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INITIAL DISTRIBUTION SYSTEM EVALUATION GUIDANCE MANUAL

FOR THE FINAL STAGE 2 DISINFECTANTS AND DISINFECTION BYPRODUCTS RULE

APPENDIX G

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http://www.epa.gov/safewater/disinfection/stage2/compliance.html

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Appendix G

Complex Modeling Analysis Example for a System with Multiple Sources

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Complex Modeling Analysis Example for a System with Multiple Sources

Chapter 6 discussed modeling in general terms and the example included in Section 6.2.2 is applicable to systems with a single water source or multiple sources with similar water quality in terms of initial DBP concentrations and DBP formation potentials. However, some systems may have multiple sources with very different water quality characteristics. For example, a system may be served by both a groundwater source with low DBP precursor concentrations and a surface water source with high DBP precursor concentrations. For these special cases, a simple water age simulation will not capture the true variation in DBP concentrations because it does not distinguish between the different quality source waters. A high water age for the low DBP source may not result in a high DBP concentration. For example, in this case study the low DBP precursor source has a TTHM formation potential of 0.022 mg/L and the high DBP precursor source has a TTHM formation potential of 0.122 mg/L. Very old water from the low DBP precursor source may have a TTHM concentration on the order of 0.020 mg/L while relatively fresh water from the high DBP precursor source could have a TTHM concentration greater than 0.100 mg/L. Similar situations arise in consecutive systems where the water age entering the distribution system is different at different entry points.

Most modeling software that is currently available cannot apply a source-specific formation rate coefficient. The formation rate coefficient is currently specified as a single, globally-applied parameter. Special provisions should be made when using models to analyze systems with multiple sources of varying water quality. A source-adjusted water age can be calculated or an estimate of maximum possible DBP concentration can be developed. These are illustrated in the following example.

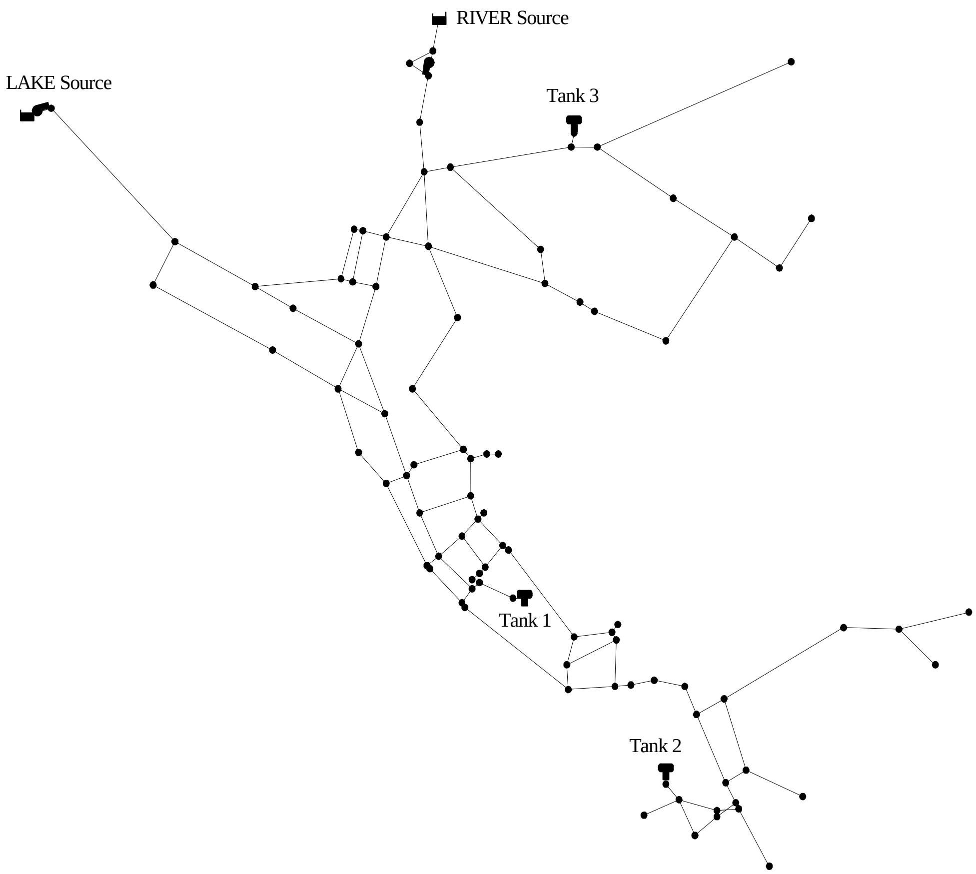
Systems in this category should submit additional documentation that describes their modeling procedures and analysis for selection of SSS monitoring sites.

