PAP-780

CITY OF FORT COLLINS

WATER AND WASTEWATER UTILITIES

15 MG RESERVOIRS BAFFLE STUDY

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The hydraulic model was designed and plumbed by Dave Woodward of Bates Engineering. The model was fabricated by AIA Plastics of Denver. The model stand, supply tank, and inlet pump were set up at the Bureau of Reclamation Hydraulics Laboratory with the help of Lee Elgin, Jerry Fitzwater and Dean Connor under the oversight of Phil Burgi, Laboratory Manager. Tom Bunnelle of the Bureau's Water Treatment and Engineering and Research Group provided the de-ionized water for the tests. Technical assistance for conductivity measurements was provided by Jim Osmun of Orion Research, Inc.

The hydraulic model tests were performed by Dave Woodward, Amy Taylor and Brenda Harwell of Bates Engineering. Dr. Hank Falvey, retired from the Bureau of Reclamation, provided the computer model of the reservoirs. This report was prepared by Dave Woodward and reviewed by Bob Bates of Bates Engineering and Owen Randall and Kelley Gonzales of FCWU.

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EXECUTIVE SUMMARY

This report discusses the results of a hydraulic model study of the City of Fort Collins Water Utilities (FCWU) East and West 15 MG Reservoirs. The purpose of the study was to find a baffle configuration for each reservoir that would efficiently increase the contact time of water in each reservoir. The study was performed by Bates Engineering in cooperation with the U.S. Bureau of Reclamation using a single 1:48 scale model representing both reservoirs. A total of 31 tests were performed between April and June 1997. A simple computer flow model of the reservoirs was also developed as an additional evaluation tool. The results of a fluoride tracer test performed by FCWU in 1996 on the East Reservoir were used as a basis for comparing model flows with the prototype.

Specific baffle configuration recommendations are made for each reservoir as well as guidance for the materials used to construct these baffles.

I. PURPOSE

The City of Fort Collins Water Utilities (FCWU) currently has three potable water storage reservoirs with a total storage volume of 34 million gallons (MG). Thirty million gallons of this storage is located on site at the Water Treatment Facility (WTF) near Soldier Canyon Dam. This 30 MG of storage is shared between two 15 MG Reservoirs. The "West" and "East" 15 MG Reservoirs were built in 1963 and 1967 respectively.

The dimensions of the reservoirs are essentially identical. They have an inverted truncated pyramidal shape ("hopper bottom") with a 160-foot square bottom area and 6:1 side slopes. The top area is 284 feet square with 18 foot vertical walls. The piping for each reservoir, however, is different. The inlet and outlet pipes for the West Reservoir are located on adjacent walls whereas the inlet and outlet pipes for the East Reservoir are located on opposite walls. The West Reservoir has a 36-inch inlet, while the East Reservoir has a 48-inch inlet. Each inlet has a 90° elbow oriented vertically upward at the wall. Both reservoirs have 60-inch outlets, but the West Reservoir also has a 36-inch outlet adjacent to its 60-inch outlet.

Because these reservoirs are located at the WTF, FCWU has been interested in maximizing the chlorine contact time in the two reservoirs in order to meet EPA and State Health Department requirements for such organisms as *cryptosporidium* and *giardia*. This is especially true during periods of high use (high flow) and low reservoir levels when the chlorine contact time is relatively short. FCWU felt that installing baffles in the reservoirs would provide some additional contact time. In January 1997, FCWU contracted with Bates Engineering to develop a means to investigate the flow through the two 15 MG Reservoirs and to recommend reservoir baffle configurations and materials.

II. BACKGROUND

Two valuable means of investigating the mixing of treated water in reservoirs are computer models and scale hydraulic models. Computer models are useful because the inputs can be readily changed to simulate various reservoir geometries and water temperatures. However, the results may be somewhat unrefined due to cell size limitations, imperfect boundary conditions and simplified flow theory models[1]. Hydraulic models provide a tangible "feel" for mixing in reservoirs, but are locked into a specific geometry and are subject to scaling factors, especially with smaller models. Both types of models are best used when they can be cross-calibrated with each other and with prototype (full-scale) data.

Walter Grayman and others have compared computer and hydraulic models of the 4 MG Ed Heck Reservoir in Azusa, California.[2] Their hydraulic model was 1:42 scale with a 3-foot, 8-inch diameter. They examined mixing with different outlet locations and shapes as well as the use of flow-directing baffles. Mixing was evaluated qualitatively by means of a tracer dye injected at the inlet. While the study was useful in terms of examining mixing in this particular reservoir, the model was of relatively small scale, the flows were of short duration and the results were primarily qualitative.

Lewis Rossman at the U.S. Environmental Protection Agency National Risk Management Research Laboratory in Cincinnati, is in the process of performing mixing tests using a 4-foot-diameter model.[3] Conductivity measurements are being used in addition to a tracer dye to quantitatively verify mixing. Mr. Rossman is investigating the effects of flow rate, reservoir diameter and water level as well as temperature differentials on reservoir mixing. In the future, he would like to vary the inlet location and configuration to determine their effects on mixing.

Bates Engineering, in conjunction with Burns and McDonnell and the U. S. Bureau of Reclamation, investigated the effect of inlet piping configuration on mixing in a 3 MG reservoir under design in 1996 for the City of Aurora, Colorado. A clear acrylic, 8-foot-diameter, 1:22.75 scale hydraulic model was constructed of the proposed reservoir. Various inlet geometries were examined in an effort to optimize mixing in the reservoir. Tracer dye was used to observe the initial effects of mixing and to locate stagnant or "dead" zones.

Sparked by the results of the Aurora study, Denver Water asked Bates Engineering to use this same 8-foot-diameter model to investigate general aspects of mixing in circular reservoirs that could be applied to three of their reservoirs: Hogback, Chatfield and Colorow. During six tests, the effects of four variables were evaluated: outlet configuration, water temperature, flow rates and the use of an air bubbler mixing system. Temperature and conductivity measurements supplemented the use of tracer dye to quantitatively evaluate test results. The report concluded that the most important influences on reservoir mixing were, in order: inlet/outlet geometry, flow rate and water temperature. An air bubbler mixing system effectively promoted mixing but required further evaluation. As part of the study, Bates Engineering also asked Dr. Hank Falvey, formerly of the U.S. Bureau of Reclamation, to develop a computer model to examine the effects of inlet and outlet location on mixing in circular reservoirs. The results of the study were incorporated into the findings of the American Waterworks Association

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1 Grayman, Walter M., et. al., "Water quality and mixing models for tanks and reservoirs," *Journal of the American Water Works Association*, Vol. 88, No. 7 (July 1996), p. 61.

2 ibid, pp. 70ff.

3 Telephone conversation with Lewis Rossman, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, October 22, 1996.

(AWWA) Research Foundation Project 260, "Water Quality Modeling of Distribution System Storage Facilities."

In order to investigate the impact of baffles in the FCWU 15 MG Reservoirs, Bates Engineering proposed using both a simple computer model and a scale hydraulic model. The computer model was developed by Dr. Hank Falvey. A copy of his report is included in Appendix D. A copy of the model program on diskette has also been provided to FCWU. This report focuses primarily on information gathered by Bates Engineering from the hydraulic model as well as information on various baffle materials.

III. MODEL DESCRIPTION

Due to the geometric similarity between the East and West 15 MG Reservoirs, testing of each reservoir was possible with a single hydraulic model. A model scale factor, L_R , of 1:48 was selected to keep the model to a size which could be readily transported and to permit use of standard plastic pipe fittings. The model is approximately 6-feet square in plan and has 196 columns (see Figures 1 and 2). The model was placed on a wood platform at the Bureau of Reclamation Hydraulics Laboratory in Lakewood, Colorado for testing (see Appendix E for photographs).

The inlet pipes for the reservoirs consisted of 90° elbows oriented upward similar to the prototype inlet pipes. Prototype outlet pipes were oriented 90° downward into a sump. However, since it was believed that the outlet pipe configuration would not significantly impact flow patterns, model outlet pipes were oriented horizontally, simplifying model construction.

Water was provided to the inlet using a 250-gallon plastic supply tank in conjunction with a small centrifugal pump and flexible plastic piping. Water was drawn through the outlet by means of a second small pump and was discharged to the below-grade channel network in the Bureau of Reclamation lab. Inflow and outflow rates were measured using valved, acrylic, panel-mount, water rotameters appropriate for the flow range.

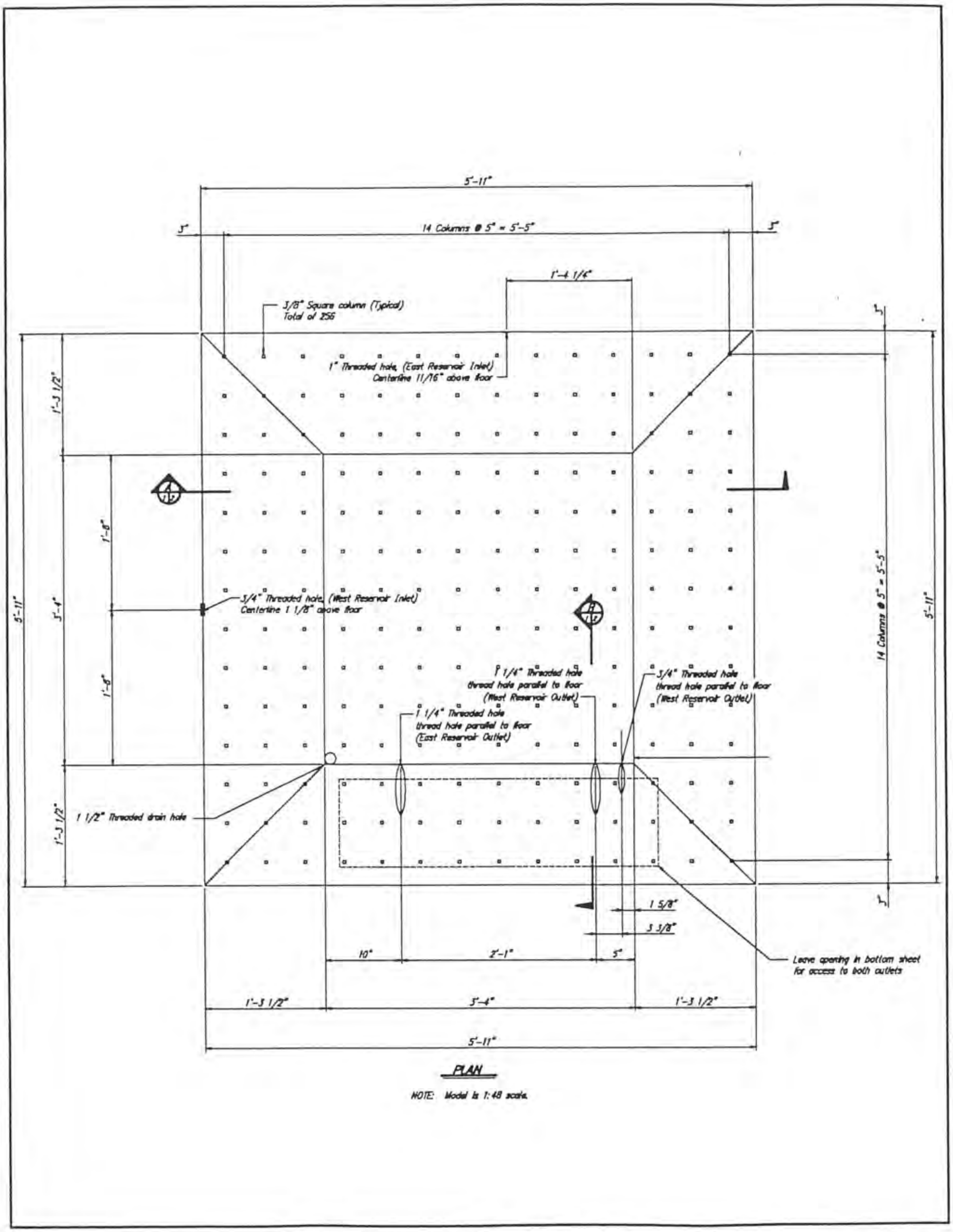


Figure 1. Hydraulic Model Plan

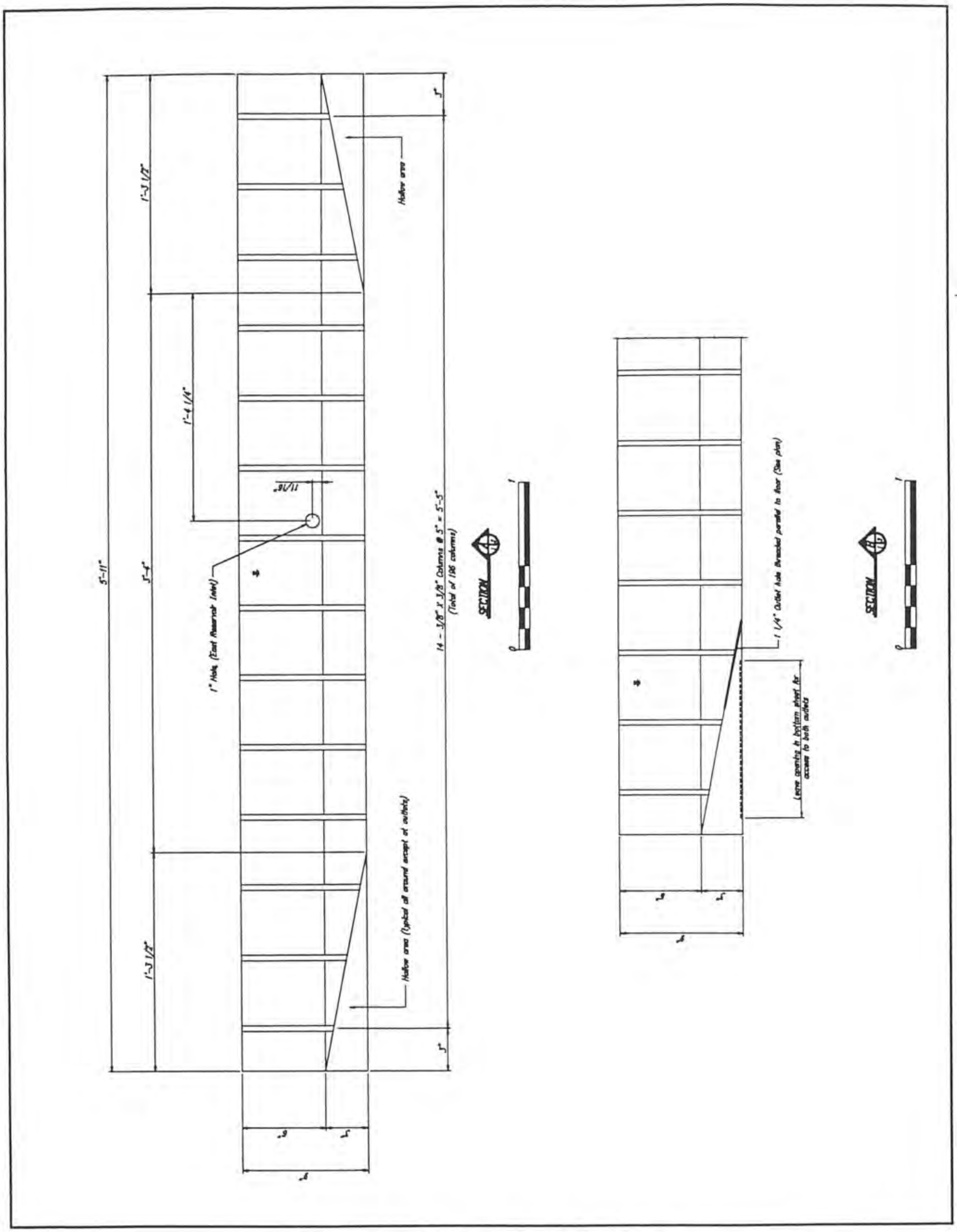


Figure 2. Hydraulic Model Sections

IV. MODEL SCALING FACTORS

In order to derive quantitative data from a hydraulic model, relationships between the prototype and model parameters such as length, flow and time must be established. These relationships are expressed in terms of similitude. For flowing water the choice of an appropriate similitude relationship is based on the forces which dominate the flow, whether inertia, friction, gravity, compressibility, surface tension or pressure. For flow under atmospheric pressures characterized by turbulence, the Froude similitude relationship is the appropriate choice.[4]

For Froude similitude, model lengths are scaled directly by the scale factor, so that, for example, at 48 scale, a 3/4-inch diameter model inlet pipe corresponds to 36-inch prototype pipe.

For Froude similitude, flow rates for the model are scaled by the five-halves power so that 11.4 MGD corresponds to a model flow rate of

$$Q_M = Q_P/L_R^{5/2} = 11.4 \times 10^6 / 48^{5/2}/(24*60) = 0.496 \text{ gpm.}$$

For Froude similitude, time is scaled by a factor of the one-half power. One minute in model time thus corresponds to

$$T_P = T_M * L_R^{1/2} = (1)(48)^{1/2} = 6.92 \text{ minutes}$$

in prototype time. Thus, a 42-hour test in the prototype corresponds to 363 minutes in model time.

For further detail on model scaling, see Appendix A.

[4] Daugherty, Robert L. and Joseph B. Franzini. *Fluid Mechanics with Engineering Applications*, 7th ed., McGraw Hill, 1977, pp. 174-181.

V. PROTOTYPE TRACER STUDY RESULTS

In order to evaluate the contact time in the 15 MG Reservoirs, FCWU had performed three fluoride tracer studies on the reservoirs in 1995 and 1996. The first tracer study was performed in June 1995 with flow through both reservoirs.[5] The T_{10}/T time was determined to be about 20% for the combination of reservoirs. In February 1996, two additional tracer studies were performed on flows through only the East Reservoir. The plant fluoride pump was turned off on February 20 for 49 hours and the decay in fluoride concentration at the outlet was measured. On February 26, the fluoride pump was turned back on and the increasing fluoride concentrations were measured at the outlet for 42 hours. The corresponding T_{10}/T times were 25% and 34% respectively.

The primary standard for measuring the contact time in basins and reservoirs is T_{10}/T. The hydraulic detention time, T, is defined as the time for one complete exchange of flow in the reservoir. For example, during the fluoride tracer study of February 26-28, 1996, the average flow in the prototype was 11.4 MGD and the average reservoir level was 14.4 feet corresponding to approximately 6.4 MG of storage (see Appendix A for details). One complete exchange of water in the reservoir thus took:

$$T = 6.4 \text{ MG}/11.4 \text{ MGD} = 0.56 \text{ days} = 13.5 \text{ hours}$$

T_{10} is defined as the time at which 10% of the inflow tracer concentration (tracer breakthrough) reaches the outlet. In this fluoride tracer test, this occurred at approximately 4.6 hours resulting in a T_{10}/T time of:

$$T_{10}/T = 4.6 \text{ hours}/13.5 \text{ hours}/100 = 34\%$$

In the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, the Environmental Protection Agency (EPA) has classified the degree of mixing in basins based on T_{10}/T time.[6] A modified version of their basin classification system is found below:

Basin Condition	T_{10}/T
Perfect Short Circuiting	0.00
Unbaffled (Completely Turbulent)	0.10
Minimal Baffling	0.30
Average Baffling	0.50
Superior Baffling	0.70
Perfect Mixing (Plug Flow)	1.00

While these guidelines appear to be more applicable to small mixing basins than to large reservoirs, they do provide some guidance on evaluating baffling configurations in reservoirs. Based on these criteria, the fluoride tracer test T_{10}/T values of 20% to 34% would qualify the 15 MG Reservoirs as minimally baffled. Although the reservoirs were not baffled at the time of the tests, **we believe there is a certain**

[5] Process Applications, Inc., *City of Fort Collins Tracer Study Preliminary Data Evaluation Results,* report prepared for City of Fort Collins Water/Wastewater Utilities, May 8, 1996.

