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Potable Water Pipe Inspection at Westover Air Reserve Base, Chicopee, MA

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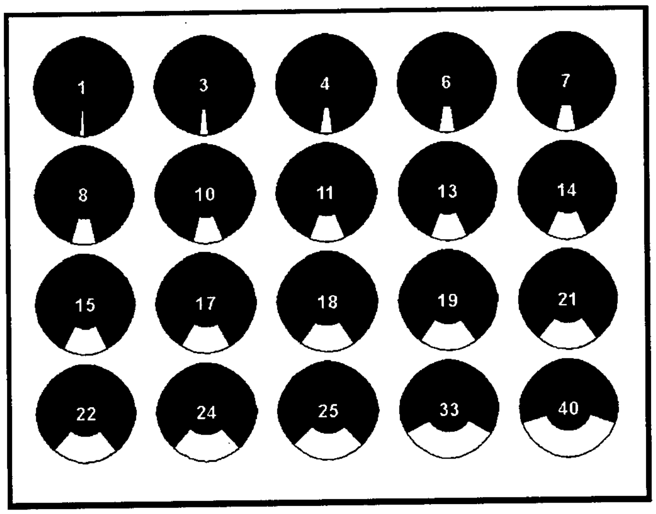

An asphaltic sealed, concrete-lined, iron water distribution system was installed at Westover ARB in 1997. Although the city water provided to the system is of good quality, various measures of water quality in the local system indicate that one or more serious problems exist in the Base's water-pipe system. This study conducted a video inspection of the pipe system, analyzed the inspection videotapes, and estimated the percentage of coating losses and cleanliness inside the various sections of water main pipe. The study concluded that the water quality problems were likely due to poor materials and workmanship during system installation, and recommended specific changes in chemical water treatment.

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An asphaltic sealed, concrete-lined, iron water distribution system was installed at Westover ARB in 1997. Although the city water provided to the system is of good quality, various measures of water quality in the local system indicate that one or more serious problems exist in the Base's water-pipe system. This study conducted a video inspection of the pipe system, analyzed the inspection videotapes, and estimated the percentage of coating losses and cleanliness inside the various sections of water main pipe. The study concluded that the water quality problems were likely due to poor materials and workmanship during system installation, and recommended specific changes in chemical water treatment.

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Foreword

This study was conducted for the Department of the Air Force under Military Interdepartmental Purchase Request (MIPR) No. NCE 0048000002; Work Unit GH8, "Water Distribution System Inspection." The technical monitor was Jack Moriarty, SPTG/CEV.

The work was performed by the Materials & Structures Branch (CF-M) of the Facilities Division (CF), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL principal investigator was Charles P. Marsh. Orange S. Marshall, Jr. was Associate Investigator and Brian Temple and James T. Petty were student contractors for the project. Ilker R. Adiguzel is Chief, CECER-CF-M and Michael Golish is Chief, CECER-CF. The CERL technical editor was William J. Wolfe, Information Technology Laboratory.

The Director of CERL is Dr. Michael J. O'Connor.

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1 Introduction

Background

An asphaltic sealed, concrete-lined, iron water distribution system was installed at Westover Air Reserve Base (ARB) in 1995. Although the water provided to the system by the town of Chicopee, MA is of good quality, various measures of water quality in the local system indicated that one or more serious problems existed. As a result, those areas of the installation served by this potable water system were forced to use bottled water. At some locations on the base, the pH was excessively high, the residual chlorine was almost undetectable, and at the time, excessive bacteria were detected. Flushing of the new water lines produced large amounts of soil, rocks, pieces of material similar to internal water pipe lining, and other foreign materials. This explained the inability to correct the problem with chemical treatment alone since the presence of soil and prolonged exposure to bare concrete were never considered nor accounted for in the design of the water treatment procedures. The nature of the material flushed from the systems indicated a strong possibility that faulty workmanship and/or the use of inferior materials at the time of installation are the root cause of ongoing and extensive water quality problems.

Objectives

The objectives of this work were to verify and document (in-situ) by video camera the extent of the asphaltic seal coat disbondment from the potable water piping and to make recommendations as to how best to solve the problem.

Approach

CERL Investigators visited Westover ARB on two occasions, 31 March and 09 June 1998, to discuss the scope of the investigation, and to test and inspect the system. A remote video camera system was inserted into multiple portions of the distribution system to record the extent and location of coating disbondment. This documented, on videotape, the current state of the pipe coating, as well as the debris still present within the system. As appropriate, samples of asphaltic coating, soil, and water were taken for later analysis and comparison with applicable commercial and military specifications.

Following the analysis of the data, recommendations for the best methods of mitigating or minimizing the problem are provided.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	54 cm
1 mil	=	0.00254 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 sq in.	=	6.452 cm^2
1 sq ft	=	0.093 m^2
1 sq yd	=	0.836 m^2
1 cu in.	=	16.39 cm^3
1 cu ft	=	0.028 m^3
1 cu yd	=	0.764 m^3
1 gal	=	3.78 L
1 lb	=	0.453 kg
1 kip	=	453 kg
1 psi	=	6.89 kPa
°F	=	(°C x 1.8) + 32

2 Preliminary Pipe Inspection/Testing

CERL Investigators visited Westover ARB to discuss the scope of the investigation and talk to those in Base Civil Engineering familiar with the history of the problem and its current status. A short piece of the 6-in water main pipe material left over from when the main was installed was given to the CERL investigators along with two petrie dishes containing samples of pipe coating material that washed out of the system when Westover conducted a "soft" pigging operation to clean the system without risking (further) damage to the system.

The 6¼-in long pipe section was evaluated in the laboratory at CERL. The pipe is made of iron with an asphaltic outer coating. The inside liner of the pipe consists of a layer of cementitious material, approximately 1/8-in thick, followed by a thin, 1-5 mil coating of asphalt epoxy material inside of that.

CERL investigators examined the coating materials in the petrie dishes. The material in the first petrie dish was soft and pliable, and appeared to be partially cured lining material (Figure 1). It was the same thickness and color as the inner lining material of the pipe previously examined. The several pieces stuck together and had to be pulled apart for examination. The material in the second petrie dish appeared to be fully cured (Figure 2). It was black in color with a thin, smooth layer of cementitious material on one side. A small portion of the inner coating material was removed for microscopic evaluation by chipping it off with a chisel and hammer. Examination of the coating pieces removed showed a much thicker layer of cementitious material, and a much rougher cementitious surface than the samples in the petrie dish.

To evaluate the susceptibility of damage to the pipe lining due to sudden impact, the outside of the pipe was struck with a sledgehammer. A small portion of the inner liner popped off at the point of impact. The piece that popped off had the same thin coat of cementitious material on it as was seen on the sample in the second petrie dish. The cementitious material remaining on the inside of the pipe appeared unaffected (Figure 3). This indicates that sudden impact will cause the inner asphalt-epoxy liner to separate, leaving bare cement. The asphalt epoxy inner lining material from the pipe provided to CERL and the two different materials provided to CERL in the petrie dishes were also examined using scanning electron microscope elemental analysis. This analysis confirmed that all of the materials were also chemically the same.

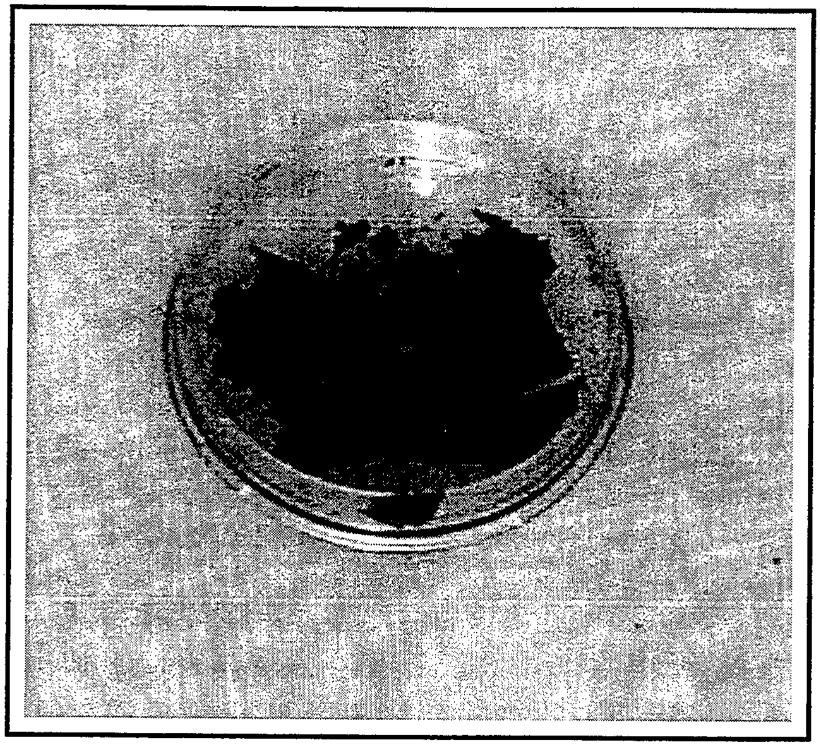

Figure 1. Uncured coating recovered following flushing.

