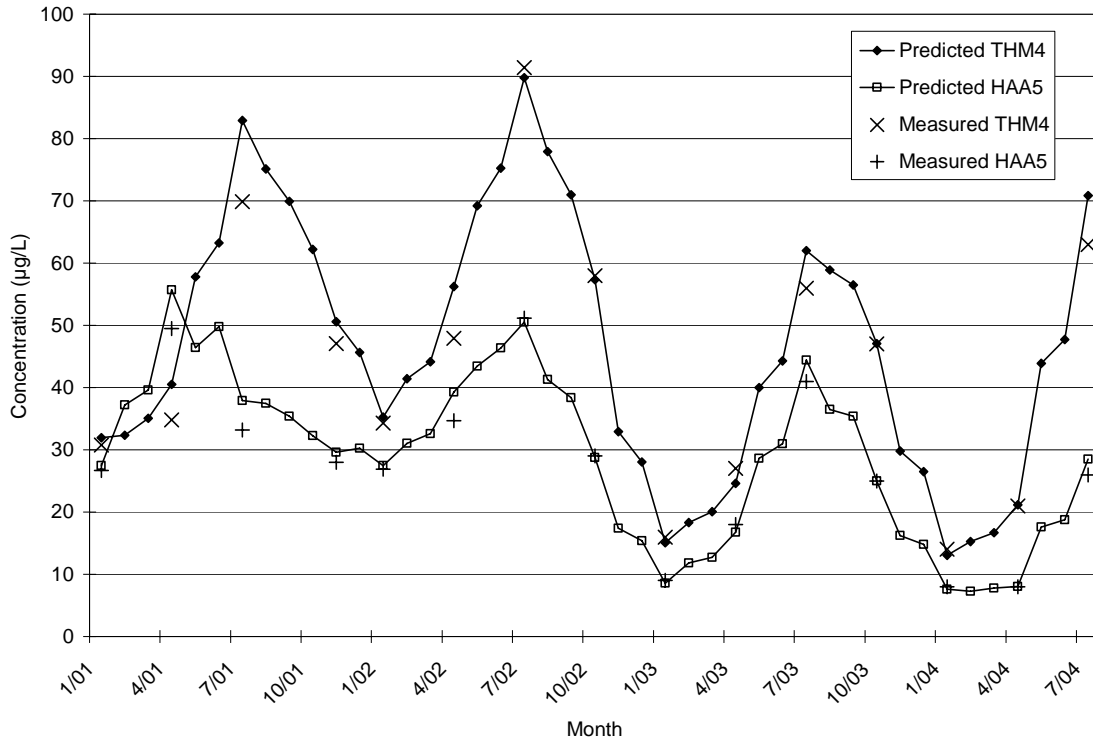


Figure A.10 Predicted Monthly LRAA Concentrations for Location 6, t = 24 hrs

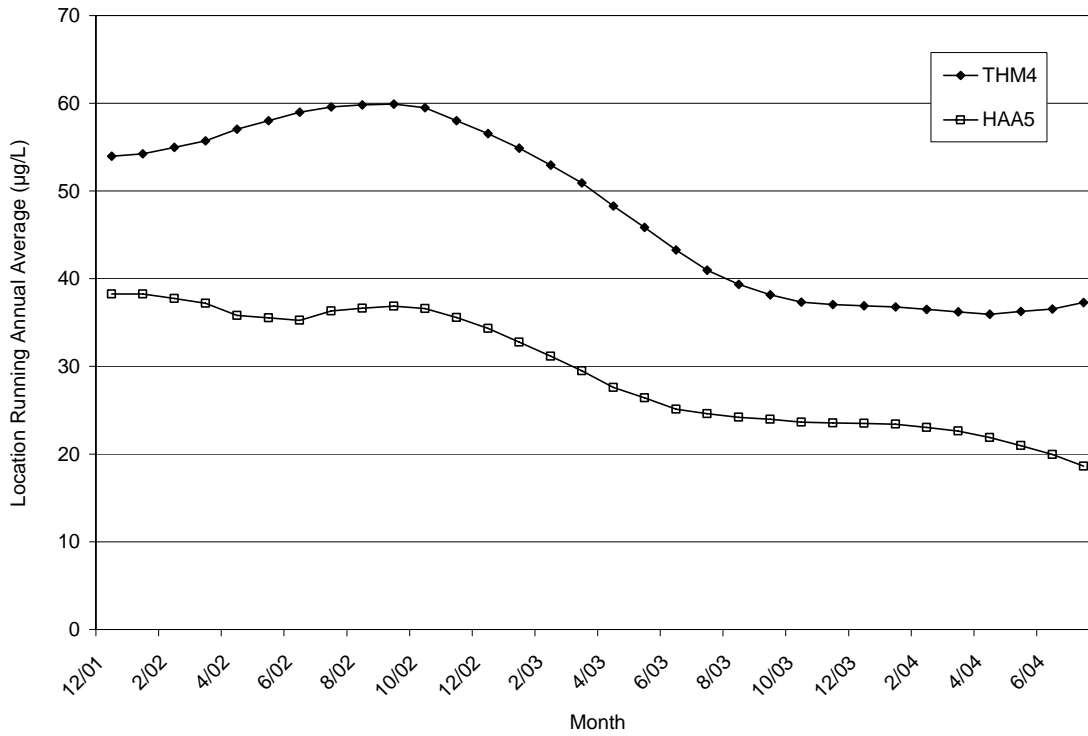


Figure A.11 Predicted and Measured DBP Concentrations for Location 8, t = 48 hrs

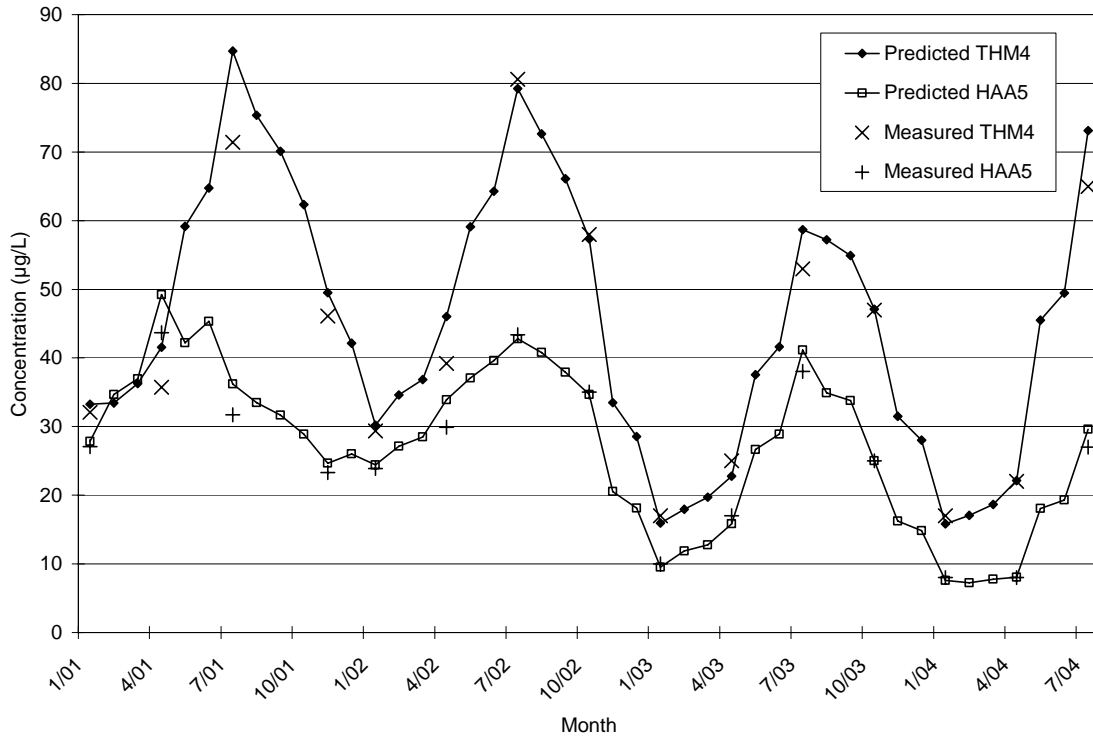


Figure A.12 Predicted Monthly LRAA Concentrations for Location 8, t = 48 hrs

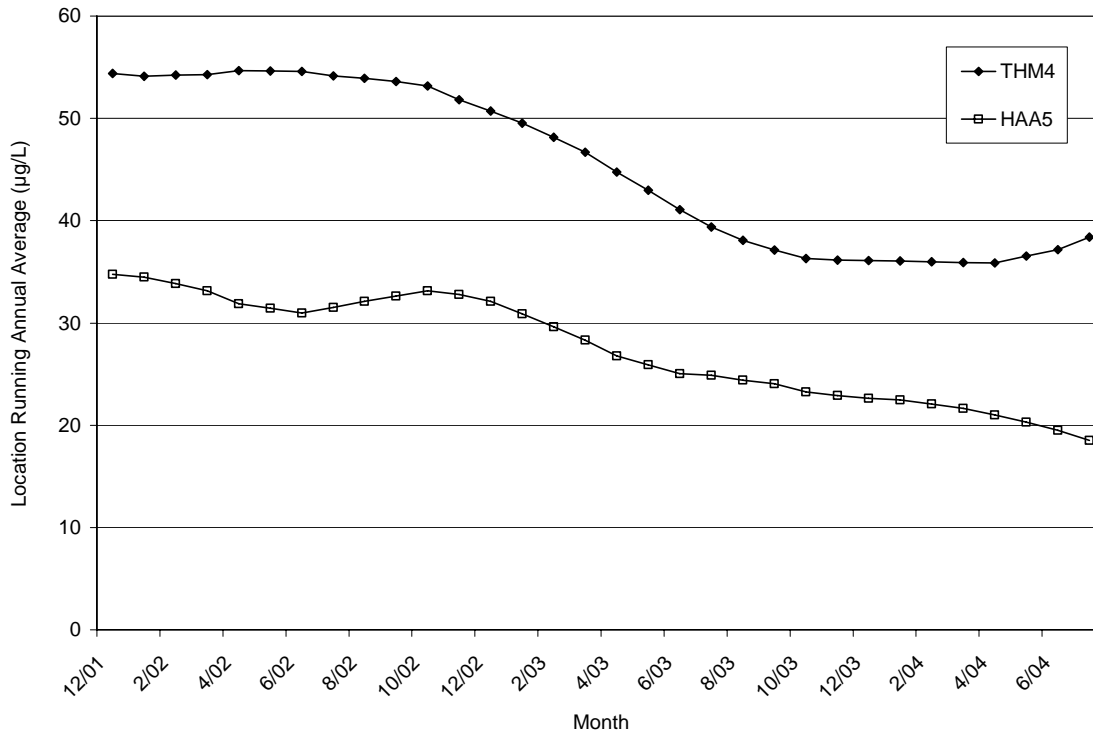


Figure A.13 Predicted and Measured DBP Concentrations for Location 9, t = 120 hrs

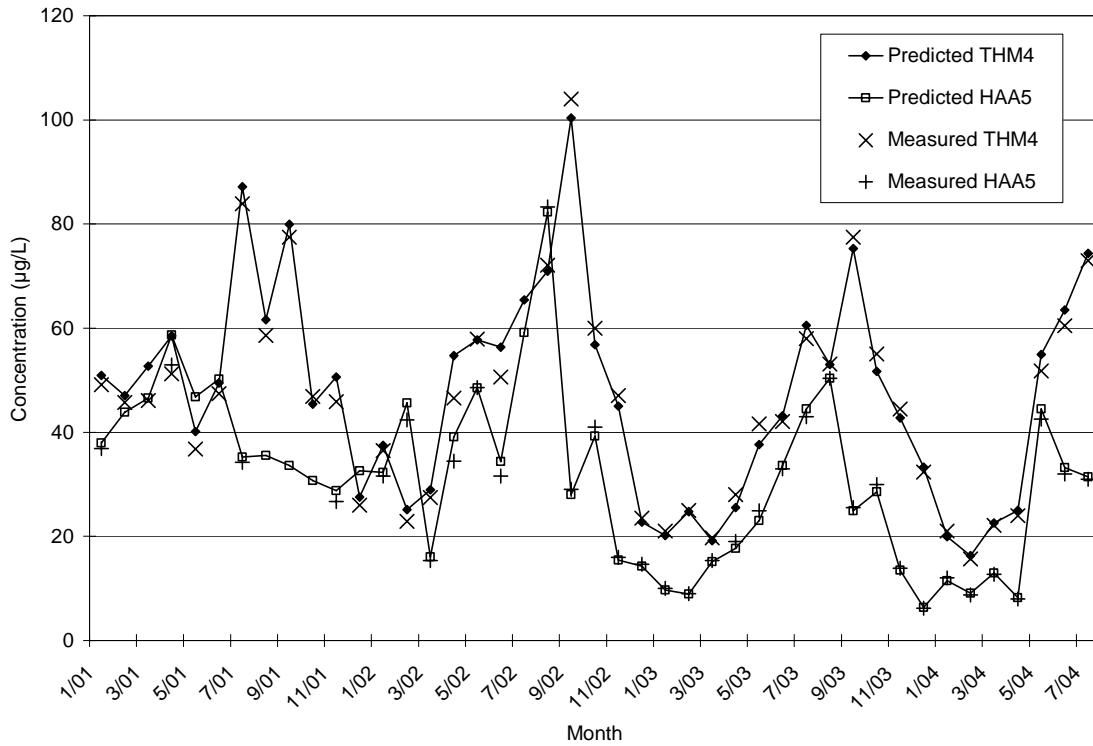
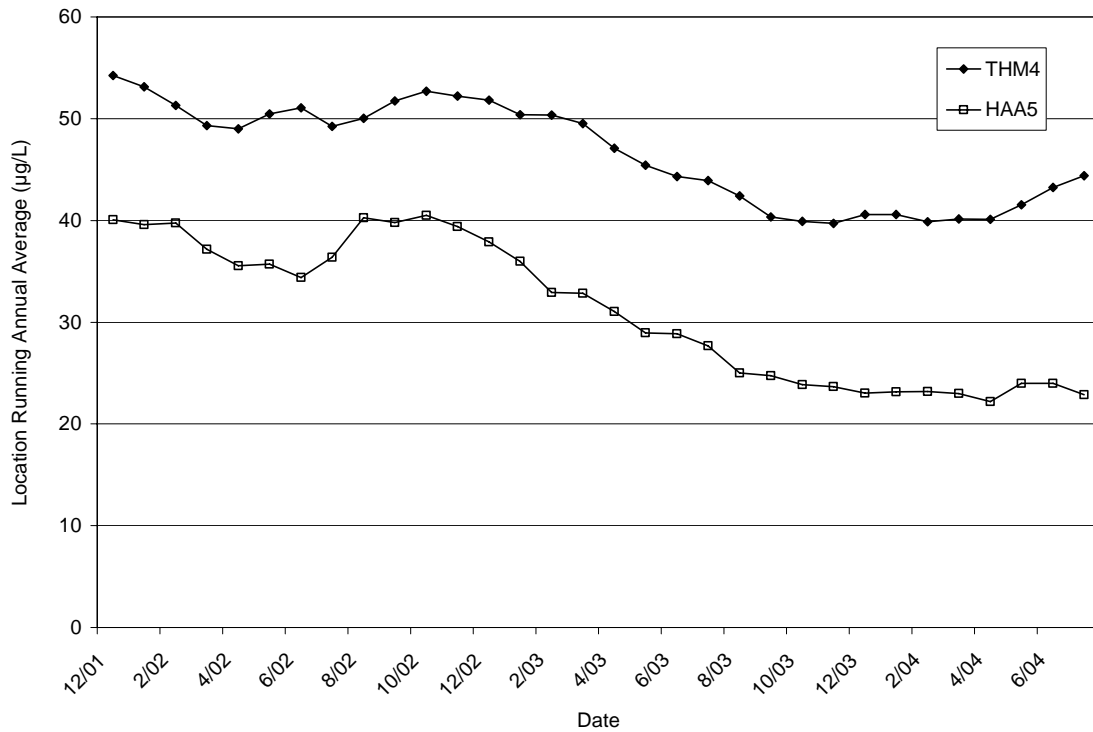


Figure A.14 Predicted Monthly LRAA Concentrations for Location 9, t = 120 hrs



Appendix B - Winston-Salem

Figure B.1 Predicted and Measured DBP Concentrations for Location 2 (t = 12 hrs)

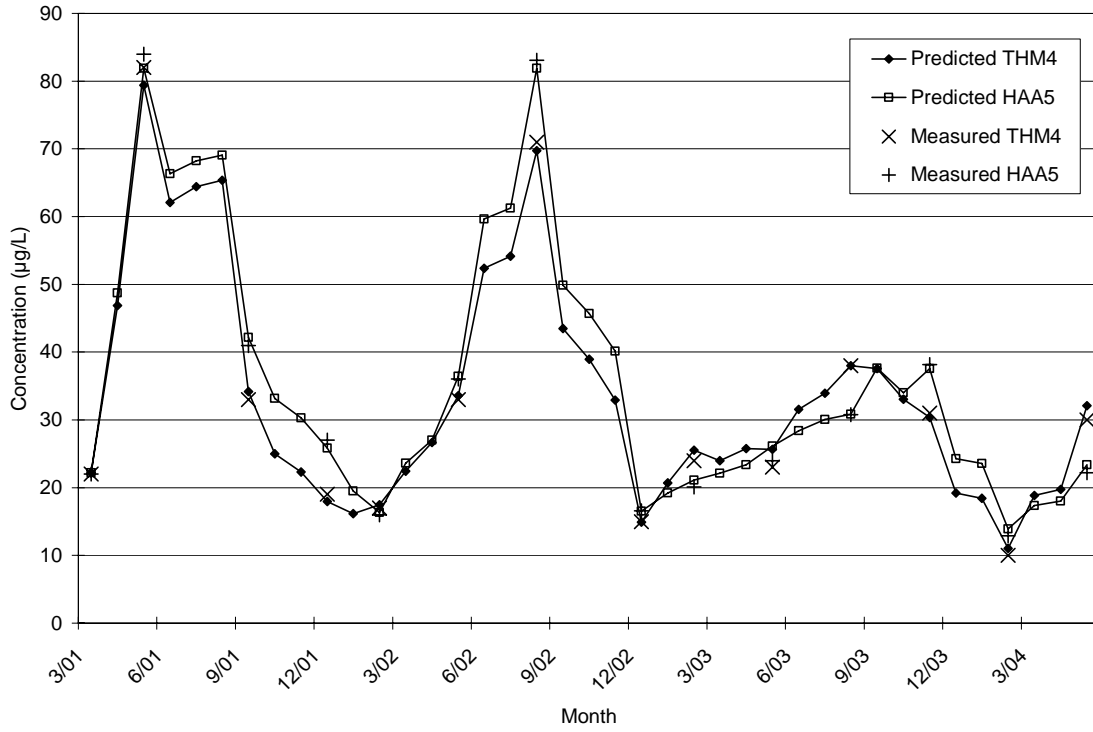


Figure B.2 Predicted Monthly LRAA DBP Concentrations for Location 2 (t = 12 hrs)

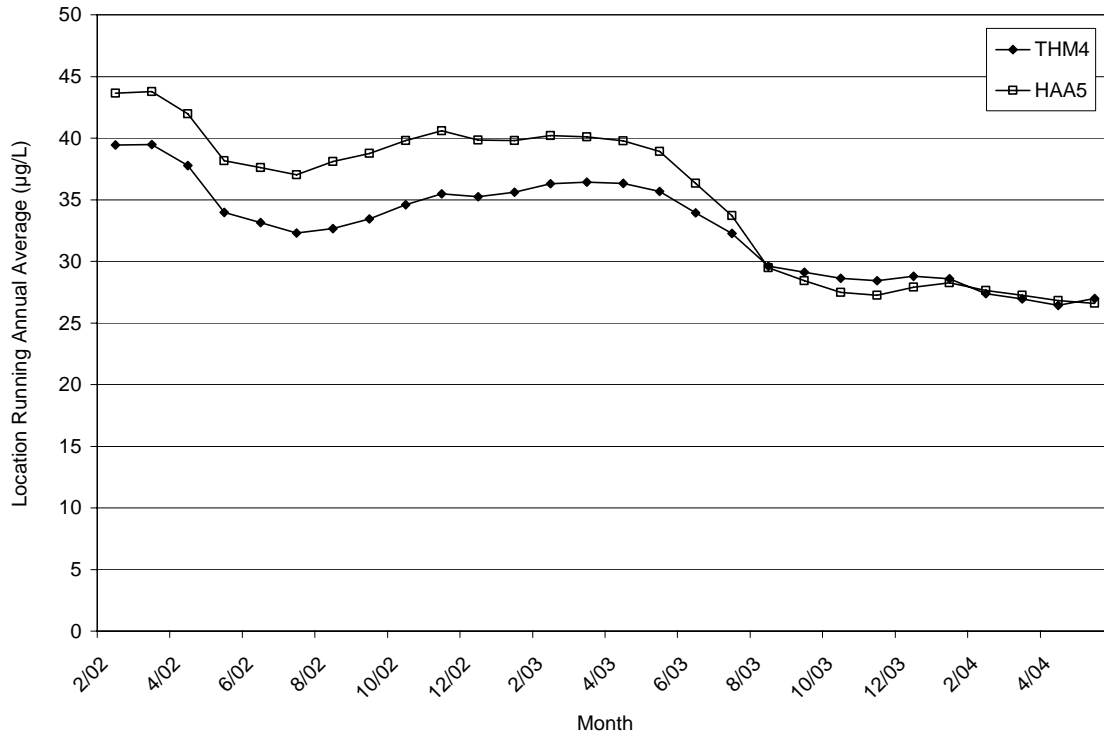


Figure B.3 Predicted and Measured DBP Concentrations for Location 4 (t = 24 or 36 hrs)

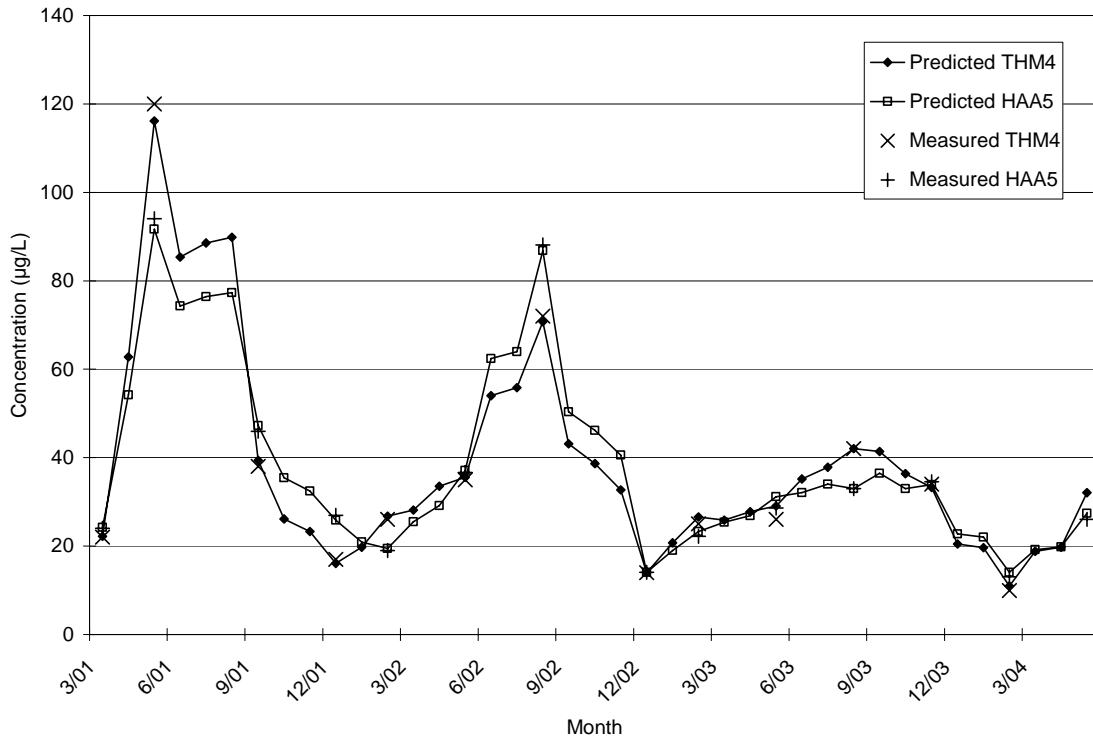


Figure B.4 Predicted Monthly LRAA DBP Concentrations for Location 4 (t = 24 or 36 hrs)

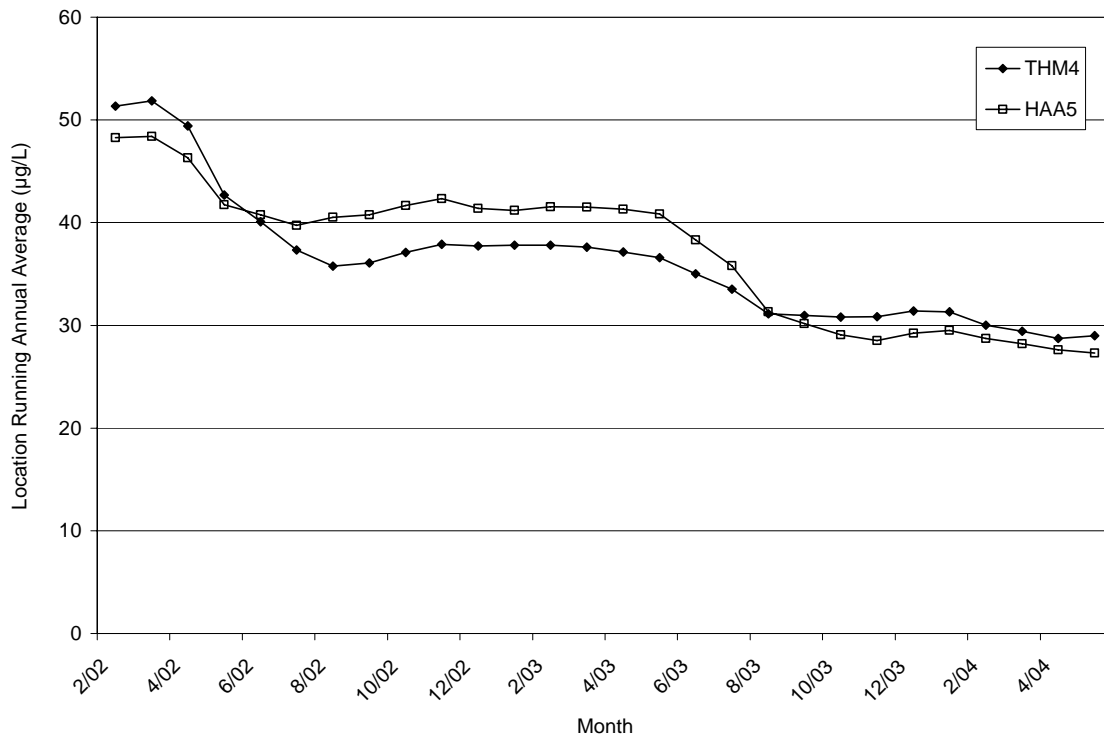


Figure B.5 Predicted and Measured DBP Concentrations for Location 5 (t = 36 or 48 hrs)

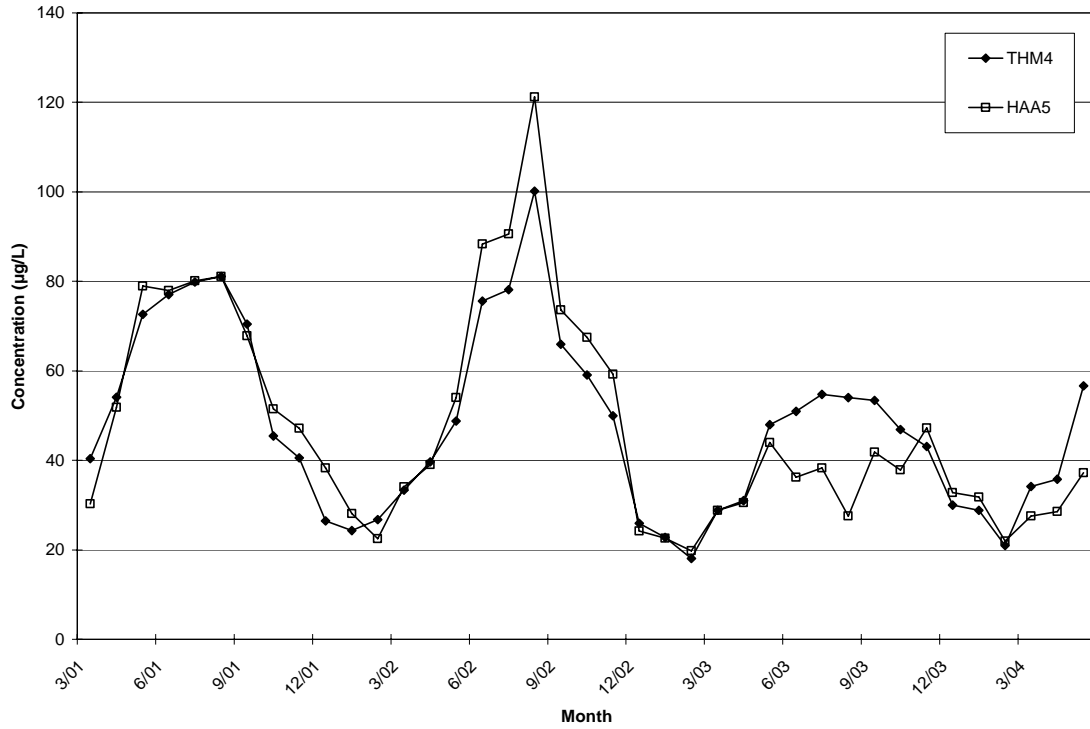


Figure B.6 Predicted Monthly LRAA DBP Concentrations for Location 5 (t = 36 or 48 hrs)