Source-Adjusted Water Age Analysis

The system schematic is shown in Exhibit G.1. If the two sources in this example have very different DBP formation rates and ultimate formation potentials, then a simple water age analysis as performed in Section 6.2.2 will not necessarily identify the locations with highest DBP levels. For example, if the water in Tank 3 comes mostly from the RIVER source and this source has a much lower DBP formation potential than the LAKE source, then this tank may no longer contain water with the highest DBP concentration, even though it has the oldest water in the system.

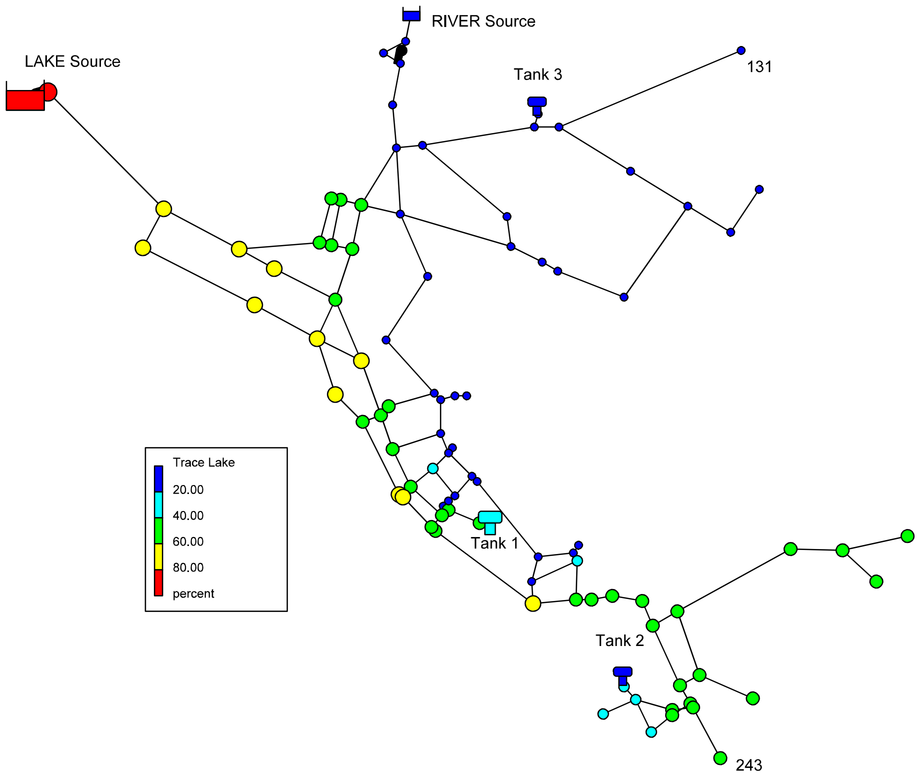
Ideally, one would like to account for both the individual DBP formation potential and kinetics for each source water as well as the blending of these waters together in an integrated fashion when simulating the system. Unfortunately, the current generation of network water quality models is not capable of directly performing this kind of analysis. However, one can perform a series of simulations and calculations to approximately account for significant differences in DBP production between different source waters.