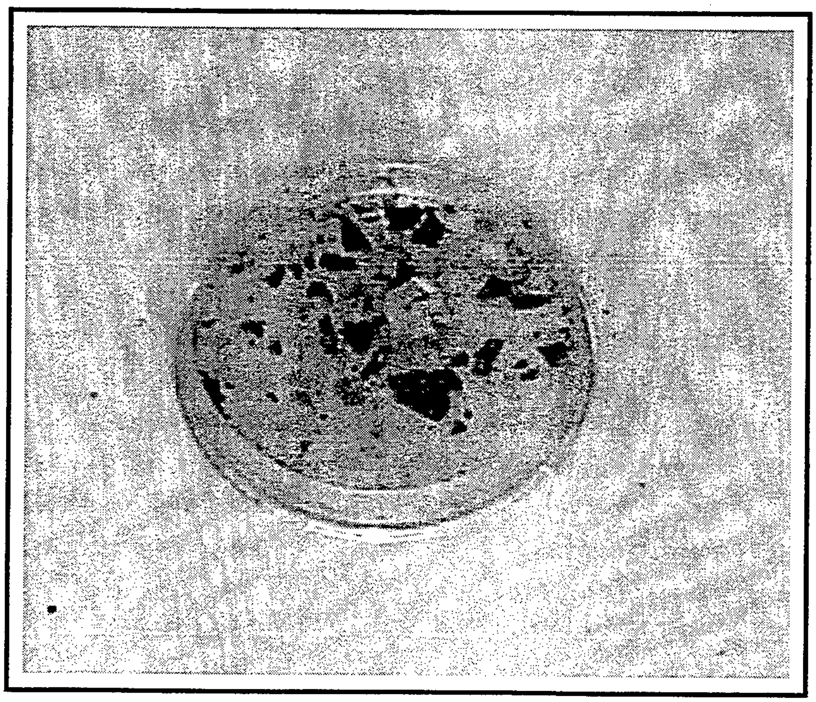

Figure 2. Cured coating recovered following flushing.

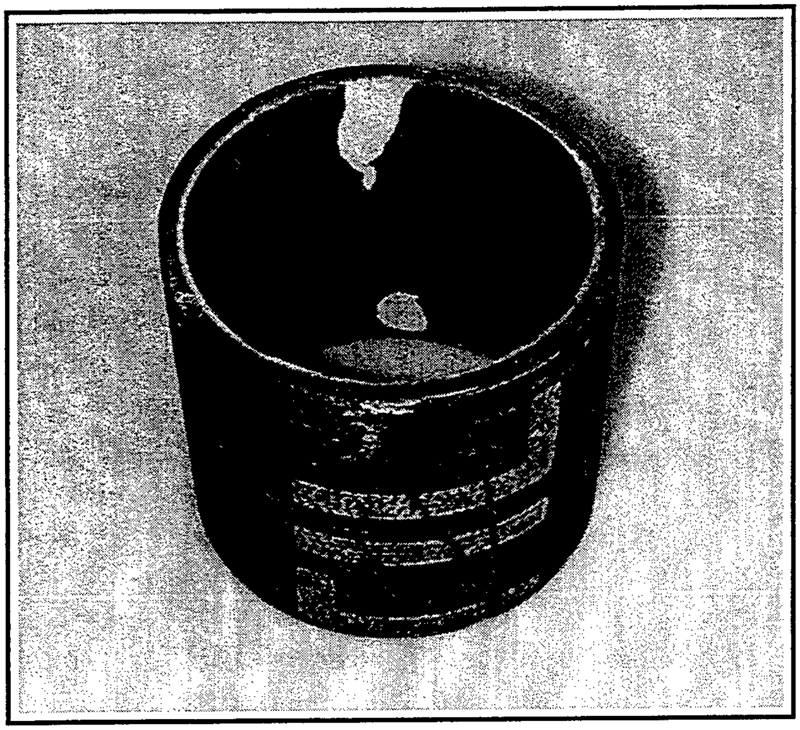

Figure 3. Inside of pipe sample where struck with sledgehammer.

3 Testing, Inspection, and Simulation

Water Chemistry Measurements

Tables 1 to 4 list the water chemistry measurements taken at Westover ARB.

Table 1. Building 7980 water chemistry data.

Date/Time	Measured Parameter	Value	Observations	Comments
31MAR9 0955	Total Alkalinity	< 10 ppm	No Color Change	First Run
31MAR98 1022	Total Alkalinity	< 10 ppm	No Color Change	Second Run
31MAR98 1000	Carbon Dioxide	< 10 ppm	No Color Change	First Run
31MAR98 1026	Carbon Dioxide	< 10 ppm	No Color Change	Second Run
31MAR98 1004	Total Hardness	< 20 ppm	No Color Change	First Run
31MAR98 1031	Total Hardness	< 20 ppm	No Color Change	Second Run
31MAR98 1009	Dissolved Oxygen	10 ppm		First Run
31MAR98 1036	Dissolved Oxygen	9 ppm		Second Run
10JUN98 1115	pH	7.8	Temperature 54 F	FcL_2=0.76, TcL_2=0.88
10JUN98 1118	Total Alkalinity	< 10 ppm	No Color Change	
10JUN98 1122	Carbon Dioxide	< 10 ppm	No Color Change	
10JUN98 1127	Total Hardness	< 20 ppm	No Color Change	
10JUN98 1131	Dissolved Oxygen	10 ppm		

Table 2. Building 1850 water chemistry data.

Date/Time	Measured Parameter	Value	Observations	Comments
31MAR9 1426	Total Alkalinity	< 10 ppm	No Color Change	First Run
31MAR98 1454	Total Alkalinity	< 10 ppm	No Color Change	Second Run
31MAR98 1422	Carbon Dioxide	< 10 ppm	No Color Change	First Run
31MAR98 1449	Carbon Dioxide	< 10 ppm	No Color Change	Second Run
31MAR98 1419	Total Hardness	< 20 ppm	No Color Change	First Run
31MAR98 1444	Total Hardness	< 20 ppm	No Color Change	Second Run
31MAR98 1431	Dissolved Oxygen	11 ppm		First Run
31MAR98 1457	Dissolved Oxygen	10 ppm		Second Run
10JUN98 0955	pH	9.3	Temperature 59 F	FcL_2=0.09, TcL_2=0.18
10JUN98 1000	Total Alkalinity	< 10 ppm	No Color Change	
10JUN98 1004	Carbon Dioxide	< 10 ppm	No Color Change	
10JUN98 1009	Total Hardness	< 20 ppm	No Color Change	
10JUN98 1015	Dissolved Oxygen	10 ppm		

Table 3. Building 2450 water chemistry data.

Date/Time	Measured Parameter	Value	Observations	Comments
10JUN98 1310	pH	7.9	Temperature 59 F	FcL_2=0.47, TcL_2=0.59
10JUN98 1314	Total Alkalinity	< 10 ppm	No Color Change	
10JUN98 1319	Carbon Dioxide	< 10 ppm	No Color Change	
10JUN98 1324	Total Hardness	< 20 ppm	No Color Change	
10JUN98 1328	Dissolved Oxygen	10 ppm		

Table 4. Building 5600 water chemistry data.

Date/Time	Measured Parameter	Value	Observations	Comments
9JUN98	Total Alkalinity	< 10 ppm	No Color Change	
9JUN98	Carbon Dioxide	< 10 ppm	No Color Change	
9JUN98	Total Hardness	< 20 ppm	No Color Change	
9JUN98	Dissolved Oxygen	8 ppm		
10JUN98 0800	pH	8.7	Temperature 59 F	FcL_2=0.14, TcL_2=0.30
10JUN98 0805	Total Alkalinity	< 10 ppm	No Color Change	
10JUN98 0809	Carbon Dioxide	< 10 ppm	No Color Change	
10JUN98 0813	Total Hardness	< 20 ppm	No Color Change	
10JUN98 0818	Dissolved Oxygen	10 ppm		

Pipeline Inspections

Two separate trips were made to Westover to perform video inspection of the potable water pipes. The main objective of the first inspection was to examine the condition of the epoxy-asphalt inner linings of the pipes and to determine the quantity of losses, if any. The purpose of the second inspection was to evaluate the cleanliness of the interior of the pipes. Figure 4 shows the Scooter Video Inspection System used to inspect the interior of the Westover water mains. The system consists of a video camera head attached to the end of a cable, which is attached to a video cassette recorder and a television monitor for viewing.

Lining Inspections

The lining of the water system was inspected using the Scooter System. Figure 5 shows a model of the Westover water distribution system. Gate valves were removed at the insertion points and the scooter camera was inserted into the pipeline. For each run, the camera was pushed by hand to the maximum extent of each run into the pipe stopping at 1-ft intervals. The camera was then extracted, also by 1-ft increments. The interior of the pipe was recorded on videotapes, and the videotapes were taken back to the laboratory for analysis. A total of 2660 ft of pipe was inspected.