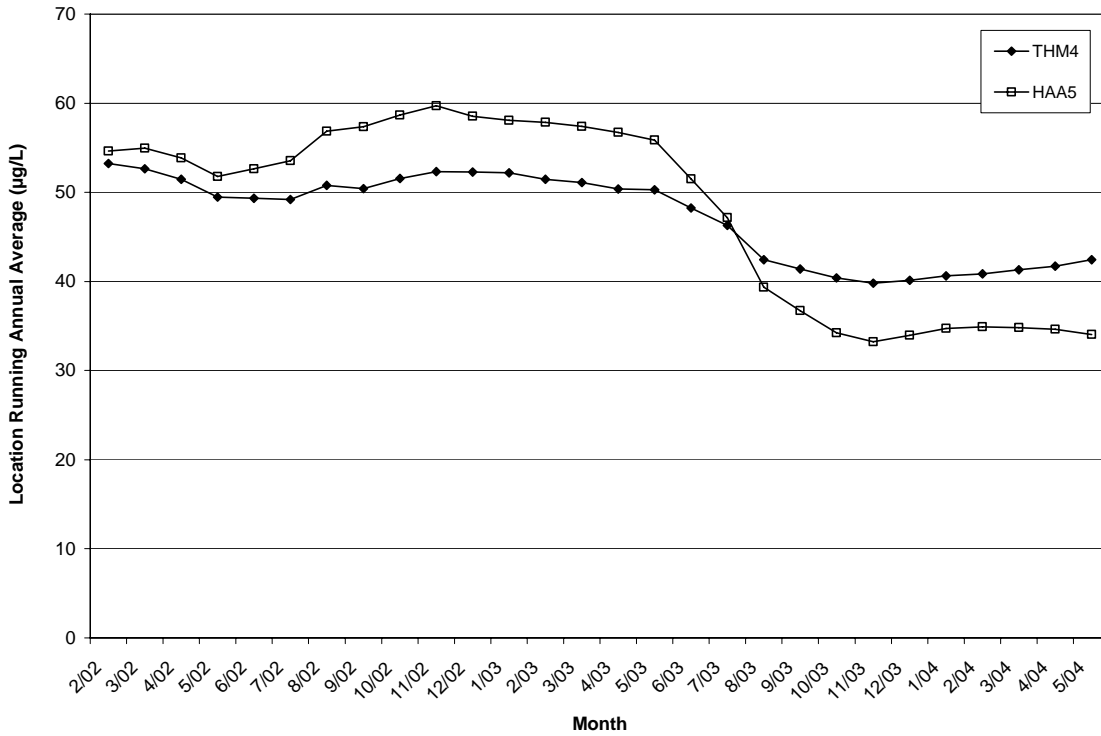


Figure B.7 Predicted and Measured DBP Concentrations for Location 7 (t = 12 hrs)

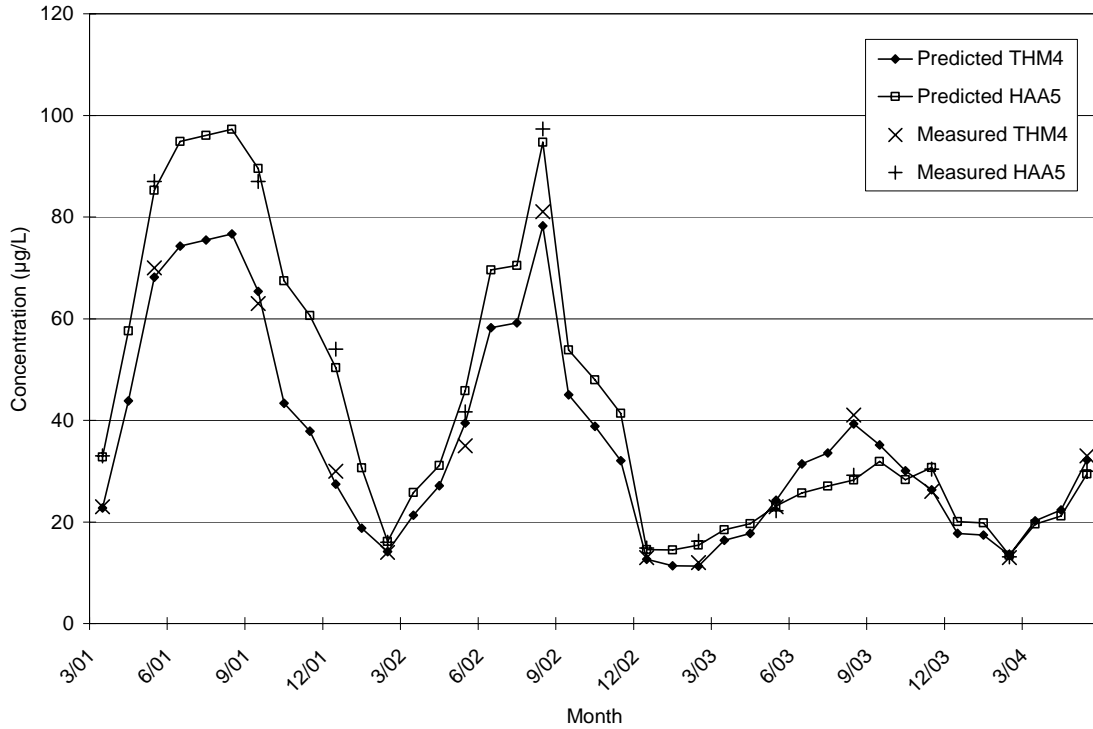


Figure B.8 Predicted Monthly LRAA DBP Concentrations for Location 7 (t = 12 hrs)

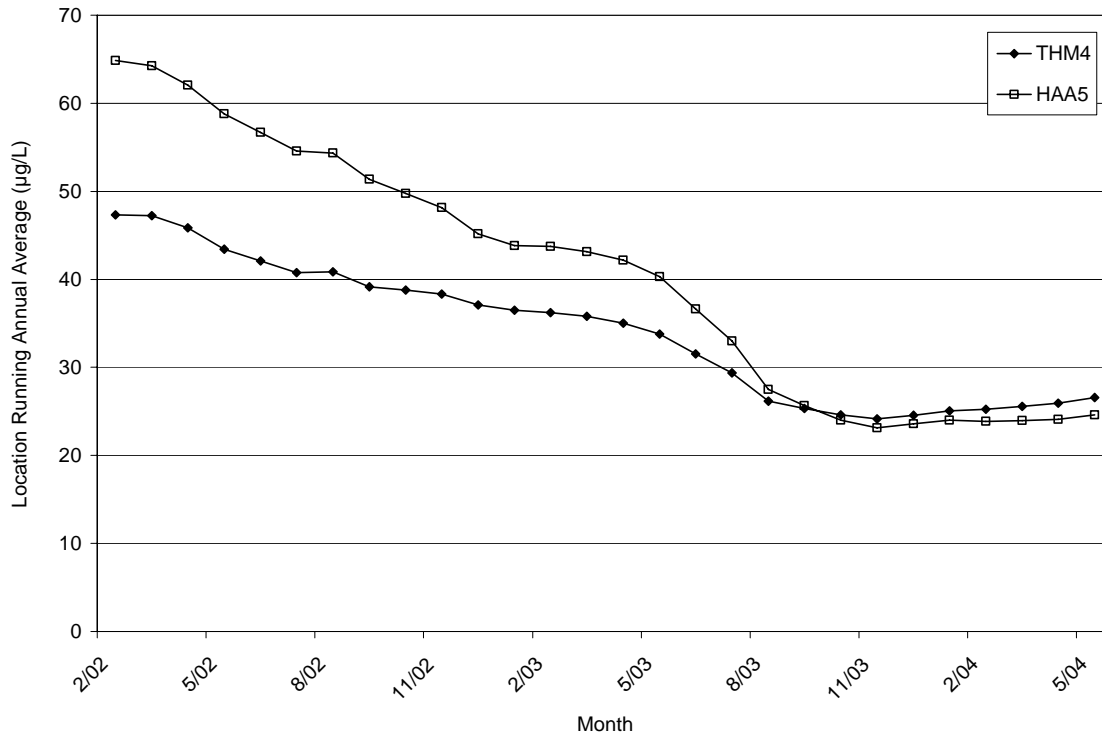


Figure B.9 Predicted and Measured DBP Concentrations for Location 8 (t = 24 hrs)

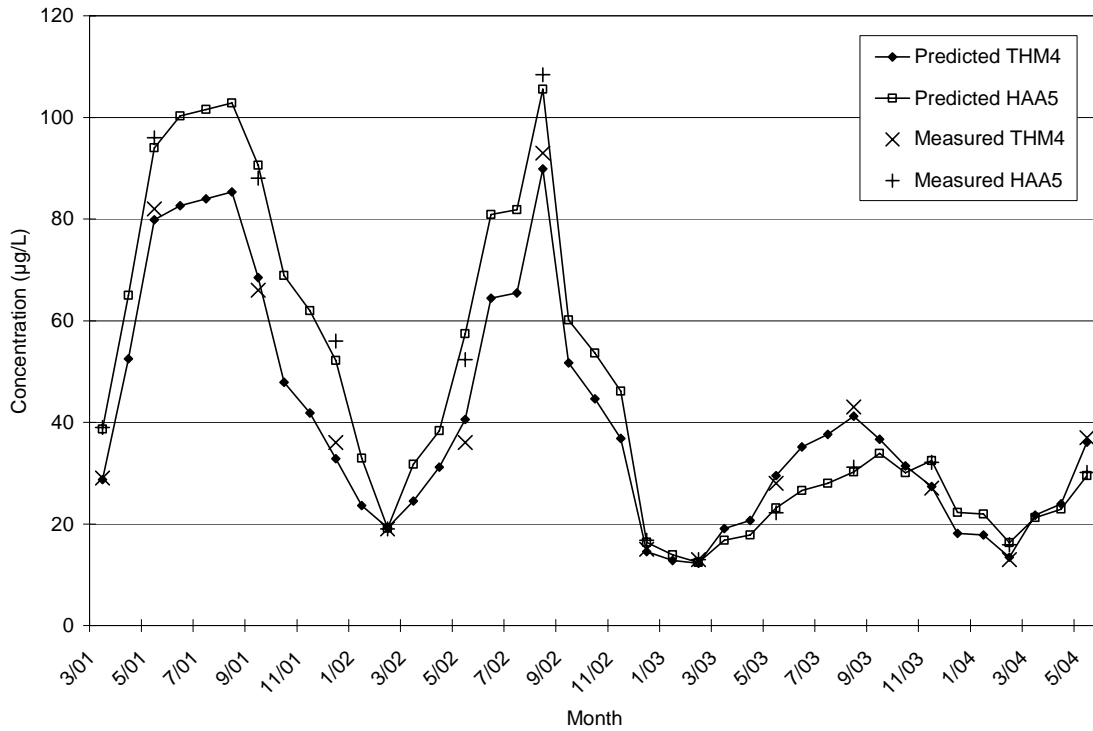


Figure B.10 Predicted Monthly LRAA DBP Concentrations for Location 8 (t = 24 hrs)

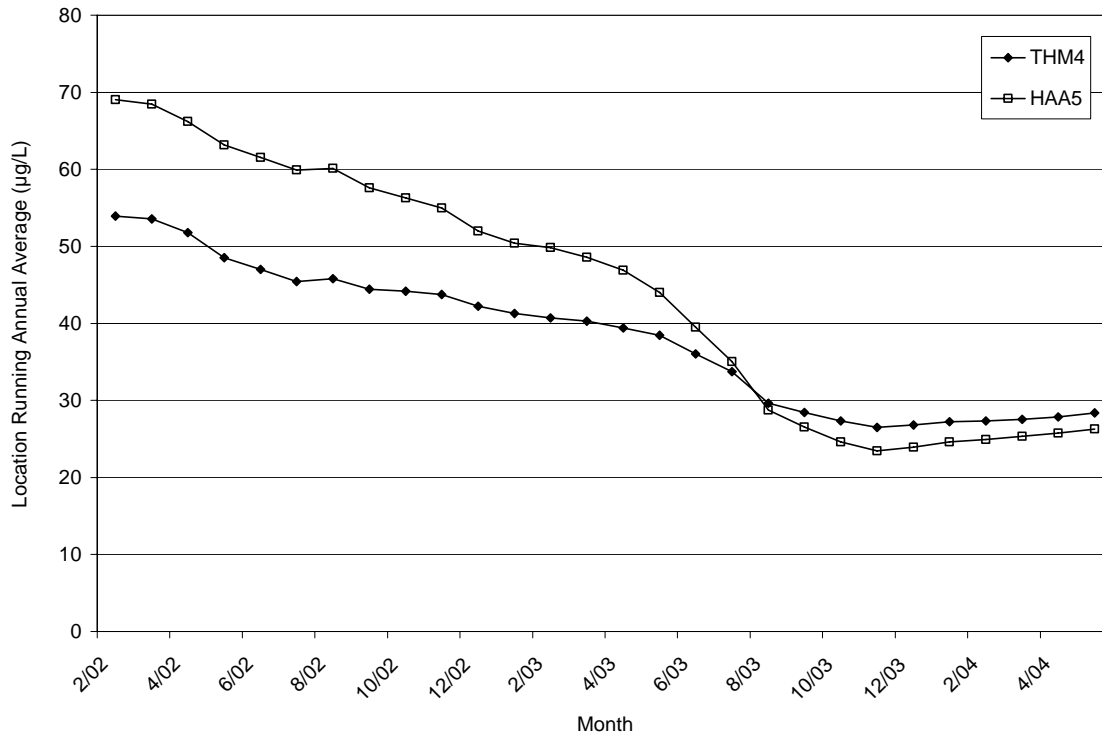


Figure B. 11 Predicted and Measured DBP Concentrations for Location 9 (t = 24 or 36 hrs)

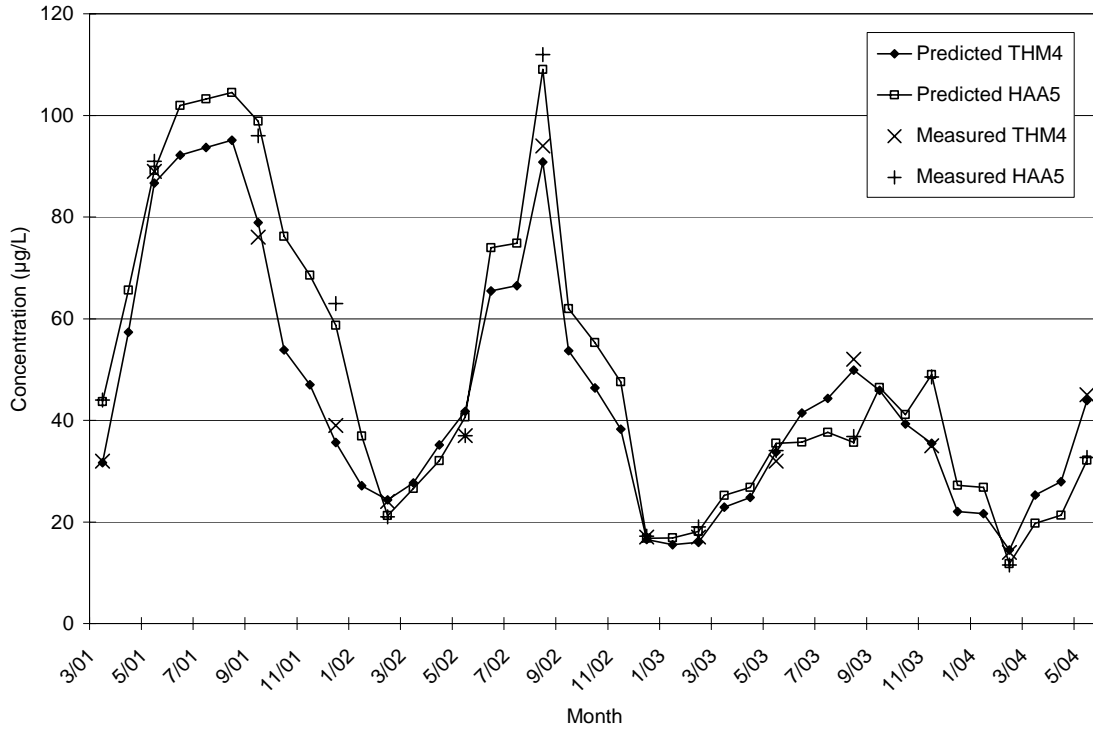


Figure B.12 Predicted Monthly LRAA DBP Concentrations for Location 9 (t = 24 or 36 hrs)

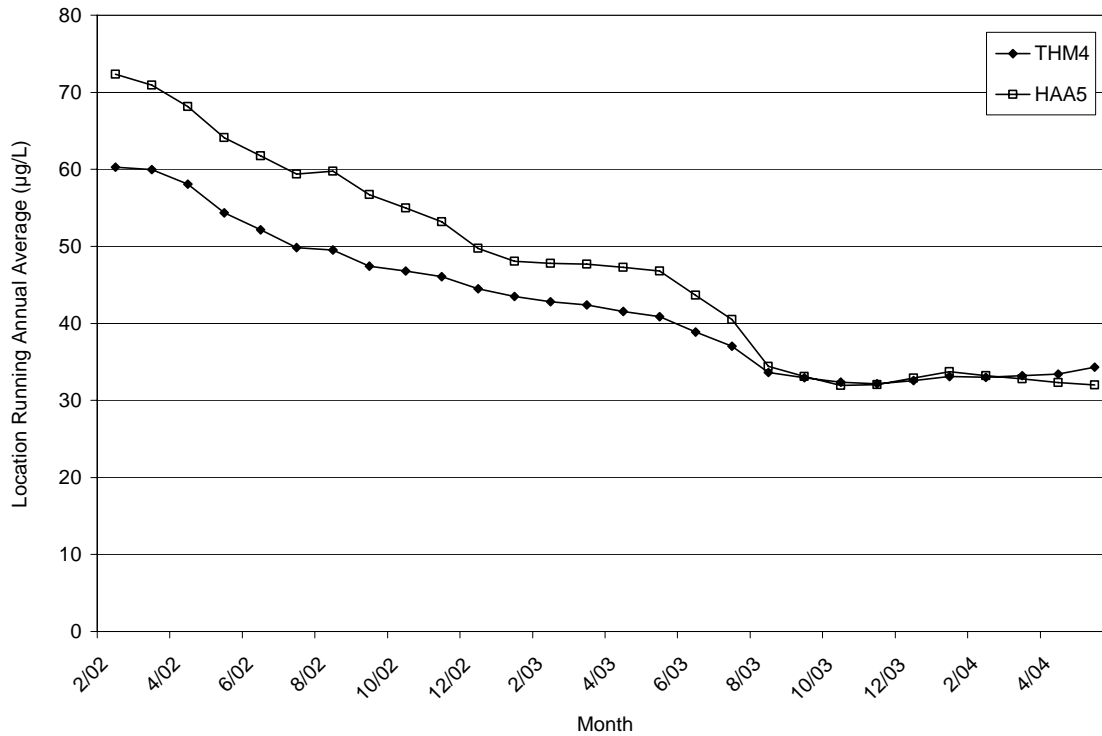


Figure B.13 Predicted and Measured DBP Concentrations for Location 10 (t = 36 or 48 hrs)

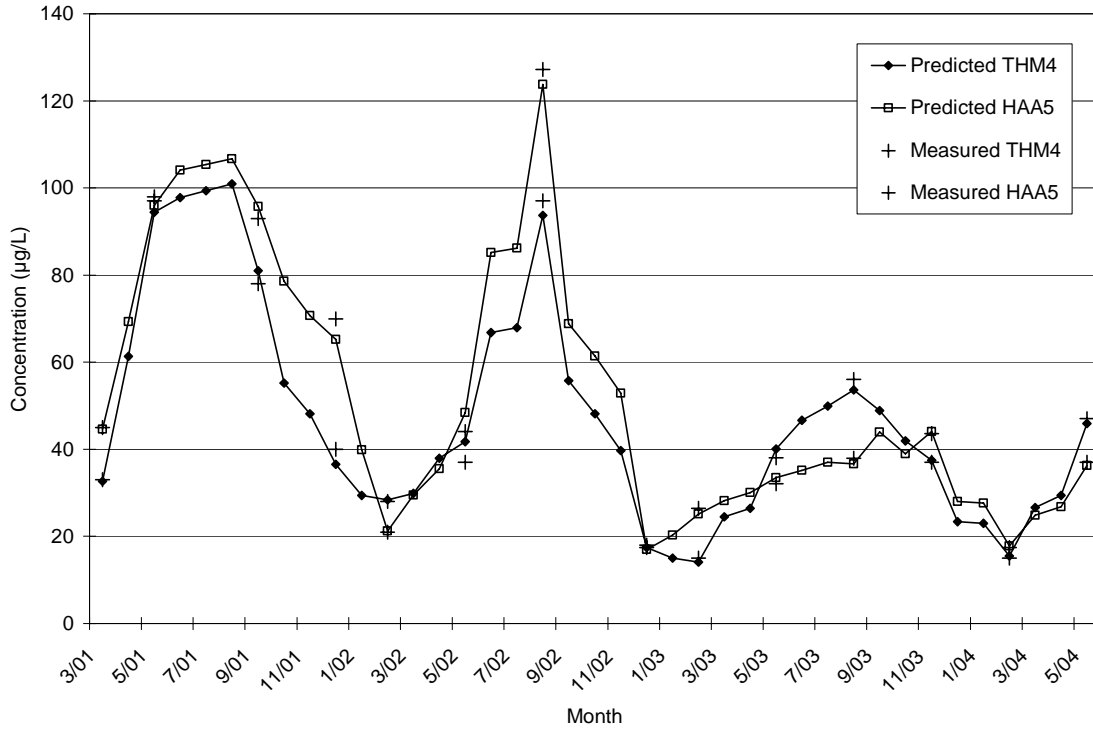


Figure B.14 Predicted Monthly LRAA DBP Concentrations for Location 10 (t = 36 or 48 hrs)

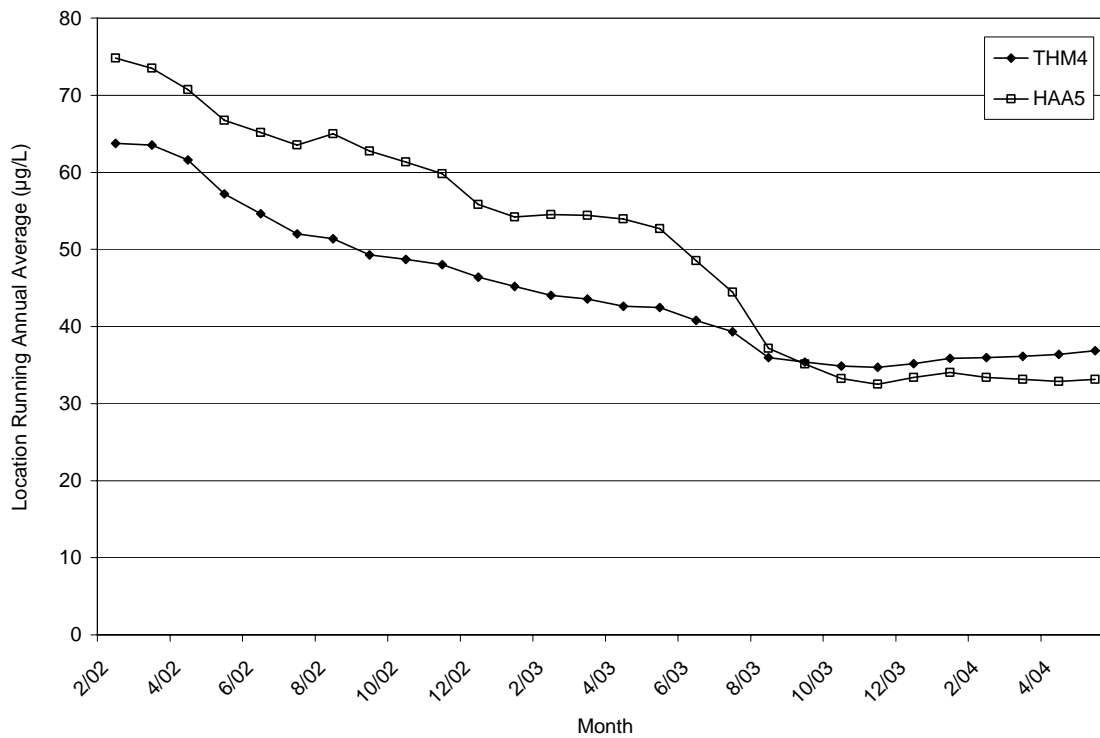


Figure B.15 Predicted and Measured DBP Concentrations for Location 11 (t = 72 hrs)

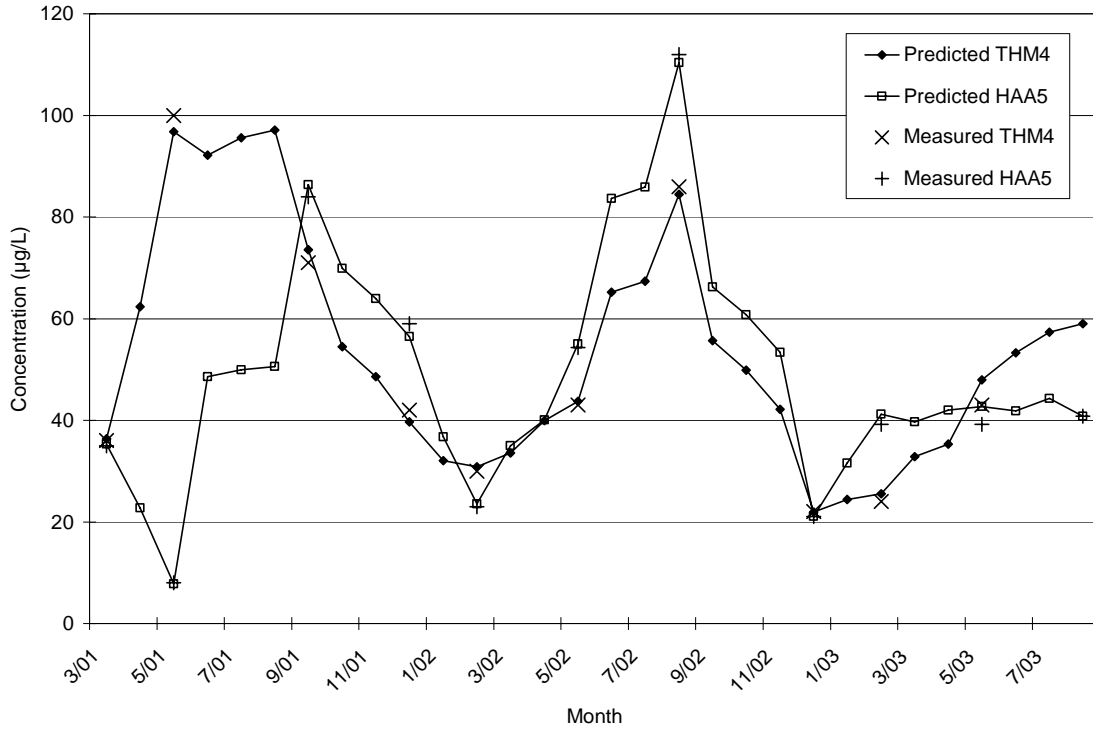
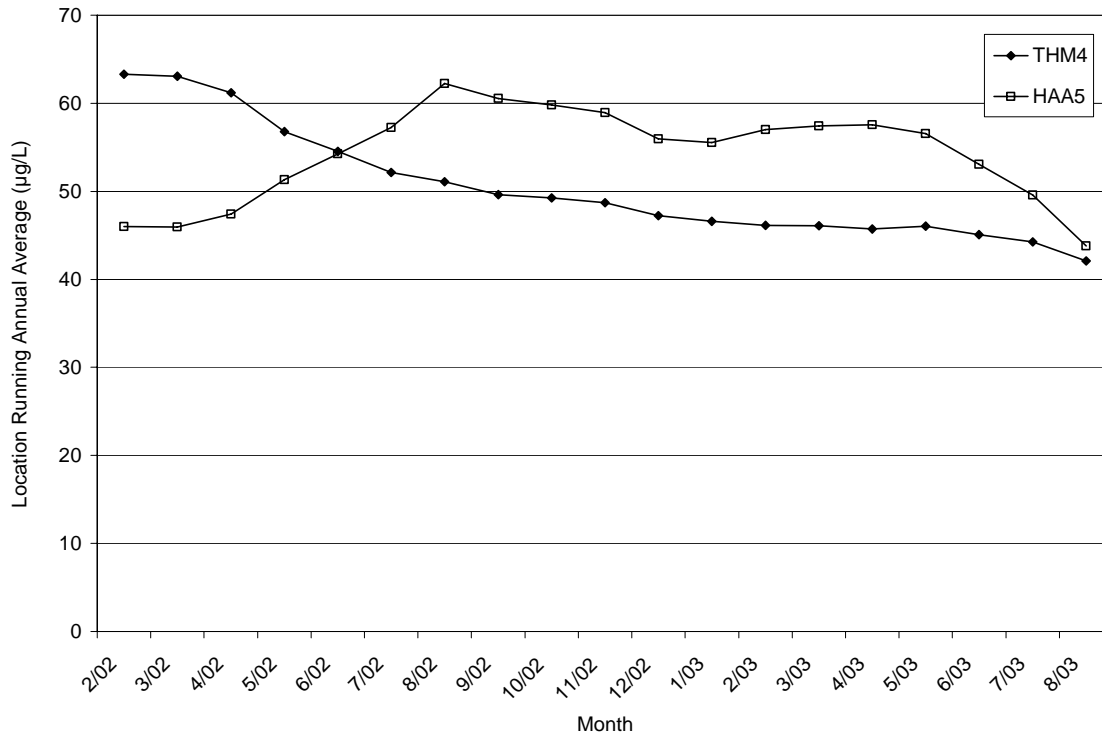


Figure B.16 Predicted Monthly LRAA DBP Concentrations for Location 11 (t = 72 hrs)