Exhibit G.1 Schematic of the Case Study Distribution System



Calculating a source-adjusted water age for this case study requires a source trace analysis and data on the ultimate DBP formation potential (maximum concentration) for each source. The first step is to calculate the percentage of water from each source for all nodes in the system. These values can be obtained by changing the type of water quality analysis from AGE to TRACE, selecting the LAKE source as the source to be traced, and re-running the simulation. Exhibit G.2 displays the average percentage of water from the LAKE source reaching each node. The percentage from the RIVER source at any node would simply be 100 minus the LAKE percentage. Note how the nodes on the left side of the network receive mainly LAKE water while the nodes in the upper right, which had the oldest water in the example in Section 6.2.2, receive the least amount of LAKE water.

Exhibit G.2 Average Percentage of Water From the LAKE Source



The adjusted water age for each node of the system can be calculated as a weighted average by using the following equation:

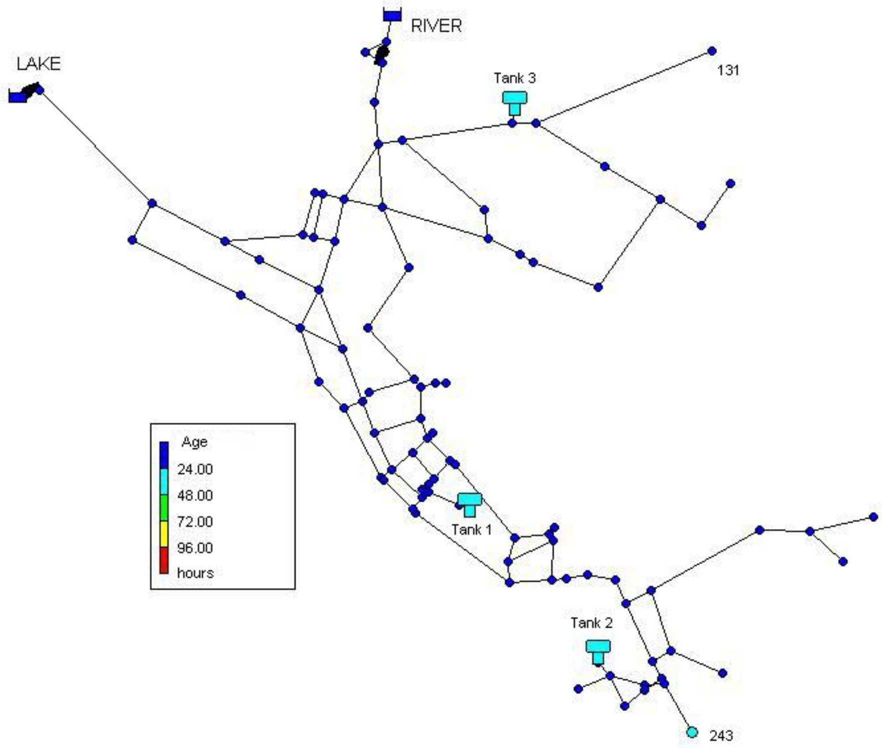
$$\text{Adjusted Age} = \text{Age} * (P_{LAKE} + P_{RIVER} / R) / 100$$

where Age = the original age estimate,
P_{LAKE} = percentage of LAKE water,
P_{RIVER} = percentage of RIVER water, and
R = ratio of LAKE DBP formation potential to RIVER DBP formation potential.

A similar version of this equation can be used with more than two sources by including all sources in the weighted average.

In this case, a review of historical data showed that R was equal to 5.5, i.e. the LAKE source has the potential to form 5.5 times greater DBP concentrations than the RIVER source. Exporting both the age results and the source tracing results from the model into a spreadsheet and applying the formula shown above gives the resulting source-adjusted water age throughout the network, as shown in Exhibit G.3. Comparing these results with the unadjusted ages in Section 6.2.2 shows a similar pattern in terms of which nodes have the highest ages but a much lower adjusted water age overall. This demonstrates that the RIVER water remains in the system the longest but has much lower potential to form DBPs than the LAKE water. The results of the adjusted water age analysis demonstrate the importance of considering different sources. For example, node 131, which was predicted to have the second highest water age in the simple water age analysis, has an adjusted water age of only 22.5 hours.