[6] U.S. Environmental Protection Agency, *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, Washington D.C., March 1991, Table C-5.

"natural" baffling that takes place in the reservoirs. This may be due to two factors: 1) because of the size of the reservoirs, flows become laminar (tranquil) as they fan away from the inlet (in contrast to the turbulent flow characteristic of smaller basins) and 2) the numerous columns between the inlet and the outlet act as "baffles" themselves. These columns block 7.5% of the cross-sectional area of the reservoirs at the column lines.

It was felt that comparing T_{10}/T times of the prototype with the model would allow model test results to be correlated back to the prototype. The specific flow rate and reservoir level used for each of the model tests (except Test #29 and #30) were developed from the average flow rate and reservoir level for the fluoride tracer study performed by FCWU on the East Reservoir from February 26-28, 1996. This test was selected because it allowed comparison of an individual reservoir (the East Reservoir) and because the increasing fluoride concentrations at the prototype outlet were believed to correlate more accurately with increasing ion concentrations in the model due to inflow of tap water.

Although the reservoir level in this third tracer test varied from about 12 feet to 20 feet and the flow rate varied from 0 to 25 MGD, the average reservoir level of 14.4 feet and the average flow rate of 11.4 MGD were used in the model to simplify the testing.

VI. MODEL CONDUCTIVITY DATA

In the same way that fluoride can be used to evaluate mixing in the prototype, the ions found in tap water can also be used as a "tracer" in the model. An ion gradient can be created if the model is initially filled of de-ionized (distilled) water and tap water is pumped into the model. By placing conductivity probes in the supply tank and at the outlet, the percent tracer breakthrough at time, t, can be calculated as:

$$\% \text{ Tracer Breakthrough } (t) = \frac{\text{Outlet Conductivity } (t) - \text{Outlet Conductivity } (t=0)}{\text{Supply Tank Conductivity} - \text{Outlet Conductivity } (t=0)}$$

In the model, the hydraulic detention time, T, was calculated based on scale inflows and model volumes. The percent tracer breakthrough and t/T calculations for each conductivity test can be found in Appendix C. **Since T_{10}/T is a dimensionless variable, in theory, the value determined in the model should be equal to that of the prototype.**

Thirteen additional conductivity probes were placed strategically at various locations in the model (see Appendix B for their locations). These probes helped identify "dead" zones since areas of relatively low ion concentrations indicated lower water turnover rates. Because a hydraulic model also provides information on *internal* aspects of mixing, it yields valuable data beyond that of tracer studies or other "black box" models where only inlet and outlet concentrations are known. This data becomes a tool for identifying potential zones for baffles.

An Orion Model 105 conductivity meter was used to measure conductivity at the 14 fixed 5-pin conductivity probes in the model. The leads from these probes were bussed into a single switch box to facilitate data recording from a single location. Although de-ionized water has a theoretical conductivity of zero, due to the presence of residual water in the model, actual initial conductivity values were 2 to 3 microSiemens per centimeter (μS/cm). The dyed tap water in the supply tank had conductivities in the range of 100 to 130 μS/cm.

A separate 8-pin conductivity probe was used to record conductivity in the supply tank and to independently verify conductivity measurements in the model. This probe was also used to record temperatures in the supply tank and the model. In general, the supply tank and model temperatures were within 1° C of each other during conductivity testing so that temperature stratification was not created in the model.

VII. SUMMARY OF TESTS PERFORMED

The variables for each of the 31 tests performed is summarized on Table 1 on the following page.

The first five tests were performed on unbaffled reservoirs as a control and for comparison of the results with the fluoride tracer study.

Tests 6-19, 21-22, 26 and 28 involved the visual evaluation of mixing in each reservoir using a tracer dye. Dye was introduced into the model by adding yellow-green Norlab liquid powder tracing dye to the water in the supply tank. The initial mixing in the model could be observed with this method. Nine different baffle configurations were tested for each reservoir for a total of 18 tests. These tests were terminated when further evaluation was not feasible due to complete dye dispersion in the model, usually after 30 to 45 minutes. The time when the dyed water made initial contact with the outlet was recorded for each baffle configuration. Overhead photographs were also taken for each test at regular intervals. A separate notebook of photographs has been provided to FCWU along with this report.

Tests 20, 23-25, 27 and 31 were conductivity tests of the three most promising baffle configurations for each reservoir based on initial contact times determined from the dye tests. These six tests were performed for the same scale duration as the prototype fluoride tracer test (approximately six hours).

Tests 29 and 30 were added to the scope of work to determine if the T_{10}/T time was constant for reservoir levels and flow rates other than those during the fluoride testing. The East Reservoir with Baffle #7 was selected as a control for these tests. In Test 29, the flow was doubled to 23.0 MGD, resulting in a halving of the time, T. In Test 30, the reservoir storage volume was doubled, corresponding to a reservoir level of 25.0 feet, so that the T time was doubled.

Table I. Summary Of Tests Performed

Test #	Date	Reservoir	Baffle #	Baffle Length (feet)	Prototype Flow (MGD)	Prototype Depth (feet)	Test Duration (min.)	Overhead Photos	Conductivity Data	Comments
Prototype	2/26/96	East	None	0	11.4	14.4	2520	N/A	Yes	Fluoride Tracer
1	4/11/97	East	None	0	11.4	14.4	345	Slides	Yes	No Inlet Pipe
2	4/15/97	West	None	0	11.4	14.4	345	Slides	Yes	Unbaffled
3	4/17/97	East	None	0	11.4	14.4	90	Slides	Yes	Unbaffled
4	5/6/97	East	None	0	11.4	14.4	30	Yes	No	For photos
5	5/6/97	West	None	0	11.4	14.4	45	Yes	No	For photos
6	5/6/97	West	1	57	11.4	14.4	45	Yes	No	Dye Test
7	5/6/97	East	1	57	11.4	14.4	40	Yes	No	Dye Test
8	5/7/97	East	2	197	11.4	14.4	30	Yes	No	Dye Test
9	5/7/97	East	3	217	11.4	14.4	30	Yes	No	Dye Test
10	5/7/97	East	4	160	11.4	14.4	30	Yes	No	Dye Test
11	5/7/97	East	5	317	11.4	14.4	30	Yes	No	Dye Test
12	5/9/97	East	6	310	11.4	14.4	30	Yes	No	Dye Test
13	5/9/97	East	7	353	11.4	14.4	35	Yes	No	Dye Test
14	5/9/97	West	2	209	11.4	14.4	30	Yes	No	Dye Test
15	5/12/97	West	3	373	11.4	14.4	35	Yes	No	Dye Test
16	5/12/97	West	4	501	11.4	14.4	30	Yes	No	Dye Test
17	5/12/97	West	5	457	11.4	14.4	30	Yes	No	Dye Test
18	5/12/97	West	6	461	11.4	14.4	30	Yes	No	Dye Test
19	5/12/97	West	7	636	11.4	14.4	30	Yes	No	Dye Test
20	5/16/97	West	3	373	11.4	14.4	345	No	Yes	Conductivity Test
21	5/16/97	West	8	332	11.4	14.4	30	Yes	No	Dye Test
22	5/16/97	West	9	376	11.4	14.4	30	Yes	No	Dye Test
23	5/20/97	West	9	376	11.4	14.4	330	No	Yes	Conductivity Test
24	5/22/97	West	7	636	11.4	14.4	345	No	Yes	Conductivity Test
25	5/30/97	East	7	353	11.4	14.4	330	No	Yes	Conductivity Test
26	5/30/97	East	8	624	11.4	14.4	40	Yes	No	Dye Test
27	6/3/97	East	8	624	11.4	14.4	330	No	Yes	Conductivity Test
28	6/3/97	East	9	420	11.4	14.4	30	Yes	No	Dye Test
29	6/5/97	East	7	353	23.0	14.4	25	Yes	Yes	Alternate Flow
30	6/11/97	East	7	353	11.4	25.0	60	Yes	Yes	Alternate Flow
31	6/24/97	East	3	217	11.4	14.4	330	No	Yes	Conductivity Test

VIII. SUMMARY OF TEST RESULTS

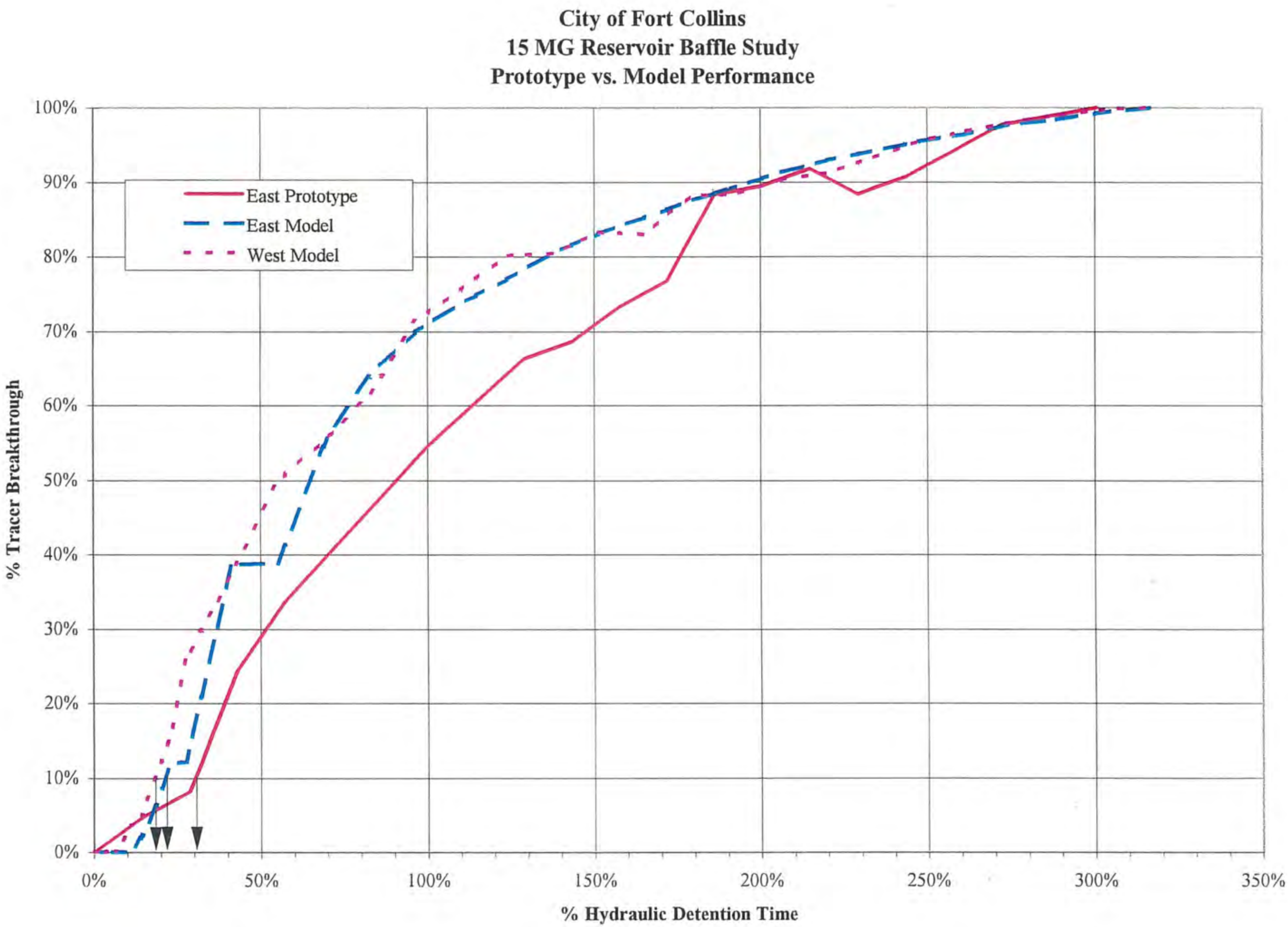
A. Comparison of Prototype and Model T_{10}/T Times

The results of the fluoride tracer test performed on February 26-28, 1997 were compared with the results of Tests 3 and 4 for the East and West Reservoirs. The results are shown graphically on the following page.

It can be seen that the general shapes of all three curves are similar. However, the model tends to see faster tracer breakthroughs. When comparing the East Reservoir prototype and model T_{10}/T times, there is a decrease from 34% to 21% (a 40% decrease). The West Reservoir would be expected to have a relatively low T_{10}/T time compared with the East Reservoir due to the relative proximity of the inlet and outlet. This proves to be the case; the West Reservoir had an unbaffled T_{10}/T time of 18% (or 14% less).

Since T_{10}/T is a dimensionless variable, in theory, prototype and model T_{10}/T times should be equal. **However, unlike the fluoride tracer tests, T_{10}/T times determined from the model study treat the reservoirs as isolated components of the WTF system.** In the model, conductivity was measured at the inlet and the outlet *inside* the model, while in the prototype, fluoride concentrations were measured in the piping *outside* the reservoir. The additional travel distance in the prototype piping exaggerates the measured T_{10} time. Lower T_{10}/T times in the model may also be related to unscalable hydraulic phenomenon occurring in the model, such as the impact of surface waves at the inlet (see Photo 2 in Appendix E).

Because the model sees faster tracer breakthroughs than the prototype, it is believed that **the results of the model tests will be conservative in estimating the T_{10}/T time of the reservoirs**. However, **relative increases in T_{10}/T time in the model due to the presence of baffles are expected to correlate to similar increases in T_{10}/T times in the prototype.**



City of Fort Collins
15 MG Reservoir Baffle Study
Prototype vs. Model Performance
East Prototype
East Model
West Model
% Tracer Breakthrough
% Hydraulic Detention Time
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0%
50%
100%
150%
200%
250%
300%
350%

B. Dye Testing

Each reservoir was subjected to nine different baffle configuration dye tests to narrow the selection of baffle configurations for the longer conductivity tests. The configurations were developed based on what appeared to be reasonable means of slowing flow towards the outlet. This usually meant trying to develop a "front" of dye moving uniformly across the width of the model towards the outlet.

In the early stages of mixing, areas of poorer mixing (dead zones) could be identified by a lack of dye. These tended to occur at points distant from the most direct path between the inlet and outlet, at corners of the model, or behind very long baffles. The first and the third of these phenomena can be dealt with successfully by modifying the baffle configuration or providing "windows" in the baffles. The dead zones at the corners of the model are more difficult to manage because of the propensity of water to flow in curvilinear streamlines, rather than at right angles (see photograph 3, Appendix E). This is an inherent problem of non-circular reservoirs, but due to the relatively small volume of water involved should not be of great concern.

The nine outlet configurations for each reservoir and the observed times at which the dye first appeared at the outlet and its path were recorded. The results can be seen visually on Figures 3 and 4.

East Reservoir

For the East Reservoir, Baffle #7 appeared to provide the greatest increase in contact time. Baffle #8, a modification of a configuration suggested by Hank Falvey which divided the reservoir into four channels, appeared to give the second best results. The third best configuration appeared to be Baffle #3. However, Baffle #3 did not greatly increase the contact time over that of the unbaffled reservoir. No other tests appeared to be effective in increasing contact time. Some configurations actually speed up the movement of dye towards the outlet. This may be because the reservoir has a certain amount of "natural" baffling discussed in Section V.

West Reservoir

For the West Reservoir, Baffle #3 was tested based on the apparent success of Baffle #7 on the East Reservoir. One modification was made so that the outlet was completely closed off on the side near the inlet. This configuration appeared to give the best results. This was followed by Baffle #9 which was identical at the outlet, but split the flow into two, rather than four, streams at the inlet. The third best time was for Baffle #7, which involved extensive baffling, breaking the reservoir into three channels. With the exception of Baffle #8, the remaining configurations did not appear to produce a significant increase in contact time.

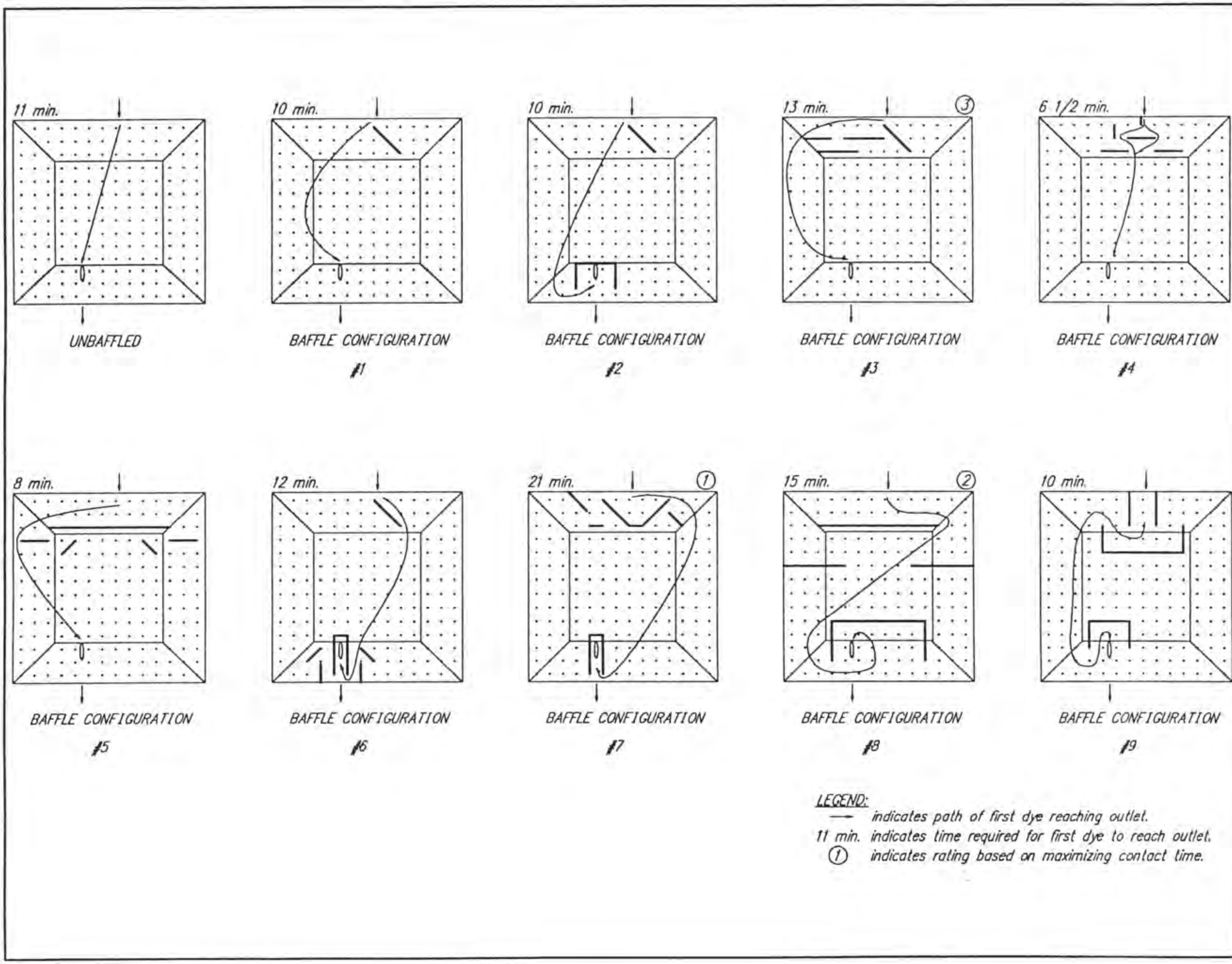
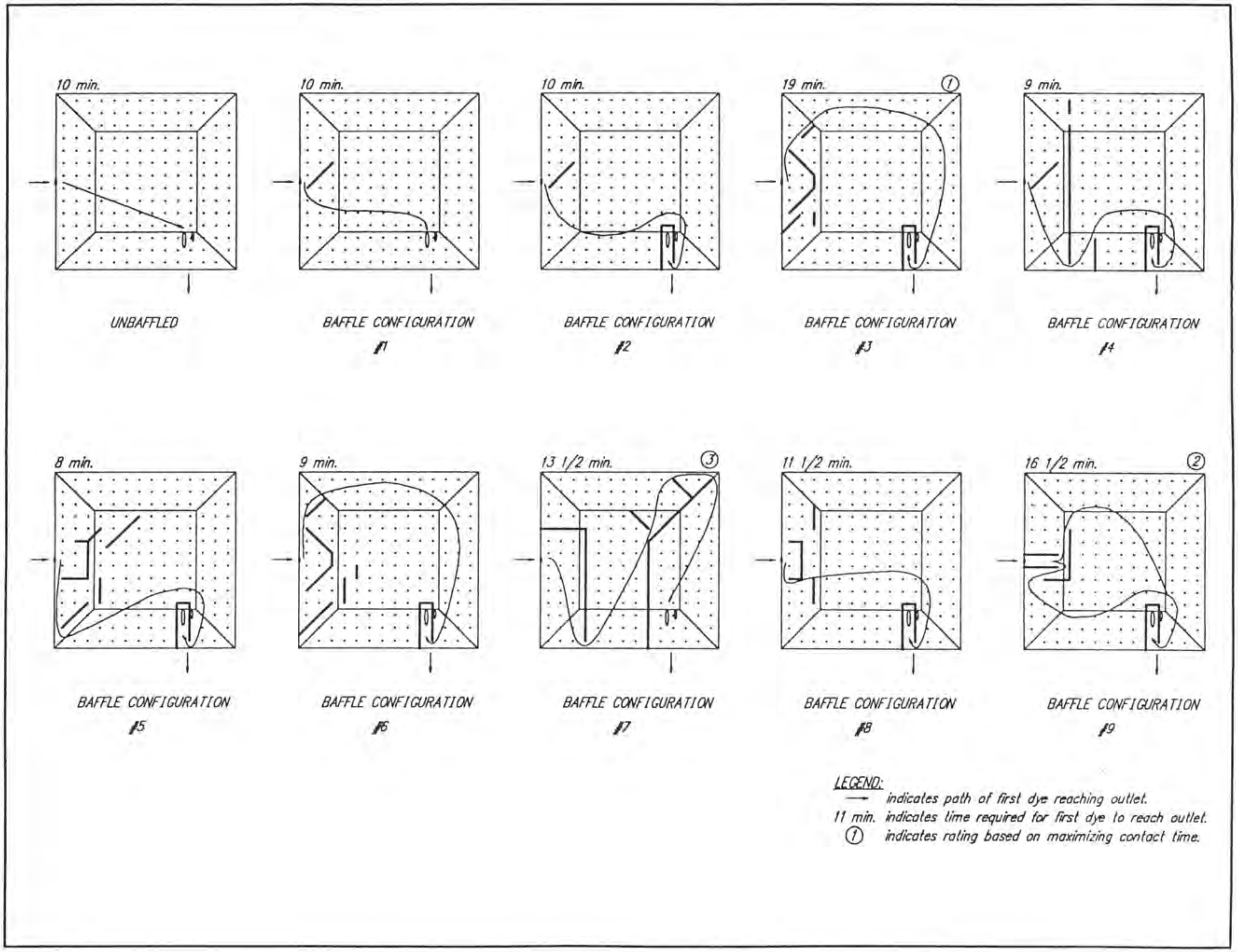