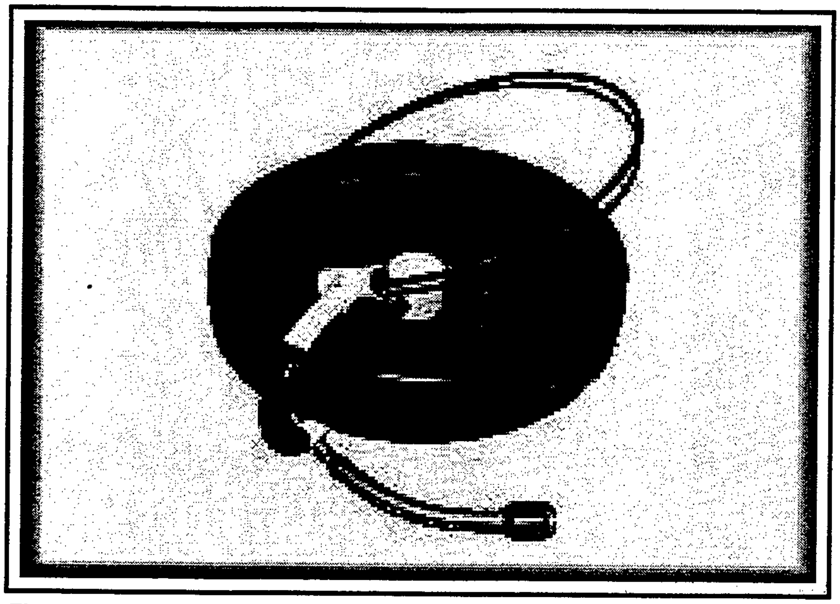

Figure 4. Scooter video camera system.

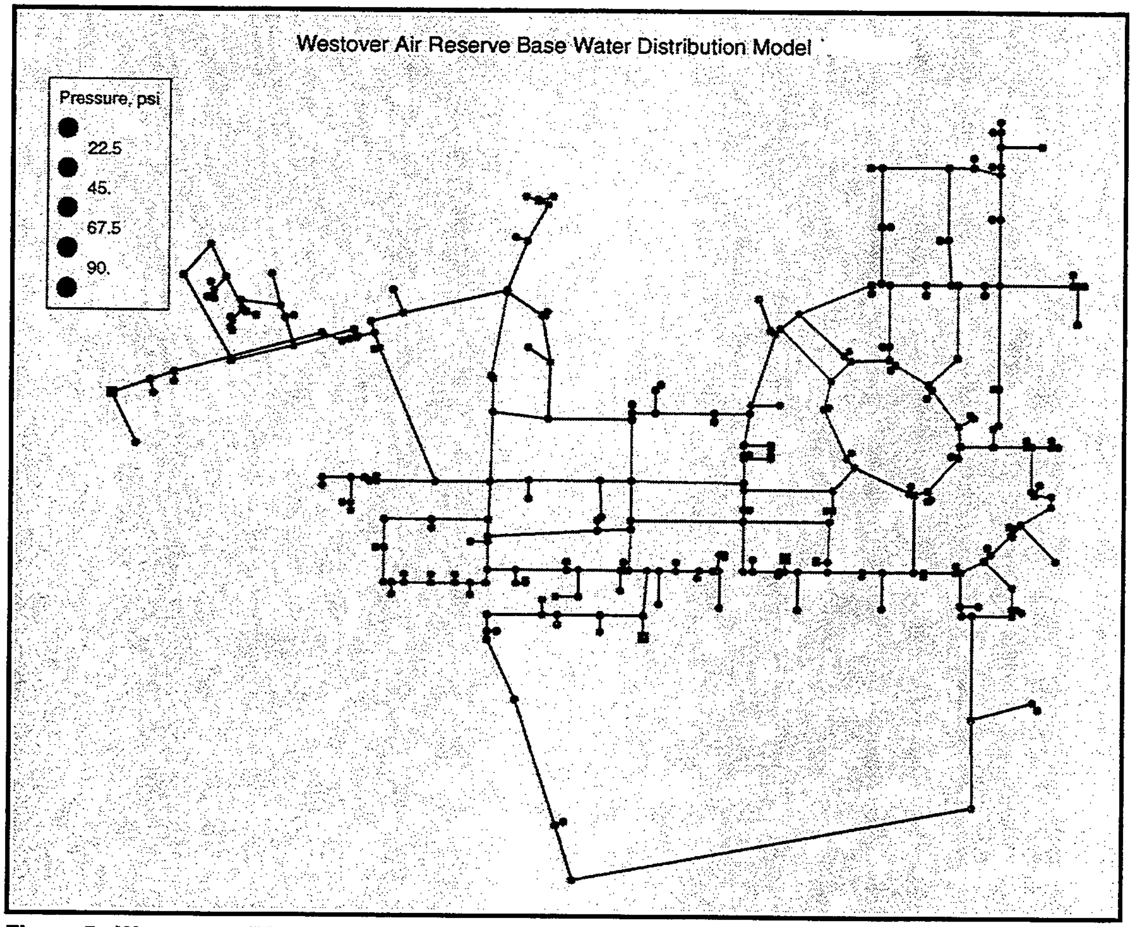

Figure 5. Westover ARB water distribution system.

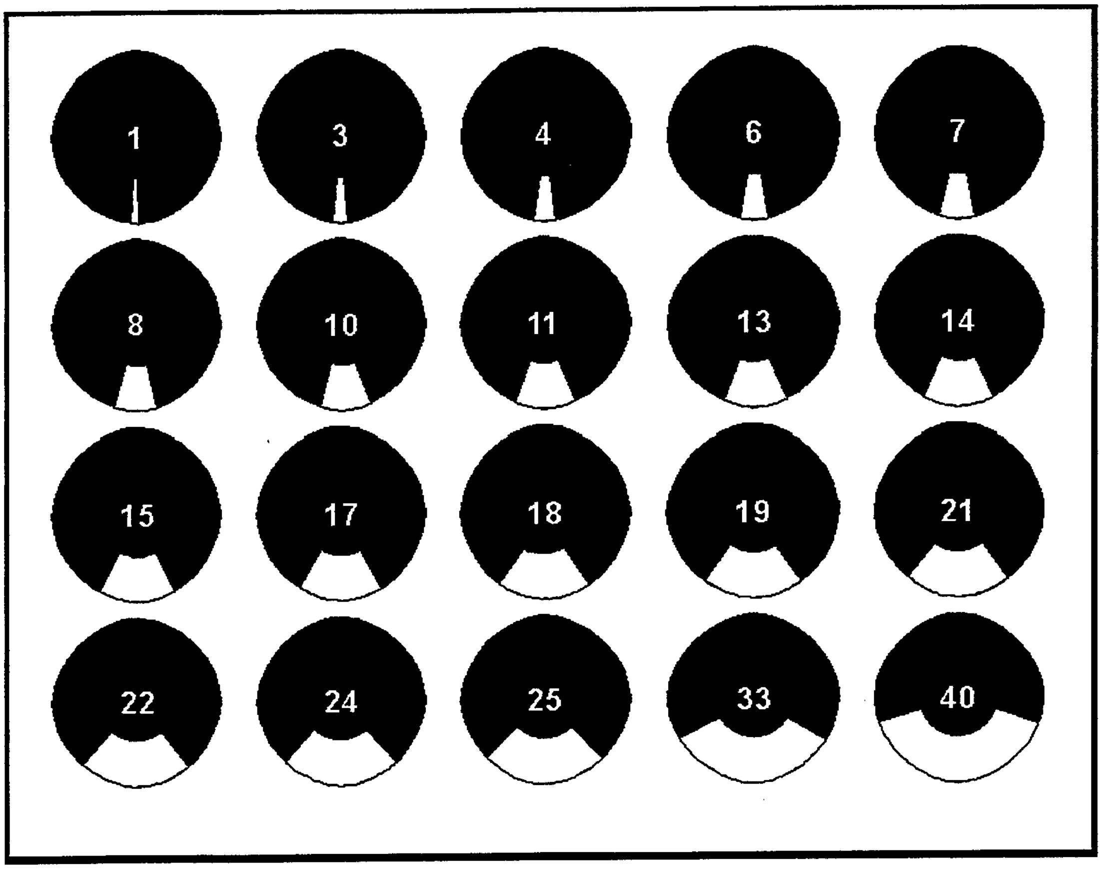

Figure 6. Coating loss estimating chart.

A loss-estimating chart (Figure 6) was developed to aid in estimating the amount of lining losses visible on the video. The videotapes were played back and the amount of missing lining was estimated for each 1-ft interval along the mains that were inspected. Table 5 lists the total length of each run and the average lining losses for each run for the first inspection visit. Appendix A contains the individual 1-ft coating loss estimates.

Table 6 lists the total length of each run, the average lining losses, and the degree of cleanliness for each run of the water mains inspected during the second inspection visit. Appendix B contains the individual 1-ft coating loss estimates and cleanliness notes.

Table 5. Estimation of coating loss in water main pipe during first site visit.