Appendix C - Greensboro

Figure C.1 Predicted and Measured DBP Concentrations for Location 2, t = 11 hrs

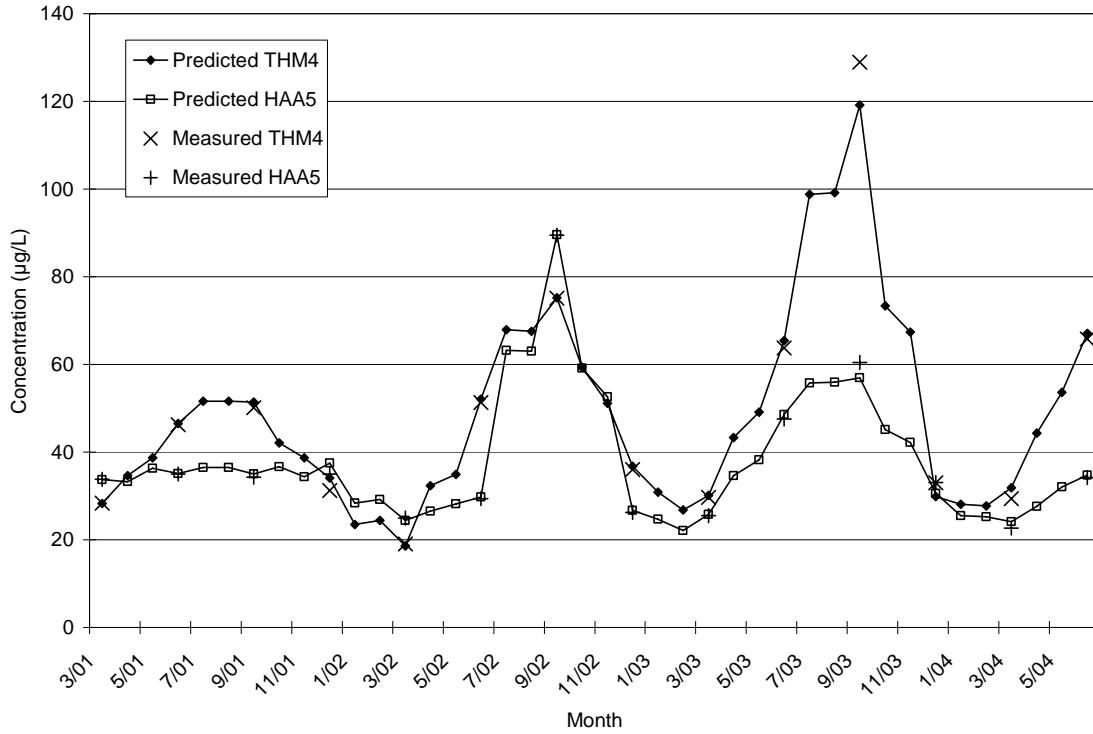


Figure C.2 Predicted Monthly LRAA Concentrations for Location 2, t = 11 hrs

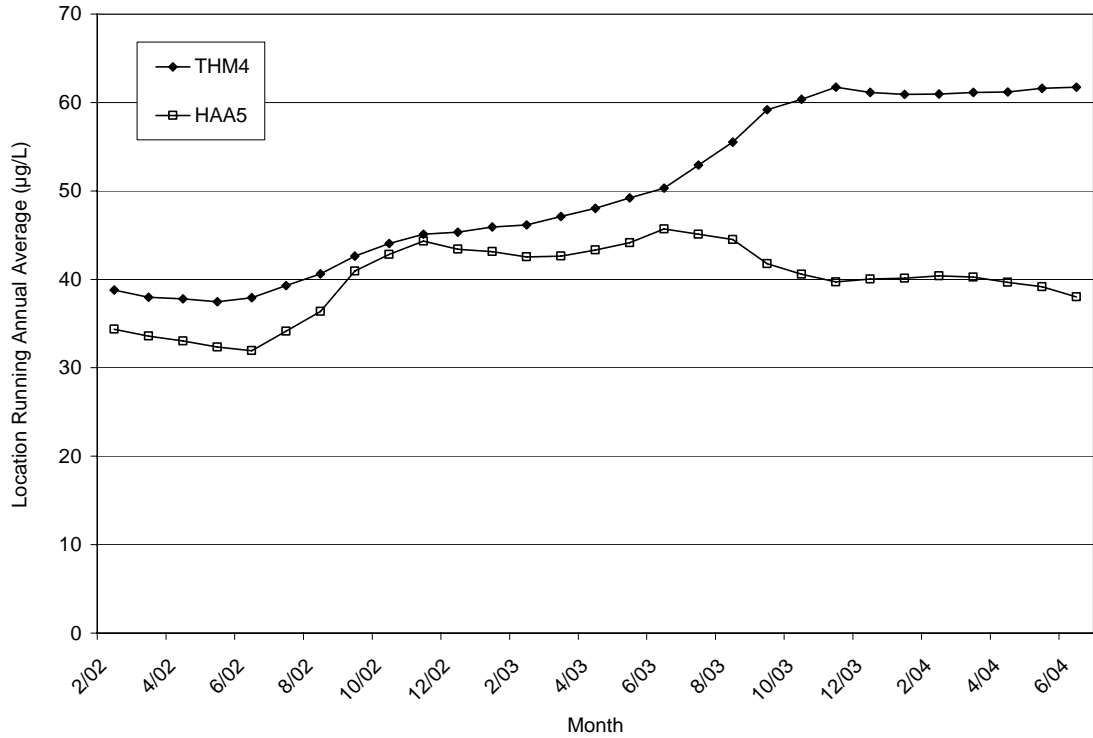


Figure C.3 Predicted and Measured DBP Concentrations for Location 3, t = 30 hrs

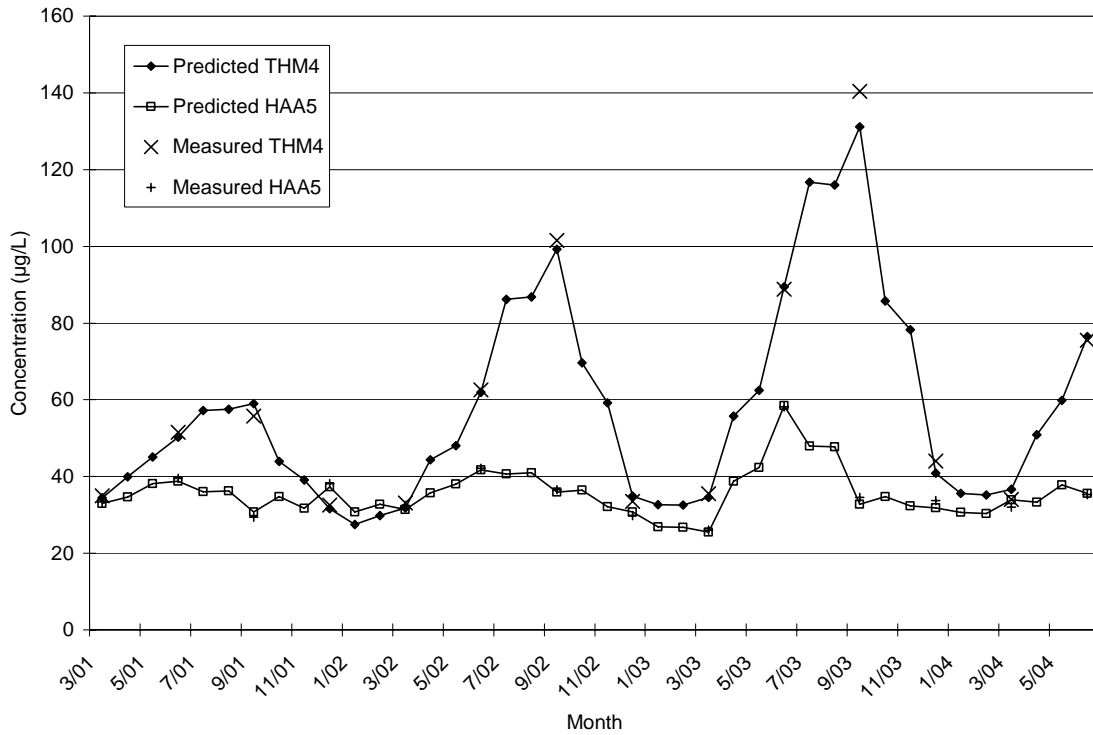


Figure C.4 Predicted Monthly LRAA Concentrations for Location 3, t = 30 hrs

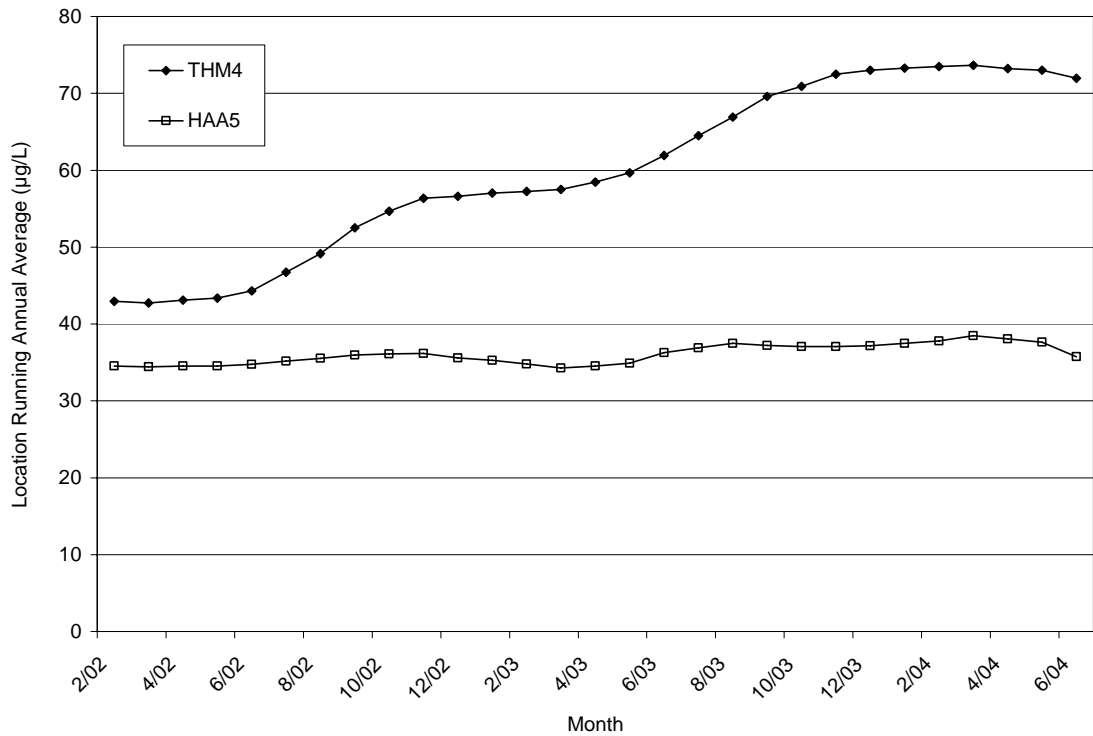


Figure C.5 Predicted and Measured DBPConcentrations for Location 4, t =20 hrs

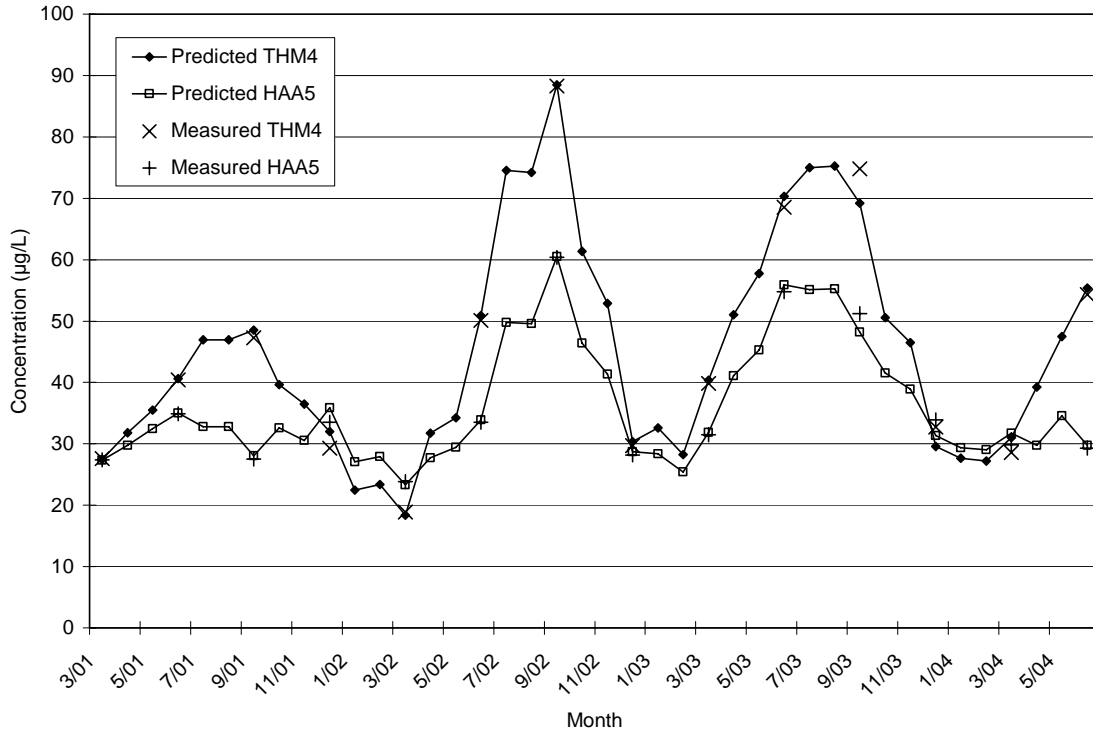


Figure C.6 Predicted Monthly LRAA Concentrations for Location 4, t = 20 hrs

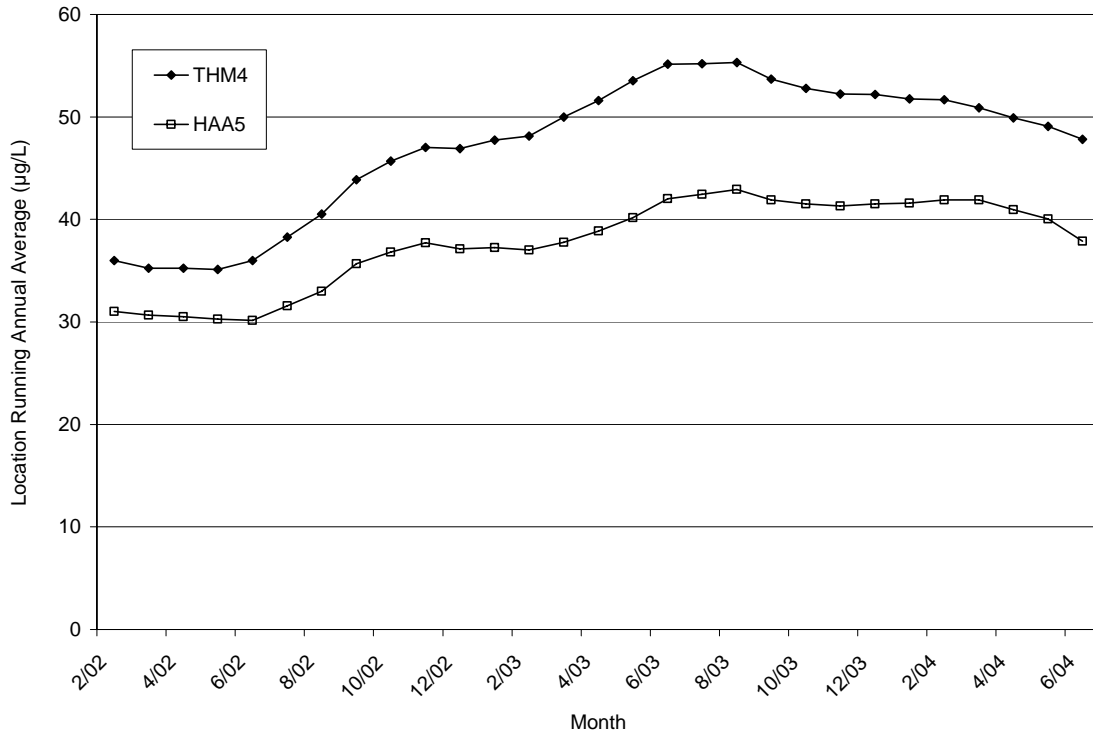


Figure C.7 Predicted and Measured DBP Concentrations for Location 5, t = 50 hrs

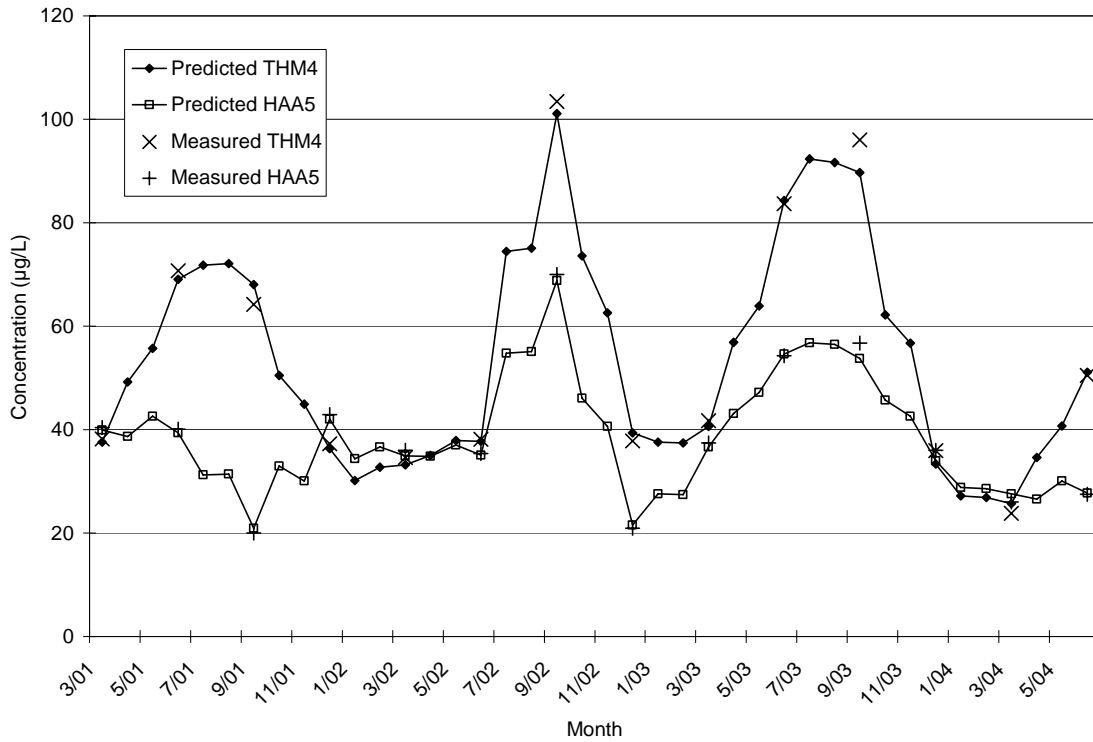


Figure C.8 Predicted Monthly LRAA Concentrations for Location 5, t = 50 hrs

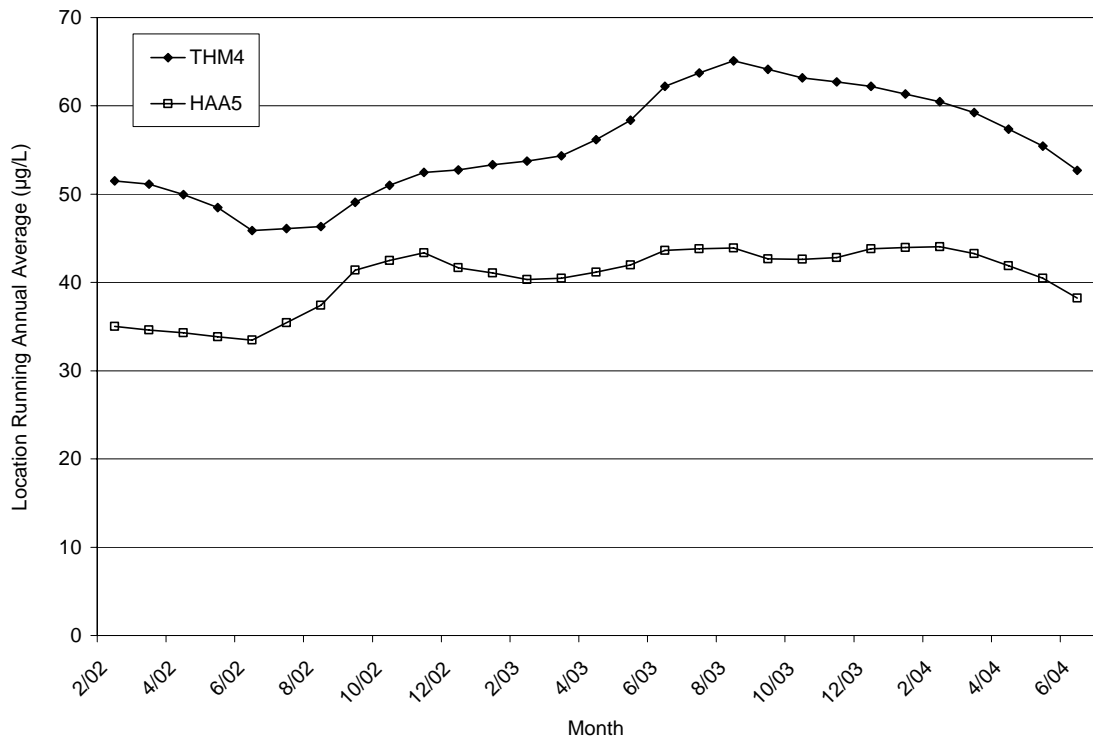


Figure C.9 Predicted Monthly and Measured DBP Concentrations for Location 6, t = 24 hrs

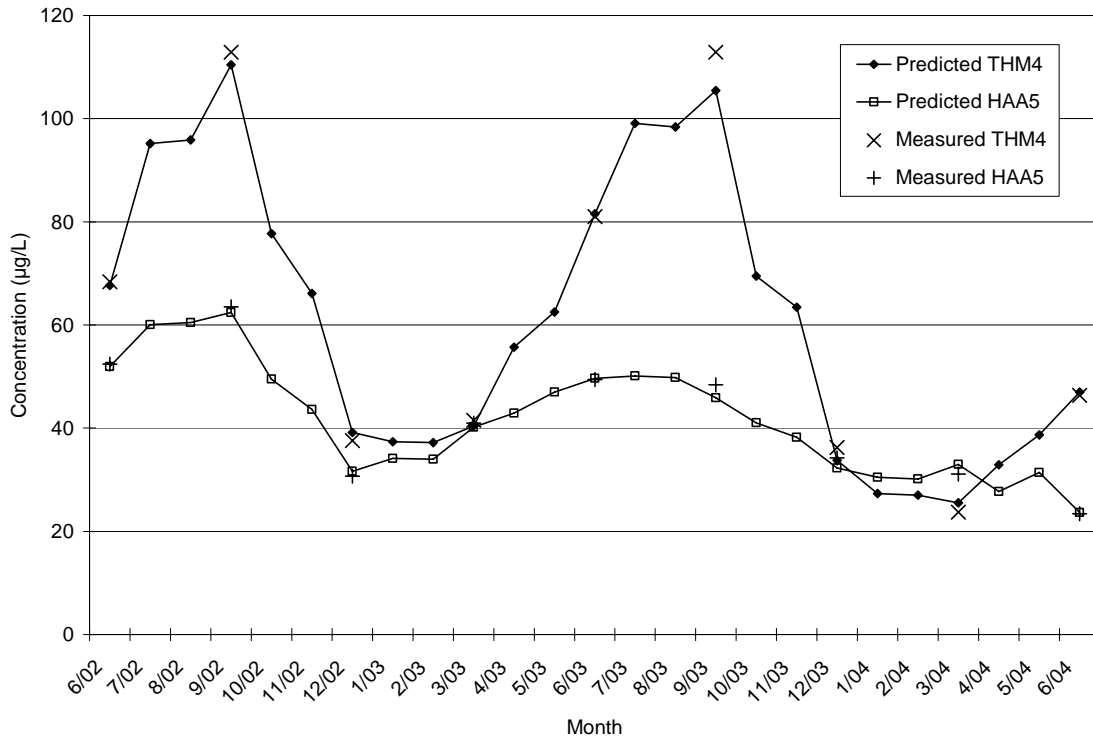


Figure C.10 Predicted Monthly LRAA Concentrations for Location 6, t = 24 hrs

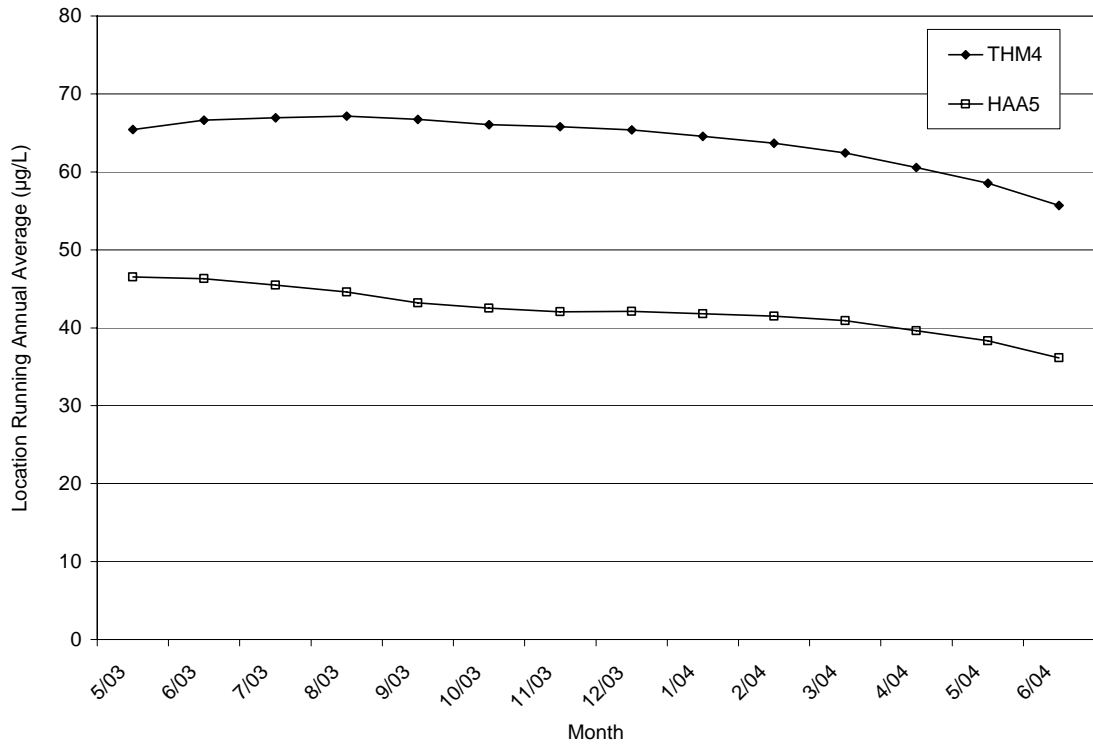


Figure C.11 Predicted and Measured DBP Concentrations for Location 7, t = 36 hrs

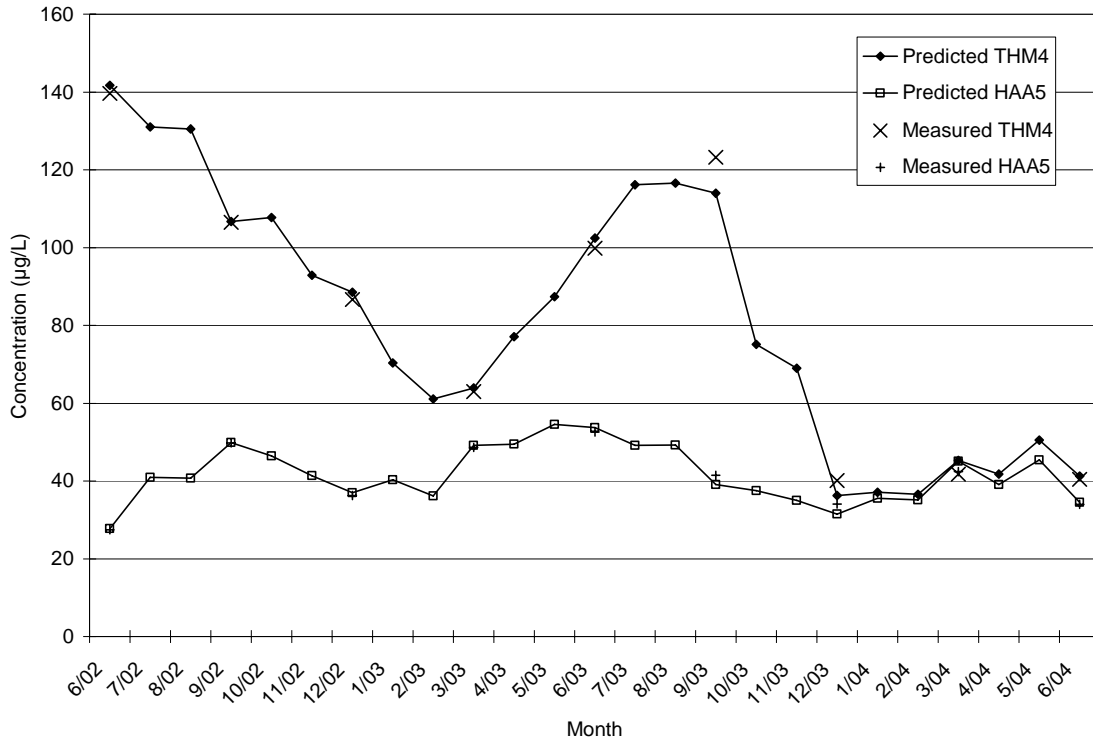


Figure C.12 Predicted Monthly LRAA Concentrations for Location 7, t = 36 hrs

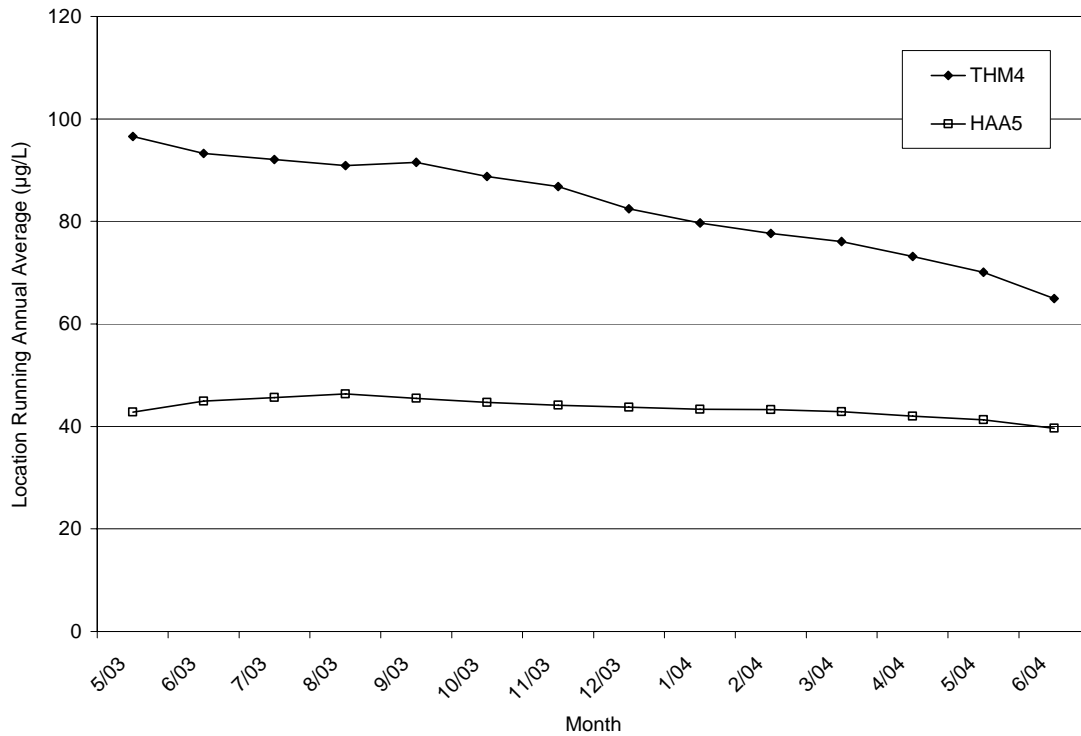


Figure C.13 Predicted and Measured DBP Concentrations for Location 8, t = 6.5 hrs