Figure 3. East Reservoir Baffle Configurations

Figure 4. West Reservoir Baffle Configuration



C. Conductivity Testing

The three baffle configurations which had the longest initial contact times during dye testing were selected to undergo conductivity testing for the full six hours to determine quantitatively which baffle configurations were most effective in increasing contact time. With conductivity testing, areas of poorer mixing (dead zones) could be identified after they could no longer be observed visually with the dye. It should be noted that the apparent dye concentrations in the model were often not indicative of actual conductivity.

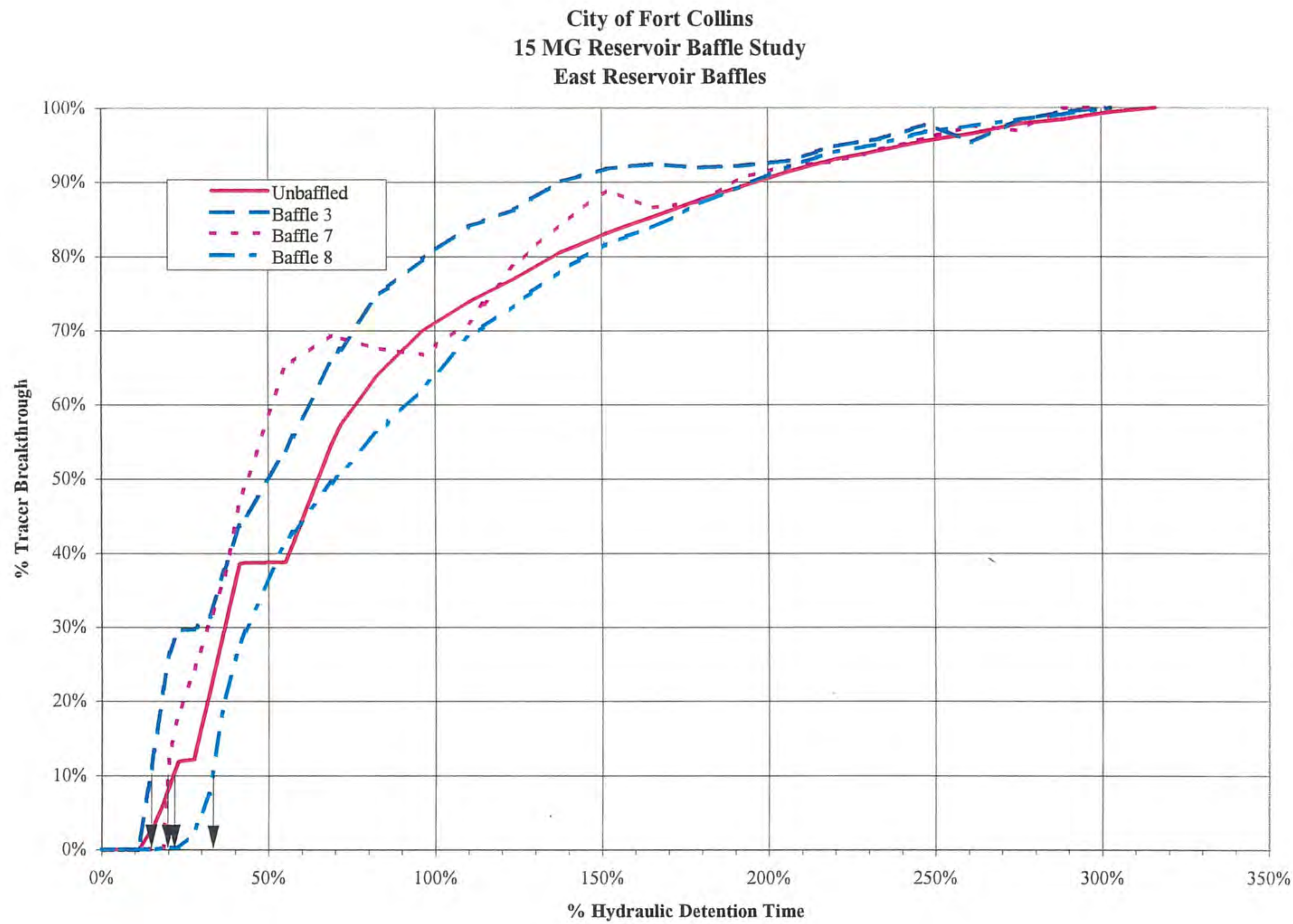
The tracer breakthrough values at the outlet for the three conductivity tests for each reservoir are graphed on the following four pages. The three configurations are compared with the unbaffled reservoir and each other. Two graphs are provided for each reservoir. One shows the overall tracer breakthrough over the entire length of the test and a second is a close-up of the lower left hand corner where the actual T_{10}/T times were determined.

East Reservoir

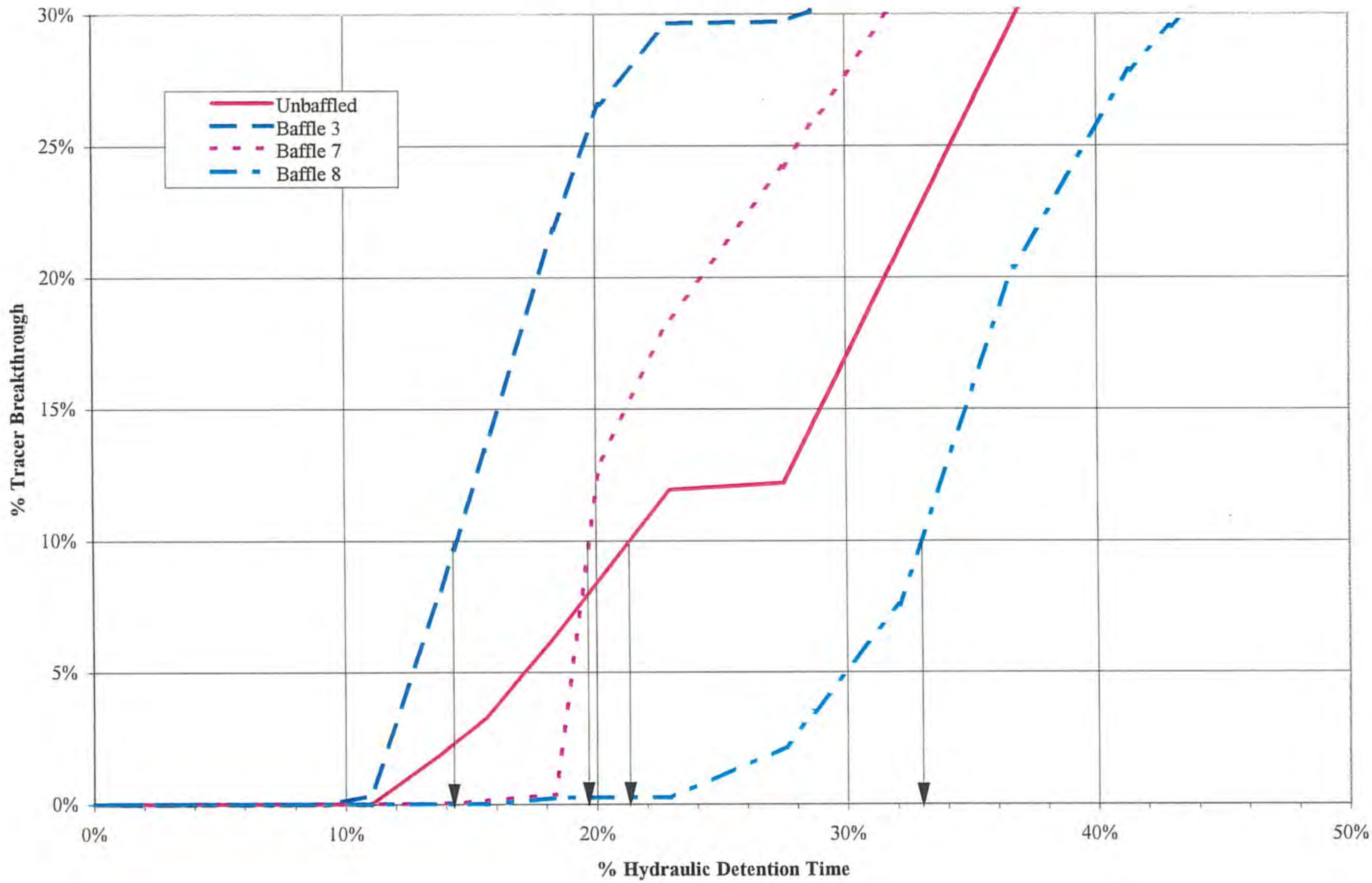
For the East Reservoir, it can be seen that although the dye contact time appeared to be better for Baffle #3 and Baffle #7, in reality the T_{10}/T time actually *decreased.* Only Baffle #8 increased the T_{10}/T time, and the increase was significant.

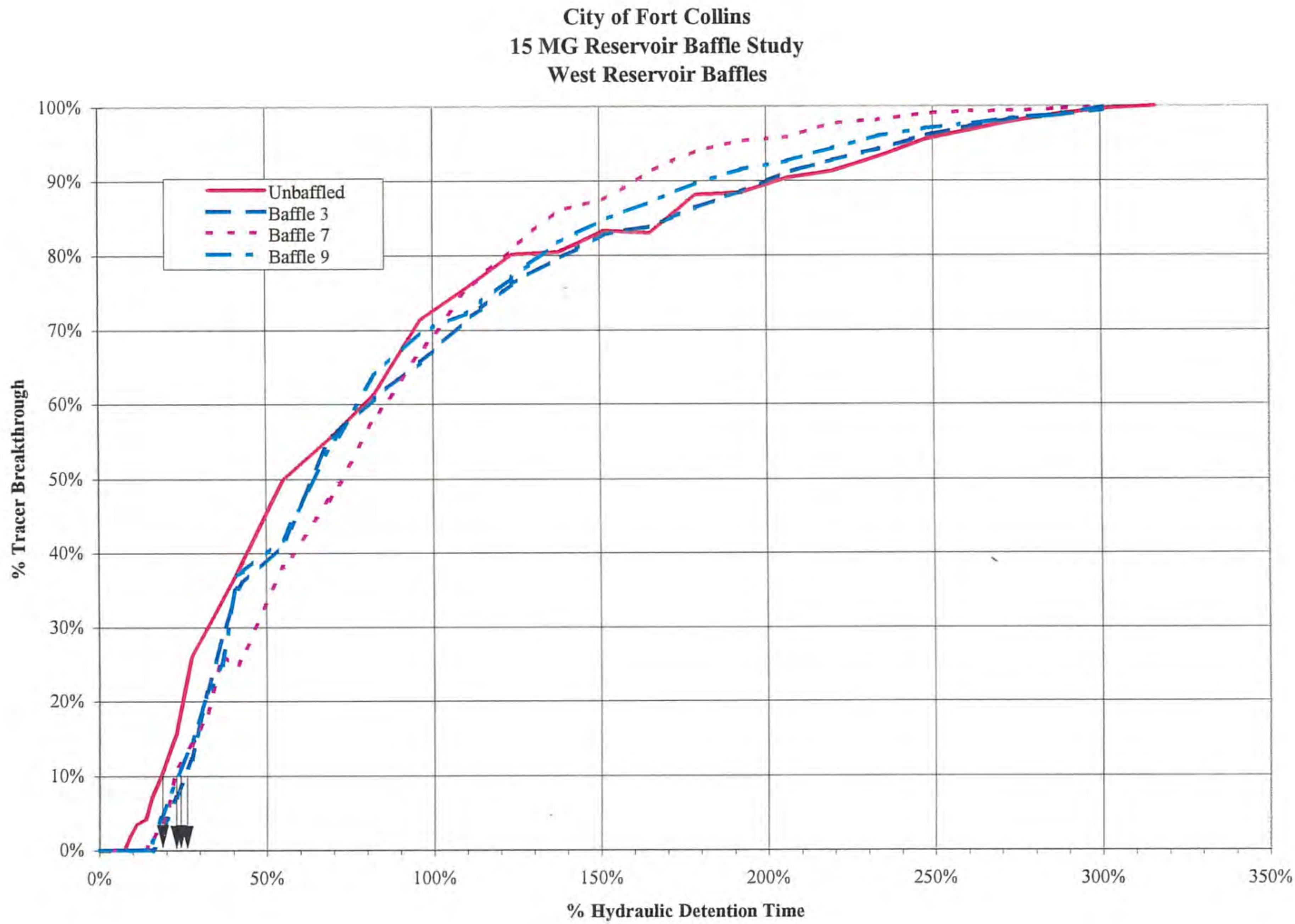
West Reservoir

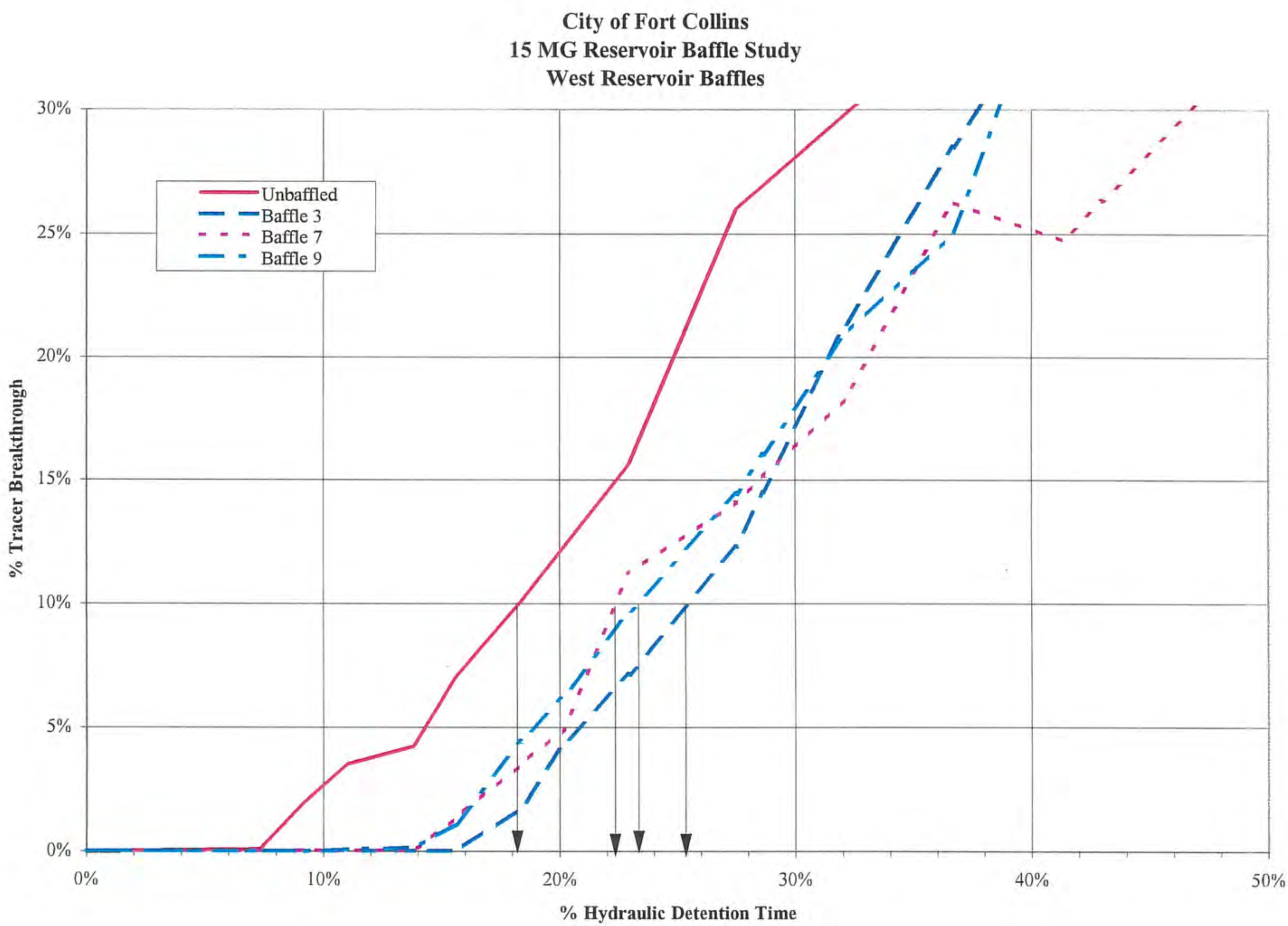
For the West Reservoir, the correlation between the dye testing and the conductivity testing was closer. All three baffle configurations increased the T_{10}/T time and the increases were relatively proportional to the increase in time seen in the dye tests.