Run	Location	Average Coating Loss (%)	Length Inspected (ft)
1	NW from Walker along Eagle at toward Monument	4.9	120
2	South from Monument along Eagle toward Walker	4.7	109
3	North from Monument South along Eagle towards Monument North	6.8	30
4	NW from Starlifter to Burke along Eagle	9.8	114

Run	Location	Average Coating Loss (%)	Length Inspected (ft)
5	SW from Starlifer along Eagle toward Monument North	21.1	86
6	NE from Starlifter along Eagle toward Globemaster	32.8	83
7	SE along Starlifter toward Eagle	27.6	93
8	NW along Starlifter toward Burke	5.9	58
9	SW from Burke along Globemaster toward Eagle	3.7	90
10	NE from Globemaster along Burke	1.7	89
11	SW from Globemaster along Burke	0.9	83
12	NW from Eagle along Globemaster	2.0	98
13	NE from Globemaster along Eagle	12.1	122
14	SW from Globemaster along Eagle	3.5	122
15	NE from Airlifter along Walker	5.2	109
16	NW from Walker along Airlifter	1.1 *	62
17	SE from Walker along Airlifter	0.3 *	66
18	West from Airlifter along Galaxy	0.3	60
19	SE from Galaxy along Airlifter	1.8	56
20	South from Bldg. 5600 along Airlifter	8.1	74
21	North from Bldg. 5600 along Airlifter	1.7	87
* Camera field of view too narrow to easily estimate coating loss in 12-in. diameter pipe			

Table 6. Estimation of coating loss and cleanliness in water main pipe during second inspection.

Run	Location	Average Coating Loss (%)	Cleanliness	Length Inspected (ft)
22	SE from behind Bldg 1601 along Hanger Ave.	1.8	Sediment in last 3 ft of pipe	23
23	NW from behind Bldg 1601 along Hanger Ave.	2.5	Viewed only first 12 ft due to bend in pipe, clean	12
24	NW from Gym along Patriot towards Pittsburgh	3.0	Relatively clean	96
25	SE from Gym along Patriot	0.7	Relatively clean	90
26	SE from Eagle along Hanger Drive Towards Pittsburgh	6.2	Relatively clean	34
27	NW from Eagle along Hanger Drive	0 *	Unknown *	0 *
28	SE from Eagle along Patriot toward Pittsburgh	1.9	Relatively clean	91
29	NW from Eagle along Patriot	0.0	5 ft of gravel towards end of pipe	63
30	SW from far hydrant along Recall	0.0	Gravel and silt throughout the 20 ft of viewable pipe	20
31	NE from far hydrant along Recall	3.4	6 ft of gravel in mid section of pipe	105

Run	Location	Average Coating Loss (%)	Cleanliness	Length Inspected (ft)
32	NW from Patriot up the hill along Sanders toward Recall	2.0	Silty/cloudy in final 5 ft of pipe	103
33	SE from Patriot along Sanders toward Hanger	0.05	Silt varied, more towards beginning, less towards end	105
34	NE from Sanders along Patriot	2.2	Moderately silty through-out pipe	107

* Approximately 1/8-in thick plastic in pipe blocking inspection access. Unable to inspect using Scooter.

EPANET Simulation

Simulations for determining flushing routines, water flow patterns, and chemical additive distribution were sought as a tool for analyzing different problems in the Westover ARB water distribution system. A program available to the public, EPANET, was obtained and initial data input gathered for use on the Westover project.* EPANET can predict flow patterns, line pressures and velocities, and chemical concentrations in the distribution network when all data input parameters are obtained. The outputs can be graphed or displayed on a model of the system to clearly illustrate the results. The EPANET program gives the operator the ability to quickly model various scenarios in the system to predict/diagnose different problems and explore the results of modifications to the distribution network. EPANET results that differ significantly from verification measurements can be used to identify problem areas in the system.

Figure 5 shows an EPANET model of the Westover water distribution system. Initial data runs for the system were made from water pressure, velocity, and chemical concentration measurements taken at Westover. (Appendix B contains the input file for the EPANET program.) Results showed that additional input data were required in the simulation. Differences in the results showed that the distribution network shown in the blue prints may not be correct.

* EPANET is a software program for modeling hydraulic and water quality behavior within water distribution systems, developed by the USEPA's Water Supply and Water Resources Division, and programmed by Computational Hydraulics, Int. (CHI). EPANET is publicly available for download through the INTERNET from the website: http://www.chi.on.ca/epanetdownload.html.

4 Discussion

Pipe Inspection

Many segments of pipe were in perfect condition (with little or no coating loss) while other segments contained coating loss of up to 50 percent. In some instances, several lengths of pipe were in near perfect condition, followed by a section or two in poor condition, then several more in great condition. In such cases, just the one length or two, from joint to joint, contained high levels of coating loss while the surrounding lengths of pipe were in good condition.

At some locations, sections of pipe contained a series of consecutive rings of coating loss (Figure 7). This occurred in one or two lengths of pipe, from joint to joint, while the other surrounding lengths of pipe are not affected. In some sections, areas of coating loss were intermittent (Figure 8).

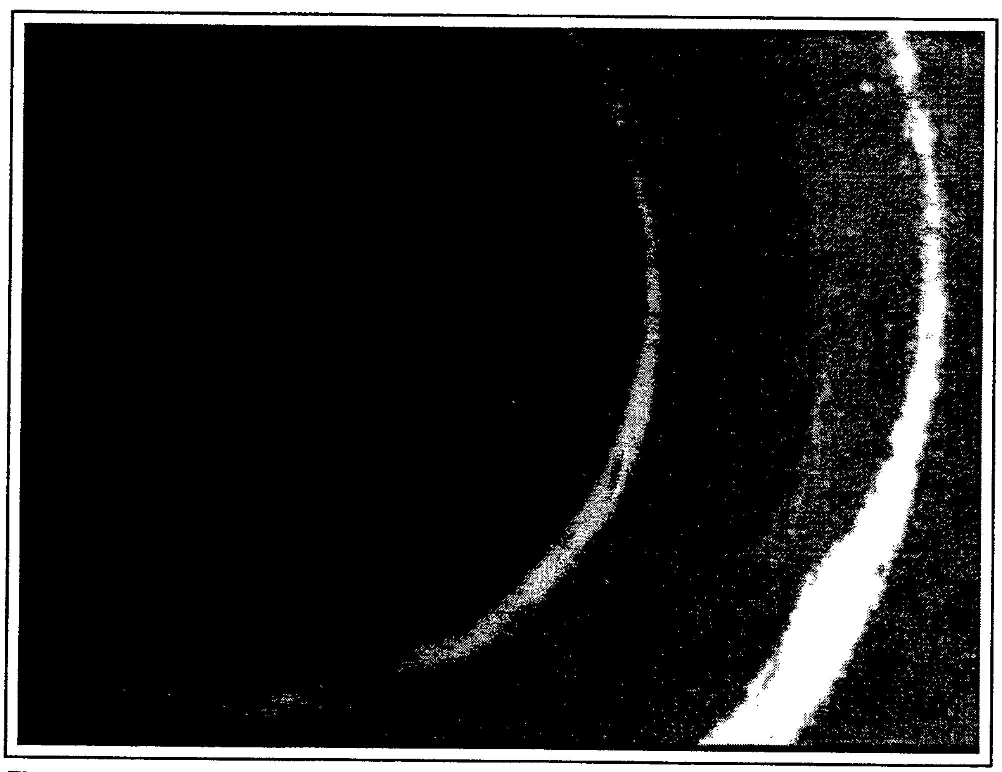

Figure 7. Rings of coating loss.

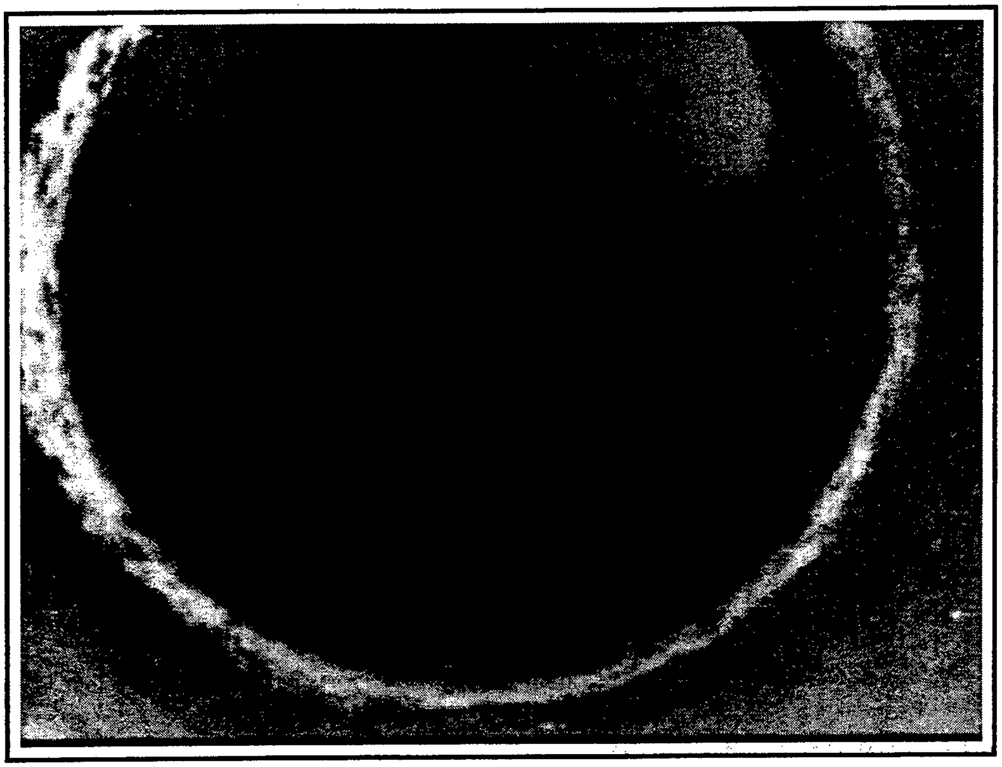

Figure 8. Period losses of coating on seen on the top of photo.