Exhibit G.3 Source-Adjusted Water Age Throughout the Study Area



Rather than using water age as the basis for selecting sampling sites, another option would be to model DBP formation and thereby directly identify locations with high levels of DBPs. The required input data for each DBP of interest (i.e., each chemical species) and for each water source must be available:

1. the DBP concentration leaving the treatment plant
2. a first-order rate constant based on laboratory tests
3. an ultimate formation potential (maximum concentration) of the DBP

Exhibit G.4 lists the values of these parameters for TTHM for the case study. Note the large difference in the formation potential and formation rate coefficient between the two sources.

Exhibit G.4 Total THM Growth Parameters for the Case Study Example

	RIVER Source	LAKE Source
Total THM at Distribution System Entry Point (mg/L)	0.012	0.108
Total THM Formation Potential, F (mg/L)	0.022	0.122
First-Order Growth Constant, k (1/days)	2.3	15.1

These parameters are normally used in the following THM growth expression that is applied system-wide:

$$C = Co + (F - Co)(1 - \exp(-kt))$$

where C = TTHM concentration (mg/L),
Co = initial TTHM concentration leaving the source (mg/L),
F = ultimate TTHM formation (mg/L),
k = growth constant (1/days), and
t = time in days
exp = natural log, e.

Because there are two distinctly different THM sources in this example, the above equation cannot be applied directly. Instead, as was done for the adjusted water age analysis, a separate THM growth simulation should be made for each individual source with the results of each combined outside of the model according to the percent of water from each source. Or, to simulate a worst case scenario, a DBP simulation could be made using the appropriate source concentrations for each source but using the highest values for F and k for the global formation equation. The results from this worst-case simulation are given in Exhibit G.5. The results for the DBP modeling are quite different from the results for the water age analysis at certain nodes, as shown in Exhibit G.6.

The results for this case study depend greatly on the system configuration and the operational conditions. This is a simple representation of a distribution system and does not reflect the level of complexity that is present in real systems. However, this example does illustrate the difficulty in predicting water age or DBP concentrations for systems with multiple sources with varying water quality characteristics.