City of Fort Collins
15 MG Reservoir Baffle Study
East Reservoir Baffles
Unbaffled
Baffle 3
Baffle 7
Baffle 8
% Tracer Breakthrough
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
50%
100%
150%
200%
250%
300%
350%
% Hydraulic Detention Time

City of Fort Collins
15 MG Reservoir Baffle Study
East Reservoir Baffles




City of Fort Collins
15 MG Reservoir Baffle Study
West Reservoir Baffles
Unbaffled
Baffle 3
Baffle 7
Baffle 9
% Tracer Breakthrough
% Hydraulic Detention Time
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0%
50%
100%
150%
200%
250%
300%
350%


City of Fort Collins
15 MG Reservoir Baffle Study
West Reservoir Baffles
Unbaffled
Baffle 3
Baffle 7
Baffle 9
30%
25%
20%
15%
10%
5%
0%
% Tracer Breakthrough
0%
10%
20%
30%
40%
50%
% Hydraulic Detention Time

D. Stability of T_{10}/T Times for Differing Flow Conditions

A comparison of T_{10}/T times for Tests 25, 29 and 30 is shown graphically on the following sheet. When the hydraulic detention time, T, is halved, the T_{10}/T time increases by about 25%. When the hydraulic detention time, T, is doubled, the T_{10}/T time decreases by about 20%. The actual differences may be slightly lower for two reasons: 1) during Test 29, the outlet flow rate was not quite able to keep up with the inlet flow rate due to pump limitations, thus slowing detention time; and 2) during Test 30, some stratification of the dyed supply water was observed due to slightly higher temperatures in the supply tank than the model. This allowed some vertical short-circuiting of the water causing a lower T_{10}/T time than would otherwise be expected.

In spite of these imperfections, it does appear that there may be a slight negative correlation between the T_{10}/T time and the hydraulic detention time, T. This, however, would prove to be a positive phenomena, since higher flows rates and lower reservoir levels (low T) would give higher T_{10}/T time rates (relatively greater contact time). **Thus, the results of this study would be expected to provide conservative results for prototype flow conditions when contact time is of greatest concern.** For example, during the peak of summer flows when the reservoir is at the nine foot level and demand is at 60 MGD (30 MGD per reservoir), the hydraulic detention time, T, is

$$T = 3.18 \text{ MG}/30 \text{ MGD} = 0.11 \text{ days} = 2.5 \text{ hours}$$

If $T_{10}/T = 25\%$, the outlet would theoretically reach 10% concentration at

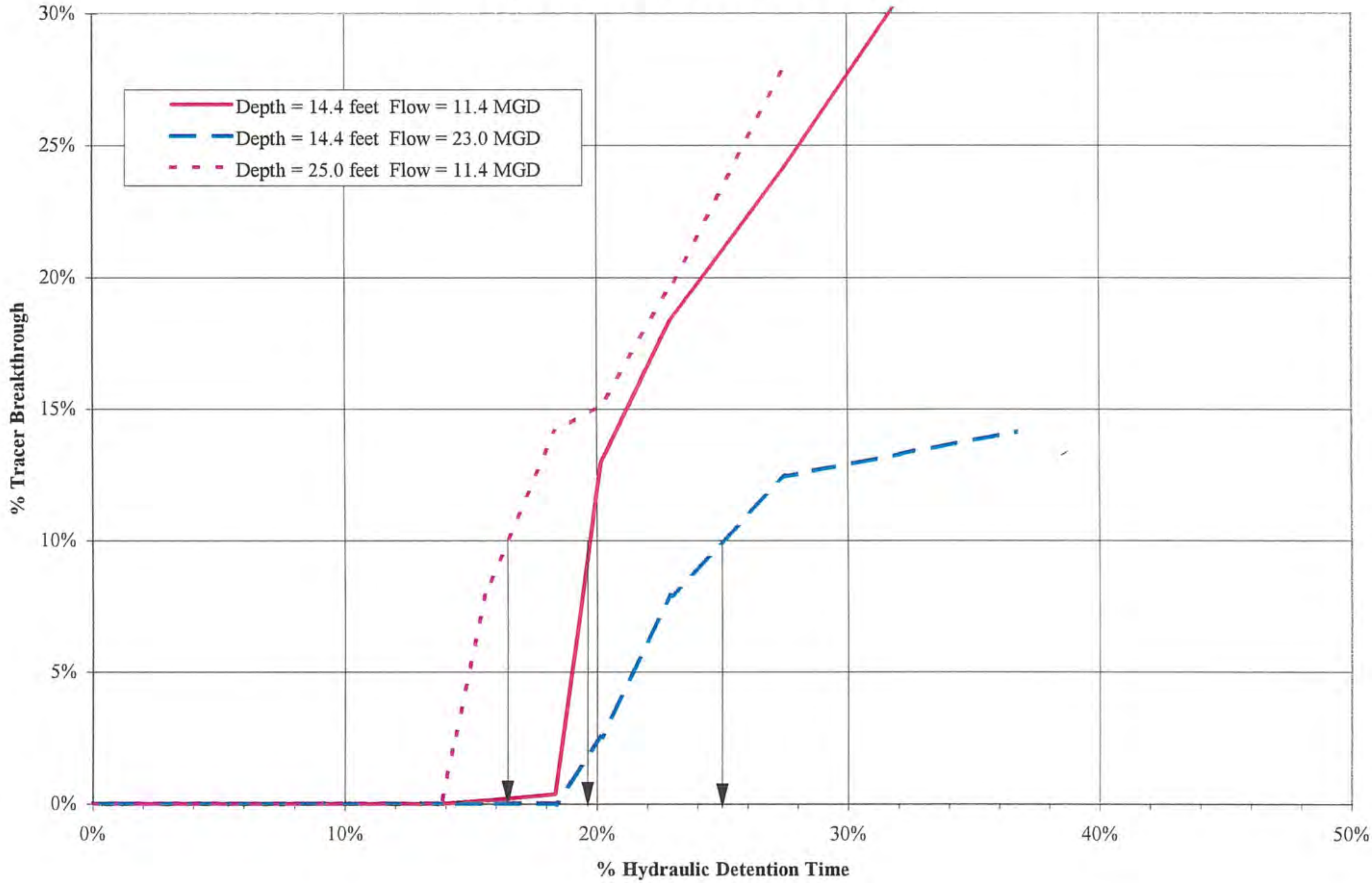
$$t = T_{10}/T \text{ time} \times T = 0.25 \times 2.5 \times 60 = 38 \text{ minutes}$$

However, for a minimal hydraulic detention time, T (rapid turnover), a higher value for T_{10}/T of 0.31 (25% increase) might be expected increasing the actual 10% tracer breakthrough time to

$$t = T_{10}/T \text{ time} \times T = 0.31 \times 2.5 \times 60 = 48 \text{ minutes}$$

a gain of 10 minutes.

City of Fort Collins
15 MG Reservoir Baffle Study
East Baffle #7 - Alternate Flow Conditions



IX. BAFFLE CONFIGURATION SELECTION

In order to compare the relative benefits of various baffle configurations, the increase in the T_{10}/T time over the unbaffled case should be weighed against the length of baffle involved. Since the length of baffle will be approximately proportional to cost, this permits an economic evaluation of the benefits of the various baffle configurations. Consequently a relationship has been developed by dividing the increase in T_{10}/T time over the unbaffled case by the length of baffle in hundreds of feet. The results are shown in Table 2.

West Reservoir

For the West Reservoir, Baffle #3 gives the greatest improvement in T_{10}/T time for the least amount of baffling. In addition, the baffling is kept away from the center of the reservoir, simplifying maintenance. A 20-foot section of baffle was added to the configuration tested to enclose the 36-inch outlet leading to a total baffle length of 393 feet. This configuration is depicted in Figure 5.

From the conductivity data, it appears that the West Reservoir will experience a minimal degree of dead zones with Baffle #3, especially when compared with the unbaffled reservoir. The conductivity levels for the baffled reservoir tended to rise more uniformly over time throughout the model than those of the unbaffled reservoir.

East Reservoir

For the East Reservoir, improving the "natural" baffling that occurs in the reservoir appears to require relatively long lengths of baffle. Since both the East and West Reservoirs are operated ("float") together, there appears to be little value in improving the T_{10}/T time in the East Reservoir beyond that of the limiting West Reservoir. Therefore a simple baffle configuration which would result in approximately the same T_{10}/T time as the baffled West Reservoir is recommended for the East Reservoir.

We believe that this can be best accomplished by using a closure baffle around the outlet. Outlet closures appeared to consistently provide small increases in T_{10}/T time during testing. It is recommended that the outlet closure found in Configurations #6 and #7 be used for the East Reservoir. Although the T_{10}/T time is not known for this outlet closure acting alone, it is reasonable to assume it would increase the T_{10}/T time for the East Reservoir into the range of the West Reservoir (from about 21% to 25%).

Similar to the West Reservoir, this closure baffle is located away from the center of the reservoir, simplifying maintenance. The total length for this baffle configuration is 140 feet. The configuration is also shown in Figure 5.

The East Reservoir may experience a greater degree of "dead zones" than the West Reservoir, but nevertheless, the baffled condition represents an improvement over the unbaffled reservoir because flows are directed towards the south wall where mixing would otherwise be minimal.

Table 2. Evaluation of Test Results

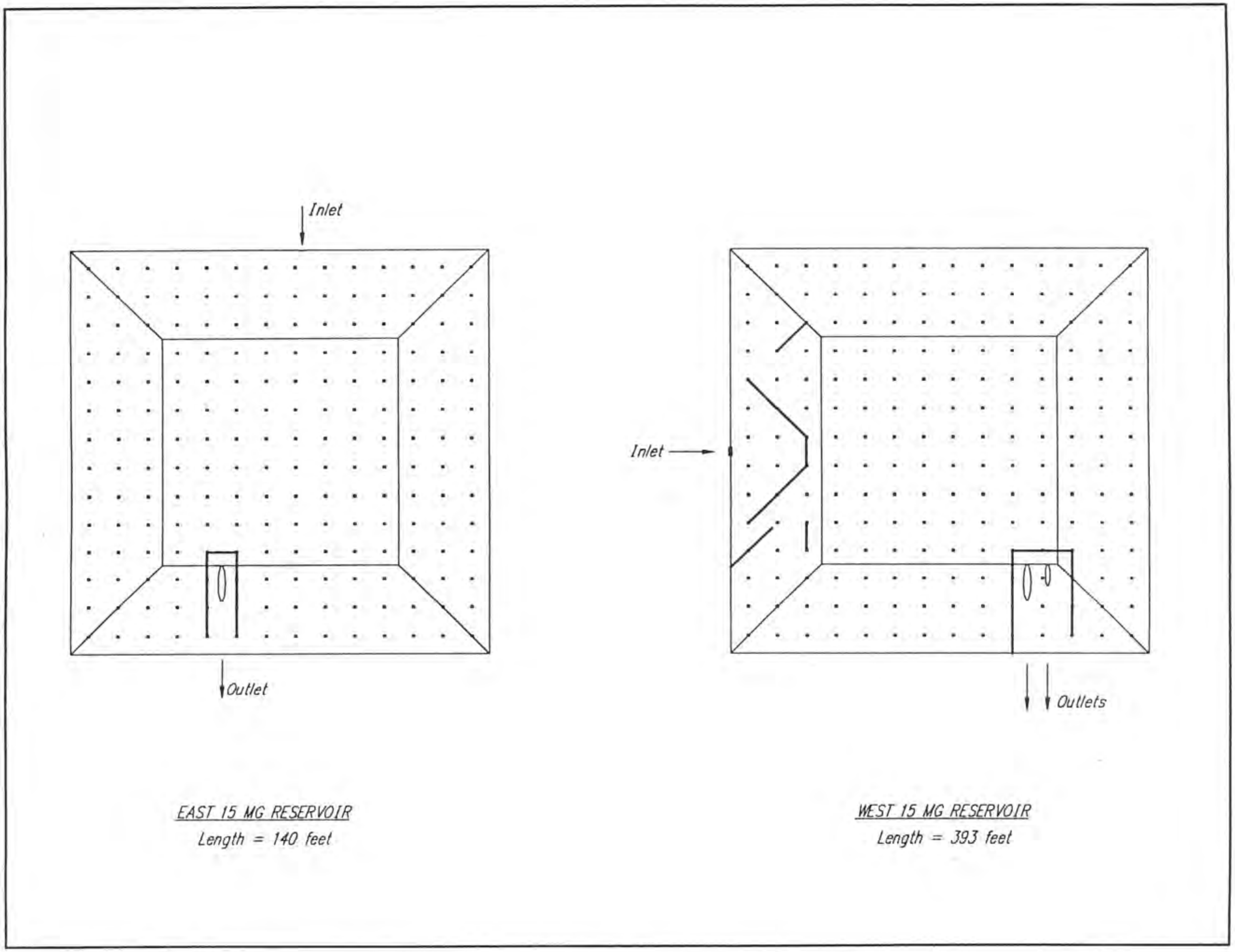
East Reservoir

Test #	Baffle #	Baffle Length (feet)	T_{10}/T (%)	Prototype $\Delta(T_{10}/T)/L$ (%/100')
4	None	0	21	
7	1	57	-	
8	2	197	-	
9, 31	3	217	14	-3.2
10	4	160	-	
11	5	317	-	
12	6	310	-	
13, 25	7	353	20	-0.3
26, 27	8	624	33	1.9
28	9	420	-	

West Reservoir

Test #	Baffle #	Baffle Length (feet)	T_{10}/T (%)	Prototype $\Delta(T_{10}/T)/L$ (%/100')
5	None	0	18	
6	1	57	-	
14	2	209	-	
15, 20	3	373	25	1.9
16	4	501	-	
17	5	457	-	
18	6	461	-	
19, 24	7	636	22	0.6
21	8	332	-	
22, 23	9	376	23	1.3

Figure 5. Recommended Baffle Configurations



X. BAFFLE MATERIAL SELECTION

Permanent baffles attached to the floor of the reservoir such as concrete or masonry are relatively expensive, require additional effort during routine maintenance and washdown, and are not easily removed or rearranged. Flexible metal curtains such as woven stainless steel strips avoid these three problems, but are still relatively expensive. The most economical solution appears to be the use of synthetic materials such as Hypalon or XR-5 supplied by various baffle manufacturers.

To be effective, the baffles should extend for the full height of the reservoir, i.e. from the overflow level to within a few inches of the floor. Keeping them slightly off the floor will permit washdown while allowing minimal flows to bypass the baffles.

Floating baffles would not be practical because of the regular fluctuation of the reservoir levels. Therefore it is recommended that the baffles be suspended by stainless steel angles, pipes or cables from the columns and, if necessary to minimize baffle sag, from the ceiling. Attachment of suspension hardware to the existing concrete can be made with stainless steel wedge anchors.

XI. CONCLUSION

Based on the results of this study, Baffle #3 has been selected for the West Reservoir and the outlet closure from Baffles #6 and #7 has been selected for the East Reservoir. These baffle configurations are expected to increase the T_{10}/T time for the West and East Reservoirs from 18% and 21% respectively to 25%. This represents a 39% improvement in contact time for the West Reservoir and a 19% improvement for the East Reservoir. The average increase based on both reservoirs operating together would be 28%. Since both reservoirs would have equal T_{10}/T times, reservoir contact time could be readily calculated whether either or both reservoirs are in operation. As an example, with both reservoirs operating at 20 MGD (40 MG total) and reservoir levels at 20 feet (9.78 MG of storage), the expected increase in contact time based on a 10% tracer breakthrough would be

$$T = 9.78 \text{ MG}/20 \text{ MGD} = 0.49 \text{ days} = 11.7 \text{ hours}$$

For the unbaffled reservoirs, $T_{10}/T_{avg} = 0.195\%$, and the outlet would reach 10% tracer breakthrough at

$$t = T_{10}/T \text{ time} \times T = 0.195 \times 11.7 \times 60 = 137 \text{ minutes}$$

With the baffles, however, at a value for T_{10}/T of 0. 25, the expected 10% tracer breakthrough time is

$$t = T_{10}/T \text{ time} \times T = 0.25 \times 11.7 \times 60 = 176 \text{ minutes}$$

a gain of 39 minutes. The contact time for other flow conditions could be calculated similarly.

We further recommend that a synthetic material such as Hypalon, XR-5 or other similar material be used for the baffle material because of their effectiveness at minimal cost. The baffles would be suspended from the columns and/or roof from approximately the overflow level to within a few inches of the floor.