Many sections of pipe contain a strip of coating loss throughout the length of that section (Figure 9). These strips typically contain a coating loss of around 2-3 percent. At times, these strips appeared to be sediment buildup at the bottom of the main. However, the strips were not always lined up across pipe joints. Figure 10 shows one such strip of lining loss next to an air bubble that appears as a black strip. Air bubbles and sediment not being opposite sides of the pipe verify that the white strips is coating loss. Strip losses are probably due to poor mixing or segregation of the chemical components during application in the factory.

Some inspected sections showed evidence of scouring from a pigging operation (Figure 11). It appears that gravel may have lodged between the pig and the pipe wall as the pig went through the main. The coating appears scratched but the scratches do not appear to penetrate the thickness of the coating. Large coating losses are evident on the left side of Figure 11.

Inspection revealed occasional holidays in the lining (Figure 12). Holidays (typically very small pin-size holes in a coating) always occur in coatings. However, the holidays observed in the Westover water mains are not pin-hole size; they are much larger. Such large holidays may occur due to lack of wetting of the substrate during manufacture, too thin an application of the coating, or dirt and other foreign objects adhering to the cement substrate during manufacture.

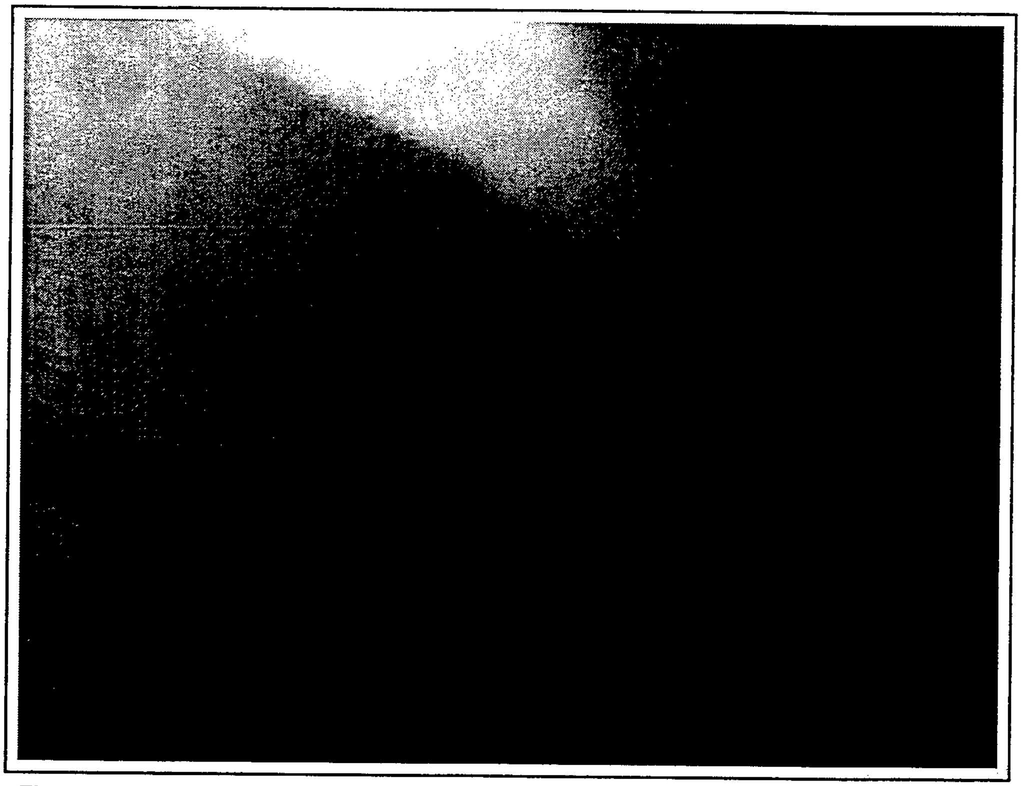

Figure 9. Strip of missing coating running the length of the pipe.

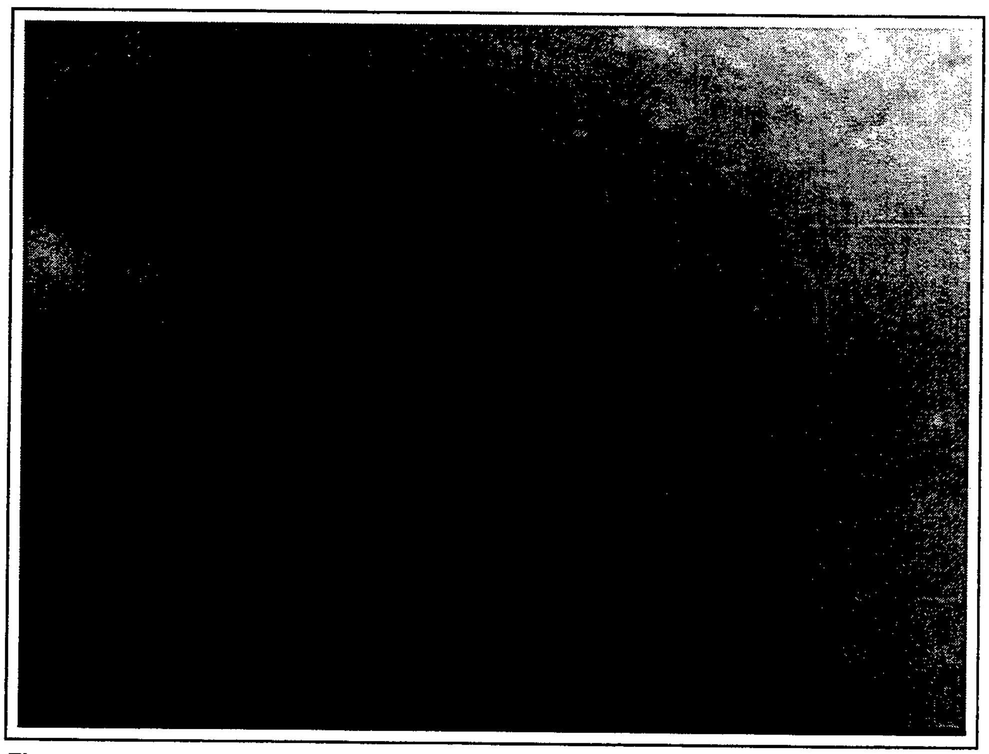

Figure 10. Black strip is an air bubble indicating white strip is not sediment.

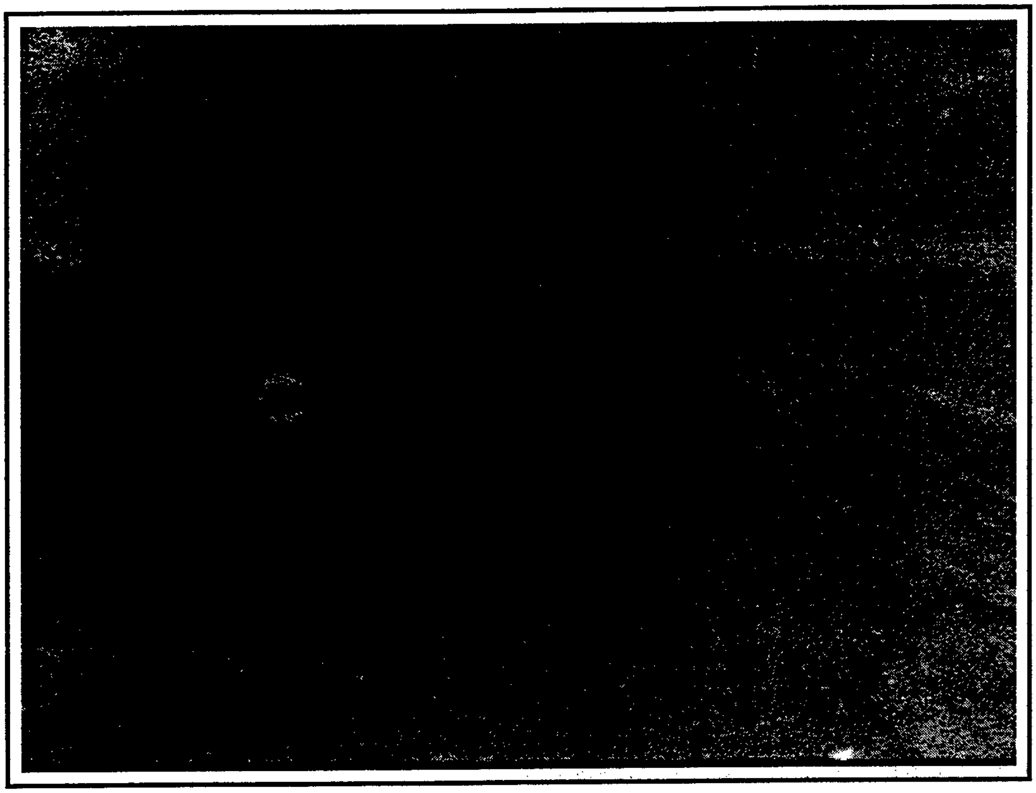

Figure 11. Scouring by pig evident from parallel lines scratched in coating.