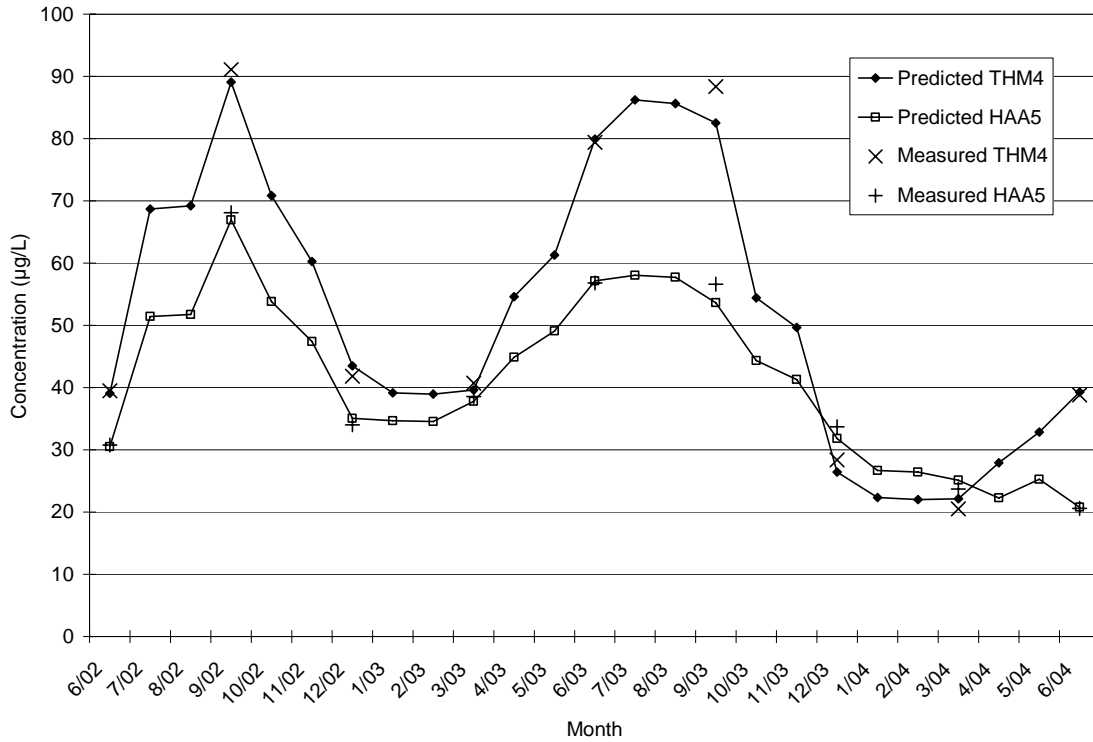
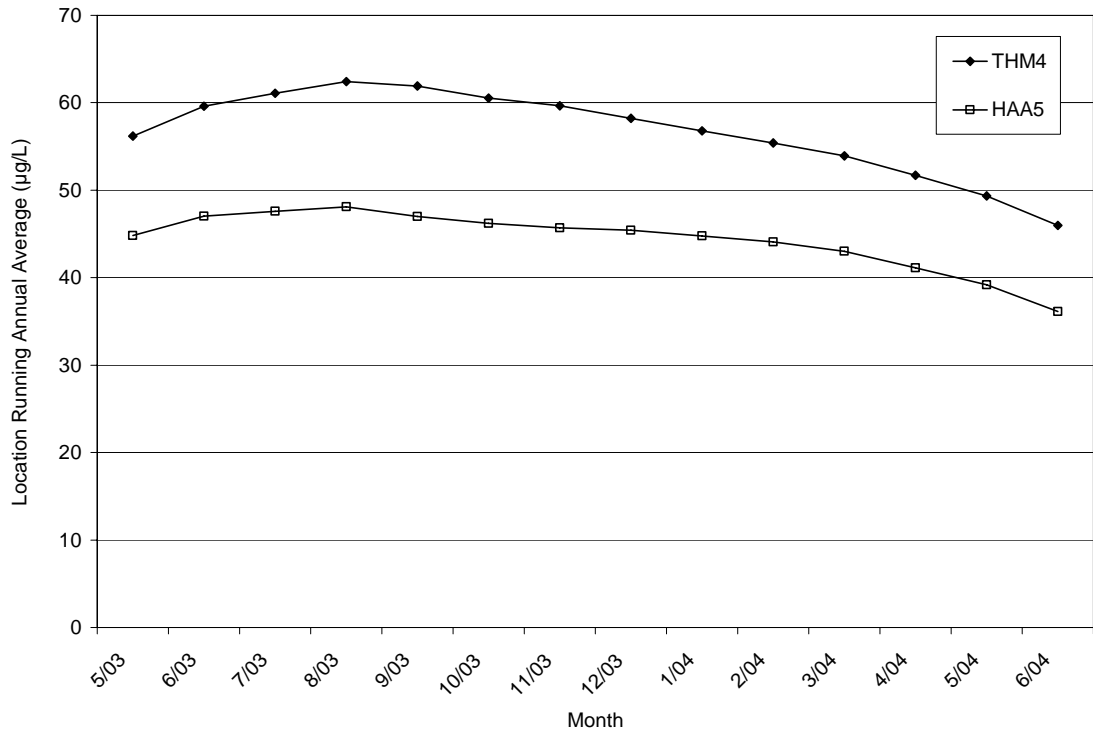