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APPENDIX A - HYDRAULIC MODEL SCALING FACTORS

Model Scaling Factors

Feature	Prototype Elev. ft.	Prototype Depth ft.	Prototype Volume (MG)	Model Depth (in.)	Model Volume (gal.)	Flow	Prototype Flow (MGD)	Model Flow (gpm)
Outlet	69.05	0	0.00	0.00	0.0		0	0.000
	70.05	1	0.21	0.25	1.8		1	0.044
	71.05	2	0.44	0.50	3.9		2	0.087
	72.05	3	0.72	0.75	6.3		3	0.131
	73.05	4	1.02	1.00	8.9		4	0.174
	74.05	5	1.37	1.25	11.8		5	0.218
	75.05	6	1.75	1.50	14.9		6	0.261
	76.05	7	2.18	1.75	18.4		7	0.305
	77.05	8	2.66	2.00	22.2		8	0.348
	78.05	9	3.18	2.25	26.4		9	0.392
Top of Slope	79.05	10	3.75	2.50	30.9		10	0.435
	80.05	11	4.35	2.75	35.8		11	0.479
	81.05	12	4.95	3.00	41.0	Tracer Test	**11.4**	**0.496**
	82.05	13	5.56	3.25	46.5		12	0.522
	83.05	14	6.16	3.50	52.0		13	0.566
Tracer Test	83.45	**14.4**	**6.40**	**3.60**	**54.1**		14	0.609
	84.05	15	6.76	3.75	57.4		15	0.653
	85.05	16	7.37	4.00	62.9	Winter Flow	16	0.696
	86.05	17	7.97	4.25	68.3		17	0.740
	87.05	18	8.57	4.50	73.8		18	0.783
	88.05	19	9.18	4.75	79.2		19	0.827
	89.05	20	9.78	5.00	84.7		20	0.870
	90.05	21	10.38	5.25	90.1		21	0.914
	91.05	22	10.99	5.50	95.6		22	0.957
	92.05	23	11.59	5.75	101.1	Test 29	23	1.001
	93.05	24	12.19	6.00	106.5		24	1.044
Test 30	94.05	25	12.80	6.25	112.0		25	1.088
	95.05	26	13.40	6.50	117.4	Summer Flow	26	1.131
	96.05	27	14.00	6.75	122.9	↓	27	1.175
Overflow	96.75	27.7	14.43	6.93	126.7	↓	28	1.218
	97.05	28	14.61	7.00	128.3	↓	29	1.262
Top of Wall	97.22	28.17	14.71	7.04	129.3	↓	30	1.305

T_{proto} = **13.5** hours (fluoride tracer test of Feb. 26-28, 1996)

T_{model} = **109.2** minutes (model tests 1-28, 31)

APPENDIX B - CONDUCTIVITY DATA

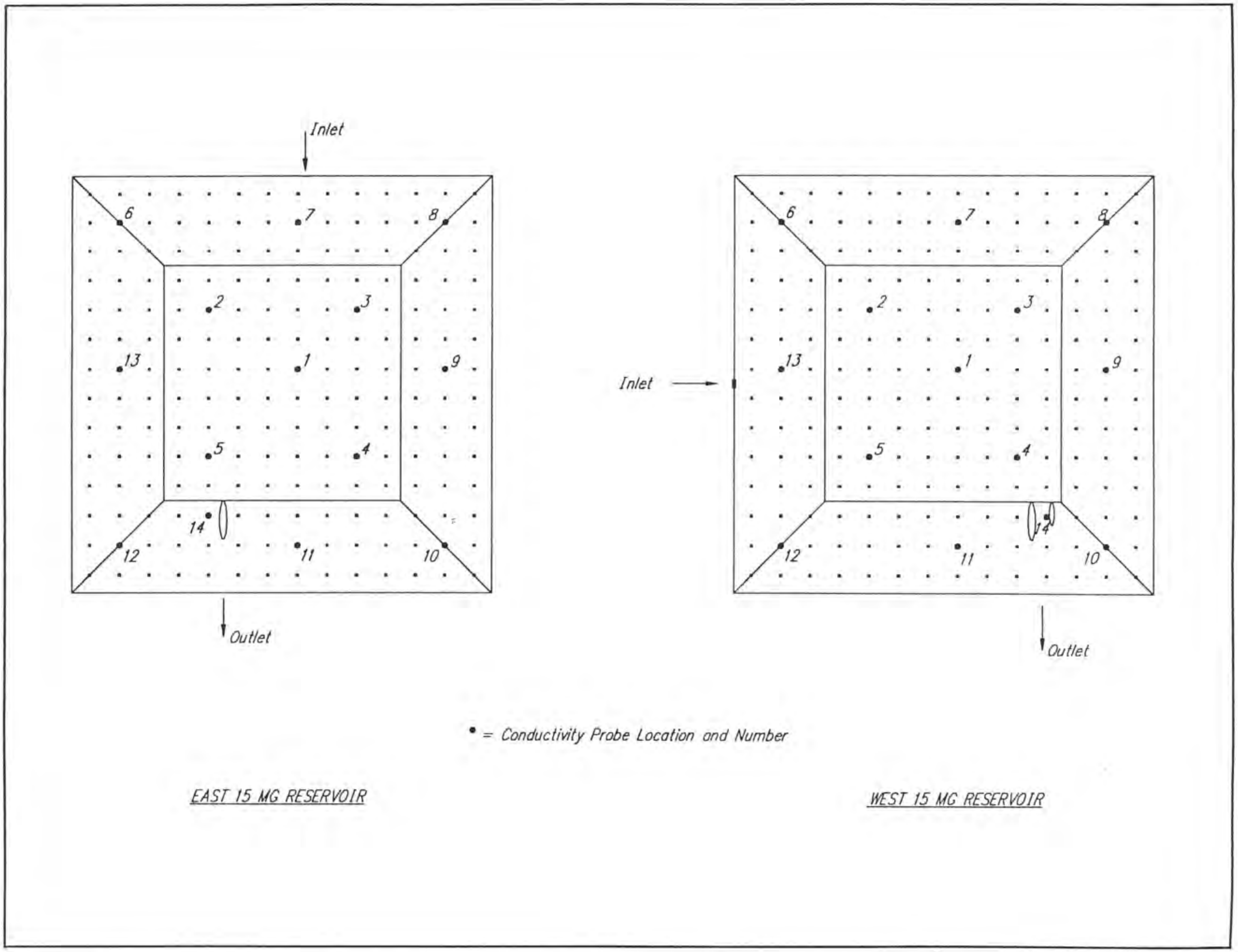

Figure 6. Conductivity Probe Locations

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 1
Date: 4/11

Reservoir: East
Inlet: Straight
Baffle: None

Flow: 11.4MGD
Depth: 14.4

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (μS)	Probe 1 Conduct. (μS)	Probe 2 Conduct. (μS)	Probe 3 Conduct. (μS)	Probe 4 Conduct. (μS)	Probe 5 Conduct. (μS)	Probe 6 Conduct. (μS)	Probe 7 Conduct. (μS)	Probe 8 Conduct. (μS)	Probe 9 Conduct. (μS)	Probe 10 Conduct. (μS)	Probe 11 Conduct. (μS)	Probe 12 Conduct. (μS)	Probe 13 Conduct. (μS)	Probe 14 Conduct. (μS)
9:05	0	1		17.4	17.0	322	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.3
9:13	8	2					42.9	21.1	17.2	28.1	28.2	1.8	71.2	22.6	29.0	36.8	40.3	39.5	33.6	45.6
9:20	15	3		17.8		319	66.0	44.6	43.8	49.6	46.8	2.0	72.2	46.9	52.1	59.7	63.0	60.5	52.4	67.0
9:35	30	4		17.7	16.1	318	103.5	83.6	87.1	93.7	85.0	57.0	123.0	87.6	95.3	100.4	102.4	99.9	92.5	103.9
9:50	45	5		17.6	16.1	320	132.7	117.0	122.7	127.1	119.4	99.9	138.7	124.7	128.3	131.0	133.5	130.1	126.3	139.1
10:05	60	6		17.3	16.3	321	162.9	146.6	145.3	152.0	146.7	130.7	175.9	148.5	153.8	151.7	158.4	154.3	151.2	164.1
10:20	75	7		17.5	16.5		178.4	166.8	161.3	174.7	173.8	152.2	196.0	170.7	174.3	171.4	181.6	175.3	171.4	185.2
10:35	90	8		17.2	16.2	327	198.8	185.4	185.8	192.6	189.6	171.9	214	186	195	190	197	192	189	202
10:50	105	9	19.9	17.8	16.6	323	216	201	203	212	210	187	232	195	211	207	215	208	206	221
11:05	120	10	18.8	18.0	16.7	325	227	215	215	222	222	198	242	212	223	215	226	220	217	233
11:20	135	11	18.8	17.9	16.9	336	239	228	227	235	234	213	252	225	235	225	237	231	227	243
11:35	150	12	18.1	17.8	17.0	334	247	239	239	244	244	229	257	237	245	241	247	241	239	254
11:50	165	13	18.3	17.9	16.8	333	258	245	248	252	253	238	268	245	252	249	255	248	247	262
12:05	180	14	18.8	18.0	17.3	334	265	253	254	261	261	246	272	254	261	257	262	256	256	269
12:20	195	15	18.8	18.0	17.1	333	271	263	263	268	268	255	278	261	267	264	269	262	261	276
12:35	210	16	18.2	17.8	17.2	335	277	270	270	275	275	263	282	269	274	270	275	268	268	282
12:50	225	17	18.5	17.9	17.1	333	282	277	277	280	280	270	285	276	277	276	280	273	274	288
1:05	240	18	18.9	17.9	17.1	333	286	283	282	285	285	277	287	284	284	281	286	278	278	293
1:20	255	19	18.7	17.9	17.1	333	289	288	287	289	289	284	293	289	288	287	290	282	284	297
1:35	270	20	18.5	17.9	17.2	333	293	291	291	294	293	288	296	293	293	290	293	285	287	301
1:50	285	21	18.1	17.8	17.1	334	296	295	295	297	297	292	299	296	296	293	297	288	290	304
2:05	300	22	18.4	17.9	17.2	333	299	299	298	301	301	295	303	299	299	296	300	290	291	308
2:20	315	23	18.3	17.7	17.5	333	301	301	300	303	303	296	306	301	301	298	303	293	294	310
2:35	330	24	18.8	17.9	17.7	331	304	303	303	305	305	299	306	303	304	301	303	294	296	313
2:50	345	25	17.6	17.5	17.3	335	305	305	304	306	307	301	309	306	306	303	306	296	298	315

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 2
Date: 4/15

Reservoir: West
Inlet: 90 up
Baffle: none

Flow: 11.4 MGD
Depth: 14.4'

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (µS)	Probe 1 Conduct. (µS)	Probe 2 Conduct. (µS)	Probe 3 Conduct. (µS)	Probe 4 Conduct. (µS)	Probe 5 Conduct. (µS)	Probe 6 Conduct. (µS)	Probe 7 Conduct. (µS)	Probe 8 Conduct. (µS)	Probe 9 Conduct. (µS)	Probe 10 Conduct. (µS)	Probe 11 Conduct. (µS)	Probe 12 Conduct. (µS)	Probe 13 Conduct. (µS)	Probe 14 Conduct. (µS)
8:50	0	1	19.5	17.9	16.3	326														1.9
8:51	1	2																		1.9
8:52	2	3																		1.9
8:53	3	4																		1.9
8:54	4	5																		2.3
8:55	5	6																		2.4
8:57	7	7											1.4	1.8	1.8	1.4	1.4	1.4	1.4	2.3
8:58	8	8					3.2	3.3	4.6	5.7	6.0	2.8	1.5	5.9	3.0	1.4	1.7	1.5	2.0	2.1
9:00	10	9					9.0	13.7	8.0											8.0
9:02	12	10								26.7	24.9	4.1	5.0	35.4	10.9	11.6	2.8	2.6	3.2	12.8
9:05	15	11					22.5	26.2	27.4	34.2	29.9	5.9	6.3	57.1	21.9	27.9	7.4	7.2	12.2	15.0
9:10	20	12					33.6	27.8	38.2	60.6	61.1	15.7	17.4	69.7	26.3	48.7	29.3	17.3	11.7	33.2
9:15	25	13					51.7	56.3	62.0	83.9	90.1	37.4	37.9	92.4	66.5	64.5	56.3	29.0	21.0	50.5
9:20	30	14	19.3			321	64.2	67.2	69.6	91.1		51.4	39.6	96.4	77.3	79.0	73.9	44.9	34.4	82.9
9:35	45		19.9			325	101.5	101.2	104.9	124.2	133.3	101.8	81.7	126.4	106.8	112.9	109.8	74.3	69.7	118.1
9:50	60		20.5			330	154.4	132.7	181.2	147.1	175.5	136.0	113.0	171.4	141.6	153.2	144.7	109.5	110.6	157.2
10:05	75						166.6	150.1		170.2	193.7	145.0	138.2	191.2	159.0	179.6	178.8	129.5	137.5	174.0
10:20	90						191	172	221	200	209	170	158	208	181	203	198	153	163	193
10:35	105				17.3	331	205	193	220	218	217	200	185	223	200	221	213	170	172	224
10:50	120			17.3	17.6	336	228	216	232	232	239	204	206	232	214	232	228	190	197	237
11:05	135						241	231	253	241	247	220	231	236	228	242	236	216	213	251
11:20	150			17.3	17.0	337	248	242	251	248	245	234	232	251	240	249	238	228	220	252
11:35	165		21.1				252	246	260	257	265	245	268	268	264	256	240	237	228	261
11:50	180		21.4	17.2	17.3	340	266	259	269	263	271	252	275	273	265	262	248	248	234	260
12:10	195						276	273	279	271	276	263	286	278	275	268	258	255	243	276
12:30	210		21.1	17.2	17.3	339	280	276	284	277	282	269	285	281	280	274	264	260	245	277
12:35	225						283	282	283	288	292	276	284	289	284	279	272	266	252	283
12:50	240						284	287	287	290	293	281	288	292	290	282	279	270	254	286
1:05	255		18.2	17.4	17.0	338	286	290	295	295	297	286	289	298	293	287	285	276	259	292

1:20	270		19.8				291	293	293	300	302	291	298	299	296	294	290	278	261	299
1:35	285		21.3	17.2	17.2	340	293	297	298	301	301	295	302	304	297	294	294	280	263	303
1:50	300		20.2				294	299	304	303	302	298	296	306	299	297	299	281	265	307
2:05	315						296	299	306	304	305	300	300	309	302	297	302	282	267	310
2:20	330			17.2	17.2	340	297	305	305	307	307	302	303	310	303	302	304	283	268	312
2:35	345						299	306	309	308	308	306	305	308	306	304	306	284	268	313

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 3
Date: 4/17

Reservoir: East
Inlet: 90 up
Baffle: none

Flow: 11.4MG
Depth: 14.4

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (μS)	Probe 1 Conduct. (μS)	Probe 2 Conduct. (μS)	Probe 3 Conduct. (μS)	Probe 4 Conduct. (μS)	Probe 5 Conduct. (μS)	Probe 6 Conduct. (μS)	Probe 7 Conduct. (μS)	Probe 8 Conduct. (μS)	Probe 9 Conduct. (μS)	Probe 10 Conduct. (μS)	Probe 11 Conduct. (μS)	Probe 12 Conduct. (μS)	Probe 13 Conduct. (μS)	Probe 14 Conduct. (μS)
8:40	0	1		17.1	17.5	309														3.2
8:41	1	2																		3.2
8:42	2	3																		3.2
8:43	3	4																		3.2
8:44	4	5																		3.2
8:45	5	6					3.8	2.5		2.8	2.7	2.6	2.6	13.3	2.5	2.5	2.5	2.5	2.5	3.2
8:47	7	7																		3.2
8:48	8	8																		3.2
8:50	10	9					34.9	2.8	27.2	37.4	2.5	15.1	7.4	11.6						3.2
8:52	12	10		17.1																3.3
8:55	15	11			17.1		59.3	15.9	33.0	63.3	6.8	50.0	12.0	52.2	35.9	36.0	6.3	2.5	2.5	9.2
9:00	20	12	19.2				56.4	33.7	32.3	80.4	34.7	85.6	13.4	67.2	56.0	63.8	19.7	2.5	6.4	23.0
9:05	25	13					63.1	42.3	48.5		34.4	103.0	26.4	76.8	68.6	92.1	31.4	2.6	15.1	40.4
9:10	30	14		17.0	15.8	311	68.8	47.2	61.5	84.8	40.4	115.6	38.8	90.0	89.3	107.9	47.1	3.2	29.4	41.2
9:25	45	15	19.8	17.1	16.9	311	93.9	90.1	119.2	124.2	102.8	126.0	117.7	104.6	121.2	136.9	128.5	105.3	88.4	123.6
9:40	60			17.1	16.6	311	147.1	109.8	137.7	183.2	135.8	128.8	123.3	194.6	195.7	149.5	147.1	138.5	99.4	124.0
9:55	75		19.6	17.0		310	167.8	135.7	173.6	197.2	163.4	192.0	147.0	200	200	181.7	187.0	146.0	120.5	173.2
10:10	90			17.3		310	188.3	203	185.0	173.8	216	232	171.6	167.0	172.0	204	209	201	214	215

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 20
Date: 5/16

Reservoir: West
Inlet: 90 Up
Baffle: #3

Flow: 11.4 MGD
Depth: 14.4

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
9:01	0		22.4	16.5	17.0	138.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	3.3
	1																			3.2
	2																			3.1
	3	18																		3.0
	4																			3.0
	5																	2.2	31.0	3.0
	6																			2.9
	7																			2.9
	8																			2.9
	9																			2.9
	10	19																		2.9
	12 1/2						35.0	47.0	5.5	2.2	5.1	2.6	2.4	2.3	2.2	2.2	2.4			2.9
	15																			2.9
	17 1/2	20																		3.2
	20						33.1	45.6	50.0											5.7
	22 1/2																		76.9	9.3
	25															10.3	4.1	4.2	76.9	13.2
	27 1/2												84.4	31.1	44.7					18.0
	30						35.7	50.1	80.8	23.3	20.4	63.3	86.3	36.4	46.5	14.8	10.9	9.2	79.6	20.3
	35			16.7	17.0	137.6														32.7
	40																			42.7
	45		21.1	16.7	17.2	138.0	60.9	56.7	72.8	60.1	35.2	71.4	96.7	63.4	68.3	49.5	22.8	19.1	97.1	52.1
	60			17.6	17.6	136.0	66.7	74.6	96.4	72.6	46.2	76.2	106.5	85.2	78.2	68.4	30.1	38.1	104.4	60.2
	75						83.2	82.3	104.7	88.2	60.7	90.1	112.4	92.6	90.6	71.0	40.8	69.7	108.5	79.6
	90		21.0	17.2	17.6	138.0	100.6	93.2	108.3	96.2	73.1	93.4	117.2	100.0	98.5	71.5	40.8	95.3	115.3	87.3
	105			17.5	18.0	137.1	105.6	94.0	113.4	97.7	70.8	97.2	119.0	105.3	108.9	93.3	59.6	85.3	119.1	94.1
	120		20.1	17.8	18.2	137.1	110.9	102.6	116.7	108.8	86.9	100.1	118.2	109.6	110.2	100.9	81.5	84.7	119.3	101.9
	135																			108.6
	150																			

	165		23.8																	117.7
	180			17.8	17.9	139.0	125.9	123.4	128.7	116.9	120.1	117.5	118.2	114.8	120.0	114.5	114.4	109.5	125.0	119.1
	195		21.6																	122.7
	210			18.4	18.7	138.1	129.2	130.2	129.2	127.1	126.7	123.5	123.5	125.4	124.0	120.3	123.1	117.3	130.8	125.7
	225		22.3																	129.0
	240			18.4	18.7	138.3	134.6	134.0	129.4	133.0	131.8	128.2	127.8	130.6	130.2	126.4	129.4	125.0	133.8	131.5
	255		22.3																	133.6
	270			18.5	18.8	138.5	136.9	137.1	129.4	136.9	134.3	131.3	129.6	134.7	133.1	130.7	134.9	130.6	135.0	136.0
	285		22.0																	137.8
	300			18.7	19.0	138.7	138.1	138.7	131.1	138.2	138.4	133.7	131.9	136.5	136.0	132.0	137.0	133.9	136.5	139.2
	315		22.6																	139.9
	330		23.6	18.9	19.1	138.8	138.7	138.8	135.7	139.2	139.5	137.0	137.0	138.8	136.7	134.2	138.8	135.8	138.2	140.9
	345																			141.5

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 23
Date: 5/20

Reservoir: West
Inlet: 90
Baffle: #9

Flow: 11.4 MGD
Depth: 14.4 feet

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
9:02	0		21.5	18.5	17.1	129.5	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.8	1.8	1.8	1.8	1.8	2.3
	1																		1.8	2.3
	2	1																1.9	1.8	2.3
	3	2										1.8				1.8	1.8			2.3
	4												1.8	1.8	1.8			1.9		2.3
	5																			2.3
	6																			2.3
	7	3							1.9	1.9	1.8									2.3
	8						1.8	2.7				5.6								2.3
	9																			2.3
	10																1.8	1.9	1.9	2.4
	12 1/2	4								12.1	3.0	11.0	1.8	1.8	1.8	1.8				2.5
	15								2.3											2.8
	17 1/2	5						27.4												3.8
	20			18.1	17.6	128.9														8.3
	22 1/2																			10.8
	25														9.1	17.1	18.9	16.0	46.0	15.4
	30									25.0	24.7	23.8	9.1	22.6	12.2	21.2	27.9	22.8	50.8	21.9
	35		21.5	18.5	18.2	130.9	63.6	68.1	50.6											30.6
	40						69.6	67.7	51.5	66.5	59.1	50.8	23.6							36.2
	45																			52.4
	60		22.1	18.3	18.3	133.6	77.6	80.3	67.9	74.4	68.1	63.9	49.9	69.5	60.8	63.1	65.0	63.7	77.9	5.9
	75						92.1	89.3	74.7	87.1	75.6	75.2	63.1	80.7	71.9	75.8	77.1	73.3	81.9	75.1
	90		22.8	18.9	19.7	130.6	95.4	102.2	73.6	102.8	83.7	80.8	72.8	86.5	80.8	86.3	83.8	78.6	83.2	88.9
	105						100.2	105.7	94.2	102.1	97.4	100.9	84.6	99.6	94.3	95.7	94.5	92.7	99.4	96.9
	120		22.9	19.0	20.3	130.8	106.5	108.4	103.0	105.3	96.1	103.8	90.6	106.4	96.3	102.0	101.2	97.9	105.6	100.1
	135						112.1	112.2	108.6	112.3	104.4	103.8	96.7	110.2	104.9	106.9	110.8	101.8	111.2	106.7
	150		23.1	19.1	20.0	130.9	116.2	116.7	109.9	116.7	106.5	105.9	101.5	116.0	109.4	110.1	114.4	104.1	116.3	113.0
	165						119.7	118.5	114.0	121.6	116.8	107.1	106.1	116.2	113.4	114.4	117.0	107.1	113.2	117.2