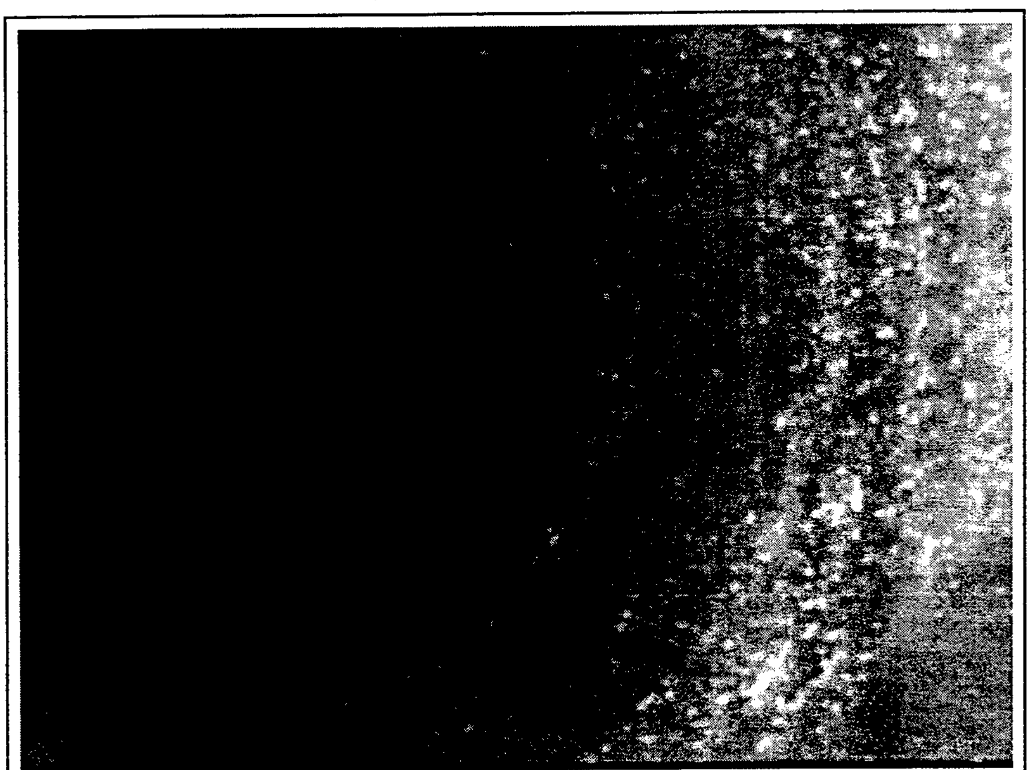

Figure 12. Holidays in the coating.

All welded joints are clearly visible in the video (Figure 13). The joints are frequently misaligned, and are always missing coating. A close-up view of one joint shows large tubercles that would indicate significant corrosion (Figure 14).

The inspection showed a problem with debris in the mains at some locations. At the corner of Eagle and Hanger, a piece of plastic material lodged in the line would not allow the camera to enter the main (Figures 15 and 16). The plastic was close enough to the entry point that attempts were made to reach in and pull the piece out of the pipe. However the plastic was wedged too tightly to move in any direction. Silt was evident in water lines (Figure 17). A few isolated pieces of gravel were observed in the mains (Figure 18). No dense concentrations of gravel were observed. The system dead ends were dirtier than the rest of the system. A few more pieces of gravel and a more silt were seen there than were seen in the mains.

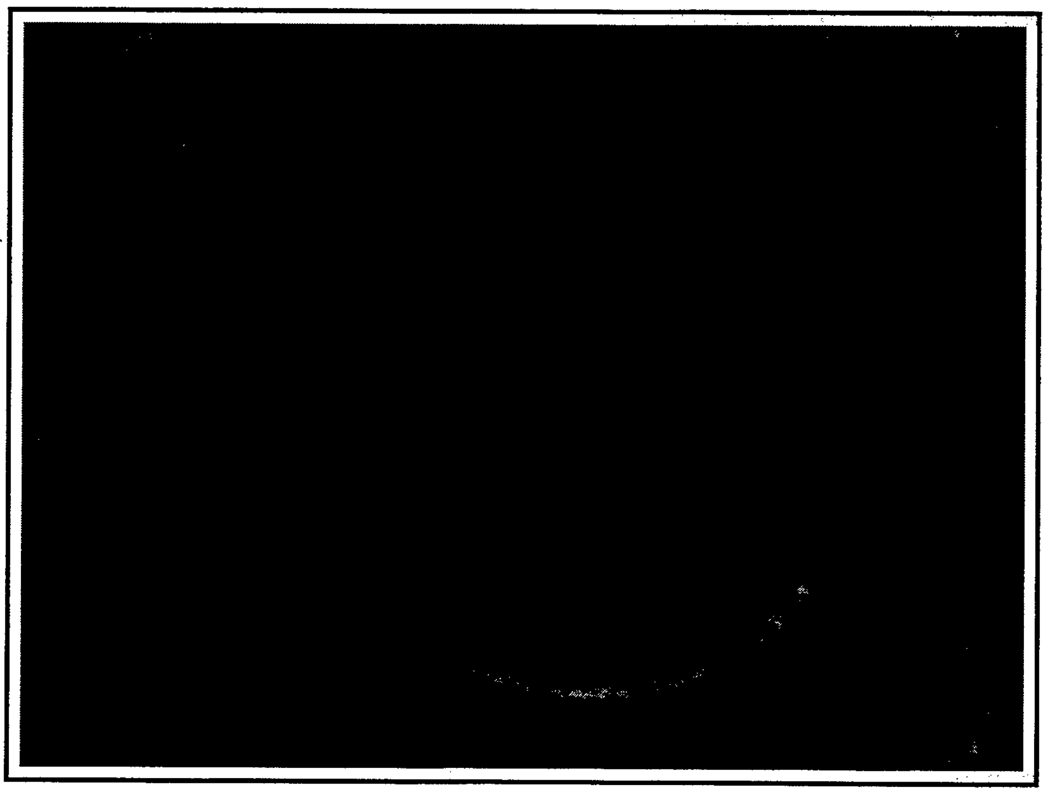

Figure 13. Pipe joint welded off center.

Figure 14. Corrosion on a pipe joint is evident on the right side of photo.

Figure 15. Plastic wedged in pipe.

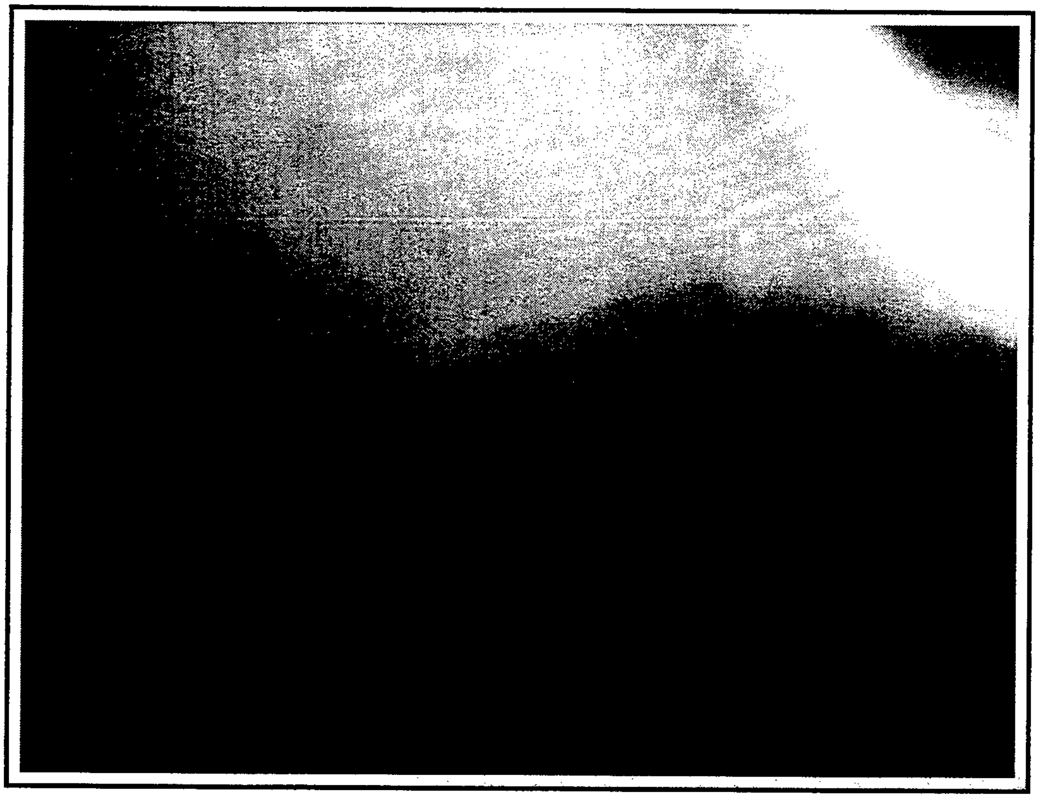

Figure 16. Different view of plastic wedged in pipe.

Figure 17. Silt resting on pipe bottom.