Exhibit G.5 Maximum Possible TTHM Simulation Results

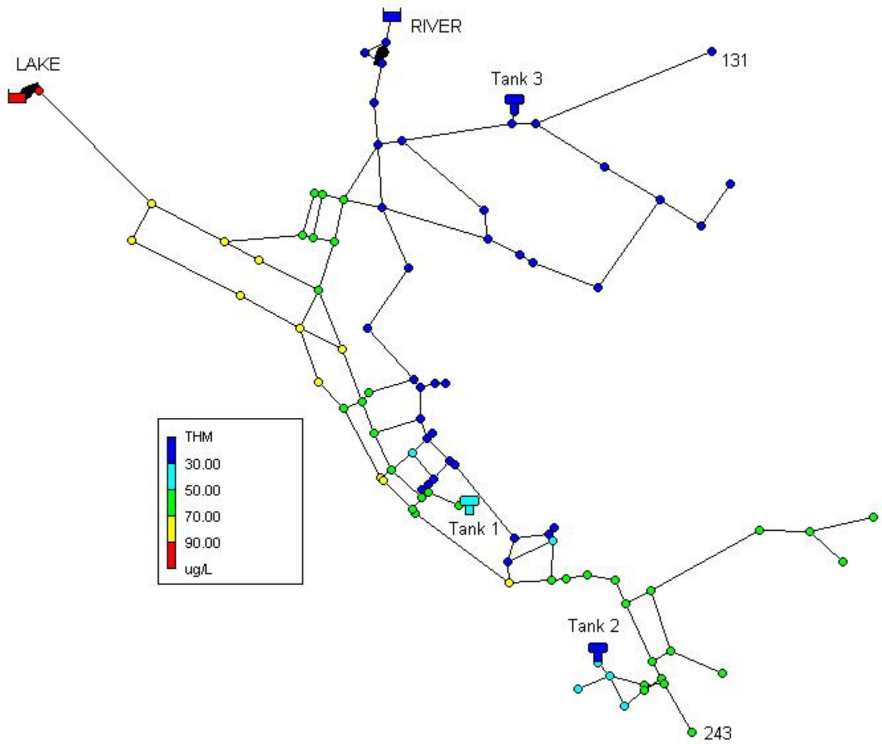


Exhibit G.6 Summary of Results from Different Analyses

Node ID	Average Water Age hours	Source Adjusted Water Age hours	Max. THM formation ug/l
10	0.03	0.03	108.00
15	72.89	12.67	12.79
20	114.22	19	11.91
35	14.9	4.53	27.86
40	31.35	17.63	57.59
50	46.22	20.49	43.86
60	0.08	0.01	12.00
601	0.8	0.13	12.00
61	0.21	0.04	12.00
101	8.33	5.85	73.77
103	6.28	5.21	88.52
105	9.06	6.15	71.02
107	9.91	7.7	82.53
109	9.86	7.29	78.01
111	8.69	6.11	73.90
113	9.68	6.49	70.14
115	9.47	6.03	66.19
117	9.16	5.88	66.86
119	11.56	2.41	16.86
120	10.69	5.91	56.55
121	10.93	1.83	12.08
123	3.39	0.57	12.00
125	67.79	11.3	11.99
127	108.72	18.09	11.92
129	113.89	18.95	11.91
131	135.44	22.53	11.90
139	108.63	18.07	11.92
141	97.77	16.46	12.16
143	76.02	13.18	12.76
145	32.38	5.92	13.87
147	24.66	4.67	14.65
149	30.58	5.88	14.96
151	39.84	7.4	14.19
153	70.11	11.7	12.02
157	10.68	2.23	16.84
159	10.54	2.19	16.73
161	10.75	2.31	17.60
163	10.75	2.31	17.59
164	20.74	4.28	16.57
166	42.97	8.85	16.51
167	11.3	2.53	18.64
169	11.16	2.5	18.66
171	11.39	2.56	18.67
173	11.38	2.55	18.64
177	22.1	13.43	62.77
179	25.41	16.16	66.04

181	14.87	4.52	27.83
183	19.29	12.76	68.97
184	15.85	10.53	69.40
185	15.68	10.45	69.55
187	10.59	7.12	70.29
189	11.59	7.37	66.08
191	10.09	6.67	68.98
193	9.58	6.03	65.33
195	10.06	6.26	64.62
197	12.26	8.72	74.89
199	11.34	2.54	18.56
201	11.32	2.58	19.02
203	11.38	2.58	18.98
204	10.3	6.95	70.65
205	15.51	10.46	70.47
206	15.29	9.2	62.13
207	15.17	9.14	62.24
208	15.62	9.39	62.07
209	14.98	9.27	64.12
211	14.7	9.47	66.99
213	15.32	9.56	64.75
215	22.64	13.76	62.86
217	24.55	14.76	62.10
219	33.48	19.68	60.53
225	34.01	20.14	61.03
229	19.75	12.01	62.84
231	31.31	18.81	62.02
237	19.98	12.13	62.75
239	25.77	14.89	59.38
241	28.85	16.34	58.05
243	78.49	44.19	57.66
247	30.62	17.24	57.66
249	28.14	16.17	59.02
251	41.28	20.12	48.96
253	46.92	22.56	48.17
255	43.68	21.09	48.41
257	9.85	5.99	62.94
259	9.6	6.06	65.60
261	9.09	5.87	67.24
263	9.14	5.94	67.76
265	10.82	2.42	18.58
267	10.36	6.44	64.48
269	11.13	4.19	36.21
271	11.14	2.7	20.71
273	10.74	3.42	29.46
275	10.39	3.55	32.22
River Source	0	0	12.00
Lake Source	0	0	108.00
Tank 1	75.35	25.63	31.97
Tank 2	122.41	35.84	26.50
Tank 3	189.26	31.48	11.85