Figure C.14 Predicted Monthly LRAA Concentrations for Location 8, t = 6.5 hrs



Appendix D - Charlotte

Figure D.1 Predicted and Measured DBP Concentrations for Location 1, t = 60 hrs

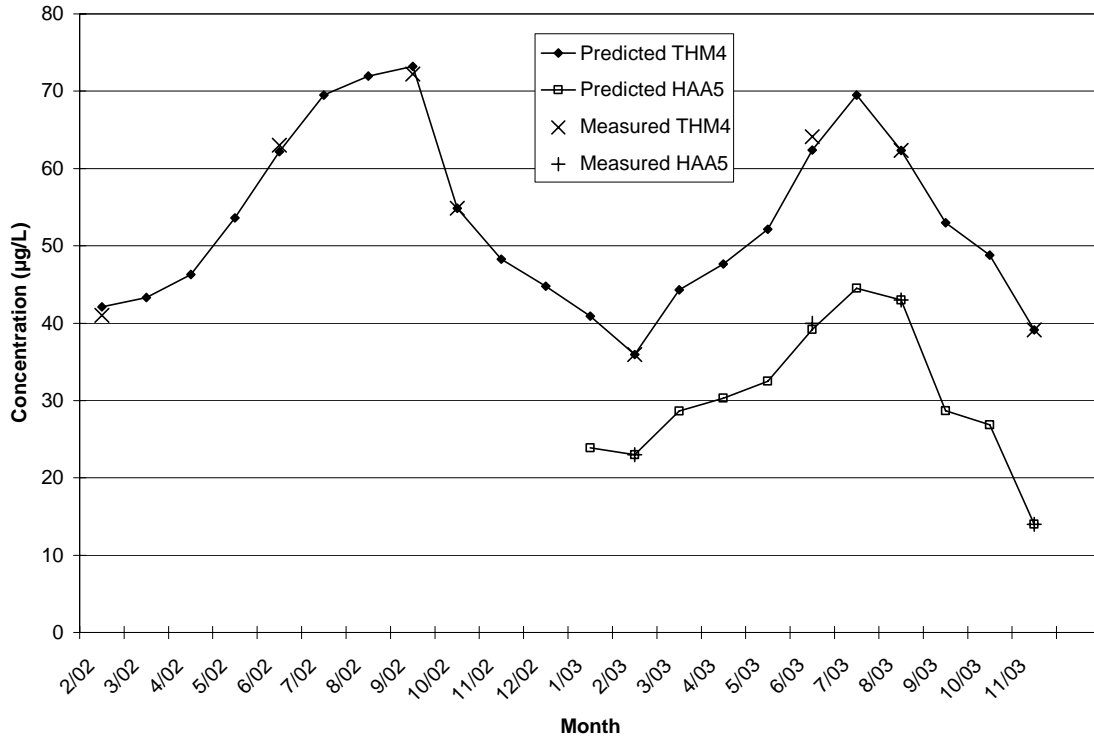


Figure D.2 Predicted Monthly THM4 LRAA Concentrations for Location 1, t = 60 hrs

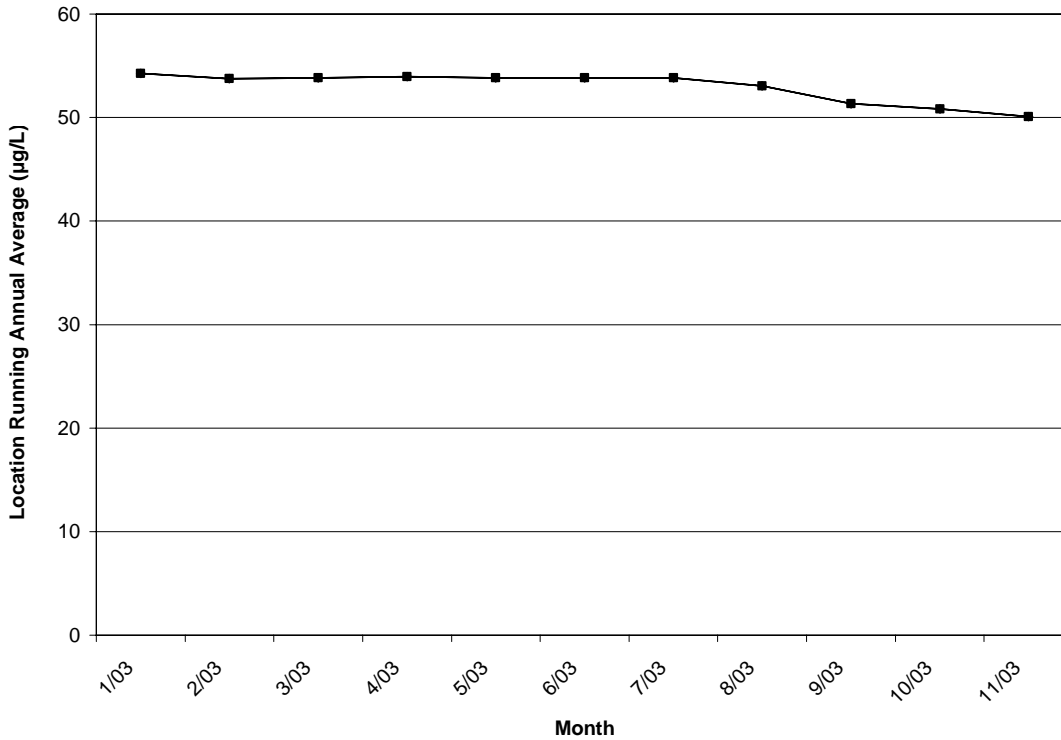


Figure D.3 Predicted and Measured DBP Concentrations for Location 2, t = 84 hrs

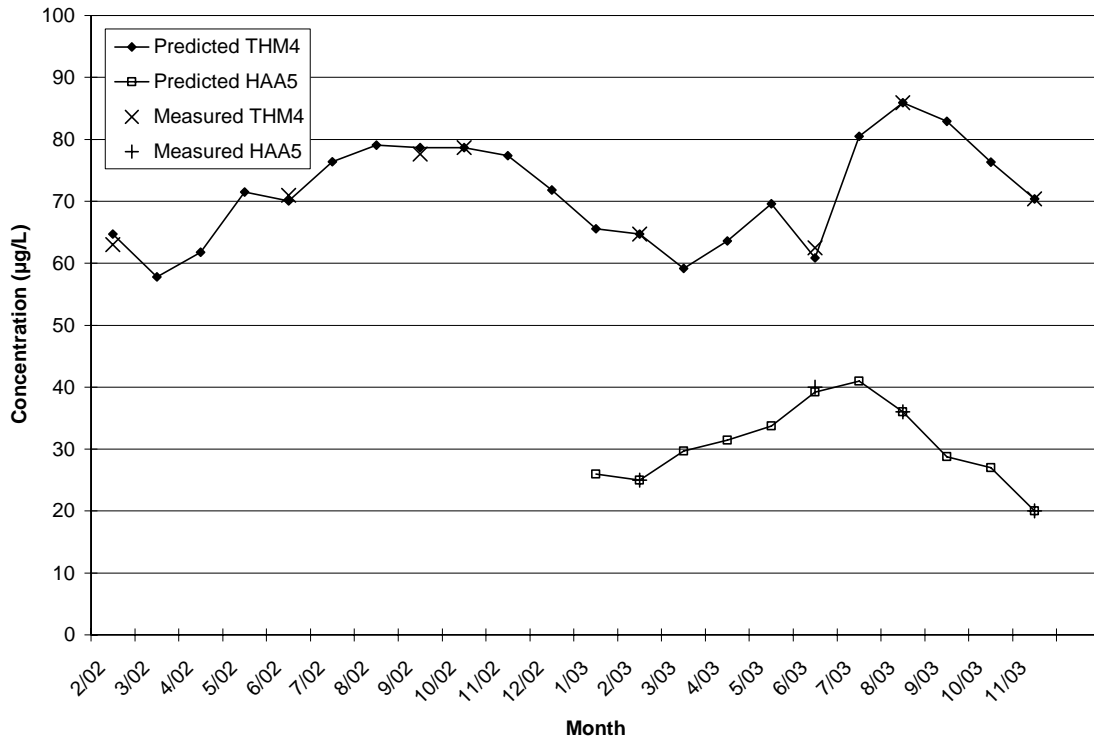


Figure D.4 Predicted Monthly THM4 LRAA Concentrations for Location 2, t = 84 hrs

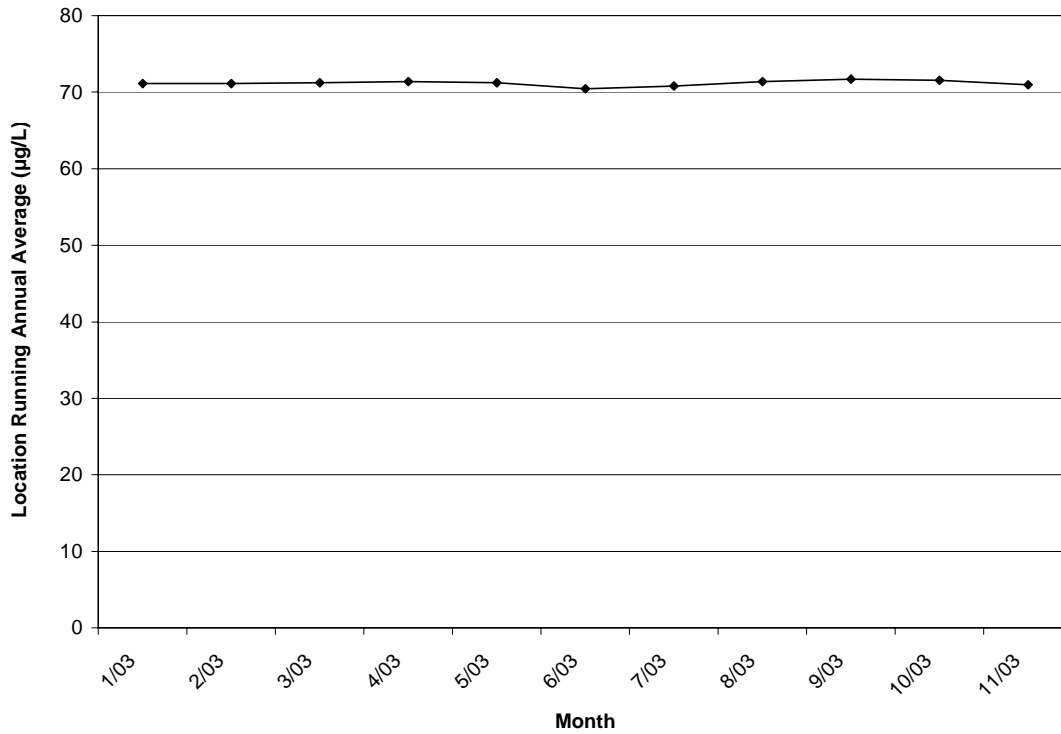


Figure D.5 Predicted and Measured DBP Concentrations for Location 4, t = 36 hrs

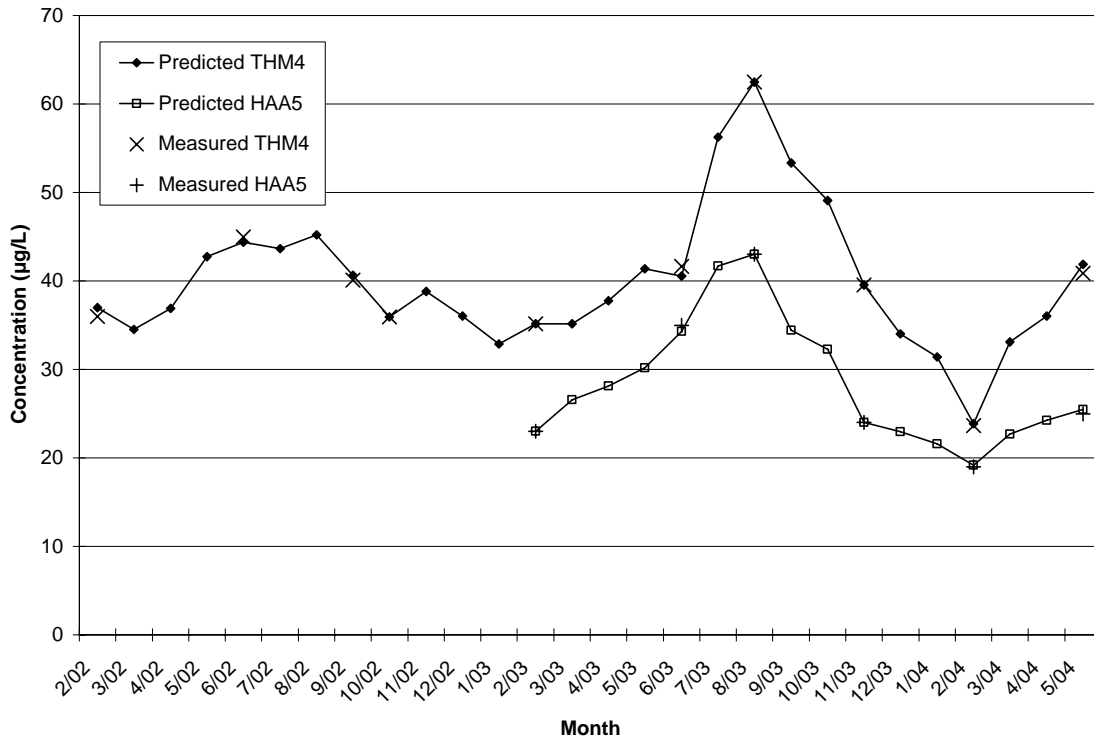


Figure D.6 Predicted Monthly LRAA Concentrations for Location 4, t = 36 hrs

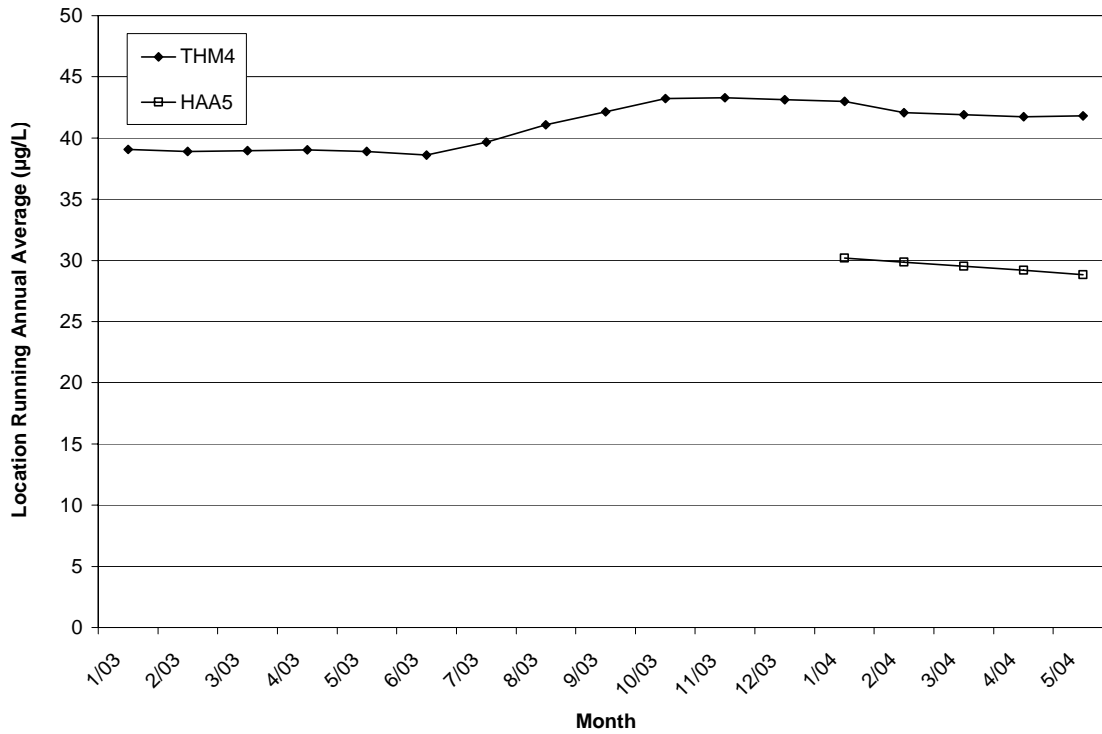


Figure D.7 Predicted and Measured DBP Concentrations for Location 5, t = 24 hrs

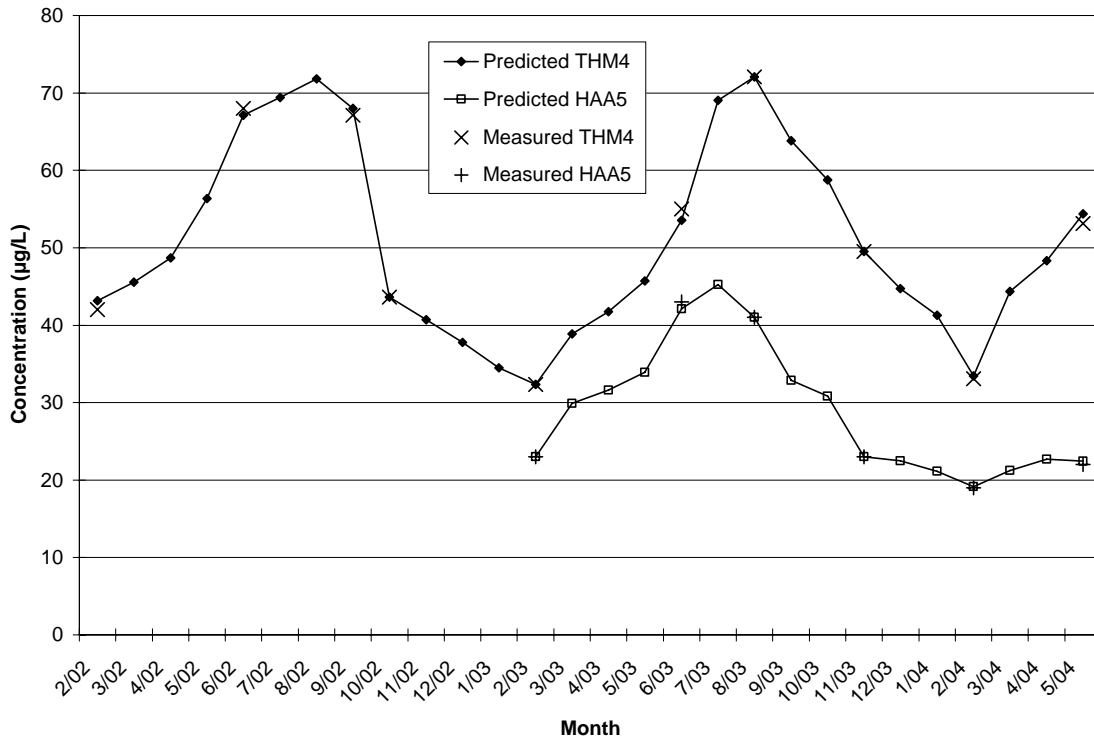


Figure D.8 Predicted Monthly LRAA Concentrations for Location 5, t = 24 hrs

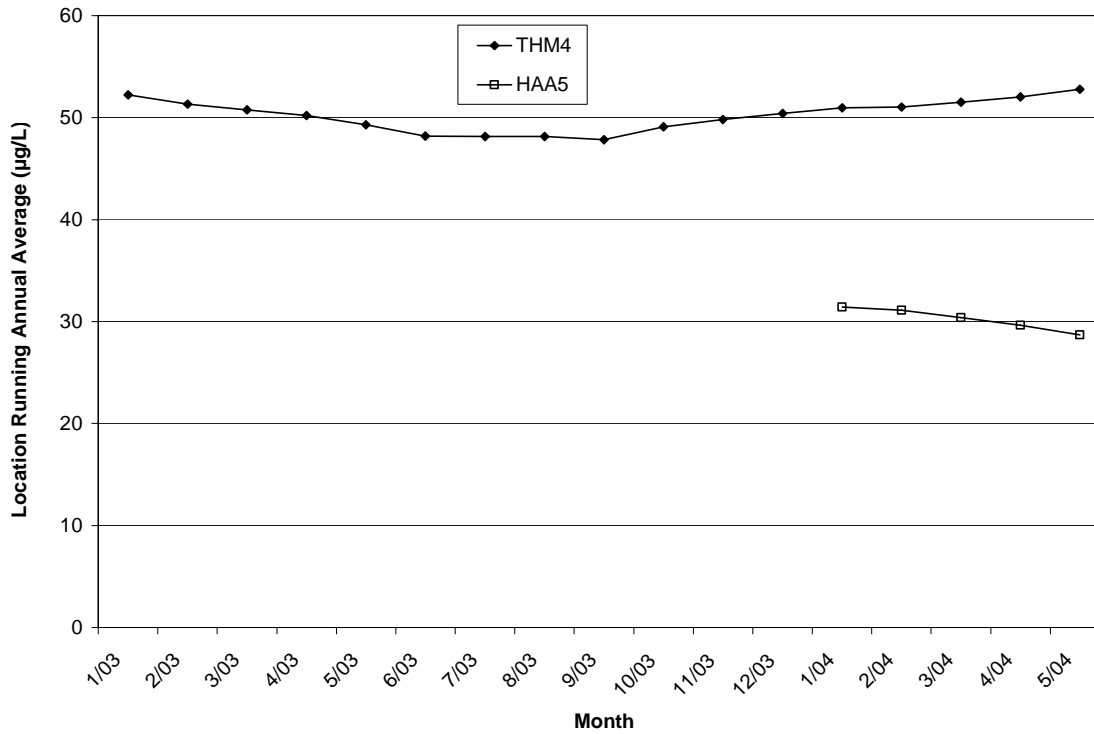


Figure D.9 Predicted and Measured DBP Concentrations for Location 6, t = 48 hrs

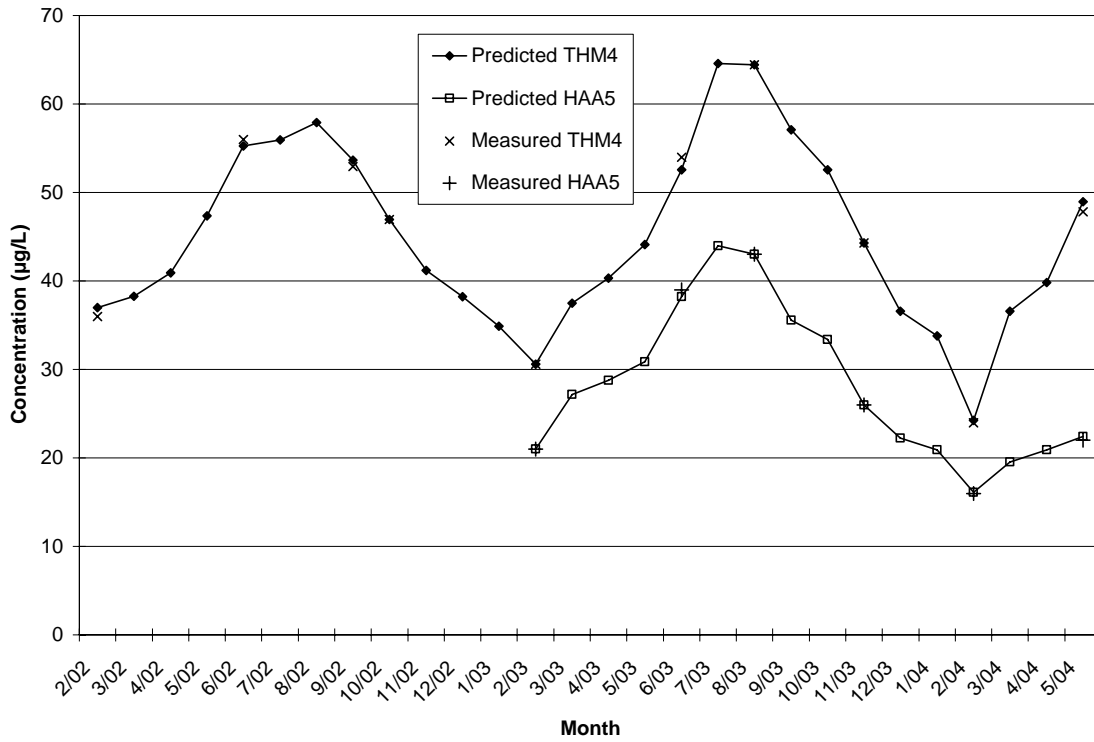


Figure D.10 Predicted Monthly LRAA Concentrations for Location 6, t = 48 hrs

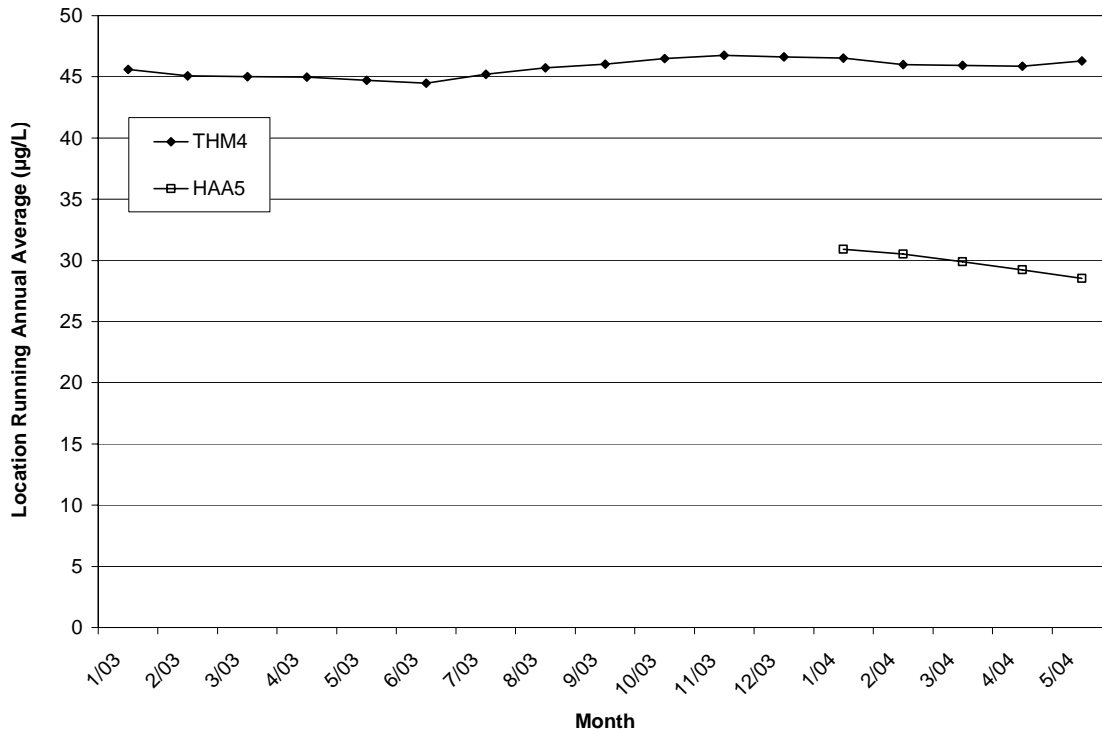


Figure D.11 Predicted and Measured DBP Concentrations for Location 7, t = 36 hrs

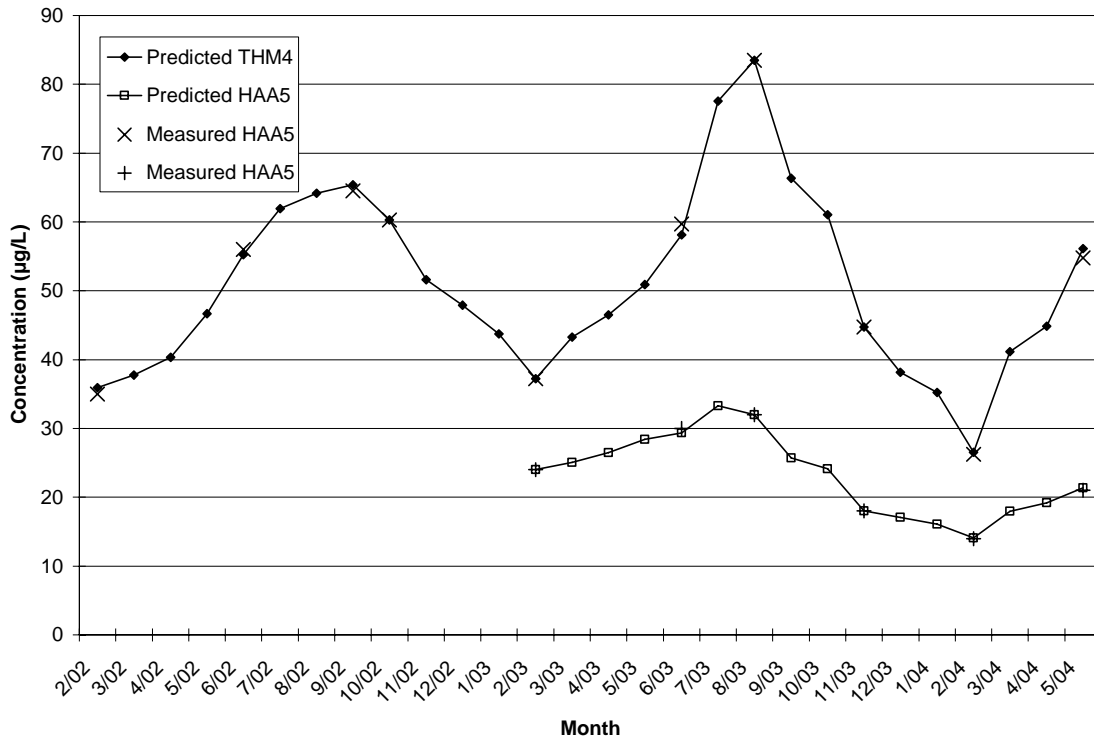


Figure D.12 Predicted Monthly LRAA Concentrations for Location 7, t = 36 hrs

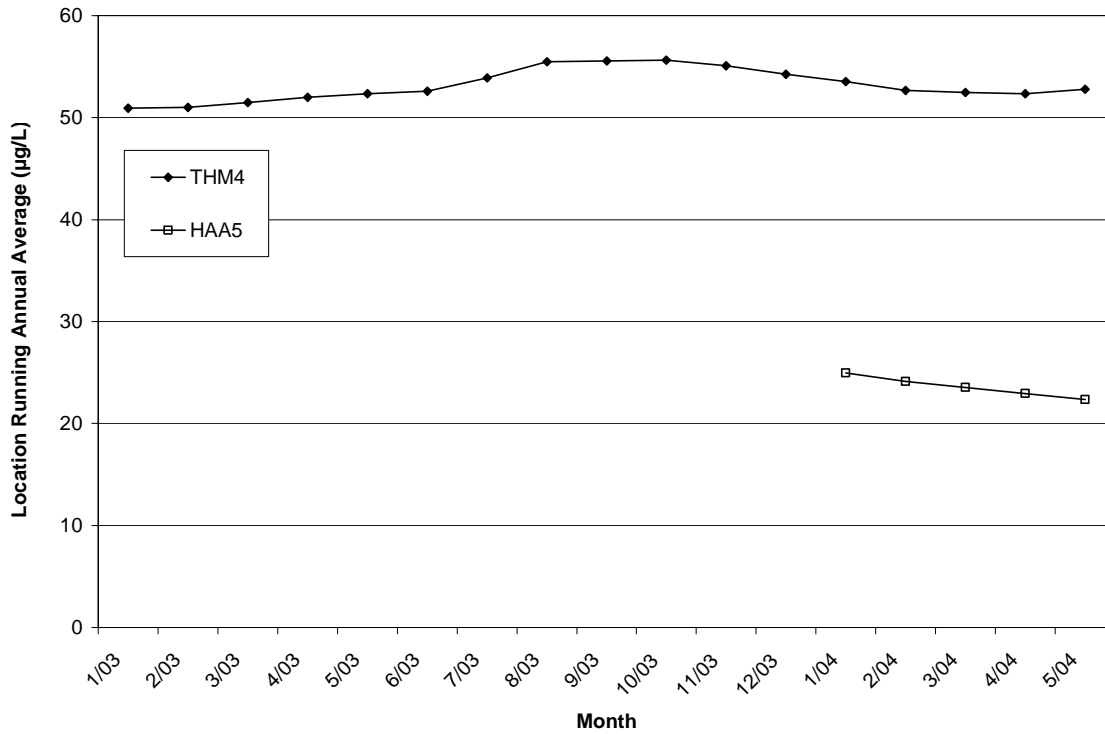


Figure D.13 Predicted and Measured DBP Concentrations for Location 8, t = 72 hrs

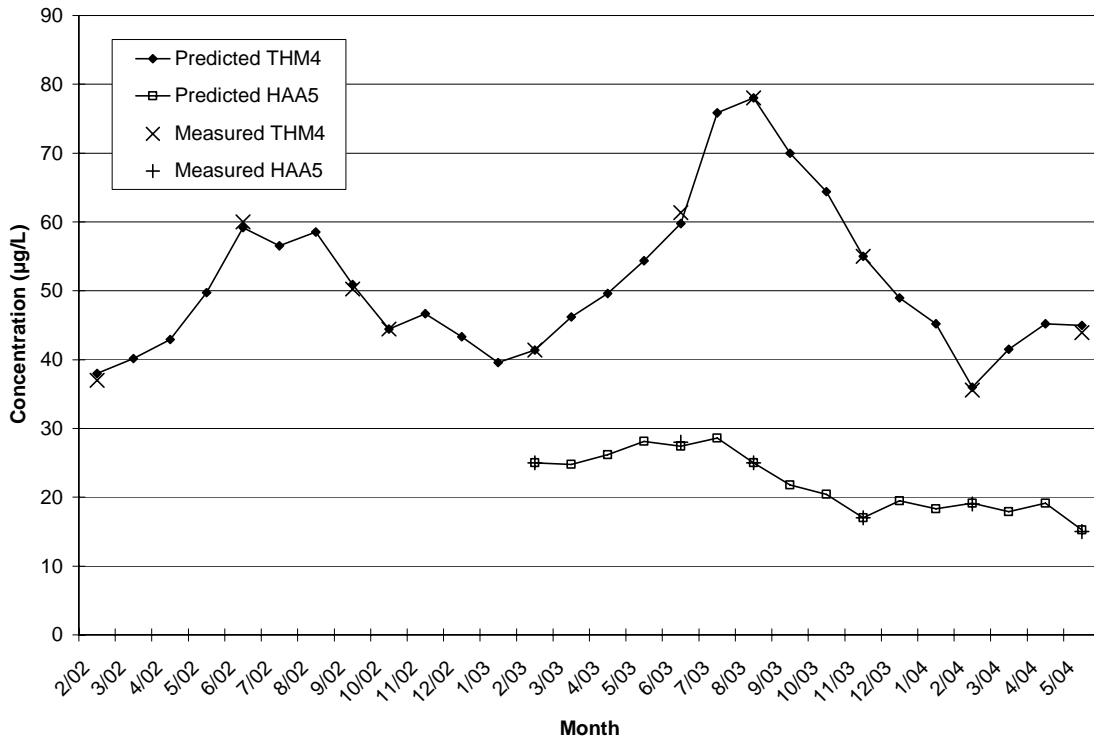


Figure D.14 Predicted Monthly LRAA Concentrations for Location 8, t = 72 hrs

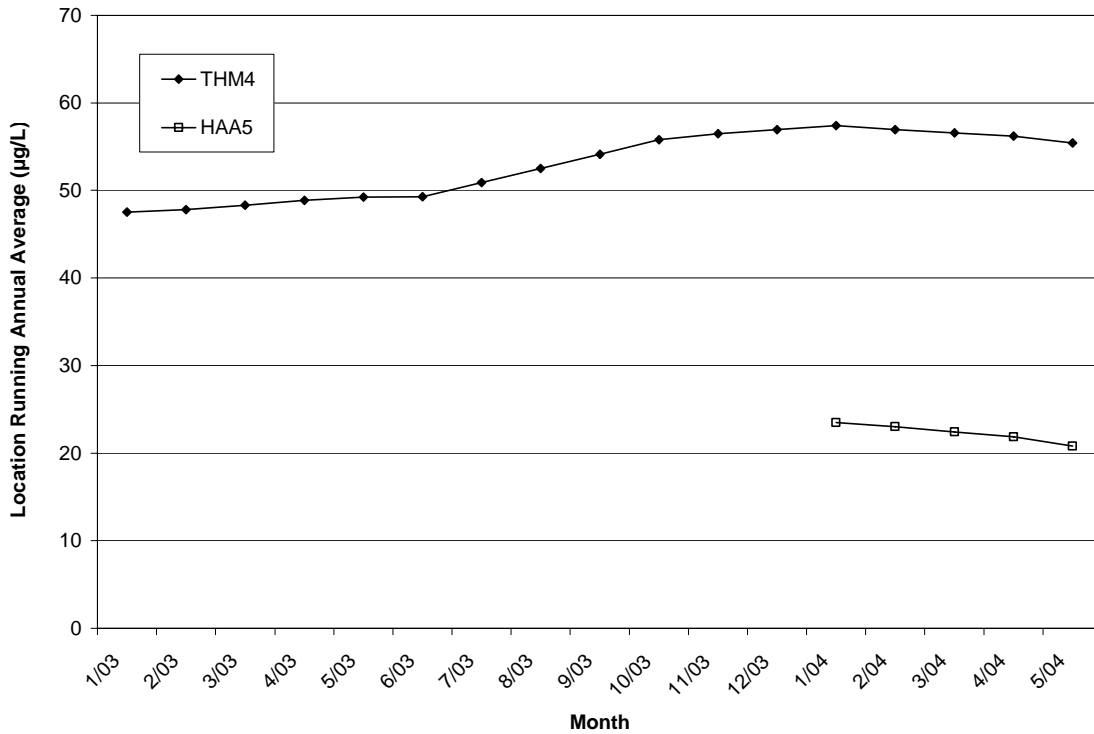


Figure D.15 Predicted and Measured DBP Concentrations for Location 9, t = 60 hrs

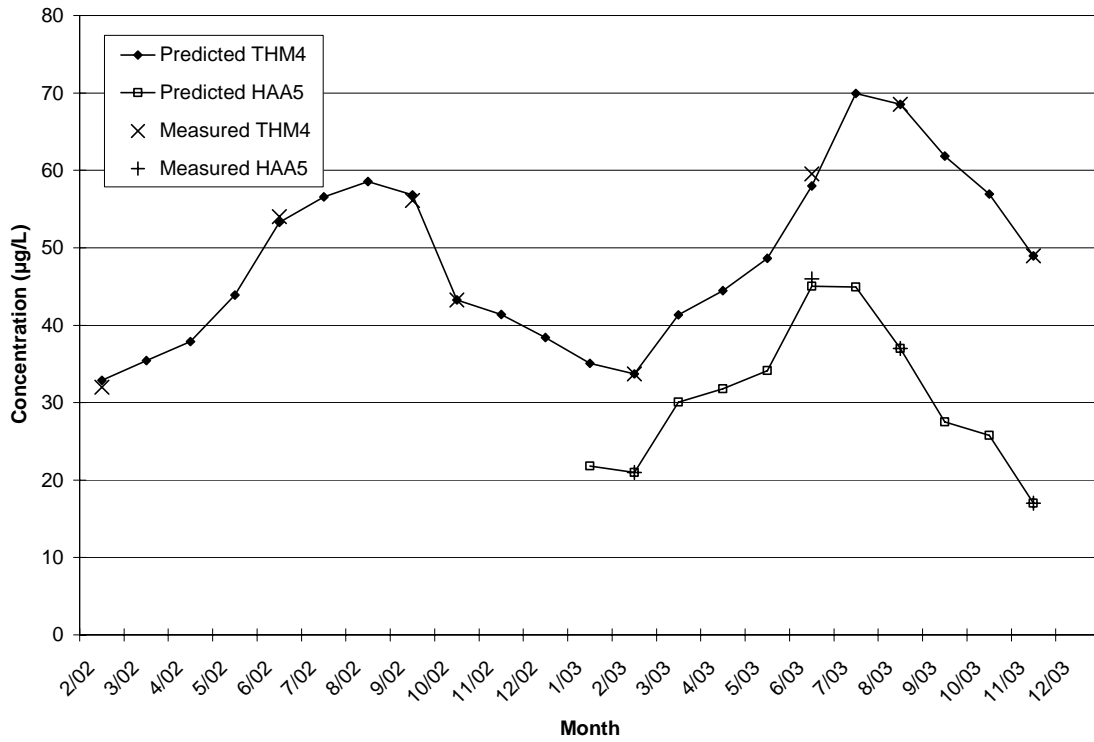


Figure D.16 Predicted Monthly THM4 LRAA Concentrations for Location 9, t = 60 hrs

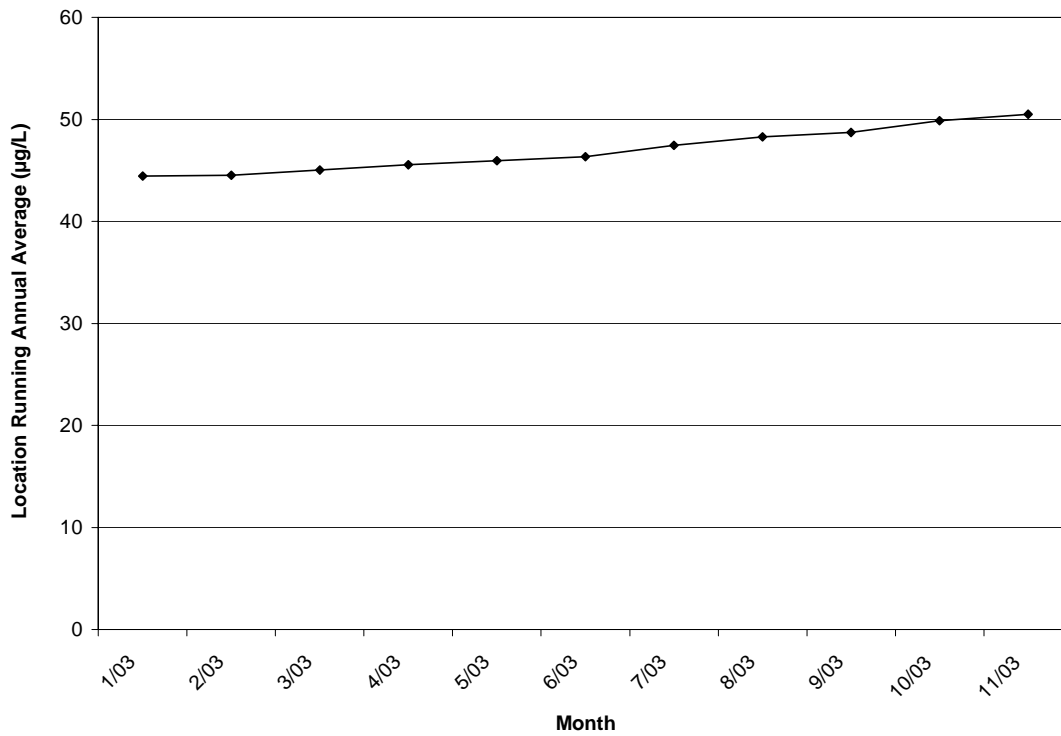


Figure D.17 Predicted and Measured DBP Concentrations for Location 10, t = 60 hrs

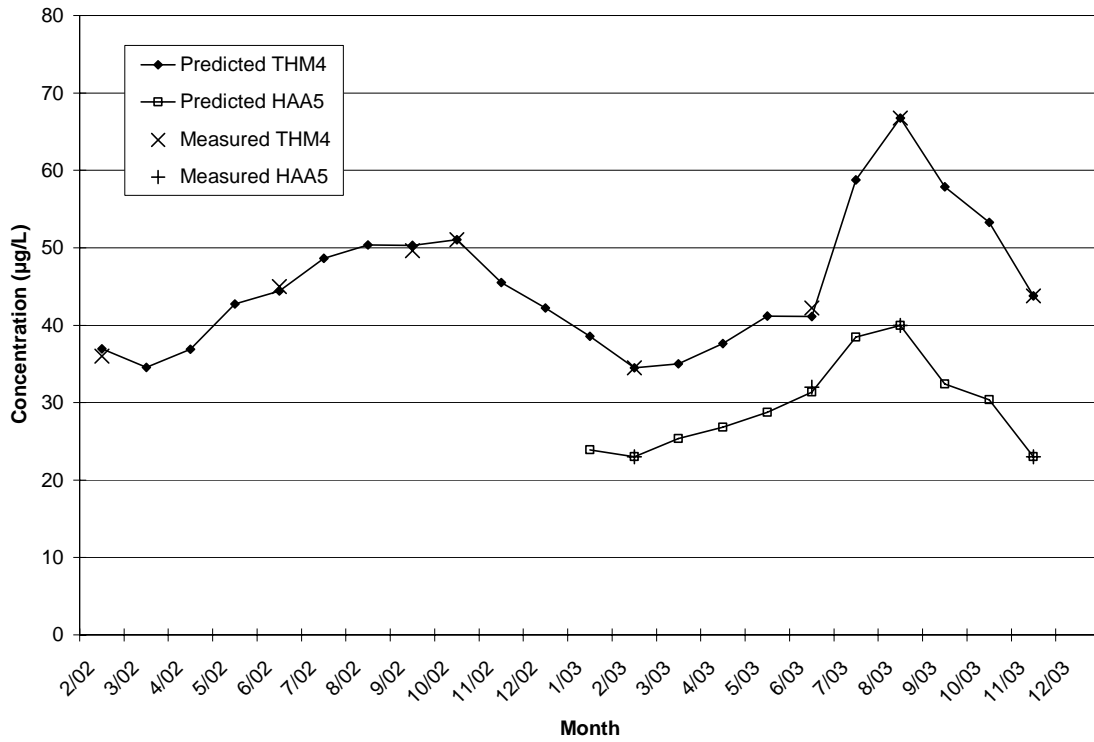


Figure D.18 Predicted Monthly THM4 LRAA Concentrations for Location 10, t = 60 hrs

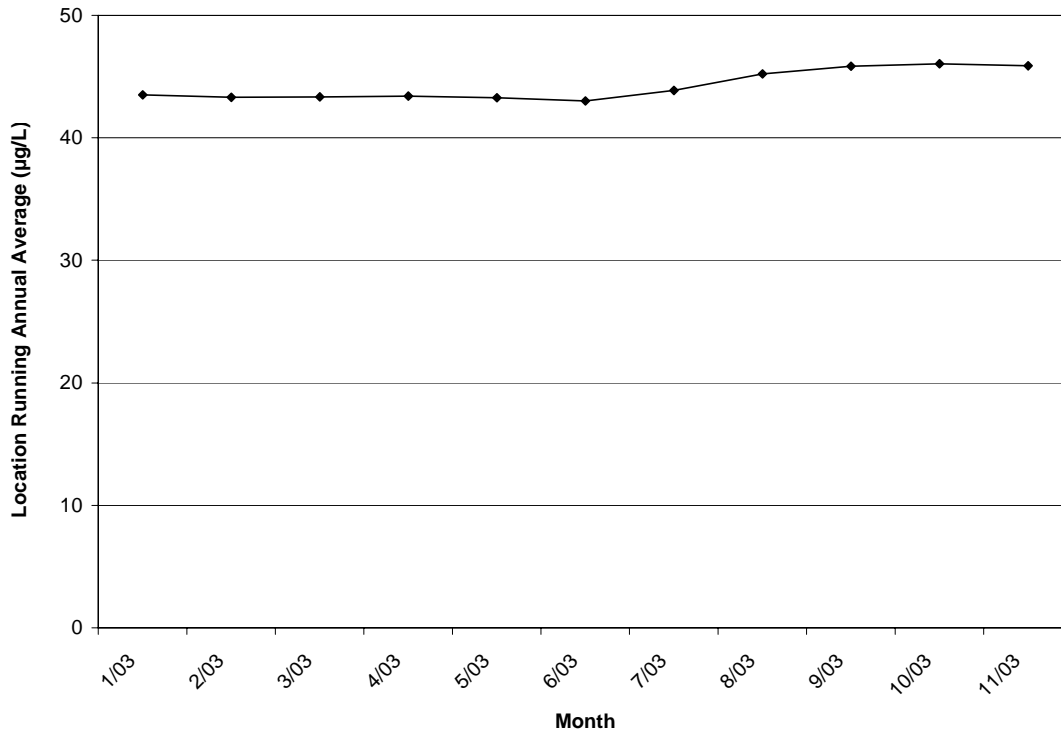


Figure D.19 Predicted and Measured DBP Concentrations for Location 11, t = 72 hrs

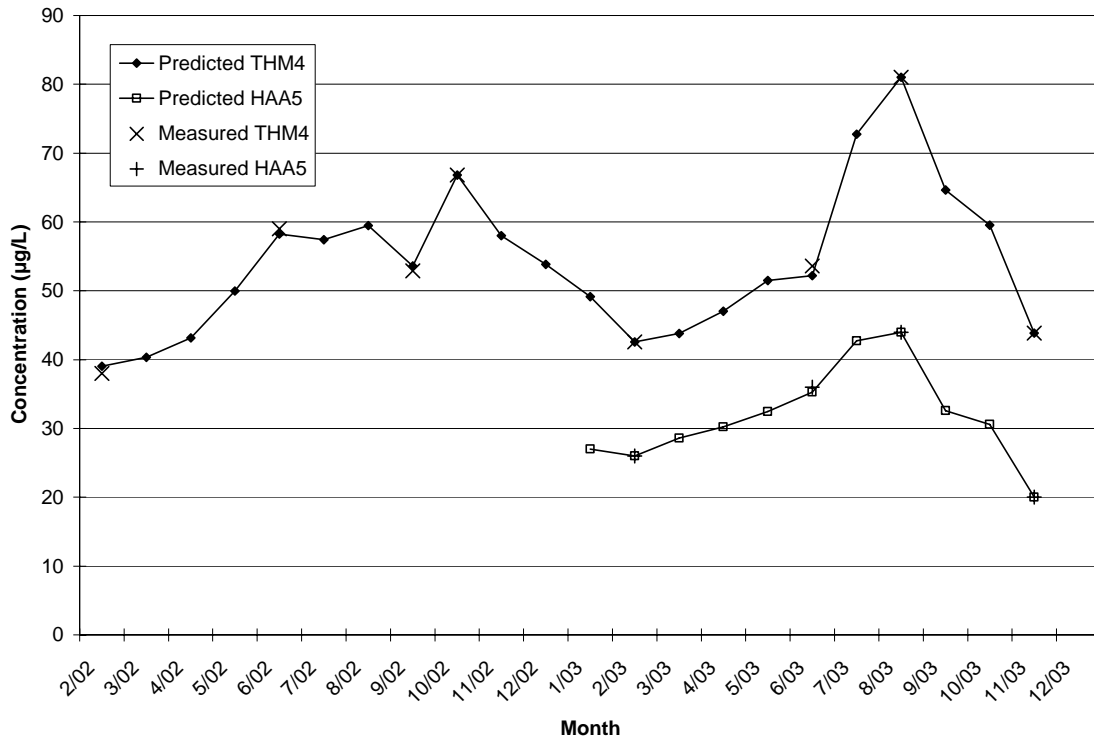


Figure D.20 Predicted Monthly THM4 LRAA Concentrations for Location 11, t = 72 hrs

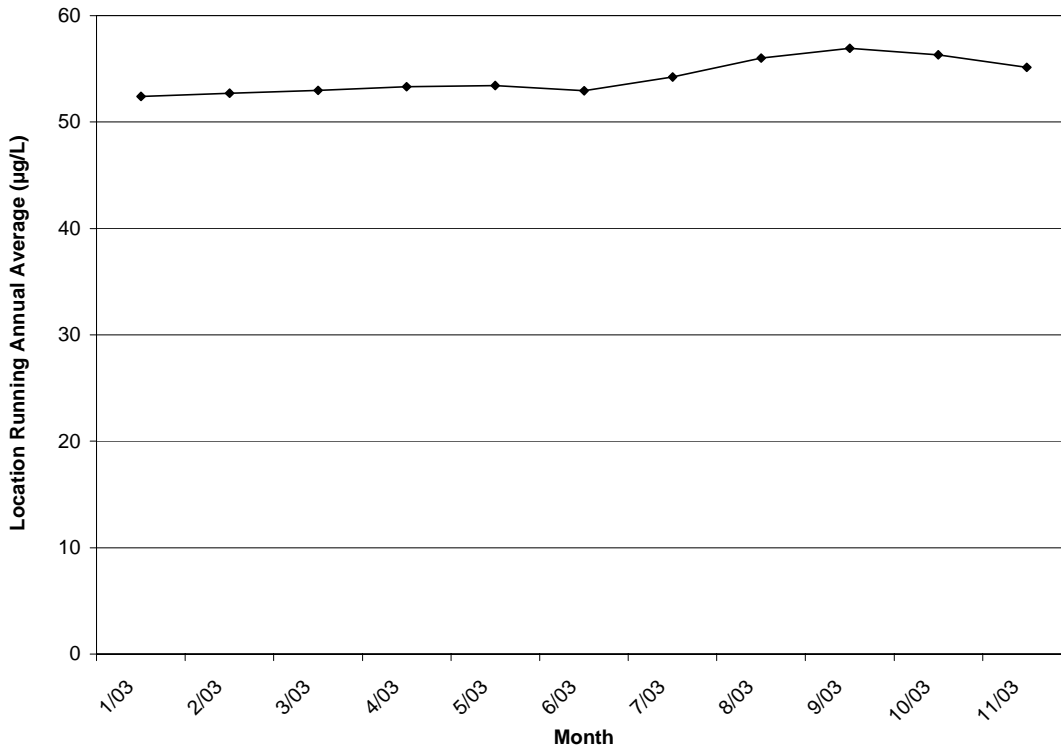


Figure D.21 Predicted and Measured DBP Concentrations for Location 12, t = 60 hrs

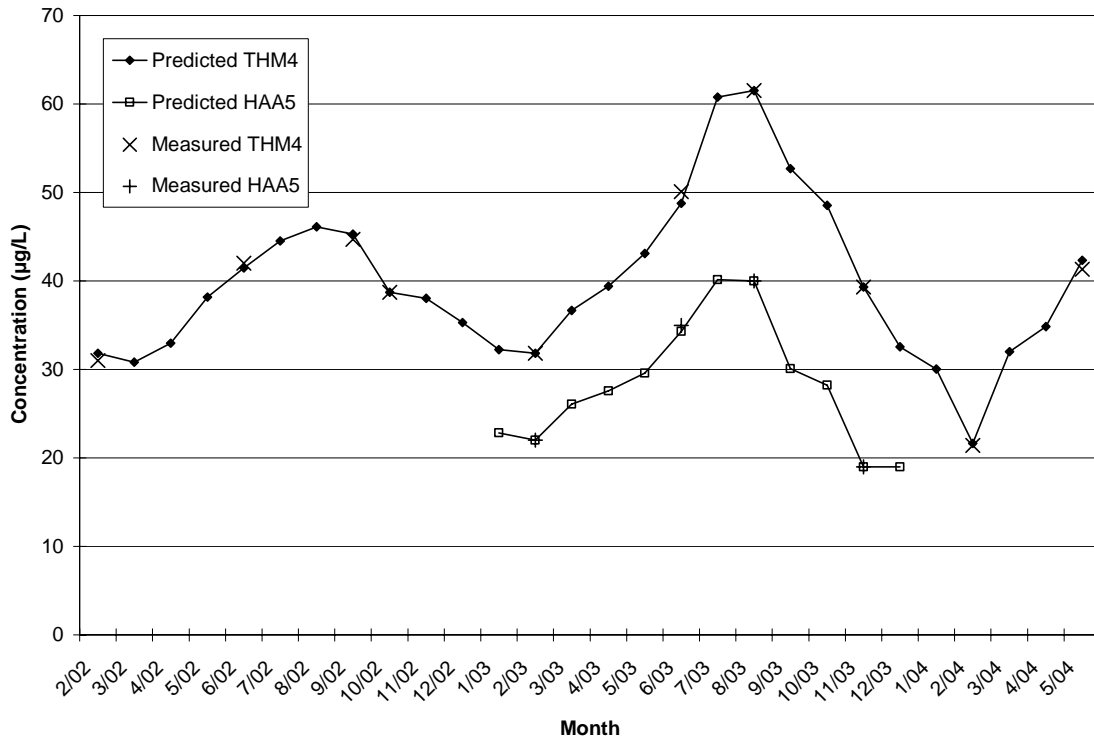


Figure D.22 Predicted Monthly THM4 LRAA Concentrations for Location 12, t = 60 hrs