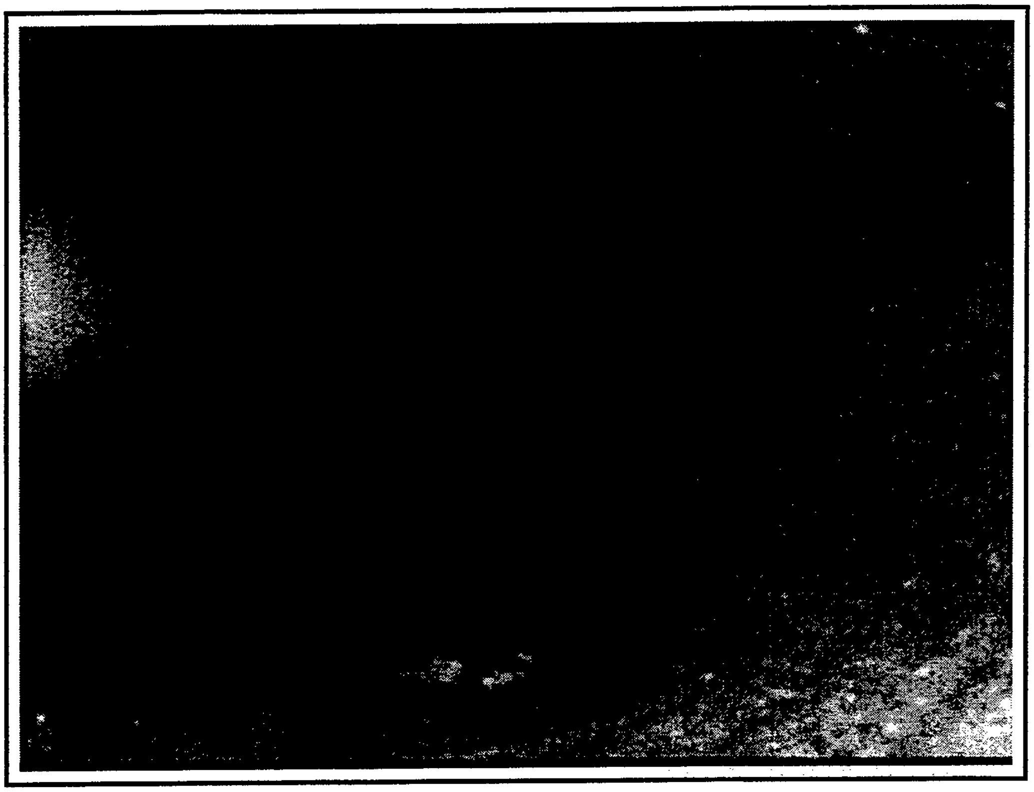

Figure 18. Two rocks resting on pipe bottom.

Water Quality Data

The water quality data supplied by Westover ARB shows a pH of 7.8, total alkalinity of less than 10 ppm, total hardness of less than 20 ppm, carbon dioxide of less than 10 ppm, and a dissolved oxygen of around 10 ppm. This indicates a very corrosive water with little buffering capacity. In addition, the municipal water treatment plant of Chicopee, MA, which currently supplies potable water to the base, adds chlorine, sodium hexa-meta-phosphate (i.e., poly-phosphate) to control corrosion at the city's raw water intake, and sodium carbonate/sodium bicarbonate to the Westover transmission supply line to raise both the pH and the alkalinity.* It is important to raise the alkalinity to ensure a sufficient buffering capacity to promote a stable pH. In addition, to avoid problems with chlorine retention, the pH should be maintained within Westover's distribution system at approximately 8.0 or below. In this approach, the poly-phosphate addition is needed to control iron corrosion and red water in the city's separate distribution system; however it is known to react with the calcium in the cement

* Note that Westover ARB has not added sodium carbonate/bicarbonate since April 1998.

lining in the ductile iron distribution pipe and to deteriorate the lining resulting in excessively high pH, and chlorine residual and bacterial problems.*

Based on the current situation, the following recommendations are made to help reduce iron corrosion, ensure compliance with the lead and copper rule, and help maintain the U.S. Environmental Protection Agency (USEPA) required chlorine residual levels at the end of the distribution pipe system:

1. Eliminate the sodium carbonate addition.
2. Continue sodium bicarbonate addition to ensure sufficient buffering and stable pH within the range of 7.8 – 8.0.
3. Maintain alkalinity within the range of 65 – 75 ppm.
4. For the poly-phosphate addition, substitute instead a blend of zinc orthophosphate/polyphosphate at the rate of approximately 2 to 3 ppm.

These recommendations are consistent with U.S. Army Corps of Engineers treatment guidelines as contained in Public Works Technical Bulletin (PWTB) 420-46-7.** At this time it is *not* recommended to clean or line the distribution piping before the effects of the new chemical treatment regime can be evaluated. The optimal treatment selection will be a function of pH, alkalinity, and other water quality parameters, including additional metal ions such as iron, copper, and lead. Evaluation of various chemical treatments can be facilitated by simulation in the CERL Pipe Test Loop system.***

Once the recommended changes in water treatment have been implemented, the effects of later bringing a 500,000-gal water tank on line should be minimal. The effect of the chemical treatment on the piping will be unchanged. With the recommended treatment, any temporary drop in pH will be slight and self correcting. More importantly, there may be a decrease in the disinfectant residual. Consideration should be given to increasing the chlorine concentration before bringing the water tank on line, and then to monitoring the residual. Another potential effect is a slight increase in turbidity.

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* *Internal Corrosion of Water Distribution Systems* (American Water Works Research Foundation, DVGW Forschungsstelle, February 1996), p 464.

** Public Works Technical Bulletin (PWTB) 420-46-7 (1 March 1996).

*** R.J. Scholze, K.A. Pontow, G. Kanchibhatia, and B.T. Ray, *Using the CERL Pipe-Loop System (PLS) To Evaluate Corrosion Inhibitors that Can Reduce Lead in Drinking Water*, Technical Report (TR) EP-94/04/ADA283637 (U.S. Army Construction Engineering Research Laboratory [USACERL], June 1994).

5 Conclusions and Recommendations

Conclusions

This study conducted a video inspection, analyzed the inspection videotapes, and estimated the percentage of coating losses and cleanliness inside the various sections of water main pipe at Westover ARB. Several important conclusions can be drawn from this data:

1. When the water mains were installed, the contractor did not demonstrate proper care of the pipe sections. Large, sporadic areas of missing pipe lining indicate that the pipe sections were impacted either during loading the pipe onto the trucks for transport to the work site, unloading the pipe after delivery to the work site or in burying the pipe once it was assembled. The plastic wedged in the pipe is an indication of the poor quality of workmanship exercised during installation of the pipeline
2. Poor quality control was exercised during the installation of the interior lining by the pipe manufacturer. The series of consecutive rings of coating loss in some pipes, and the linear strips of missing coating in others, indicate improper cure of the lining material. Improper cure occurs when manufacturer-specified proportions the epoxy resin and hardener are not maintained during manufacture, or when the components are not adequately mixed prior to application. The observed patterns indicate that it is likely that there was a problem with the mixing during the pipe manufacture process.
3. The flushing and pigging done by Westover ARB was effective in cleaning most of the debris out of the mains. A small quantity of debris still exists in the system. If one large piece of plastic shipping material was found during the Scooter inspection, it is statistically probable that several more were left in the remaining uninspected parts of the system. There is some silt and some gravel in the system, but not a significant amount.
4. Note that Westover used "soft" pigs to avoid damaging the system during the cleaning operation. The pigging operation conducted by Westover did cause some scouring of the pipe liner due to pieces of gravel being trapped between the pig and the pipe main wall. However, this scouring could not have caused the degree of damage to the lining observed during the Scooter video inspection of the water mains.

Recommendations

The following recommendations are made to help reduce iron corrosion, ensure compliance with the lead and copper rule, and help maintain the USEPA-required chlorine residual levels at the end of the distribution pipe system:

1. Eliminate the sodium carbonate addition.
2. Continue sodium bicarbonate addition to ensure sufficient buffering and stable pH within the range of 7.8 – 8.0.
3. Maintain alkalinity within the range of 65 – 75 ppm.
4. For the poly-phosphate addition, substitute instead a blend of zinc orthophosphate/polyphosphate at the rate of approximately 2 to 3 ppm.

These recommendations are consistent with U.S. Army Corps of Engineers treatment guidelines as contained in Public Works Technical Bulletin (PWTB) 420-46-7. At this time, it is not recommended to clean or line the distribution piping before the effects of the new chemical treatment regime can be evaluated. The optimal treatment selection will be a function of pH, alkalinity and other water quality parameters, including additional metal ions such as iron, copper, and lead. Evaluation of various chemical treatments can be facilitated by simulation in the CERL Pipe Test Loop System.