	180		23.0	19.4	20.6	129.7	122.2	122.7	111.3	123.8	116.4	109.1	110.1	120.5	115.2	115.9	116.1	109.4	110.1	120.3
	195						125.8	122.7	115.8	126.6	120.3	113.2	112.9	121.8	120.0	119.5	118.3	112.6	111.6	123.8
	210		23.7	20.1	21.7	126.6	126.2	127.7	121.8	127.3	125.2	116.9	114.7	124.3	124.0	121.2	118.8	115.7	115.0	126.3
	225						129.8	127.2	126.6	127.9	126.1	118.9	117.6	126.4	125.3	124.3	119.9	116.5	118.7	127.8
	240		23.8	19.3	19.7	129.6	129.1	130.0	127.8	128.5	130.1	121.0	120.6	129.0	127.9	125.6	126.1	117.4	121.2	130.2
	255		21.6																	132.4
	270		23.3	19.9	21.2	127.9	134.5	133.4	129.7	129.8	131.3	130.3	125.2	131.0	130.9	127.8	127.1	122.5	131.6	133.8
	285		22.2																	134.6
	300		23.1	19.6	20.2	129.2	134.9	134.8	125.9	132.5	132.9	131.8	125.5	135.8	133.7	129.1	129.8	128.9	134.8	135.7
	315		22.3																	136.4
	330		23.2	19.8	20.8	130.6	136.3	135.4	131.5	136.3	136.7	133.3	131.5	137.0	133.4	131.8	132.9	132.8	132.8	137.8

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 24
Date: 5/22

Reservoir: West
Inlet: 90 up
Baffle: #7

Flow: 11.4 MGD
Depth: 14.4'

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
9:03	0		19.4	18.4	17.9	135.2	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	2.3
	1	1																		2.3
	2																			2.3
	3																			2.3
	4																			2.3
	5																			2.5
	6																	1.9	10.2	2.9
	7																	5.3	16.9	2.8
	8	2											1.8	1.8	1.8	1.8	1.9			2.4
	10																2.0	58.5	37.8	2.3
	12 1/2									1.8	3.5	1.8	1.8	1.8	1.8	1.8				2.3
	15	4											2.8	1.8	2.1	1.8	2.5	78.6	62.0	2.7
	17 1/2									1.8	30.0	1.8	4.6	2.5	2.5	1.8	4.3	88.0	70.0	4.3
	20						76.8	18.6	2.4	1.8	32.0	1.8								7.5
	22 1/2											2.7	11.3	5.5	4.1	1.9	14.8	100.0	85.0	9.6
	25						76.8	45.6	2.4	3.8	57.1	14.8	16.8	7.3	4.9	3.2	23.8	103.0	88.0	19.0
	30		23.0	19.2	20.3	135.1														23.3
	35																	116.9	109.3	29.5
	40																			41.4
	45						115.5	73.3	7.8	42.2	99.1	56.0	49.5	47.7	22.3	23.4	70.6	126.1	117.2	39.1
	60		21.8	19.2	20.0	134.8	119.8	96.3	33.1	64.1	99.0	90.7	70.7	63.8	46.9	68.4	80.8	131.7	123.5	59.1
	75						130.0	110.8	54.6	77.0	119.9	102.7	86.7	80.2	62.2	79.8	94.8	135.9	125.9	72.4
	90		21.6	19.1	20.9	135.4	133.7	113.5	63.0	88.4	130.4	109.5	101.4	96.7	78.8	91.2	109.1	137.5	126.0	88.6
	105						138.7	123.3	79.1	104.2	135.2	114.0	111.2	109.1	92.6	100.2	118.9	138.3	125.8	102.0
	120		21.7	19.3	20.2	137.0	138.7	129.3	92.3	112.7	140.5	122.7	118.4	116.9	101.8	104.9	126.8	138.7	124.5	114.3
	135				19.7		141.1	134.6	102.0	120.2	144.2	128.7	125.6	125.1	110.8	119.4	134.4	138.7	123.3	122.6
	150		21.6	19.1	19.7	136.7	142.9	138.0	108.3	122.9	145.2	131.2	130.7	130.2	119.1	120.4	137.8	139.1	123.8	130.3
	165						143.7	141.2	117.3	129.6	145.5	136.8	133.8	134.4	122.1	123.5	139.7	139.0	122.2	132.4
	180		21.5	19.0	19.5	137.0	144.8	142.5	123.6	131.7	146.2	139.2	136.6	137.0	126.5	129.2	141.8	138.6	120.9	138.0

	195						145.1	144.0	128.0	134.2	146.6	141.8	140.0	138.4	130.3	131.4	143.0	138.9	119.8	142.1
	210		21.2	19.2	19.9	137.5	145.8	144.6	132.9	137.9	147.0	141.7	142.1	140.7	134.0	135.9	144.5	139.6	120.7	144.2
	225						146.2	145.7	135.0	140.2	147.5	143.7	143.7	141.9	137.9	137.5	145.2	142.0	119.9	144.9
	240		21.6	19.4	20.3	135.5	146.5	146.4	138.6	142.2	147.6	144.4	145.0	143.7	140.6	141.2	146.1	141.7	117.9	147.7
	255		20.9				146.6	146.6	140.5	144.4	147.9	144.7	145.6	144.5	141.9	141.0	146.5	141.4	116.3	148.4
	270		21.9	19.4	20.5	135.4	147.0	147.0	142.2	145.5	147.9	145.6	145.9	145.5	143.4	144.0	146.8	141.2	114.6	149.6
	285		21.3				147.5	147.4	142.9	146.0	148.2	145.9	146.2	146.2	144.3	143.6	147.2	141.0	113.6	150.0
	300		22.1	19.4	20.0	135.8	147.7	147.7	143.8	146.3	148.5	146.1	146.6	146.5	144.9	143.8	147.5	140.9	115.5	150.1
	315		21.4				147.8	147.8	144.1	146.7	148.6	146.4	147.0	146.9	145.2	144.4	147.6	140.8	114.1	150.6
	330		21.9	19.2	19.8	136.2	147.8	147.9	144.4	146.6	148.5	146.5	147.0	147.3	145.6	144.4	147.7	140.6	119.1	151.0
	345		20.7																	151.1

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 26
Date: 5/30

Reservoir: East
Inlet: 90 up
Baffle: #8

Flow: 11.4 MGD
Depth: 14.41

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
	0		20.7	19.0	17.7	150.8	1.5	1.5	1.4	1.4	1.4	1.5	1.7	1.5	1.4	1.4	1.5	1.5	1.4	2.1
	1																			2.1
	2																			2.1
	3																			2.1
	4																			2.1
	5												146.0	1.5	1.5	1.5	1.5	1.6		2.1
	6																			2.1
	7										1.7	1.8	157.0	1.5	1.4	1.5	1.6	1.6	1.6	2.0
	8						1.6	2.1	1.7	3.5	1.5	1.6								2.0
	10	5							2.3	17.9	1.5	1.7	164.4	2.0	1.7	1.5	1.5	1.6	1.6	2.0
	12 1/2						15.3	3.2	4.3	40.0	1.5	2.0								2.0
	15										5.2	2.3	168.4	6.7	2.8	10.1	1.6	1.5	1.5	2.0
	17 1/2													11.2	9.4	15.1	3.0	1.6	1.7	2.3
	20						38.5	11.0	25.2	46.9	17.1									2.7
	22 1/2														17.8	26.3	10.1	3.6	3.5	23.8
	25						58.7	21.4	35.2	31.8	33.3	16.6	169.3	24.6	19.3	31.6	17.2	5.2	4.2	32.8
	30						57.2	28.9	38.9	54.1	41.6	24.0	169.4	23.5	26.4	36.3	31.9	9.4	7.0	42.5
	35									59.3	48.0	34.7	169.6	30.7	28.0	52.3	47.0	15.8	15.9	53.2
	40										55.0	40.3	169.5	30.5	33.0	64.6	57.0	21.4	21.0	63.3
	45		22.4	19.5	20.0	149.2	62.0	45.6	59.5	64.2	70.9	44.2	167.3	35.1	39.7	82.5	65.0	28.0	28.9	80.2
	60		21.8	19.3	19.4	149.7	87.2	59.3	66.3	70.9	75.2	48.4	158.4	46.3	50.3	96.1	61.5	43.3	44.7	110.9
	75						99.2	80.0	94.0	96.7	85.5	56.8	154.6	68.0	65.3	117.7	52.2	54.6	66.3	118.0
	90																			115.0
	105		22.3	19.5	19.9	149.4	129.0	92.1	112.9	147.0	106.3	86.5	170.4	106.4	98.2	125.1	88.6	91.3	100.0	113.6
	120		21.6	19.5	19.9	148.6	136.1	106.7	111.0	149.3	124.3	91.7	170.3	130.9	109.3	133.8	115.8	102.2	104.3	120.9
	135						136.8	119.1	123.1	145.5	135.5	105.5	170.0	120.9	118.7	137.5	127.3	108.8	108.8	133.7
	150		22.1	19.5	19.8	148.3	142.8	121.5	130.2	136.6	136.6	113.3	168.7	120.9	125.4	138.3	131.0	110.2	111.2	143.0
	165						142.9	128.5	134.5	148.6	137.7	121.3	165.5	129.4	130.5	146.7	133.9	115.2	120.0	150.6
	180		22.7	19.7	20.6	147.3	142.6	136.6	140.4	155.6	140.0	131.6	166.3	135.5	142.7	145.0	128.3	125.1	124.9	146.7

	195		21.5				148.5	144.4	142.6	159.4	140.0	141.0	167.3	132.2	138.9	154.4	134.8	135.2	133.5	148.0
	210		22.4	19.7	20.2	148.6	151.5	147.7	149.0	157.7	147.0	143.2	167.5	136.9	143.5	154.2	146.2	139.6	138.2	153.6
	225						155.1	152.2	153.8	163.7	146.5	146.8	168.3	143.3	152.2	153.5	144.5	143.4	144.3	156.0
	240		22.4	19.7	20.3	148.0	157.5	156.7	155.8	164.3	145.0	152.8	169.6	146.3	150.8	156.5	148.7	147.1	147.1	157.0
	255		21.6				158.7	156.0	158.0	166.7	156.9	156.2	170.4	152.5	151.4	160.3	151.6	151.6	149.8	159.7
	270		22.6	19.9	20.4	147.2	164.2	163.5	159.4	167.3	161.2	154.4	170.9	150.9	152.7	159.3	160.3	155.2	152.8	162.3
	285		22.2				164.1	163.0	162.3	167.7	166.4	156.9	170.9	155.7	164.5	161.3	162.2	156.9	156.0	165.1
	300		22.9	20.0	20.7	142.2	167.7	164.1	163.5	170.1	168.5	161.7	170.9	156.0	168.9	163.5	160.3	158.5	160.4	164.0
	315						165.1	164.9	164.3	168.5	164.4	163.2	170.9	161.8	165.2	164.0	159.3	159.8	161.3	169.0
	330		22.7	20.8	20.5	146.8	165.8	167.1	164.2	168.7	166.3	164.1	171.0	163.2	162.0	163.7	159.6	161.3	162.9	169.2

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 27
Date: 6/3

Reservoir: East
Inlet: 90 up
Baffle: #8

Flow: 11.4 MGD
Depth: 14.41

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
8:24	0		22.5	21.3	20.1	136.7	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.0	1.0	1.6
	1	10																		1.6
	2	11																		1.6
	3																			1.6
	4	12										1.2								1.6
	5												36.0	4.6						1.6
	6											1.2	40.0							1.6
	7												42.5	1.2						1.6
	8														1.1	1.1	1.1	1.0	1.0	1.6
	10										7.4	8.3	55.0	6.3	1.1	1.1	1.1	1.0	1.0	1.6
	12 1/2						50.0	46.1	12.5											1.6
	15													41.6	1.1	1.1	1.2	1.4	1.1	1.6
	17 1/2						78.6	54.4	23.8	1.2	43.8									1.6
	20																		4.6	2.0
	22 1/2	13												42.0	6.2	5.3	2.8	5.9	4.7	2.0
	25												82.2	40.2	8.6	9.0	17.6	12.5	6.7	2.0
	30											63.0	66.8	90.5	21.6	18.6	14.3	22.4	11.0	5.2
	35						97.1	88.9	58.9	33.1	84.2	75.9	60.0							14.2
	40																			35.5
	45						101.0	112.0	79.8	55.6	116.6	100.7	83.5	92.6	60.3	45.7	64.1	56.3	35.3	48.0
	60		23.3	21.5	21.5	136.5	112.7	121.1	109.9	64.4	120.0	110.8	102.2							70.8
	75						110.8	125.4	117.3	64.7	128.3	115.4	118.4	105.2	99.1	81.3	86.4	93.3	72.5	84.0
	90		23.3	21.3	21.4	137.8	113.3	132.7	131.0	74.2	133.1	123.8	114.5	111.5	111.5	93.7	97.1	106.5	81.5	95.2
	105		23.3	21.3	21.4	137.8	113.3	132.7	131.0	74.2	136.1	129.4	125.6	112.4	119.4	112.2	108.9	113.1	90.6	105.3
	120						114.0	137.5	139.4	88.9	136.1	129.4	125.6	112.4	119.4	112.2	108.9	113.1	90.6	105.3
	135					143.2	147.6	146.3	146.3	148.5	142.8	142.0	144.5	132.5	127.0	126.7	120.1	122.0	99.0	116.7
	150		23.3	21.0	21.1	150.3	148.6	151.3	153.8	121.5	152.4	144.9	149.9	148.6	140.9	135.9	131.3	133.9	118.9	131.6
	165		22.7				154.0	154.1	153.0	128.0	154.9				145.3	141.9	140.0	139.0	121.3	137.7
	180		23.4	21.5	21.6	143.6	156.1	155.2	153.2	135.7	158.2	153.4	155.0	155.3	149.0	146.1	145.1	141.7	124.2	141.2

	195						157.7	156.8	155.3	137.3	158.9	155.6	157.1	153.9	152.8	148.8	147.5	143.6	124.8	146.4
	210		23.9	21.6	22.0	142.5	159.9	158.8	158.6	143.1	161.1	157.4	159.8	159.7	154.7	151.5	151.3	147.6	128.6	150.8
	225		23.4				161.0	160.3	158.4	148.5	161.9	159.9	161.0	162.1	156.6	153.6	154.0	151.1	130.5	155.0
	240		23.9	21.7	22.2	141.7	162.0	161.5	160.7	152.6	163.5	161.3	162.3	163.8	159.0	155.3	156.0	153.9	132.6	158.2
	255		23.2				163.1	163.1	162.5	154.3	164.4	162.0	163.2	165.0	160.6	157.5	157.0	154.7	137.1	160.0
	270		23.7	21.7	22.1	141.2	164.0	163.8	163.0	155.8	164.5	162.7	164.6	164.6	161.1	158.4	159.3	156.2	138.6	162.7
	285		23.0				164.0	164.8	164.7	158.4	166.1	163.5	165.1	167.0	162.5	160.2	161.1	156.7	140.8	164.0
	300		23.5	21.7	22.2	141.1	165.5	165.8	165.8	160.3	166.9	164.8	166.1	167.6	163.6	161.4	162.7	158.5	141.0	165.5
	315		23.0				166.2	166.8	166.1	161.2	167.3	165.7	166.9	168.0	164.5	162.2	163.1	159.2	143.2	166.7
	330						167.2	167.6	167.3	162.3	168.0	166.8	167.6	168.9	165.2	163.3	164.3	159.9	144.5	168.1

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 29
Date: 6/11

Reservoir: East
Inlet: 90 up
Baffle: #7

Flow: 23.0 MGD
Depth: 14.4 feet

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
	0	1	23.8		22.1															2.6
	1/2	2																		2.7
	1	3																		2.7
	1 1/2	4																		2.7
	2	5																		2.6
	2 1/2	6																		2.6
	3	7																		2.5
	3 1/2	8																		2.5
	4	9																		2.5
	5	10																		2.5
	6	11																		2.5
	7 1/2	12																		2.5
	8 1/2	13																		2.5
	10	14																		2.5
	11	15																		5.9
	11 1/2	16																		9.5
	12	17																		11.2
	12 1/2	18																		12.9
	13	19																		16.0
	15	20																		18.8
	17 1/2	21																		
	20	22																		21.0
	25	23																		33.5

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 30
Date: 6/11

Reservoir: East
Inlet: 90 up
Baffle: #7

Flow: 11.4 MGD
Depth: 25.0'

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (mS)	Probe 1 Conduct. (mS)	Probe 2 Conduct. (mS)	Probe 3 Conduct. (mS)	Probe 4 Conduct. (mS)	Probe 5 Conduct. (mS)	Probe 6 Conduct. (mS)	Probe 7 Conduct. (mS)	Probe 8 Conduct. (mS)	Probe 9 Conduct. (mS)	Probe 10 Conduct. (mS)	Probe 11 Conduct. (mS)	Probe 12 Conduct. (mS)	Probe 13 Conduct. (mS)	Probe 14 Conduct. (mS)
7:43	0	2	20.6	20.4	19.7	130.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.4
	2	3																		2.4
	4	4																		2.5
	6	5																		2.5
	8	6																		2.5
	10	7					1.8	2.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.7	2.4
	12	8																		2.4
	14	9																		2.4
	16	10					1.9	3.0	3.5	2.0	1.9	1.9	2.8	2.1	1.8	1.8	1.8	1.7	1.7	2.4
	20	11		20.8	21.3	130.0														2.4
	24	12																		2.4
	26																			4.0
	27																			3.8
	28																			4.0
	29																			6.9
	30	13																		8.6
	33																			13.0
	34						4.2	5.3	6.4	3.1	6.2	16.8	8.0	6.4	2.7	7.3	5.2	4.5	5.3	12.9
	39																			20.8
	40																			22.1
	43																	23.6	24.4	24.4
	44																	27.9	28.1	22.1
	45																	21.9	22.3	21.9
	50		23.5	20.8	21.0	128.7														27.9
	60						16.6	16.5	15.8	9.6	17.8	38.3	41.7	19.8	15.3	16.8	12.7	26.8	22.0	38.7