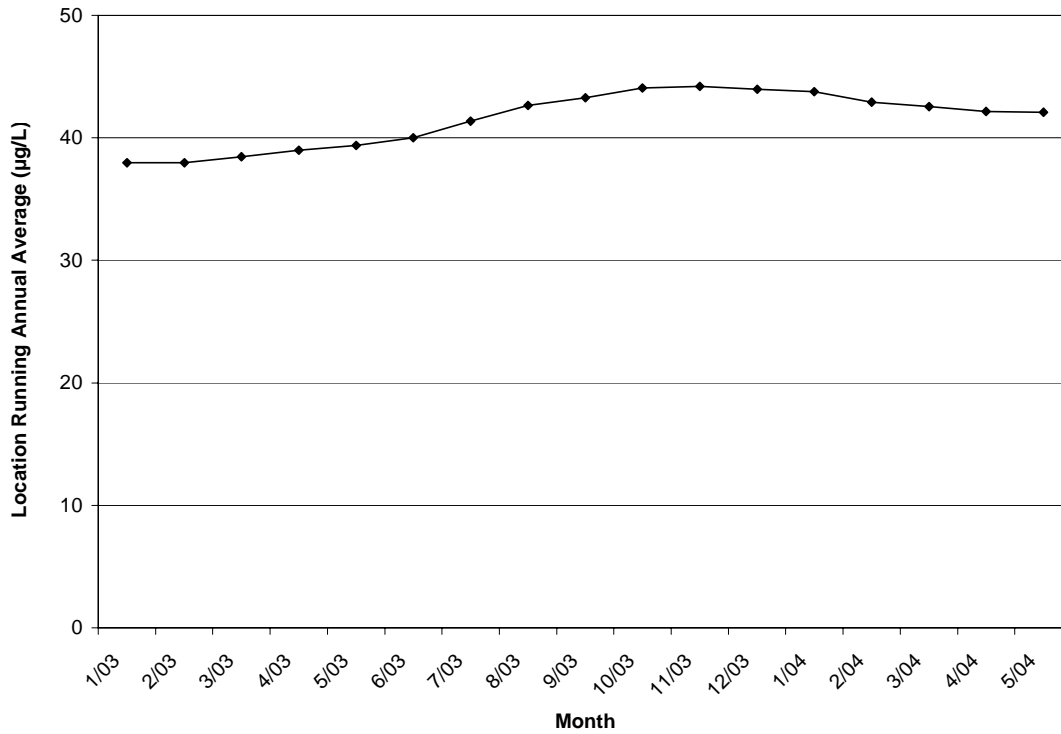


Figure D.23 Predicted and Measured DBP Concentrations for Location 13, t = 48 hrs

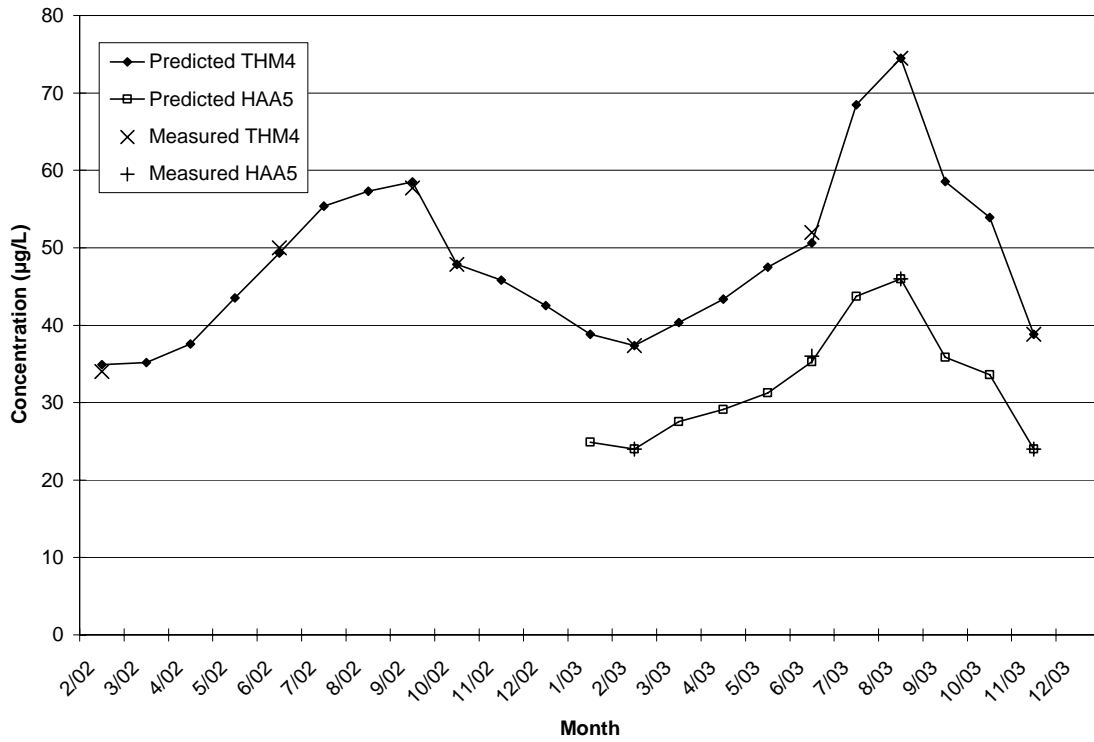


Figure D.24 Predicted Monthly THM4 LRAA Concentrations for Location 13, t = 48 hrs

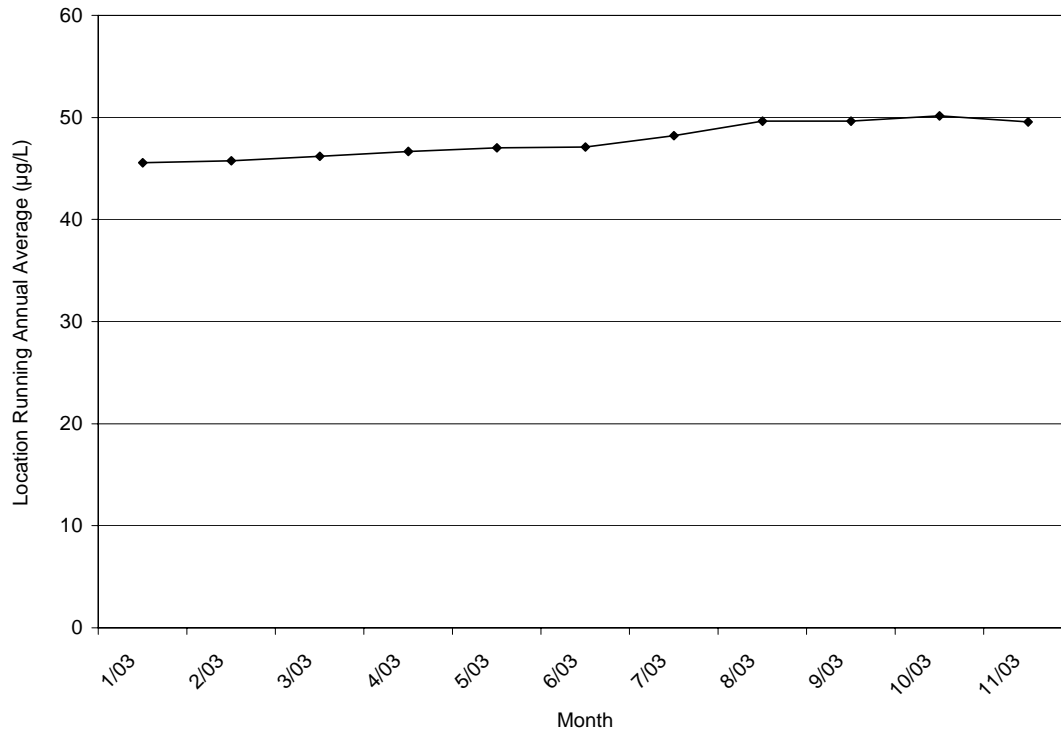


Figure D.25 Predicted and Measured DBP Concentrations for Location 14, t = 36 hrs

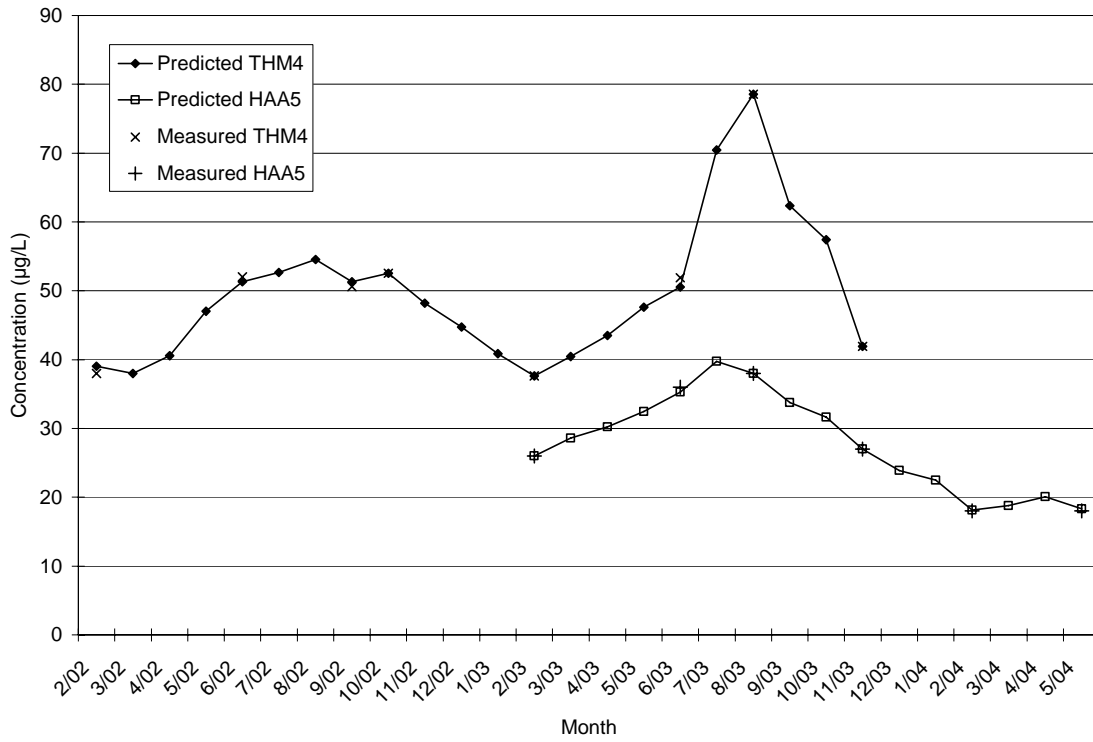


Figure D.26 Predicted Monthly LRAA Concentrations for Location 14, t = 36 hrs

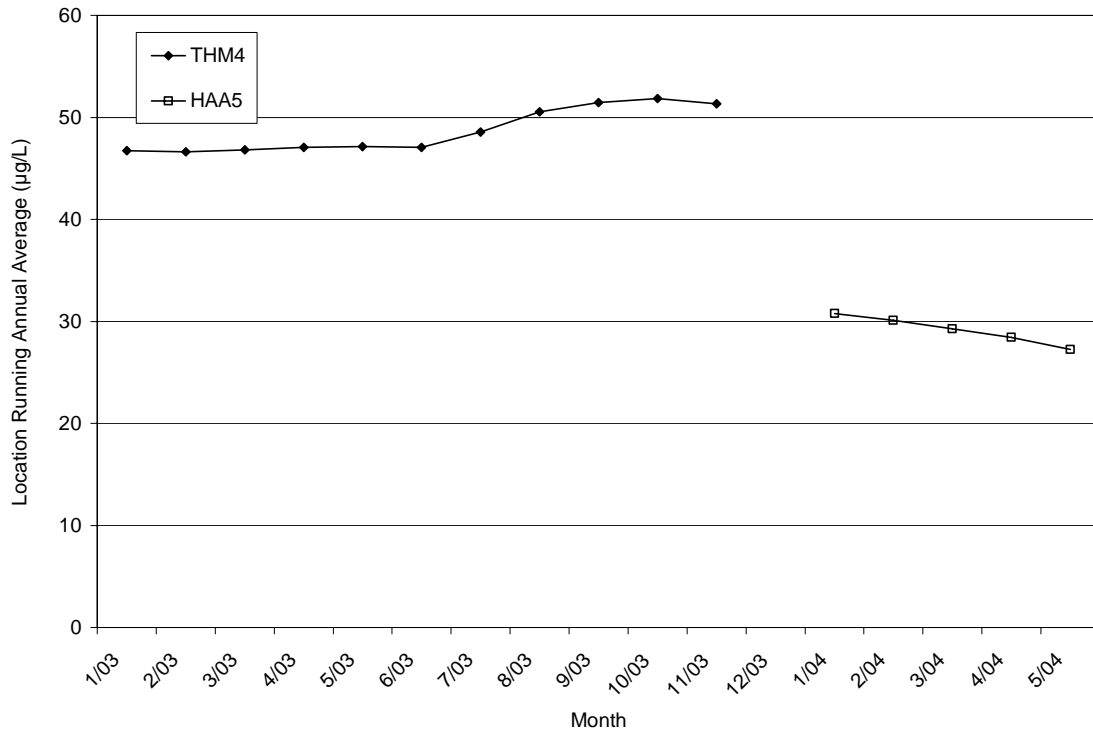


Figure D.27 Predicted and Measured DBP Concentrations for Location 15, t = 72 hrs

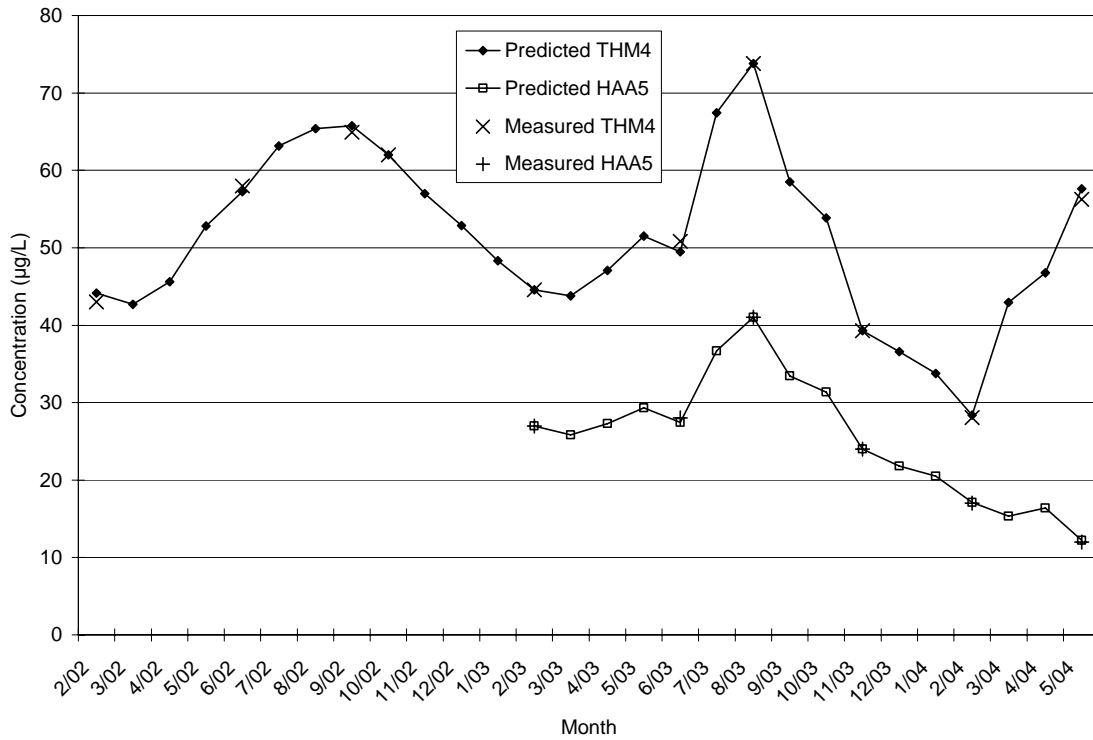


Figure D.28 Predicted Monthly LRAA Concentrations for Location 15, t = 72 hrs

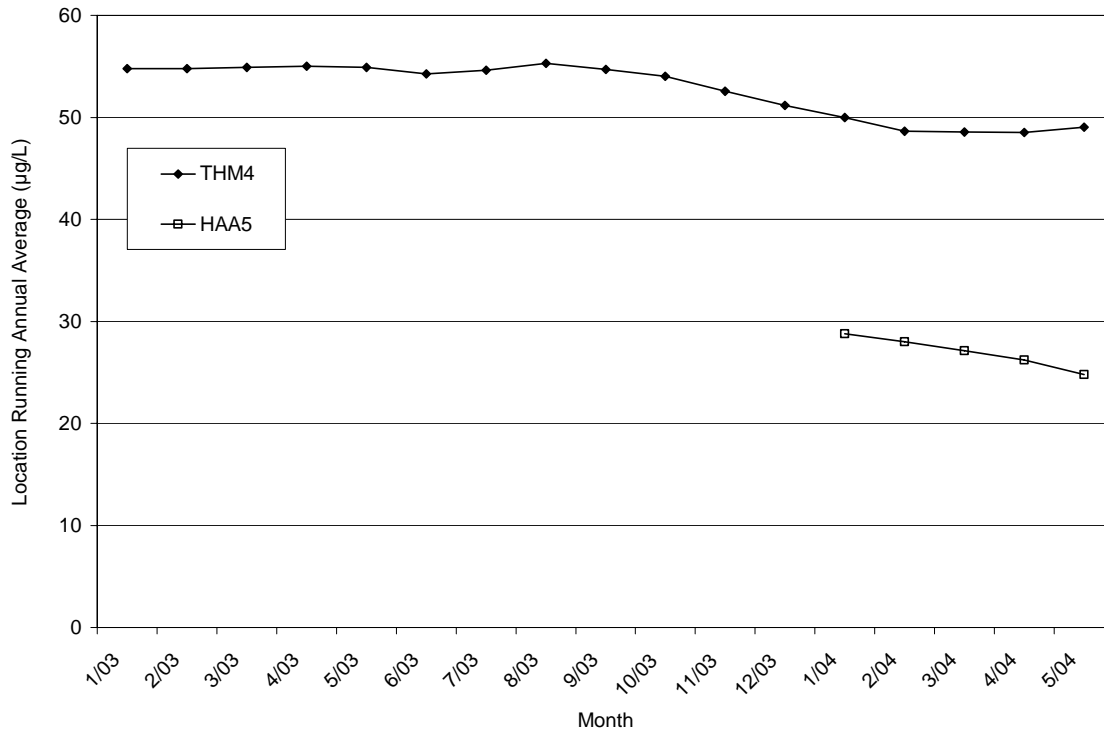


Figure D.29 Predicted and Measured DBP Concentrations for Location 16, t = 84 hrs

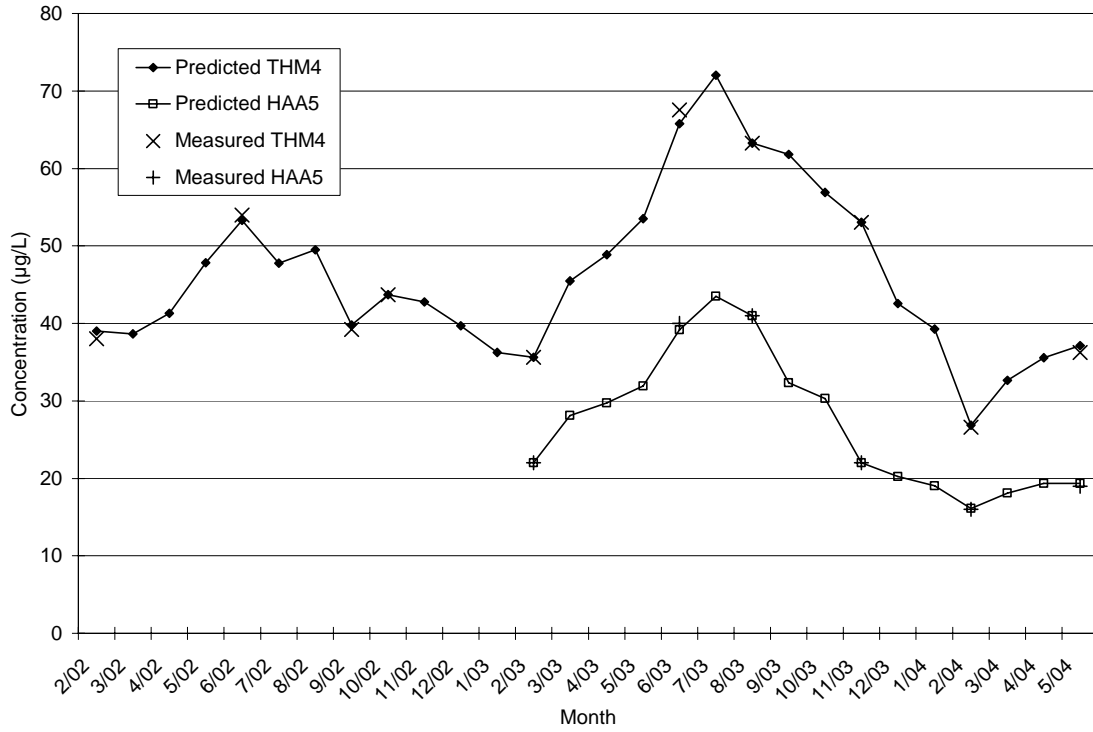


Figure D.30 Predicted Monthly LRAA Concentrations for Location 16, t = 84 hrs

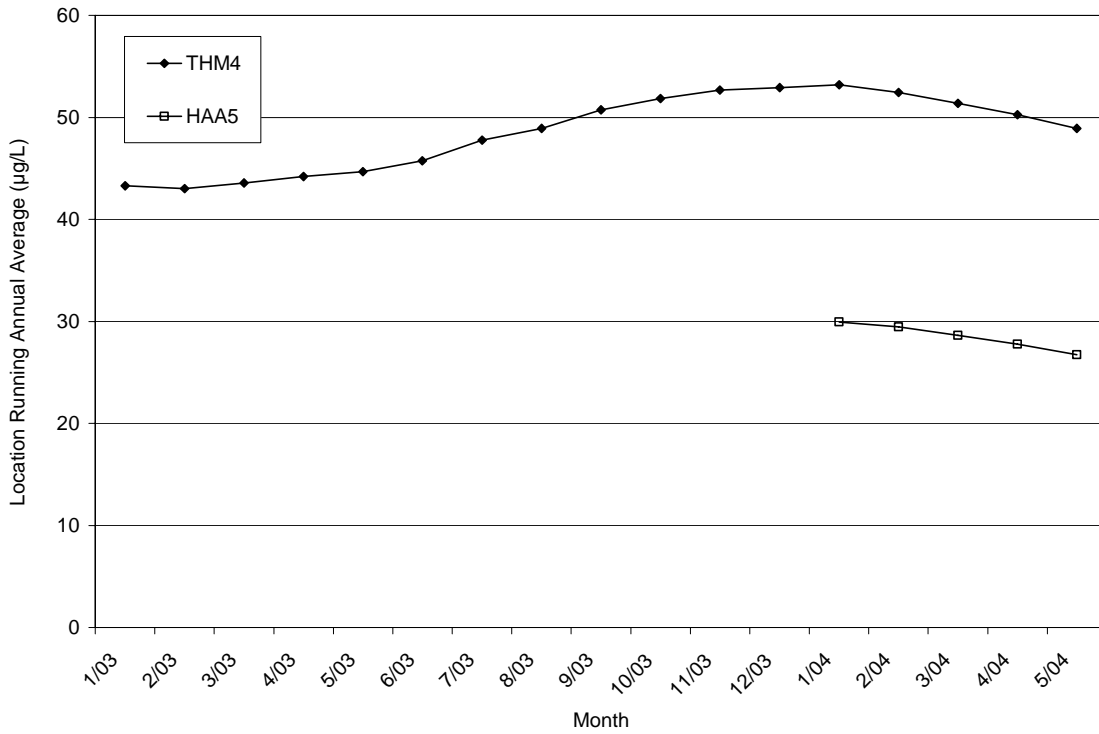


Figure D.31 Predicted and Measured DBP Concentrations for Location 17, t = 96 hrs

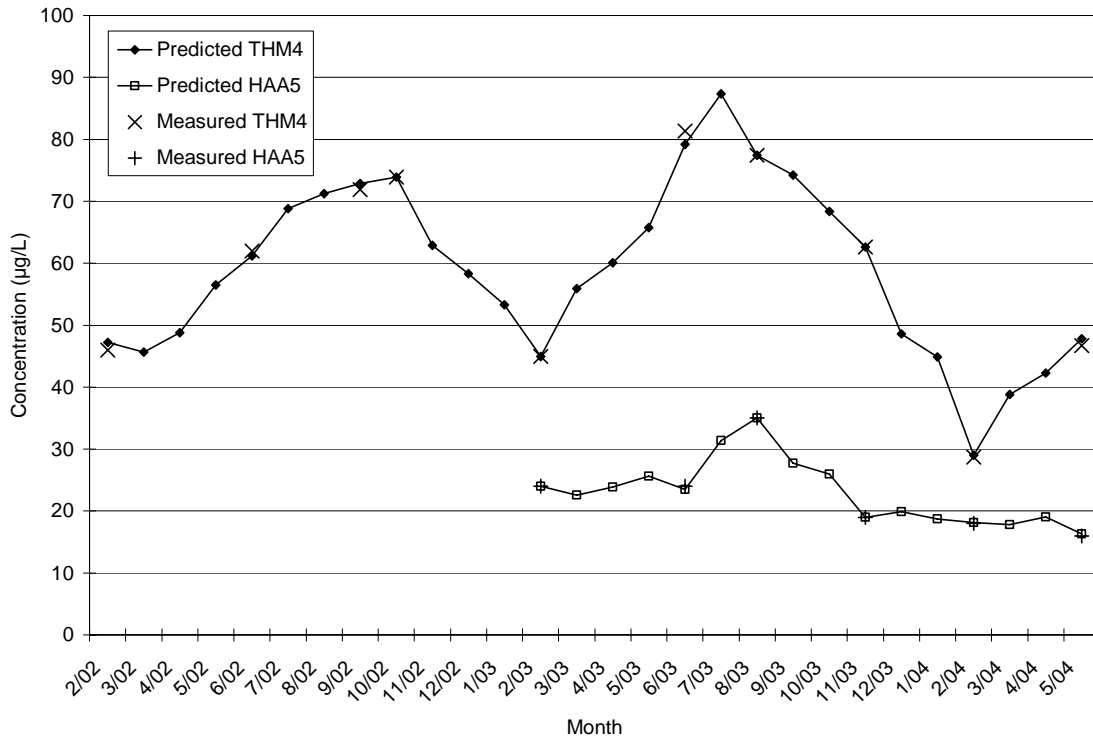


Figure D.32 Predicted Monthly LRAA Concentrations for Location 17, t = 96 hrs

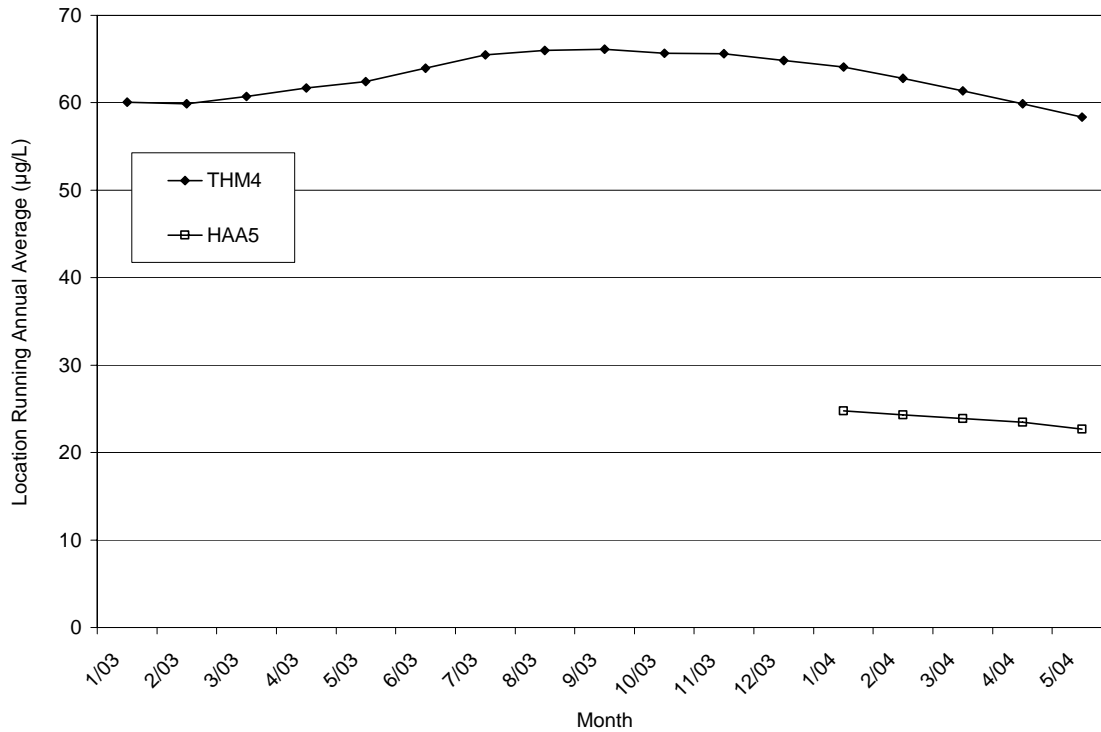


Figure D.33 Predicted and Measured DBP Concentrations for Location 18, t = 96 hrs

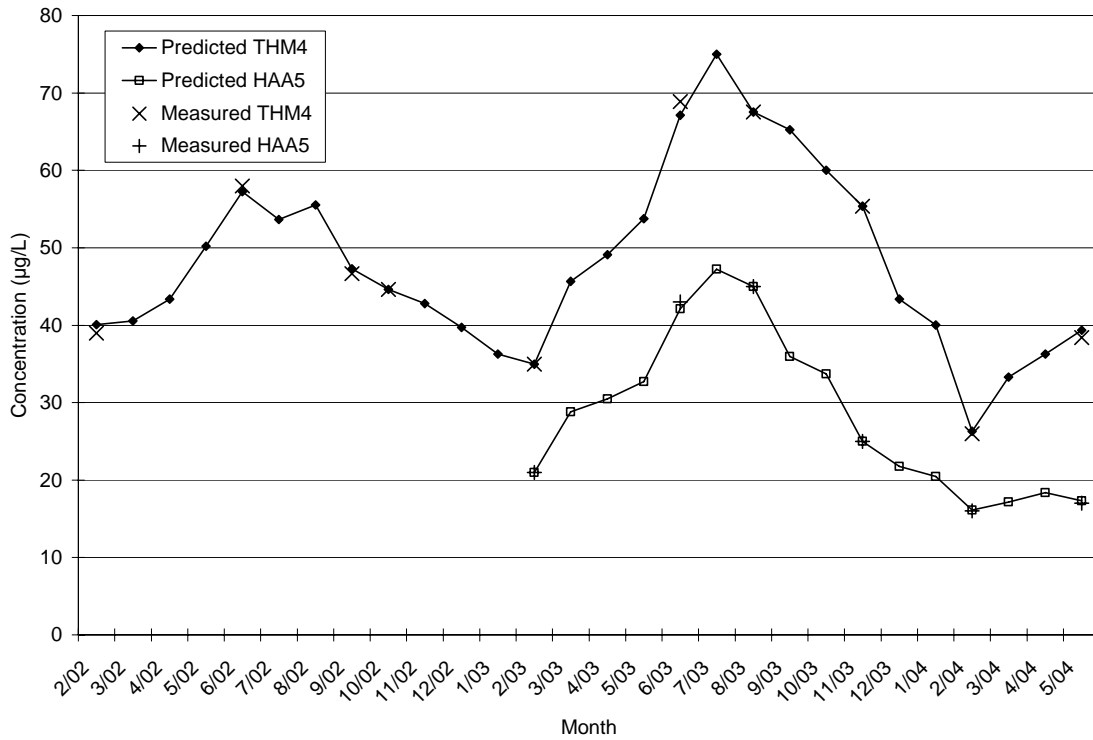


Figure D.34 Predicted Monthly LRAA Concentrations for Location 18, t = 96 hrs

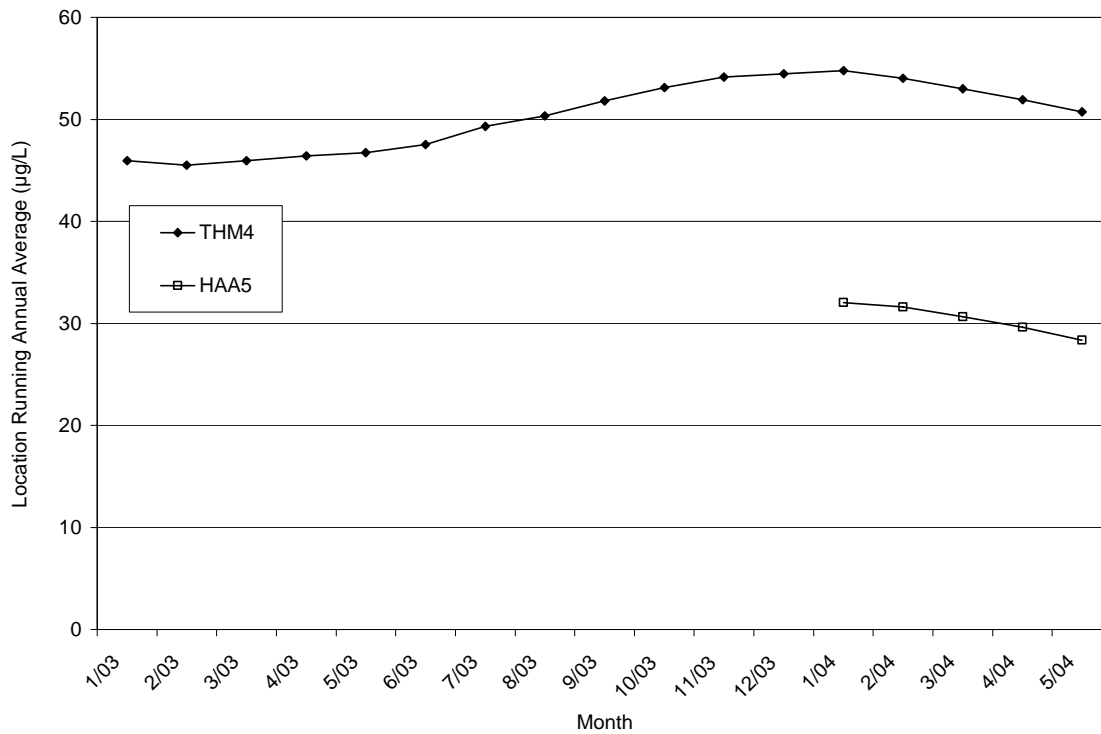


Figure D.35 Predicted and Measured DBP Concentrations for Location 19, t = 48 hrs

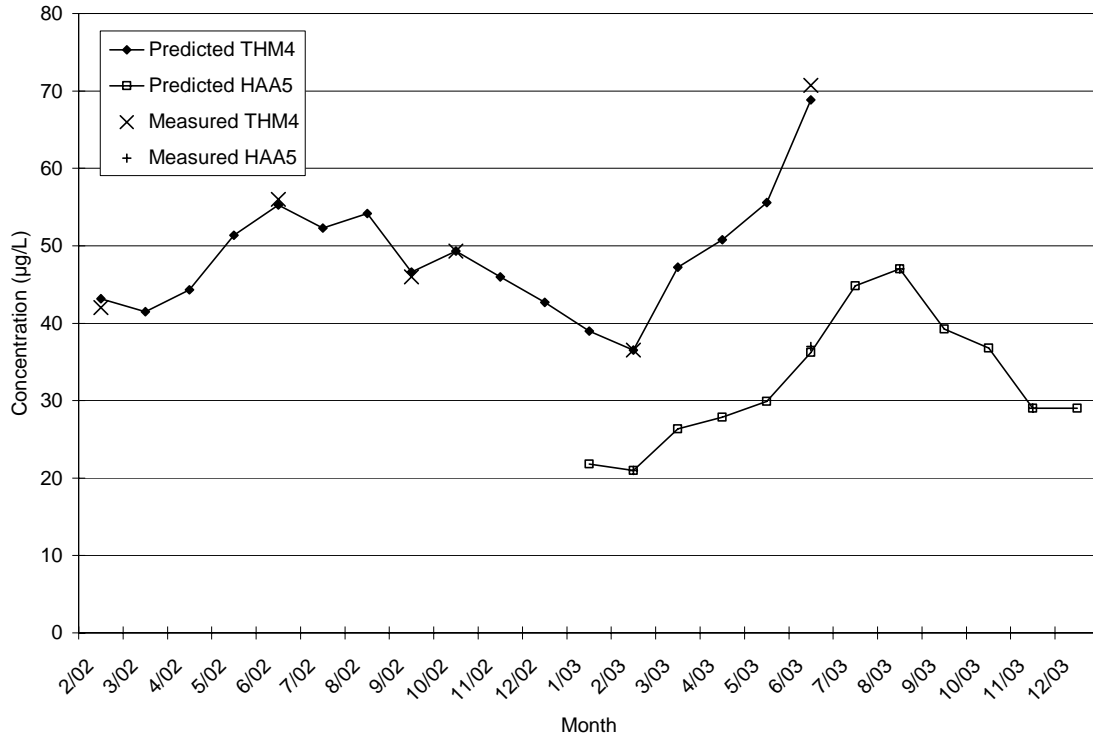


Figure D.36 Predicted Monthly THM4 LRAA Concentrations for Location 19, t = 48 hrs

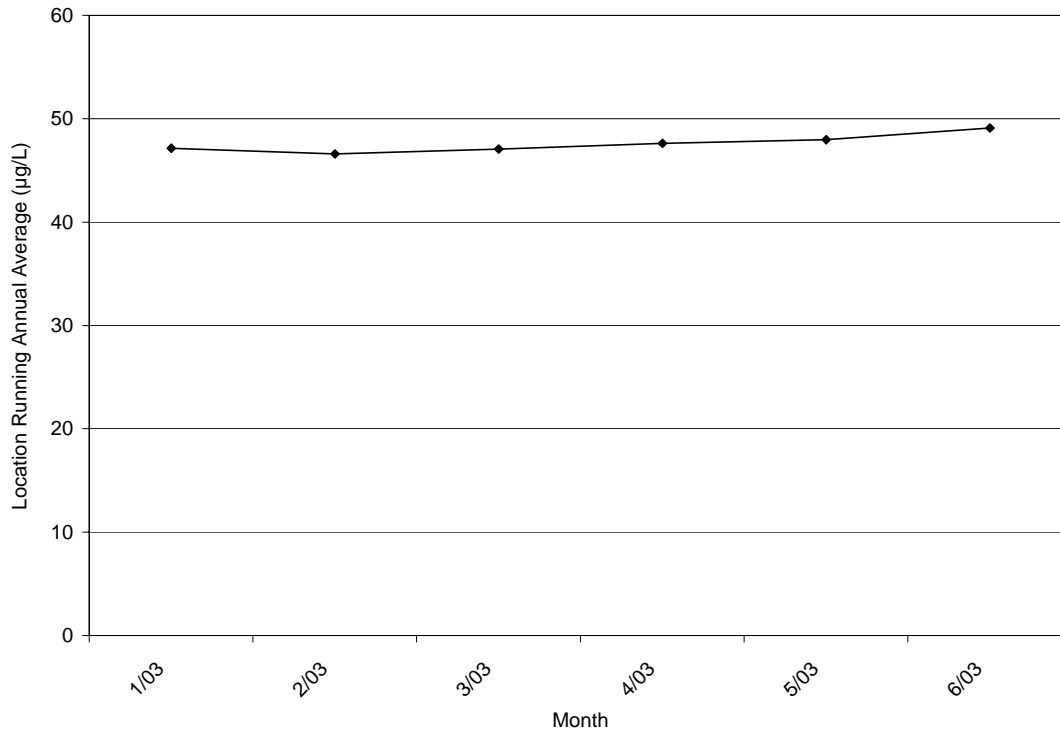


Figure D.37 Predicted and Measured DBP Concentrations for Location 20, t = 96 hrs

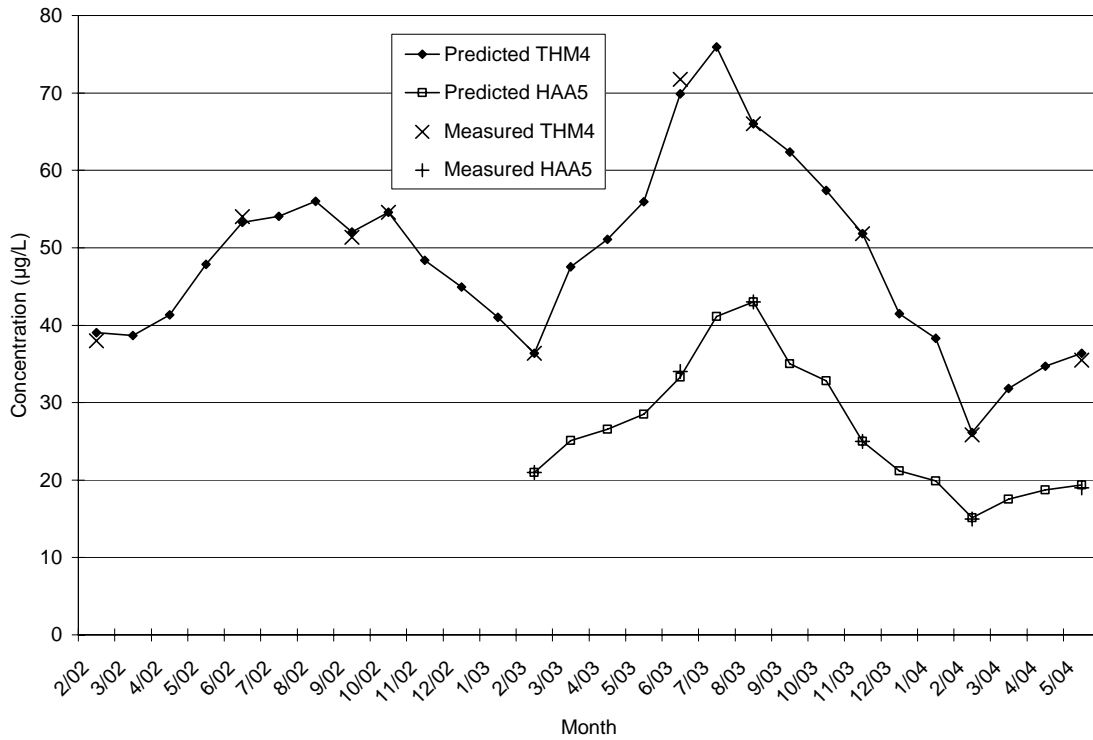


Figure D.38 Predicted Monthly LRAA Concentrations for Location 20, t = 96 hrs

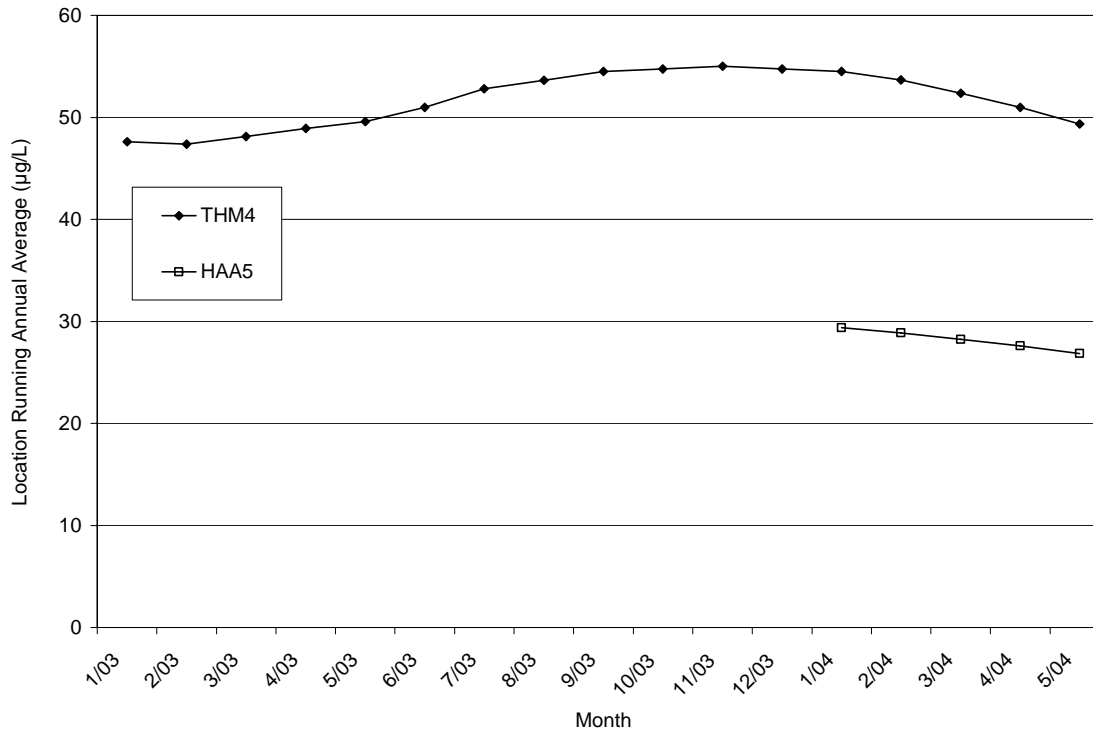


Figure D.39 Predicted and Measured DBP Concentrations for Location 21, t = 48 hrs

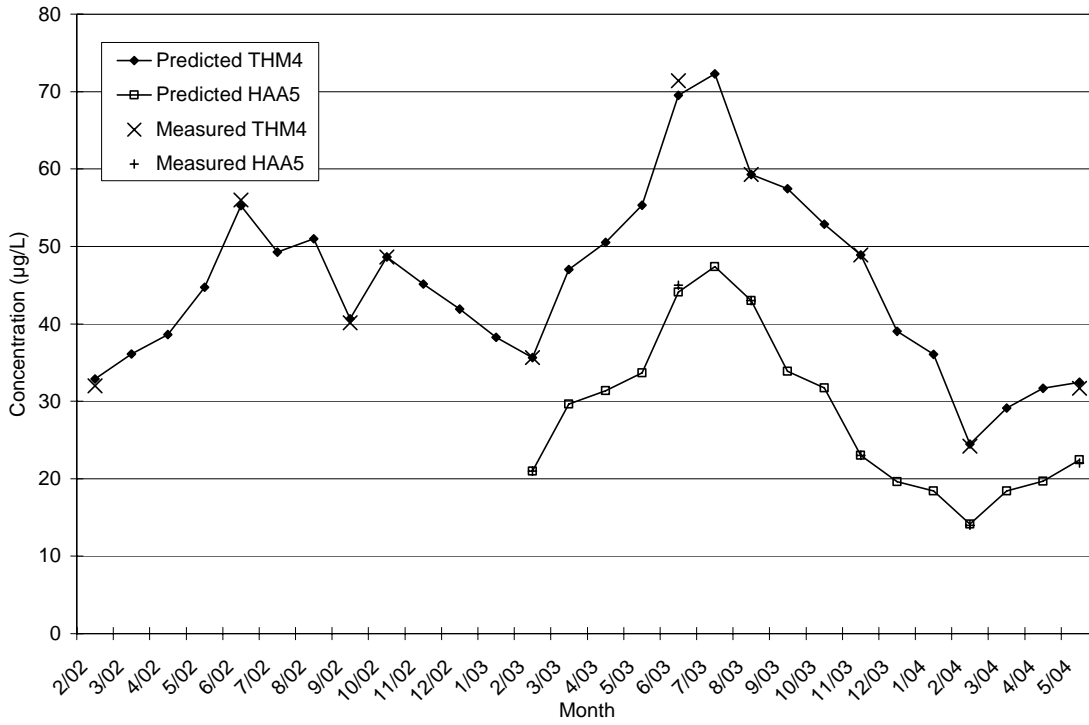


Figure D.40 Predicted Monthly LRAA Concentrations for Location 21, t = 48 hrs

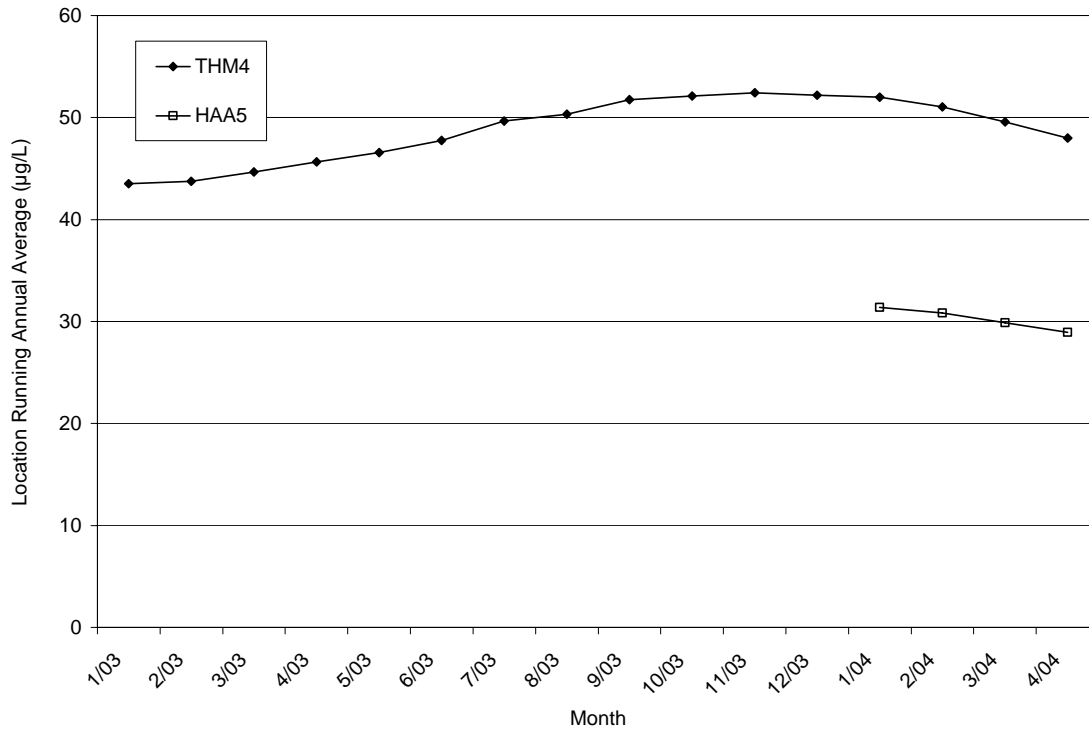


Figure D.41 Predicted and Measured DBP Concentrations for Location 22, t = 36 hrs

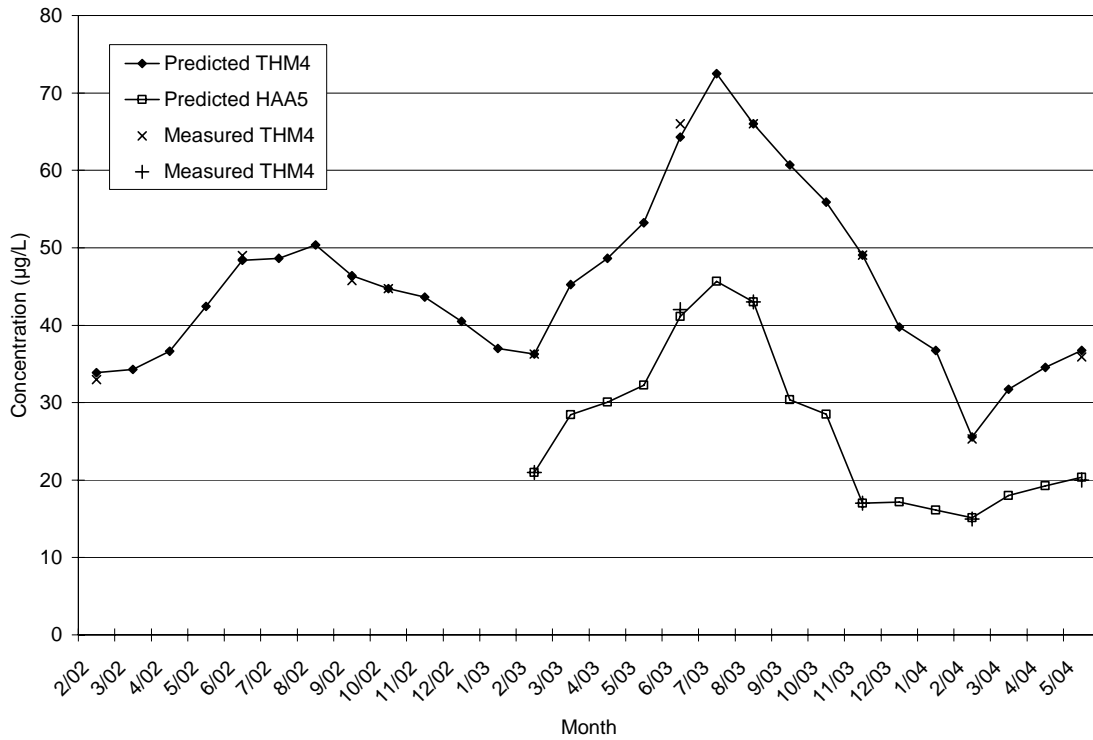
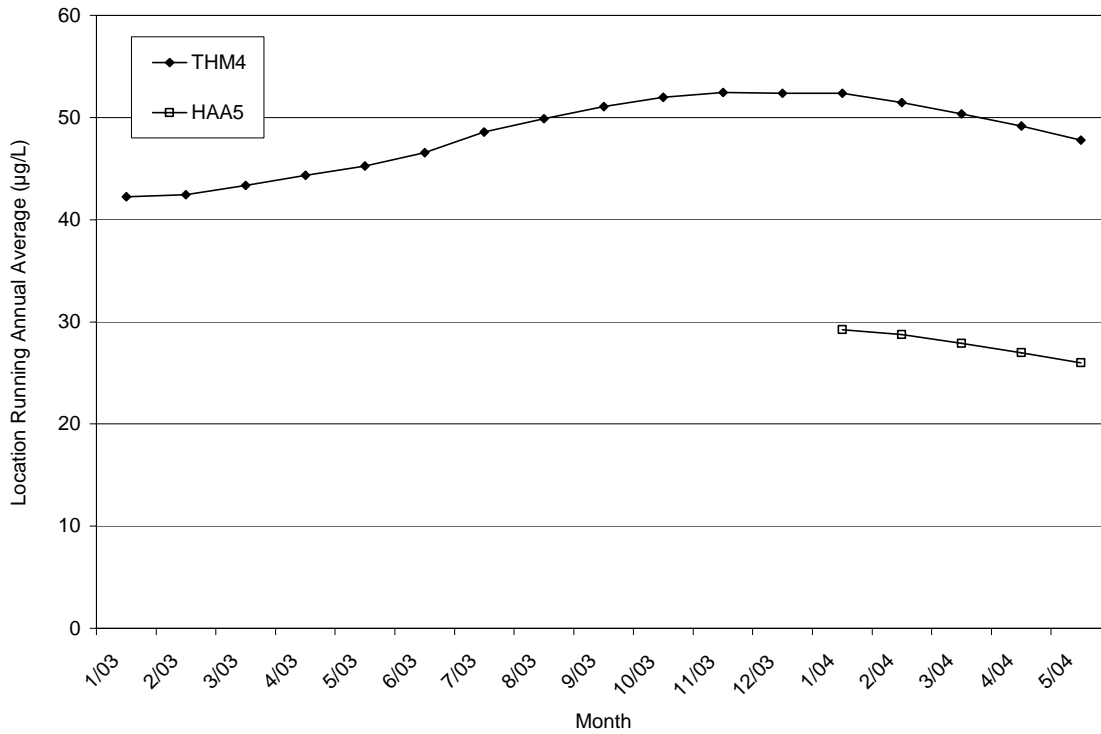