BATES ENGINEERING, INC.
CITY OF FORT COLLINS 15 MG RESERVOIRS
HYDRAULIC MODEL STUDY

Test: 31
Date: 6/24

Reservoir: East
Inlet: 90° up
Baffle: #3

Flow: 11.4 MGD
Depth: 14.4 feet

Time	Time (t)	Photo No(s)	Air Temp. (° C)	Supply Temp. (° C)	Model Temp. (° C)	Supply Conduct. (μS)	Probe 1 Conduct. (μS)	Probe 2 Conduct. (μS)	Probe 3 Conduct. (μS)	Probe 4 Conduct. (μS)	Probe 5 Conduct. (μS)	Probe 6 Conduct. (μS)	Probe 7 Conduct. (μS)	Probe 8 Conduct. (μS)	Probe 9 Conduct. (μS)	Probe 10 Conduct. (μS)	Probe 11 Conduct. (μS)	Probe 12 Conduct. (μS)	Probe 13 Conduct. (μS)	Probe 14 Conduct. (μS)
7:02	0		22.1	22.4	21.8	121.4	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.1	3.0	3.0	2.9	2.8	2.8	3.8
	1																			3.8
	2																			3.8
	3																			3.8
	4																			3.8
	5																			3.8
	6																			3.8
	7																			3.8
	8																			3.8
	10																			3.8
	12																			4.3
	15																			15.8
	17																			23.6
	20																			36.0
	22													11.5	4.7	34.6	20.3	20.1	3.2	43.0
	25										49.5	8.2	43.1							47.5
	27						42.2	39.1	24.6	58.2										49.2
	30													36.6	18.0	60.7	35.1	26.8	9.6	47.6
	35								40.5	80.6	54.3	35.4	58.8							50.1
	40						51.1	61.8												59.4
	45		23.8	22.4	21.7	121.6	59.0	74.9	41.6	84.4	66.3	44.4	66.0	61.0						68.3
	60																			83.1
	75		23.6				92.3	90.5	77.6	95.8	86.6	70.4	83.5	58.6	52.2	97.3	85.7	66.9	56.0	100.6
	90			22.7	22.3	123.0	106.4	93.3	94.3	117.6	102.0	85.5	96.4	68.2	63.1	101.4	93.8	96.0	60.1	113.9
	105						118.4	106.7	100.5	121.0	112.1	97.4	105.6	79.2	95.8	111.2	101.5	104.5	64.0	121.2
	120		23.3	22.7	22.7	126.9	115.8	115.5	131.6	119.5	90.0	108.9	120.0	117.5	124.6	110.8	111.4	111.5	90.2	127.7
	135			22.5	22.4	126.4	131.3	119.5	122.6	133.6	126.8	108.9	116.4	119.8	133.1	119.1	106.6	121.3	92.0	131.0
	150		23.7	22.4	22.7	125.5	133.6	123.3	125.8	140.2	130.3	117.0	125.0	115.7	126.9	127.9	112.0	122.7	96.6	136.6

	165		23.5		22.8		137.0	125.2	130.7	142.4	136.5	119.8	127.3	122.6	139.5	135.3	119.4	126.3	104.3	139.1
	180			22.1	22.2	128.2	136.2	129.4	127.2	143.8	134.6	120.1	129.3	132.0	140.2	138.1	127.8	131.2	108.7	140.0
	195		22.9	22.3	22.3	129.0	137.7	132.1	135.1	146.0	136.0	129.9	132.7	139.1	140.0	137.4	137.7	127.2	111.8	139.4
	210		24.4	22.0	23.0	128.2	141.0	133.9	134.3	146.0	135.3	129.6	132.3	144.3	132.8	136.8	138.9	127.7	113.2	139.7
	225		23.3	22.4	22.9	125.9	142.0	134.7	137.5	145.7	136.6	131.6	134.2	143.7	144.2	137.7	140.1	127.9	117.2	140.7
	240		23.1	22.2	22.9	125.7	143.9	138.2	140.8	148.0	138.2	131.3	138.4	142.8	144.3	138.7	141.3	129.9	124.3	143.6
	255		21.2	22.1	22.6	127.0	144.8	140.4	142.3	14.7.7	140.9	135.9	140.0	146.9	147.4	142.0	144.7	131.8	126.5	145.0
	270		23.5	22.2	23.0	129.9	143.9	142.4	142.8	145.5	143.9	140.2	142.1	147.6	148.4	143.9	145.1	134.9	130.4	147.9
	285		23.4	22.1	22.8	128.3	146.8	143.5	143.8	148.5	144.7	142.1	142.3	148.3	148.7	144.7	147.7	135.8	132.9	144.3
	300		23.7	22.2	22.9	127.9	146.9	144.9	145.1	149.8	146.0	143.3	144.7	149.4	149.4	146.0	147.8	138.6	134.0	148.7
	315		23.4	22.1	22.9	127.4	146.0	146.6	144.9	148.9	147.2	145.0	145.1	151.1	149.5	146.6	146.9	142.5	135.2	150.4
	330		22.8	22.1	22.5	126.1	148.7	147.9	146.4	150.0	148.2	146.5	146.6	150.4	150.5	146.9	148.2	143.7	135.5	151.2

APPENDIX C - TRACER BREAKTHROUGH CALCULATIONS

TRACER BREAKTHROUGH CALCULATIONS

Prototype				Test 1 - E0 (Straight Inlet)				Test 2 - W0				Test 3 - E0			
Time	Time	Fluoride	Outlet	Time	Time	Conduct.	Outlet	Time	Time	Conduct.	Outlet	Time	Time	Conduct.	Outlet
(hours)	t/T	mg/L	%	(minutes)	t/T	µS	%	(minutes)	t/T	µS	%	(minutes)	t/T	µS	%
0	0.0%	0.14	0.0%	0	0.0%	2	0.0%	0	0.0%	2	0.0%	0	0.0%	3	0.0%
2	14.3%	0.18	4.7%	8	7.3%	46	14.1%	1	0.9%	2	0.0%	1	0.9%	3	0.0%
4	28.6%	0.21	8.1%	15	13.8%	67	20.8%	2	1.8%	2	0.0%	2	1.8%	3	0.0%
6	42.9%	0.35	24.4%	30	27.5%	104	32.6%	3	2.8%	2	0.0%	3	2.8%	3	0.0%
8	57.3%	0.43	33.7%	45	41.3%	139	43.8%	4	3.7%	2	0.1%	4	3.7%	3	0.0%
10	71.6%	0.49	40.7%	60	55.0%	164	51.8%	5	4.6%	2	0.2%	5	4.6%	3	0.0%
12	85.9%	0.55	47.7%	75	68.8%	185	58.5%	7	6.4%	2	0.1%	7	6.4%	3	0.0%
14	100.2%	0.61	54.7%	90	82.5%	202	63.9%	8	7.3%	2	0.1%	8	7.3%	3	0.0%
16	114.5%	0.66	60.5%	105	96.3%	221	70.0%	10	9.2%	8	2.0%	10	9.2%	3	0.0%
18	128.8%	0.71	66.3%	120	110.0%	233	73.8%	12	11.0%	13	3.5%	12	11.0%	3	0.0%
20	143.2%	0.73	68.6%	135	123.8%	243	77.0%	15	13.8%	15	4.2%	15	13.8%	9	1.9%
22	157.5%	0.77	73.3%	150	137.5%	254	80.5%	20	18.3%	33	10.1%	20	18.3%	23	6.4%
24	171.8%	0.80	76.7%	165	151.3%	262	83.1%	25	22.9%	51	15.6%	25	22.9%	40	11.9%
26	186.1%	0.90	88.4%	180	165.0%	269	85.3%	30	27.5%	83	26.0%	30	27.5%	41	12.2%
28	200.4%	0.91	89.5%	195	178.8%	276	87.5%	45	41.3%	118	37.4%	45	41.3%	124	38.6%
30	214.7%	0.93	91.9%	210	192.5%	282	89.5%	60	55.0%	157	49.9%	60	55.0%	124	38.7%
32	229.1%	0.90	88.4%	225	206.3%	288	91.4%	75	68.8%	174	55.3%	75	68.8%	173	54.5%
34	243.4%	0.92	90.7%	240	220.0%	293	93.0%	90	82.5%	193	61.4%	90	82.5%	215	67.9%
36	257.7%	0.95	94.2%	255	233.8%	297	94.2%	105	96.3%	224	71.4%				
38	272.0%	0.98	97.7%	270	247.5%	301	95.5%	120	110.0%	237	75.6%				
40	286.3%	0.99	98.8%	285	261.3%	304	96.5%	135	123.8%	251	80.1%				
42	300.6%	1.00	100.0%	300	275.1%	308	97.8%	150	137.5%	252	80.4%				
				315	288.8%	310	98.4%	165	151.3%	261	83.3%				
				330	302.6%	313	99.4%	180	165.0%	260	83.0%				
				345	316.3%	315	100.0%	195	178.8%	276	88.1%				
								210	192.5%	277	88.4%				
								225	206.3%	283	90.4%				
								240	220.0%	286	91.3%				
								255	233.8%	292	93.2%				
								270	247.5%	299	95.5%				
								285	261.3%	303	96.8%				
								300	275.1%	307	98.1%				
								315	288.8%	310	99.0%				
								330	302.6%	312	99.7%				
								345	316.3%	313	100.0%				

TRACER BREAKTHROUGH CALCULATIONS

Test 20 - W3				Test 23 - W9				Test 24 - W7				Test 25 - E7			
Time (minutes)	Time t/T	Conduct. µS	Outlet %	Time (minutes)	Time t/T	Conduct. µS	Outlet %	Time (minutes)	Time t/T	Conduct. µS	Outlet %	Time (minutes)	Time t/T	Conduct. µS	Outlet %
0	0.0%	3.3	0.0%	0	0.0%	2.3	0.0%	0	0.0%	2.3	0.0%	0	0.0%	2.1	0.0%
1	0.9%	3.3	0.0%	1	0.9%	2.3	0.0%	1	0.9%	2.3	0.0%	1	0.9%	2.1	0.0%
2	1.8%	3.3	0.0%	2	1.8%	2.3	0.0%	2	1.8%	2.3	0.0%	2	1.8%	2.1	0.0%
3	2.8%	3.3	0.0%	3	2.8%	2.3	0.0%	3	2.8%	2.3	0.0%	3	2.8%	2.1	0.0%
4	3.7%	3.3	0.0%	4	3.7%	2.3	0.0%	4	3.7%	2.3	0.0%	4	3.7%	2.1	0.0%
5	4.6%	3.3	0.0%	5	4.6%	2.3	0.0%	5	4.6%	2.3	0.0%	5	4.6%	2.1	0.0%
6	5.5%	3.3	0.0%	6	5.5%	2.3	0.0%	6	5.5%	2.3	0.0%	6	5.5%	2.1	0.0%
7	6.4%	3.3	0.0%	7	6.4%	2.3	0.0%	7	6.4%	2.3	0.0%	7	6.4%	2.1	0.0%
8	7.3%	3.3	0.0%	8	7.3%	2.3	0.0%	8	7.3%	2.3	0.0%	8	7.3%	2.1	0.0%
10	9.2%	3.3	0.0%	10	9.2%	2.4	0.1%	10	9.2%	2.3	0.0%	10	9.2%	2.1	0.0%
12	11.0%	3.3	0.0%	12	11.0%	2.5	0.1%	12	11.0%	2.3	0.0%	12	11.0%	2.1	0.0%
15	13.8%	3.3	0.0%	15	13.8%	2.8	0.4%	15	13.8%	2.7	0.3%	15	13.8%	2.1	0.0%
17	15.6%	3.3	0.0%	17	15.6%	3.8	1.1%	17	15.6%	4.3	1.3%	17	15.6%	2.3	0.1%
20	18.3%	5.7	1.7%	20	18.3%	8.3	4.4%	20	18.3%	7.5	3.5%	20	18.3%	2.7	0.4%
22	20.2%	9.3	4.3%	22	20.2%	10.8	6.3%	22	20.2%	9.6	4.9%	22	20.2%	23.8	13.0%
25	22.9%	13.2	7.2%	25	22.9%	15.4	9.7%	25	22.9%	19.0	11.2%	25	22.9%	32.8	18.4%
30	27.5%	20.3	12.3%	30	27.5%	21.9	14.5%	30	27.5%	23.3	14.1%	30	27.5%	42.5	24.2%
35	32.1%	32.7	21.3%	35	32.1%	30.6	20.9%	35	32.1%	29.5	18.3%	35	32.1%	53.2	30.6%
40	36.7%	42.7	28.5%	40	36.7%	36.2	25.0%	40	36.7%	41.4	26.3%	40	36.7%	63.3	36.6%
45	41.3%	52.1	35.3%	45	41.3%	52.4	37.0%	45	41.3%	39.1	24.7%	45	41.3%	80.2	46.7%
60	55.0%	60.2	41.2%	60	55.0%	59.1	41.9%	60	55.0%	59.1	38.2%	60	55.0%	110.9	65.1%
75	68.8%	79.6	55.2%	75	68.8%	75.1	53.7%	75	68.8%	72.4	47.1%	75	68.8%	118.0	69.4%
90	82.5%	87.3	60.8%	90	82.5%	88.9	63.9%	90	82.5%	88.6	58.0%	90	82.5%	115.0	67.6%
105	96.3%	94.1	65.7%	105	96.3%	96.9	69.8%	105	96.3%	102.0	67.0%	105	96.3%	113.6	66.7%
120	110.0%	101.9	71.3%	120	110.0%	100.1	72.2%	120	110.0%	114.3	75.3%	120	110.0%	120.9	71.1%
135	123.8%	108.6	76.2%	135	123.8%	106.7	77.0%	135	123.8%	122.6	80.8%	135	123.8%	133.7	78.8%
150	137.5%	113.2	79.5%	150	137.5%	113.0	81.7%	150	137.5%	130.3	86.0%	150	137.5%	143.0	84.3%
165	151.3%	117.7	82.8%	165	151.3%	117.2	84.8%	165	151.3%	132.4	87.4%	165	151.3%	150.6	88.9%
180	165.0%	119.1	83.8%	180	165.0%	120.3	87.1%	180	165.0%	138.0	91.2%	180	165.0%	146.7	86.5%
195	178.8%	122.7	86.4%	195	178.8%	123.8	89.7%	195	178.8%	142.1	94.0%	195	178.8%	148.0	87.3%
210	192.5%	125.7	88.6%	210	192.5%	126.3	91.5%	210	192.5%	144.2	95.4%	210	192.5%	153.6	90.7%
225	206.3%	129.2	91.1%	225	206.3%	127.8	92.6%	225	206.3%	144.9	95.8%	225	206.3%	156.0	92.1%
240	220.0%	131.5	92.8%	240	220.0%	130.2	94.4%	240	220.0%	147.7	97.7%	240	220.0%	157.0	92.7%
255	233.8%	133.6	94.3%	255	233.8%	132.4	96.0%	255	233.8%	148.4	98.2%	255	233.8%	159.7	94.3%
270	247.5%	136.0	96.0%	270	247.5%	133.8	97.0%	270	247.5%	149.6	99.0%	270	247.5%	162.3	95.9%
285	261.3%	137.8	97.3%	285	261.3%	134.6	97.6%	285	261.3%	150.0	99.3%	285	261.3%	165.1	97.5%
300	275.1%	139.2	98.3%	300	275.1%	135.7	98.5%	300	275.1%	150.1	99.3%	300	275.1%	164.0	96.9%
315	288.8%	139.9	98.8%	315	288.8%	136.4	99.0%	315	288.8%	150.6	99.7%	315	288.8%	169.0	99.9%
330	302.6%	140.9	99.6%	330	302.6%	137.8	100.0%	330	302.6%	151.0	99.9%	330	302.6%	169.2	100.0%
345	316.3%	141.5	100.0%	345				345	316.3%	151.1	100.0%				

TRACER BREAKTHROUGH CALCULATIONS

Test 27 - E8			
Time (minutes)	Time t/T	Conduct. µS	Outlet %
0	0.0%	1.6	0.0%
1	0.9%	1.6	0.0%
2	1.8%	1.6	0.0%
3	2.8%	1.6	0.0%
4	3.7%	1.6	0.0%
5	4.6%	1.6	0.0%
6	5.5%	1.6	0.0%
7	6.4%	1.6	0.0%
8	7.3%	1.6	0.0%
10	9.2%	1.6	0.0%
12	11.0%	1.6	0.0%
15	13.8%	1.6	0.0%
17	15.6%	1.6	0.0%
20	18.3%	2.0	0.2%
22	20.2%	2.0	0.2%
25	22.9%	2.0	0.2%
30	27.5%	5.2	2.2%
35	32.1%	14.2	7.6%
40	36.7%	35.5	20.4%
45	41.3%	48.0	27.9%
60	55.0%	70.8	41.6%
75	68.8%	84.0	49.5%
90	82.5%	95.2	56.2%
105	96.3%	105.3	62.3%
120	110.0%	116.7	69.1%
135	123.8%	123.9	73.5%
150	137.5%	131.6	78.1%
165	151.3%	137.7	81.7%
180	165.0%	141.2	83.8%
195	178.8%	146.4	87.0%
210	192.5%	150.8	89.6%
225	206.3%	155.0	92.1%
240	220.0%	158.2	94.1%
255	233.8%	160.0	95.1%
270	247.5%	162.7	96.8%
285	261.3%	164.0	97.5%
300	275.1%	165.5	98.4%
315	288.8%	166.7	99.2%
330	302.6%	168.1	100.0%

Test 29 - E7 (23.0 MGD)			
Time (minutes)	Time t/T	Conduct. µS	Outlet %
0	0.0%	2.6	0.0%
0.5	0.9%	2.6	0.0%
1	1.8%	2.6	0.0%
1.5	2.8%	2.6	0.0%
2	3.7%	2.6	0.0%
2.5	4.6%	2.6	0.0%
3	5.5%	2.6	0.0%
3.5	6.4%	2.6	0.0%
4	7.3%	2.6	0.0%
5	9.2%	2.6	0.0%
6	11.0%	2.6	0.0%
7.5	13.8%	2.6	0.0%
8.5	15.6%	2.6	0.0%
10	18.3%	2.6	0.0%
11	20.2%	5.9	2.5%
12.5	22.9%	12.9	7.9%
15	27.5%	18.8	12.5%
17.5	32.1%	19.9	13.3%
20	36.7%	21.0	14.2%

Test 30 - E7 (25.0 Feet)			
Time (minutes)	Time t/T	Conduct. µS	Outlet %
0	0.0%	2.4	0.0%
2	0.9%	2.4	0.0%
4	1.8%	2.4	0.0%
6	2.8%	2.4	0.0%
8	3.7%	2.4	0.0%
10	4.6%	2.4	0.0%
12	5.5%	2.4	0.0%
14	6.4%	2.4	0.0%
16	7.3%	2.4	0.0%
20	9.2%	2.4	0.0%
24	11.0%	2.4	0.0%
30	13.8%	8.6	4.8%
34	15.6%	12.9	8.1%
40	18.3%	20.8	14.2%
44	20.2%	22.1	15.2%
50	22.9%	27.9	19.6%
60	27.5%	38.7	27.9%