Figure D.42 Predicted Monthly LRAA Concentrations for Location 22, t = 36 hrs



Appendix E - Burlington

Figure E.1 Predicted and Measured DBP Concentrations for Location 1, t = 3 hrs

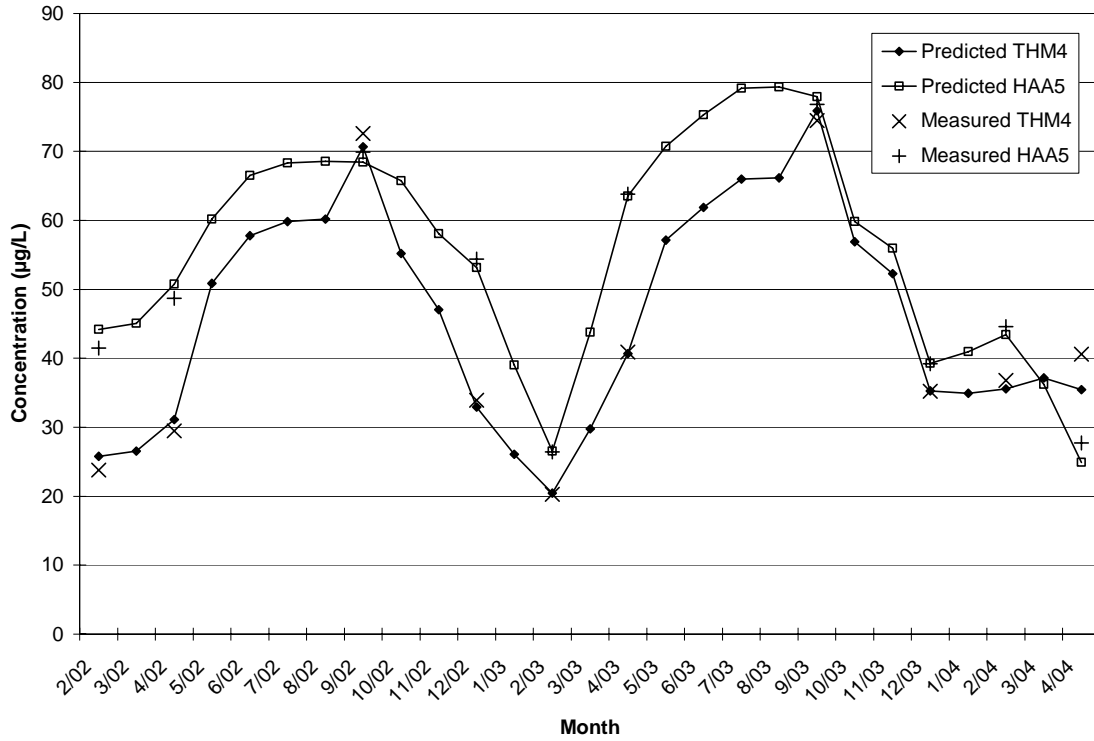


Figure E.2 Predicted Monthly LRAA Concentrations for Location 1, t = 3 hrs

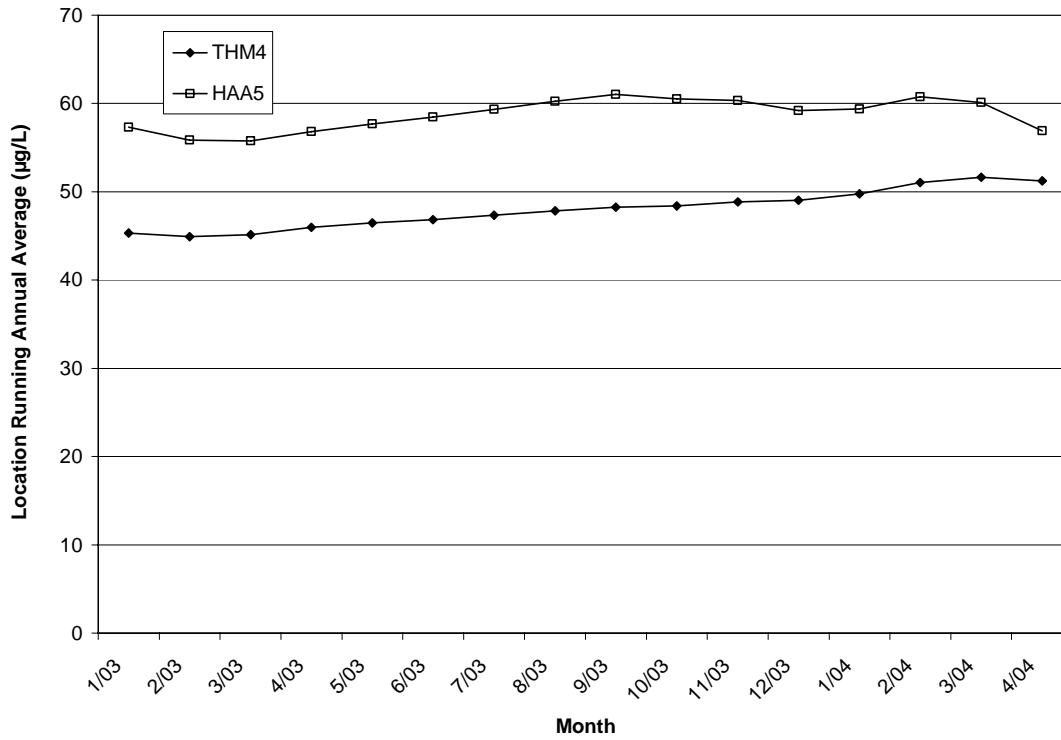


Figure E.3 Predicted and Measured DBP Concentrations for Location 2, t = 20 hrs

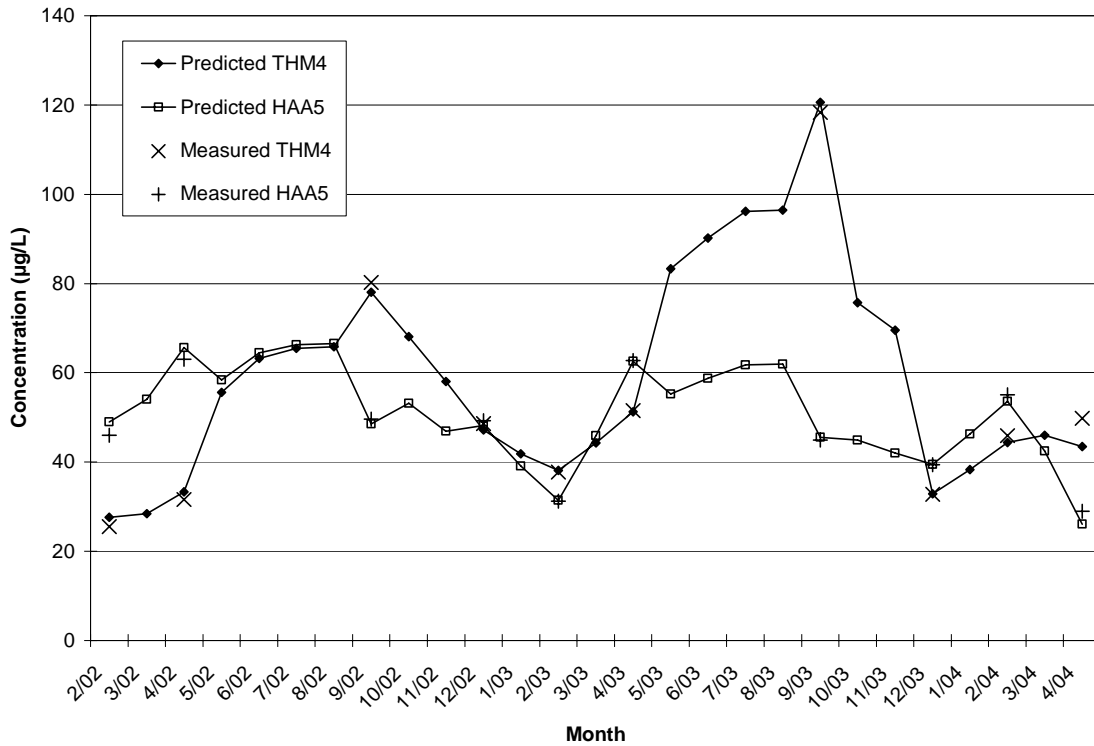


Figure E.4 Predicted Monthly LRAA Concentrations for Location 2, t = 20 hrs

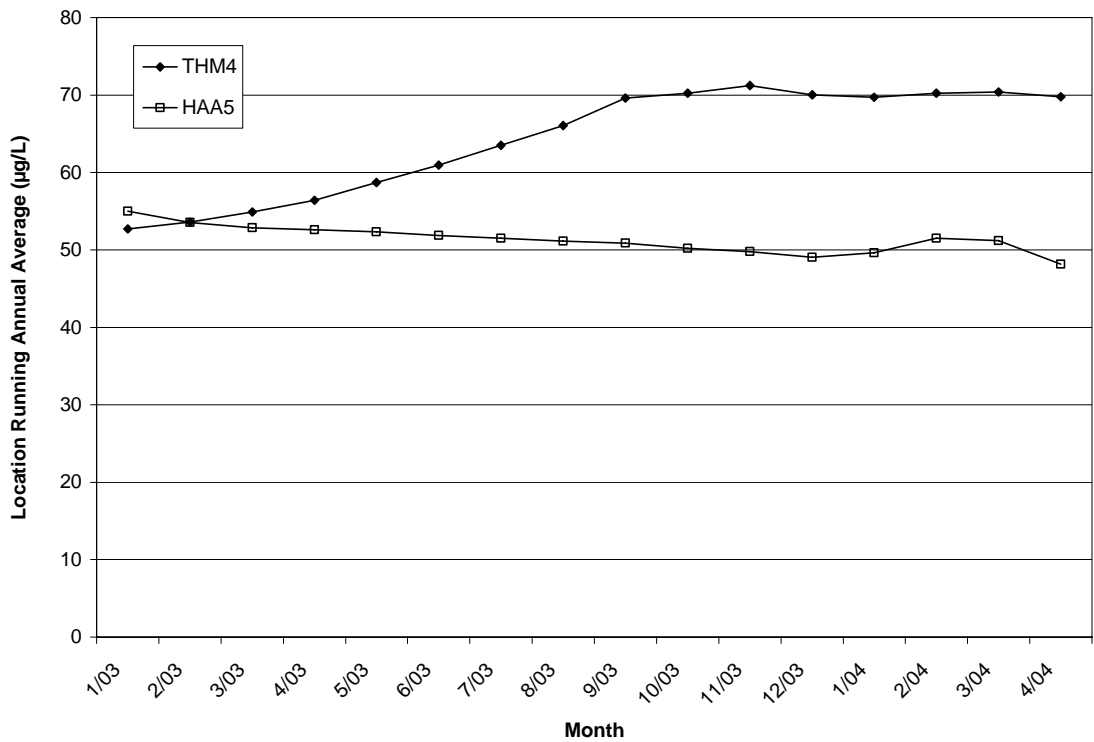


Figure E.5 Predicted and Measured DBP Concentrations for Location 3, t = 16 hrs

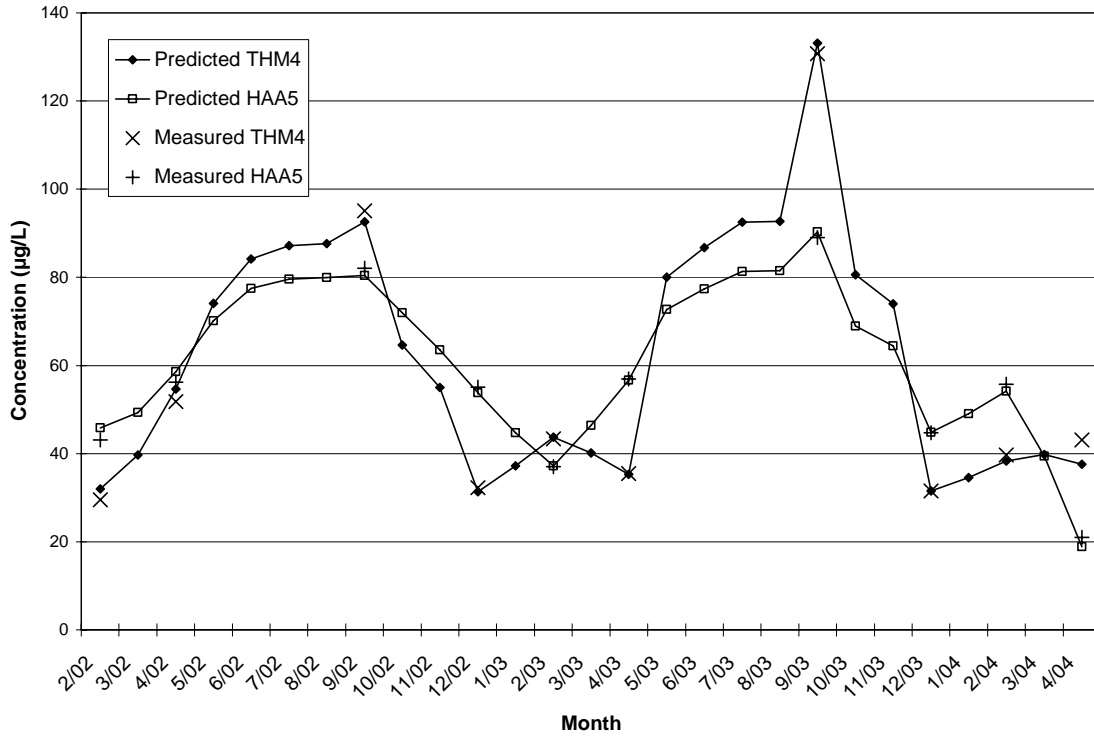


Figure E.6 Predicted Monthly LRAA Concentrations for Location 3, t = 16 hrs

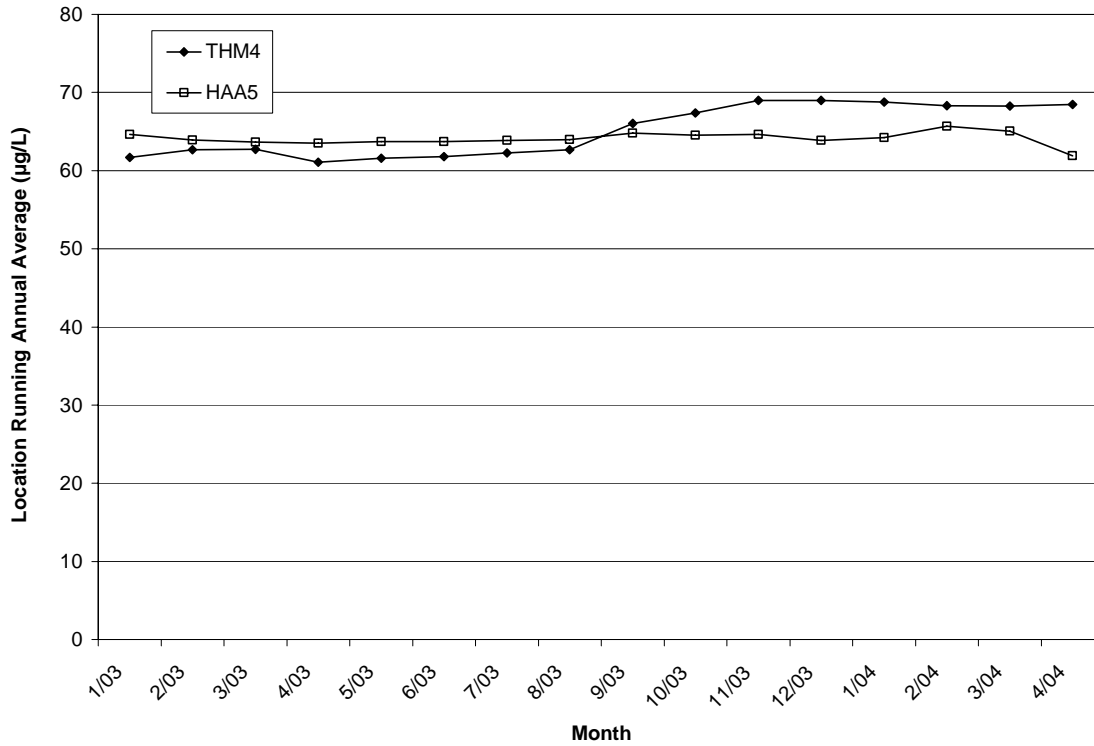


Figure E.7 Predicted and Measured DBP Concentrations for Location 5, t = 24 hrs

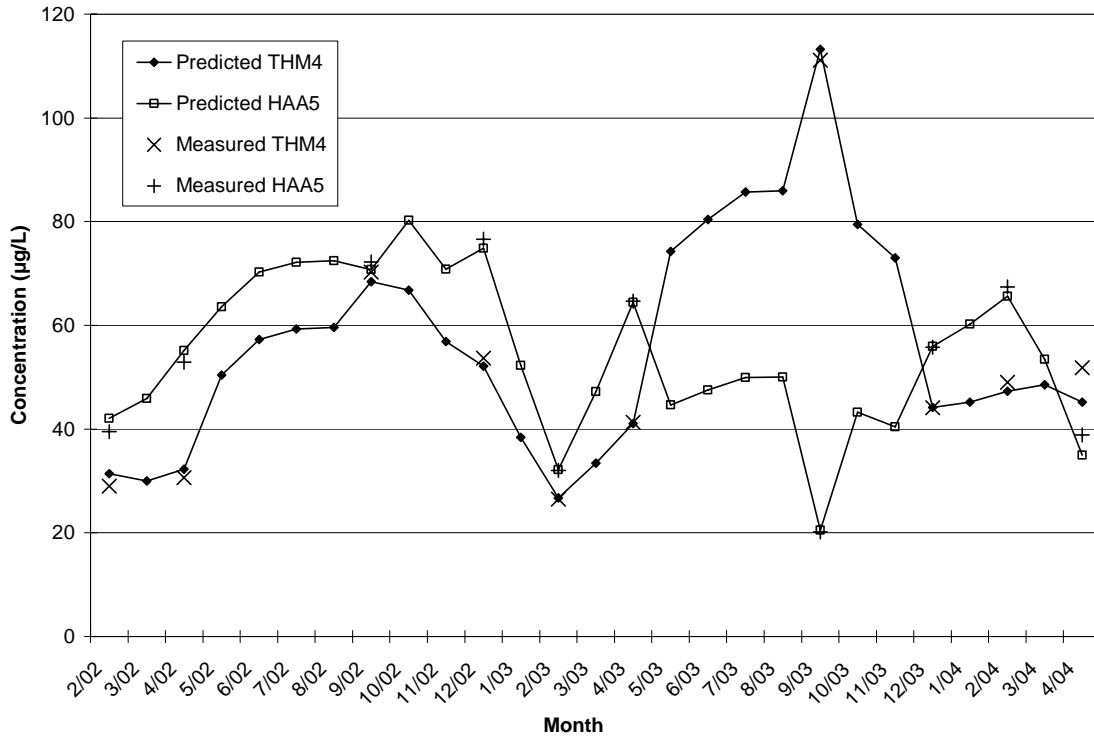


Figure E.8 Predicted Monthly LRAA Concentrations for Location 5, t = 24 hrs

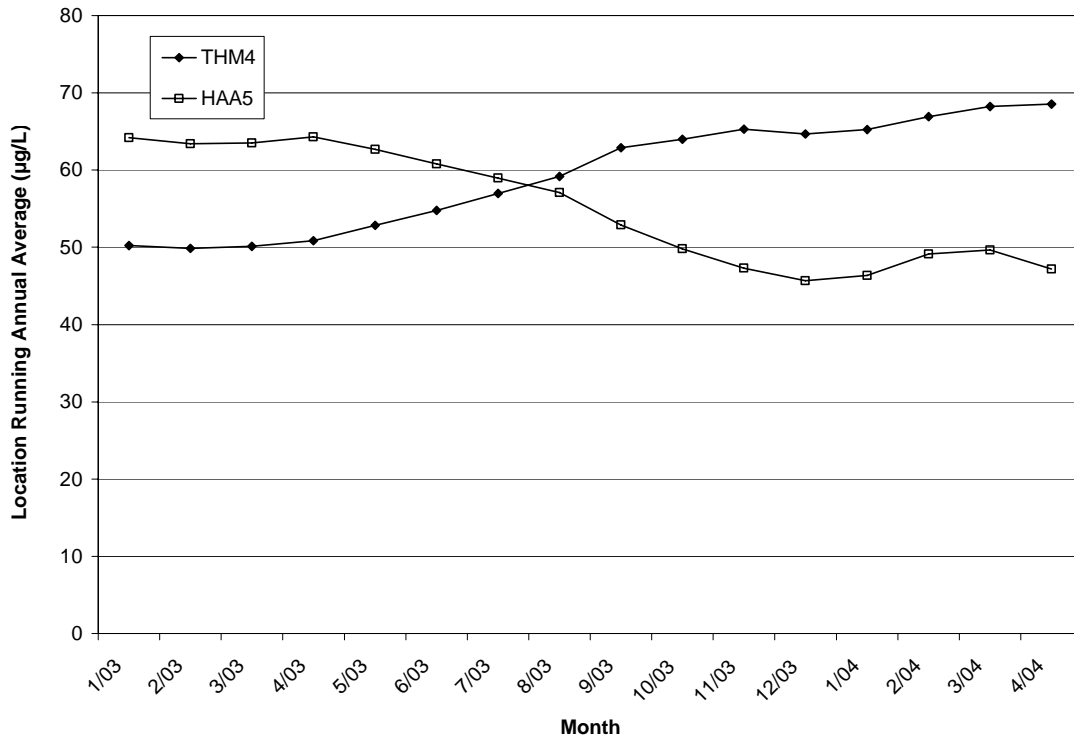


Figure E.9 Predicted and Measured DBP Concentrations for Location 6, t = 48 or 85 hrs

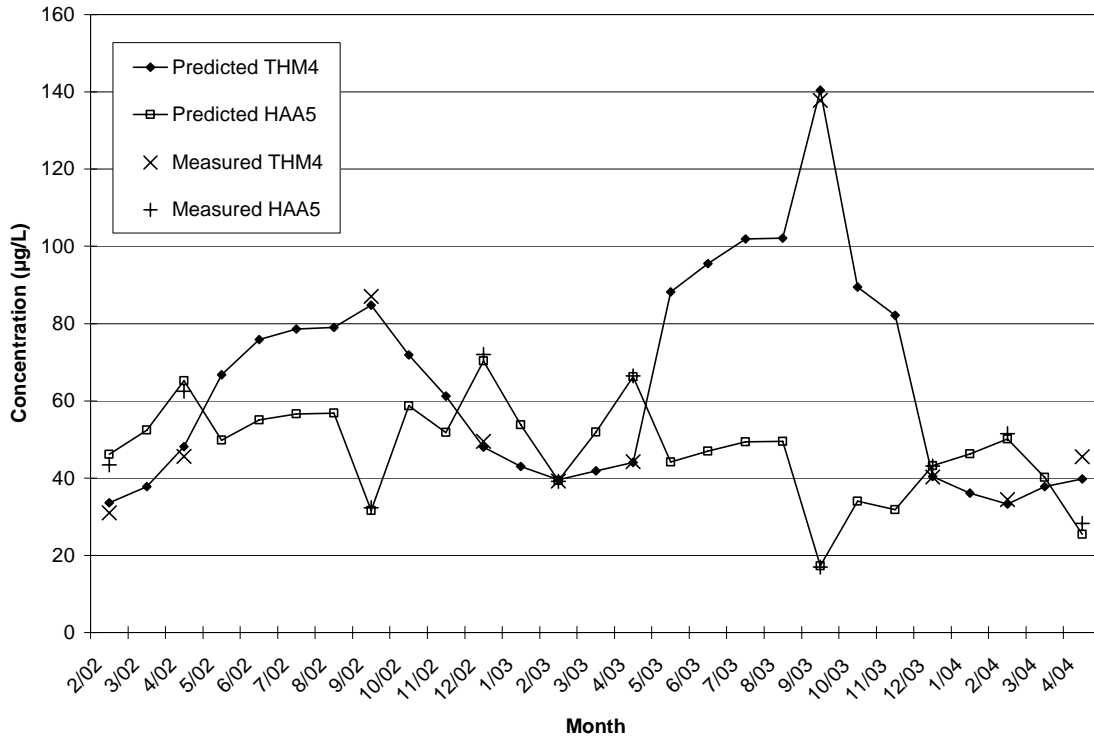


Figure E.10 Predicted Monthly LRAA Concentrations for Location 6, t = 48 or 85 hrs

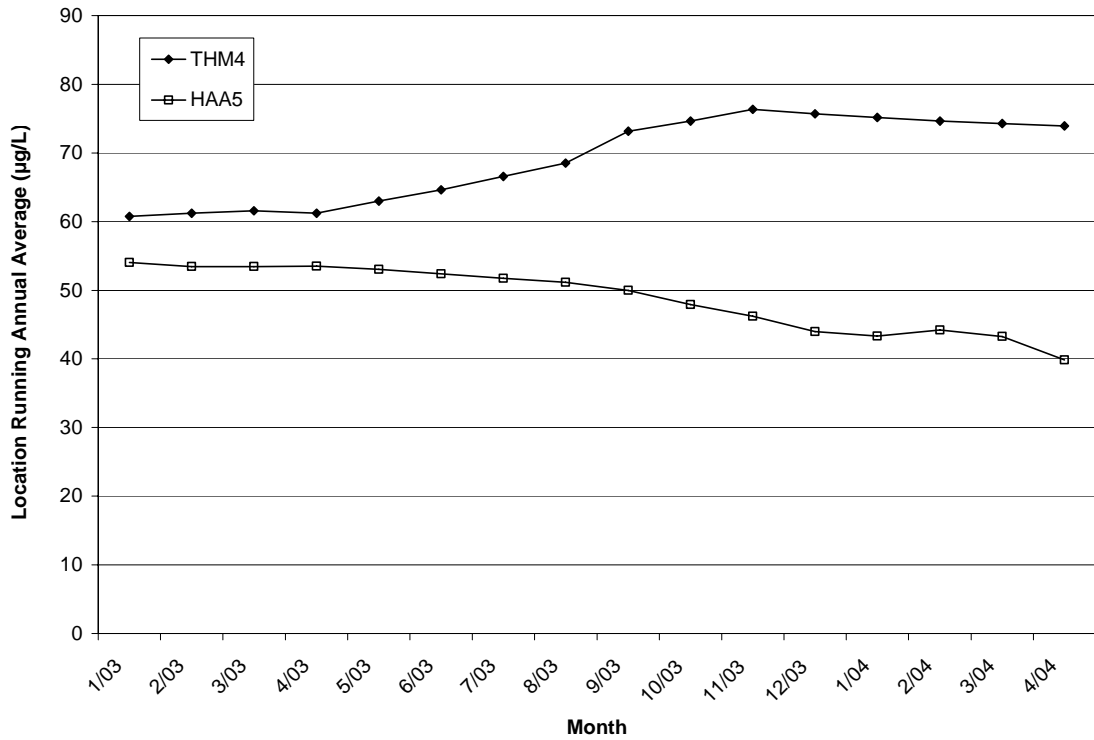


Figure E.11 Predicted and Measured DBP Concentrations for Location 7, t = 4 hrs

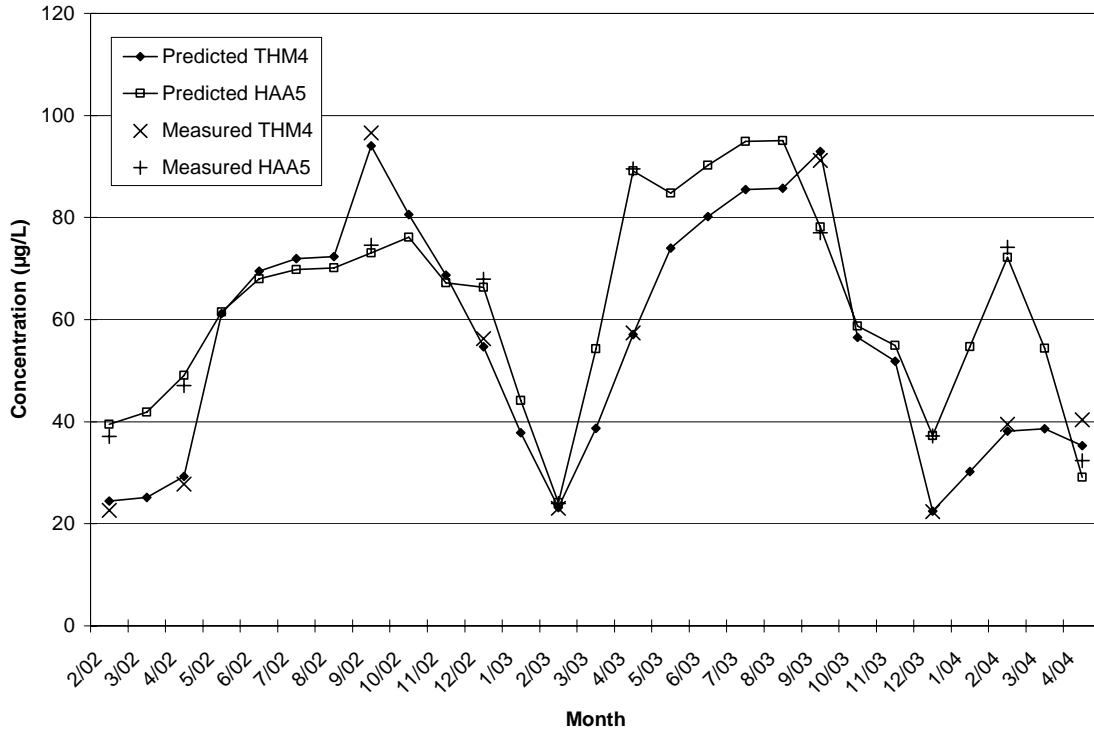


Figure E.12 Predicted Monthly LRAA Concentrations for Location 7, t = 4 hrs

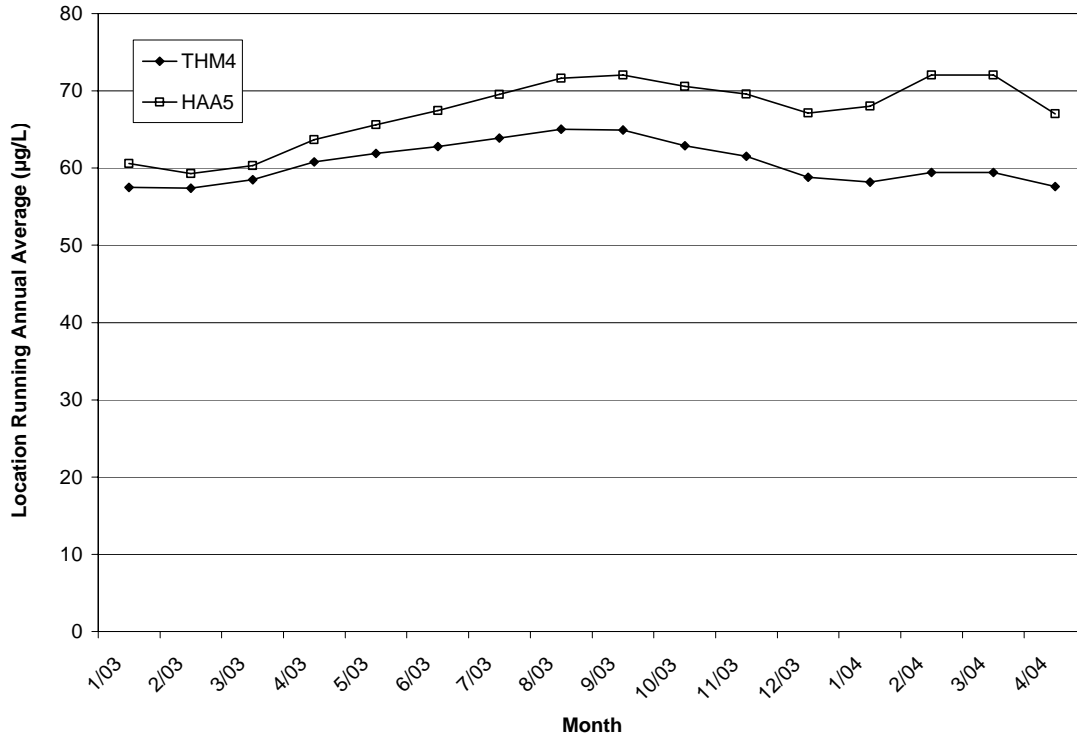


Figure E.13 Predicted and Measured DBP Concentrations for Location 8, t = 24 or 68 hrs

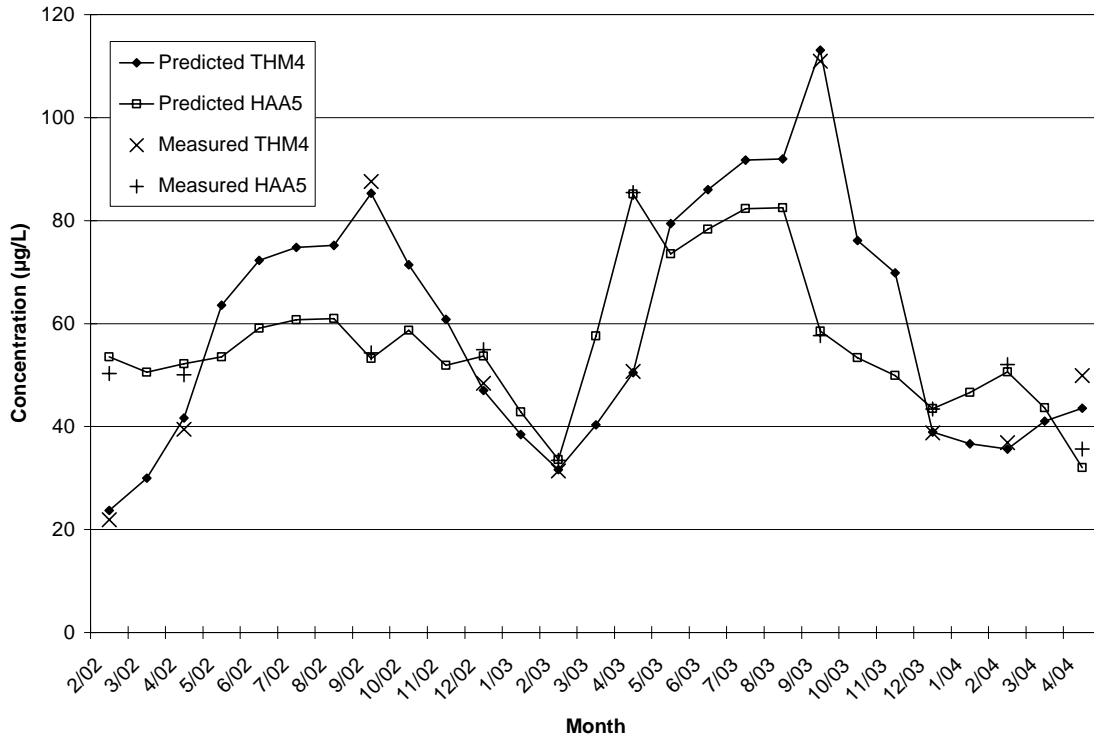


Figure E.14 Predicted Monthly LRAA Concentrations for Location 8, t = 24 or 68 hrs