COMPARISON OF TRACER BREAKTHROUGH FOR VARIOUS TESTS

t_{model}	%T	Prototype	E0 (Str.)	W0	E0	E0 (Blend)	W3	W9	W7	E7	E8	E7(23.0)	E7 (25.0)
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.9%	0.3%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	1.8%	0.6%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	2.8%	0.9%	5.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	3.7%	1.2%	7.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	4.6%	1.5%	8.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	5.5%	1.8%	10.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	6.4%	2.1%	12.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	7.3%	2.4%	14.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10	9.2%	3.0%	16.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12	11.0%	3.6%	17.9%	3.5%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
15	13.8%	4.5%	20.8%	4.2%	1.9%	1.9%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	14.3%	4.7%	21.2%	5.0%	2.3%	2.3%	0.0%	0.4%	0.4%	0.0%	0.0%	0.0%	2.3%
17	15.6%	5.0%	22.3%	7.1%	3.3%	3.3%	0.0%	1.1%	1.3%	0.1%	0.0%	0.0%	8.1%
20	18.3%	5.6%	24.7%	10.1%	6.4%	6.4%	1.7%	4.4%	3.5%	0.4%	0.2%	0.0%	14.2%
22	20.2%	6.1%	26.3%	12.3%	8.6%	8.6%	4.3%	6.3%	4.9%	13.0%	0.2%	2.5%	15.2%
25	22.9%	6.7%	28.7%	15.6%	11.9%	11.9%	7.2%	9.7%	11.2%	18.4%	0.2%	7.9%	19.6%
30	27.5%	7.9%	32.6%	26.0%	12.2%	12.2%	12.3%	14.5%	14.1%	24.2%	2.2%	12.5%	27.9%
	28.6%	8.1%	33.5%	27.0%	14.4%	14.4%	14.5%	16.0%	15.1%	25.8%	3.5%	12.7%	
35	32.1%	12.1%	36.3%	29.8%	21.0%	21.0%	21.3%	20.9%	18.3%	30.6%	7.6%	13.3%	
40	36.7%	17.3%	40.0%	33.6%	29.8%	29.8%	28.5%	25.0%	26.3%	36.6%	20.4%	14.2%	
45	41.3%	22.5%	43.8%	37.4%	38.6%	38.6%	35.3%	37.0%	24.7%	46.7%	27.9%		
	42.9%	24.4%	44.8%	38.9%	38.7%	38.7%	36.0%	37.6%	26.3%	49.0%	29.5%		
60	55.0%	32.2%	51.8%	49.9%	38.7%	38.7%	41.2%	41.9%	38.2%	65.1%	41.6%		
	57.3%	33.7%	52.9%	50.8%	41.3%	41.3%	43.5%	43.9%	39.6%	65.8%	42.9%		
75	68.8%	39.3%	58.5%	55.3%	54.5%	54.5%	55.2%	53.7%	47.1%	69.4%	49.5%		
	71.6%	40.7%	59.6%	56.6%	57.2%	57.2%	56.3%	55.8%	49.3%	69.0%	50.9%		
90	82.5%	46.0%	63.9%	61.4%	67.9%	63.9%	60.8%	63.9%	58.0%	67.6%	56.2%		
	85.9%	47.7%	65.4%	63.9%		65.4%	62.0%	65.4%	60.2%	67.4%	57.7%		
105	96.3%	52.7%	70.0%	71.4%		70.0%	65.7%	69.8%	67.0%	66.7%	62.3%		
	100.2%	54.7%	71.1%	72.6%		71.1%	67.3%	70.5%	69.4%	68.0%	64.2%		
120	110.0%	58.6%	73.8%	75.6%		73.8%	71.3%	72.2%	75.3%	71.1%	69.1%		
	114.5%	60.5%	74.9%	77.0%		74.9%	72.9%	73.8%	77.1%	73.6%	70.5%		
135	123.8%	64.2%	77.0%	80.1%		77.0%	76.2%	77.0%	80.8%	78.8%	73.5%		
	128.8%	66.3%	78.3%	80.2%		78.3%	77.4%	78.8%	82.8%	80.8%	75.2%		
150	137.5%	67.7%	80.5%	80.4%		80.5%	79.5%	81.7%	86.0%	84.3%	78.1%		
	143.2%	68.6%	81.6%	81.6%		81.6%	80.8%	83.0%	86.6%	86.2%	79.6%		
165	151.3%	71.2%	83.1%	83.3%		83.1%	82.8%	84.8%	87.4%	88.9%	81.7%		
	157.5%	73.3%	84.1%	83.1%		84.1%	83.2%	85.8%	89.1%	87.8%	82.7%		
180	165.0%	75.1%	85.3%	83.0%		85.3%	83.8%	87.1%	91.2%	86.5%	83.8%		
	171.8%	76.7%	86.4%	85.5%		86.4%	85.1%	88.4%	92.6%	86.9%	85.4%		
195	178.8%	82.4%	87.5%	88.1%		87.5%	86.4%	89.7%	94.0%	87.3%	87.0%		
	186.1%	88.4%	88.6%	88.3%		88.6%	87.6%	90.7%	94.7%	89.1%	88.4%		
210	192.5%	88.9%	89.5%	88.4%		89.5%	88.6%	91.5%	95.4%	90.7%	89.6%		
	200.4%	89.5%	90.6%	89.5%		90.6%	90.0%	92.1%	95.6%	91.5%	91.1%		
225	206.3%	90.5%	91.4%	90.4%		91.4%	91.1%	92.6%	95.8%	92.1%	92.1%		
	214.7%	91.9%	92.4%	91.0%		92.4%	92.1%	93.7%	97.0%	92.5%	93.3%		
240	220.0%	90.6%	93.0%	91.3%		93.0%	92.8%	94.4%	97.7%	92.7%	94.1%		
	229.1%	88.4%	93.8%	92.6%		93.8%	93.8%	95.5%	98.0%	93.8%	94.8%		
255	233.8%	89.1%	94.2%	93.2%		94.2%	94.3%	96.0%	98.2%	94.3%	95.1%		
	243.4%	90.7%	95.1%	94.8%		95.1%	95.5%	96.7%	98.7%	95.4%	96.3%		
270	247.5%	91.7%	95.5%	95.5%		95.5%	96.0%	97.0%	99.0%	95.9%	96.8%		
	257.7%	94.2%	96.2%	96.4%		96.2%	97.0%	97.5%	99.2%	97.1%	97.3%		
285	261.3%	95.1%	96.5%	96.8%		96.5%	97.3%	97.6%	99.3%	97.5%	97.5%		
	272.0%	97.7%	97.5%	97.8%		97.5%	98.1%	98.3%	99.3%	97.0%	98.2%		
300	275.1%	97.9%	97.8%	98.1%		97.8%	98.3%	98.5%	99.3%	96.9%	98.4%		
	286.3%	98.8%	98.3%	98.9%		98.3%	98.8%	98.9%	99.6%	99.3%	99.0%		
315	288.8%	99.0%	98.4%	99.0%		98.4%	98.8%	99.0%	99.7%	99.9%	99.2%		
	300.6%	100.0%	99.3%	99.6%		99.3%	99.5%	99.9%	99.9%	100.0%	99.9%		
330	302.6%		99.4%	99.7%		99.4%	99.6%	100.0%	99.9%	100.0%	100.0%		
345	316.3%		100.0%	100.0%		100.0%	100.0%		100.0%				

APPENDIX D - COMPUTER MODEL

POTENTIAL FLOW SOLUTION
FLOW IN A WATER SUPPLY TANK

HENRY T. FALVEY

May 6, 1997

INTRODUCTION

The program uses a finite difference scheme to solve the Euler equation for flow in a rectangular tank. This equation is also known as the potential flow equation. The Euler equation is given by

$$\frac{\partial^2 \psi}{\partial X^2} + \frac{\partial^2 \psi}{\partial Y^2} = 0$$

in which ψ is a stream function. The width of the flow path between lines of equal values of the stream function indicate the flow velocity. The equation is applicable for non viscous flow and a constant depth. If bottom and wall friction are not large, then this equation can be used to estimate the circulation patterns in a water storage tank.

The Euler equation can be solved for a wide variety of shapes through the use of a finite difference grid that has equal increments in the X and Y directions. If values of the stream function can be specified on the boundaries, then the value of the stream function can be determined by successive application of the following equation to all points within the boundary until the value of $\psi_{i,j}$ changes by only a negligible amount.

$$\psi_{i,j} = (1 - \omega)\, \psi_{i,j} + \frac{\omega}{4}\, [\psi_{i-1,j} + \psi_{i+1,j} + \psi_{i,j-1} + \psi_{i,j+1}]$$

In this equation ω is called an over-relaxation operator and is defined as

$$\omega_{opt} = \frac{8 - 4\sqrt{4 - \alpha^2}}{\alpha^2}$$

in which

$$\alpha = \cos\left(\frac{\pi}{m}\right) + \cos\left(\frac{\pi}{n}\right)$$

and m and n are, respectively the total number of increments along the X and Y axes. The

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counters i and j are taken in the X and Y directions respectively.
The stream function for the Fort Collins reservoirs was calculated by assigning a value of 1.0 to stream function of the outer boundary. The line between the inlet and the outlet was assigned a value of 0.0. The extension of the line beyond the outlet was assigned a value of 1.0. Fifty increments along each side were used to simulate the flow in the reservoir. Simulations showed that 35 iterations were needed to reduce the maximum error in the stream function to a value of about 0.0001. The results are shown in bands of stream functions in which each corresponds to a change of 0.1 units.

PRACTICAL CONSIDERATIONS

Predictions from the programs should be verified with the physical model investigations. The potential flow solution should reproduce streamlines observed in the physical model with two exceptions. First, the depth is assumed to be uniform in the mathematical model. The sloping areas are expected to have some affect on the distribution of the streamlines. Secondly, the potential flow solution assumes that the inflow and the outflow are distributed uniformly over the depth of the tank. The inflow and outflow enter the tank through finite diameter ports near the floor. Some distance is required for the flow to become distributed over the entire depth of the tank. Thus, the streamlines from the program may not be accurate near the inlet and outlet portions of the tank.

PROGRAM DESCRIPTION

The program is supplied on a 3 1/2 inch diskette named **Bates.exe.** The program can be run from Windows 3.x or Windows 95. All that is necessary is to locate the program in either operating system and double click on the file. A form will appear that shows the coordinates of the inlet and outlet pipes. The X coordinate of the inlet cannot be changed, but all other coordinates can be varied by the user. The **Help** menu gives the appropriate coordinates for both the east and the west reservoir configurations. The user can investigate the effect of moving either the inlet or the outlet to other locations by inputting the appropriate coordinates. After entering the appropriate coordinates, the user should click on the **Calculate** button. The text on the button will change and show the status of the computations. First, the progress of the computations are shown (as a percentage) and then the progress of the plot are shown (also as a percentage). When the computations are completed, a display of the streamlines is presented in shades of yellow and green. These show the approximate path that would be taken by dye if it were injected within the flow. The thickness of the band is an indicator of the flow velocity. Thin bands correspond to high velocities and thick bands to low velocities. As an example, the yellow band that defines the axis between the inlet and outlet is so thin that it disappears near the inlet and the outlet pipes. The disappearance is a result of such high velocities along the axis that the plotting resolution is unable to exactly define its boundary. At the other extreme, the velocities are very low near the corners of the tank as evidenced by the large thickness of the bands. After completing a computation, the location of the inlet or the outlet can be changed and the simulation repeated. To exit the program, the user should click on the **File** menu and select **Exit**.

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This will return the user to Windows . The **PlotForm** and a **PlotGraph** options on the **File** menu are still under development.

APPENDIX E - SELECTED PHOTOGRAPHS

Photo Captions

1. Overall view of the model looking from the southeast during Test 4. 250-gallon plastic supply tank is at top left. West Reservoir 36-inch inlet at left center. East Reservoir 60-inch outlet at bottom center and West Reservoir 60- and 36-inch outlets at right center. Fourteen black conductivity probes are secured to columns and are fed to an electric switchbox and conductivity meter at right (not shown).

2. Close-up of West Reservoir 36-inch inlet during Test 3. In background, Jim Light of Denver Water is measuring conductivity values at column D3.

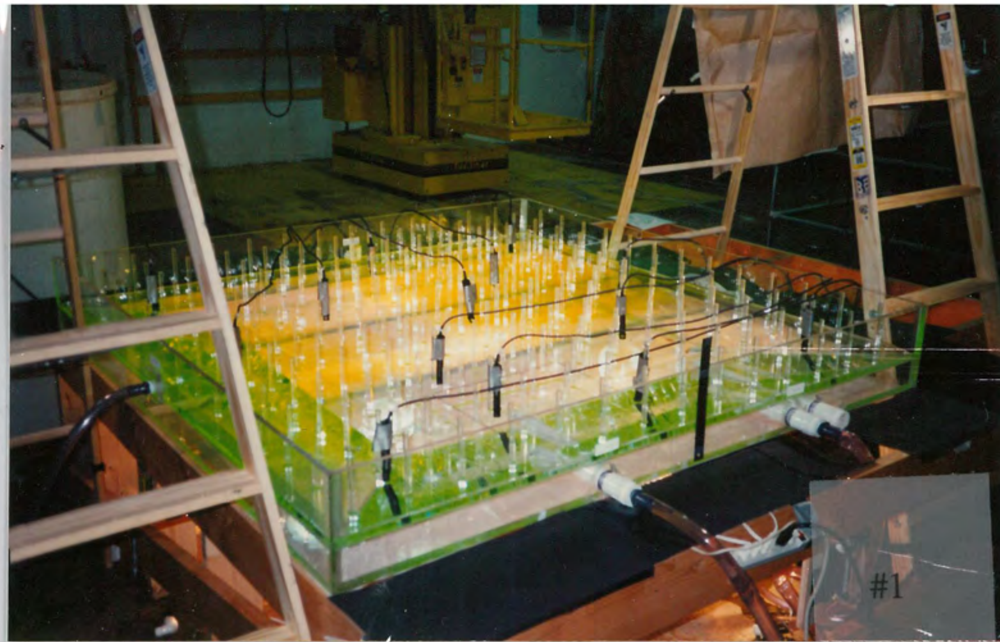
3. Close-up of short circuiting of model corners. Taken at southeast corner at t=30 minutes during Test 13.

4. Close-up of the recommended baffle configuration (Baffle #3) for the West Reservoir inlet (Test 15, t=2 minutes).

5. Close-up of the recommended baffle configuration (Baffle #3) for the West Reservoir outlet (Test 15, t=19 minutes).

6. Close-up of the recommended baffle configuration for the West Reservoir outlet (Test 13, t=22 minutes).

Note: Photographs taken above the model at regular time intervals are included in a separate binder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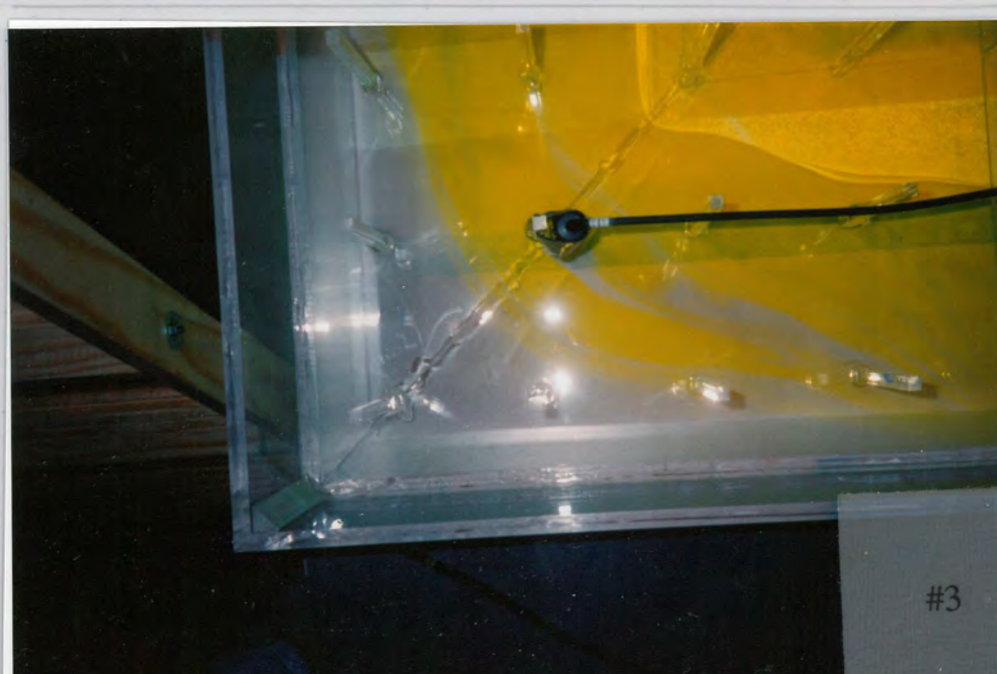
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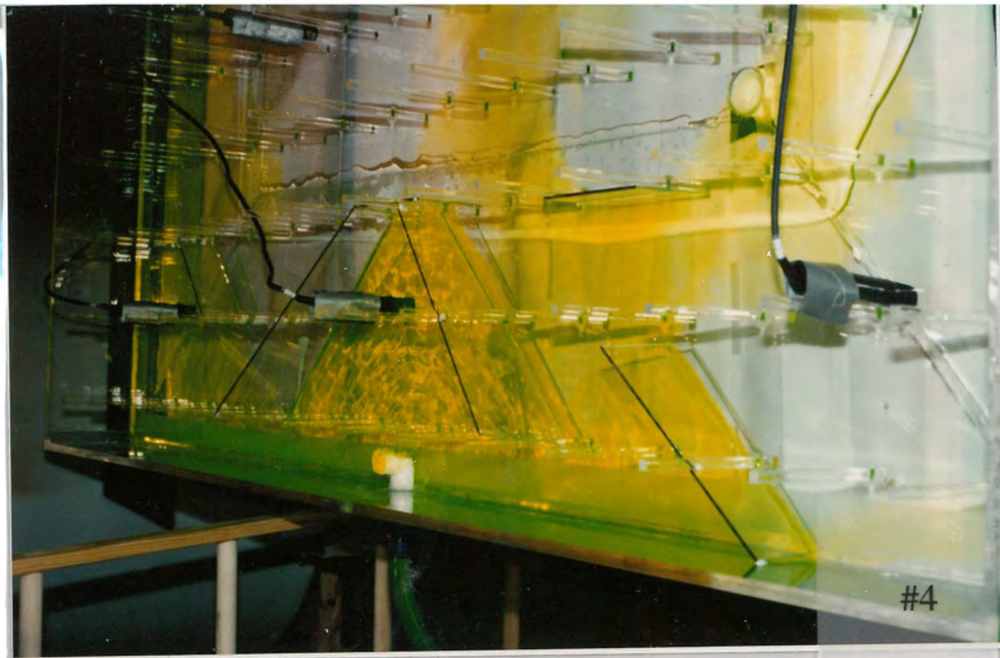
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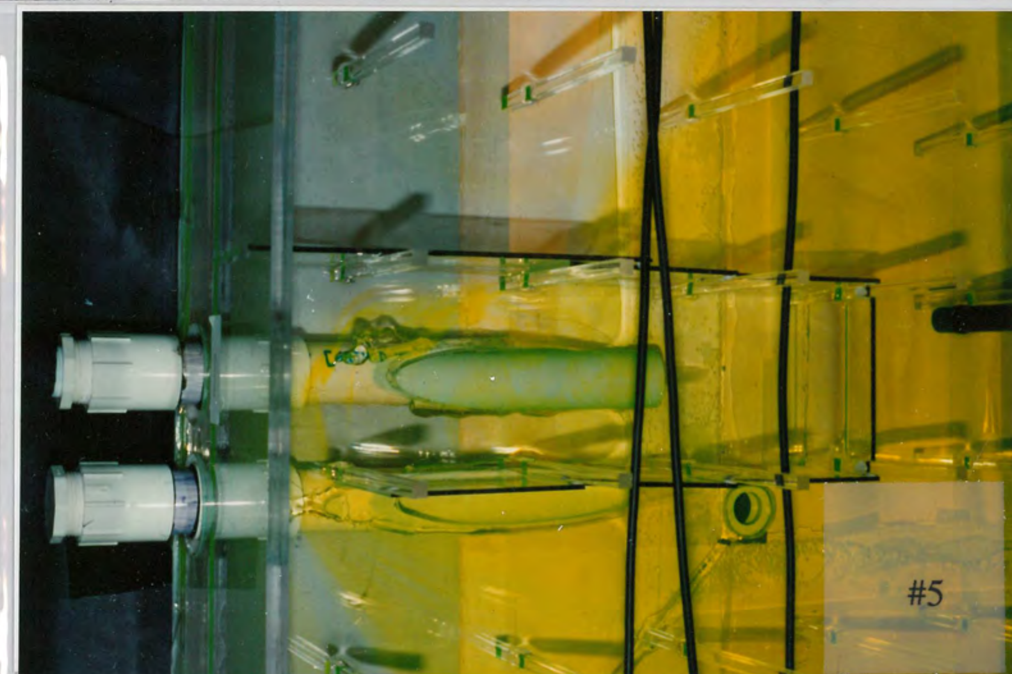
#5


#6