Appendix A: Coating Losses for Inspection Runs

Run 1		Run 2		Run 3		Run 4	
NW from Walker along Eagle at toward Monument		South from Monument along Eagle toward Walker		North from Monument South along Eagle towards Monument North		NW from Starlifter to Burke along Eagle	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
1	0	1	0	1	0	1	3
2	10	2	0	2	6	2	3
3	0	3	0	3	6	3	3
4	0	4	0	4	0	4	3
5	0	5	15	5	0	5	3
6	0	6	15	6	0	6	3
7	0	7	25	7	0	7	3
8	0	8	30	8	0	8	3
9	0	9	10	9	0	9	3
10	6	10	3	10	0	10	3
11	6	11	3	11	0	11	50
12	6	12	1	12	1	12	10
13	20	13	1	13	1	13	10
14	6	14	1	14	0	14	4
15	6	15	1	15	0	15	4
16	6	16	1	16	0	16	4
17	6	17	1	17	0	17	4
18	6	18	1	18	40	18	4
19	6	19	1	19	40	19	4
20	6	20	1	20	40	20	4
21	6	21	1	21	0	21	4
22	6	22	0	22	0	22	3
23	6	23	3	23	0	23	3
24	0	24	3	24	0	24	3
25	0	25	3	25	0	25	3
26	0	26	0	26	0	26	3
27	0	27	0	27	30	27	7
28	0	28		28	40	28	0
29	0	29	0	29	0	29	0
30	4	30	0	30	0	30	0
31	4	31	0			31	0

Run 1		Run 2		Run 3		Run 4	
NW from Walker along Eagle at toward Monument		South from Monument along Eagle toward Walker		North from Monument South along Eagle towards Monument North		NW from Starlifter to Burke along Eagle	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
32	4	32	0			32	0
33	4	33	0			33	0
34	4	34	1			34	0
35	4	35	1			35	0
36	4	36	1			36	0
37	4	37	1			37	0
38	4	38	1			38	0
39	0	39	1			39	0
40	0	40	1			40	0
41	0	41	1			41	0
42	0	42	3			42	0
43	0	43	3			43	0
44	0	44	1			44	0
45	0	45	1			45	0
46	4	46	1			46	0
47	4	47	0			47	0
48	4	48	0			48	0
49	4	49	0			49	0
50	4	50	0			50	0
51	4	51	20			51	0
52	4	52	25			52	0
53	4	53	25			53	0
54	4	54	0			54	0
55	4	55	0			55	0
56	4	56	0			56	0
57	4	57	0			57	0
58	4	58	0			58	0
59	4	59	0			59	0
60	3	60	40			60	0
61	3	61	40			61	0
62	3	62	40			62	0
63	1	63	0			63	0
64	1	64	0			64	0
65	6	65	0			65	0
66	6	66	0			66	0
67	6	67	0			67	0
68	6	68	0			68	0
69	6	69	15			69	0
70	6	70	0			70	0

Run 1		Run 2		Run 3		Run 4	
NW from Walker along Eagle at toward Monument		South from Monument along Eagle toward Walker		North from Monument South along Eagle towards Monument North		NW from Starlifter to Burke along Eagle	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
71	6	71	0			71	0
72	6	72	0			72	0
73	6	73	0			73	0
74	6	74	0			74	0
75	6	75	0			75	0
76	6	76	6			76	0
77	6	77	7			77	0
78	6	78	0			78	0
79	6	79	1			79	0
80	6	80	1			80	0
81	6	81	1			81	0
82	4	82	1			82	0
83	4	83	3			83	0
84	4	84	3			84	0
85	4	85	0			85	0
86	4	86	0			86	0
87	4	87	10			87	0
88	4	88	75			88	10
89	4	89	50			89	30
90	4	90	0			90	10
91	4	91	0			91	10
92	4	92	0			92	10
93	4	93	0			93	5
94	4	94	0			94	5
95	4	95	0			95	5
96	4	96	0			96	5
97	4	97	0			97	0
98	4	98	0			98	0
99	4	99	0			99	0
100	4	100	0			100	40
101	4	101	0			101	50
102	50	102	0			102	60
103	50	103	0			103	60
104	6	104	0			104	60
105	6	105	0			105	60
106	6	106	0			106	60
107	6	107	6			107	60
108	6	108	7			108	60
109	6	109	0			109	60

Run 1		Run 2		Run 3		Run 4	
NW from Walker along Eagle at toward Monument		South from Monument along Eagle toward Walker		North from Monument South along Eagle towards Monument North		NW from Starlifter to Burke along Eagle	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
110	6					110	60
111	6					111	60
112	6					112	60
113	6					113	60
114	6					114	60
115	6						
116	6						
117	6						
118	4						
119	4						
120	4						
Average %	4.9	Average %	4.7	Average %	6.8	Average %	9.8

Run 5		Run 6		Run 7		Run 8	
SW from Starlifer along Eagle toward Monument North		NE from Starlifter along Eagle toward Globemaster		SE along Starlifter toward Eagle		NW along Starlifter toward Burke	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
1	3	1	40	1	30	1	30
2	3	2	40	2	30	2	30
3	3	3	40	3	30	3	30
4	3	4	40	4	30	4	30
5	3	5	40	5	30	5	30
6	3	6	40	6	30	6	30
7	3	7	40	7	30	7	30
8	3	8	40	8	50	8	30
9	3	9	40	9	75	9	30
10	3	10	40	10	100	10	0
11	20	11	40	11	100	11	0
12	20	12	40	12	100	12	0
13	10	13	40	13	100	13	4
14	10	14	50	14	100	14	4
15	4	15	50	15	100	15	4
16	4	16	50	16	80	16	4
17	3	17	50	17	80	17	4
18	3	18	50	18	80	18	4
19	3	19	50	19	90	19	3

Run 5		Run 6		Run 7		Run 8	
SW from Starlifer along Eagle toward Monument North		NE from Starlifter along Eagle toward Globemaster		SE along Starlifter toward Eagle		NW along Starlifter toward Burke	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
20	3	20	50	20	90	20	3
21	3	21	30	21	90	21	0
22	3	22	30	22	90	22	0
23	3	23	30	23	90	23	0
24	4	24	30	24	90	24	0
25	25	25	30	25	75	25	0
26	50	26	30	26	75	26	0
27	50	27	30	27	75	27	0
28	50	28	40	28	75	28	0
29	75	29	40	29	50	29	0
30	75	30	30	30	50	30	3
31	75	31	50	31	50	31	2
32	75	32	50	32	50	32	4
33	75	33	50	33	50	33	3
34	50	34	40	34	20	34	3
35	40	35	40	35	20	35	2
36	30	36	40	36	20	36	4
37	30	37	40	37	20	37	10
38	50	38	40	38	20	38	2
39	40	39	40	39	20	39	0
40	30	40	30	40	10	40	0
41	3	41	20	41	20	41	0
42	0	42	20	42	10	42	0
43	0	43	30	43	5	43	0
44	40	44	30	44	5	44	0
45	40	45	30	45	5	45	0
46	30	46	20	46	10	46	1
47	50	47	30	47	20	47	0
48	25	48	50	48	0	48	0
49	40	49	50	49	0	49	0
50	25	50	50	50	0	50	0
51	25	51	50	51	0	51	0
52	30	52	50	52	0	52	0
53	35	53	30	53	5	53	0
54	40	54	30	54	0	54	1
55	4	55	20	55	0	55	0
56	4	56	20	56	0	56	0
57	8	57	20	57	0	57	3
58	10	58	30	58	0	58	3

Run 5		Run 6		Run 7		Run 8	
SW from Starlifer along Eagle toward Monument North		NE from Starlifter along Eagle toward Globemaster		SE along Starlifter toward Eagle		NW along Starlifter toward Burke	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
59	5	59	30	59	0		
60	0	60	40	60	0		
61	4	61	30	61	0		
62	3	62	40	62	0		
63	3	63	40	63	0		
64	3	64	40	64	0		
65	0	65	40	65	0		
66	10	66	40	66	5		
67	30	67	20	67	0		
68	40	68	30	68	0		
69	40	69	20	69	0		
70	1	70	5	70	0		
71	1	71	5	71	0		
72	1	72	5	72	0		
73	0	73	20	73	5		
74	0	74	30	74	5		
75	0	75	30	75	5		
76	0	76	30	76	5		
77	0	77	10	77	5		
78	0	78	0	78	5		
79	10	79	0	79	5		
80	10	80	0	80	5		
81	40	81	0	81	5		
82	35	82	0	82	5		
83	50	83	25	83	5		
84	40			84	0		
85	60			85	3		
86	75			86	4		
				87	4		
	21.1			88	4		
				89	4		
				90	4		
				91	4		
				92	3		
				93	3		
Average %	21.1	Average %	32.8	Average %	27.6	Average %	9.8

Run 9		Run 10		Run 11		Run 12	
SW from Burke along Globemaster toward Eagle		NE from Globemaster along Burke		SW from Globemaster along Burke		NW from Eagle along Globemaster	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
1	0	1	0	1	0	1	0
2	0	2	0	2	0	2	1
3	0	3	0	3	0	3	20
4	0	4	0	4	0	4	30
5	0	5	0	5	0	5	40
6	0	6	10	6	0	6	20
7	0	7	10	7	0	7	20
8	0	8	0	8	3	8	25
9	0	9	8	9	0	9	20
10	3	10	0	10	0	10	0
11	1	11	5	11	0	11	0
12	0	12	0	12	0	12	0
13	0	13	0	13	0	13	0
14	0	14	0	14	0	14	0
15	0	15	0	15	0	15	0
16	0	16	0	16	0	16	0
17	0	17	5	17	5	17	0
18	5	18	0	18	3	18	0
19	0	19	0	19	0	19	0
20	0	20	0	20	0	20	0
21	0	21	0	21	0	21	0
22	0	22	0	22	0	22	0
23	0	23	7	23	0	23	0
24	0	24	7	24	0	24	0
25	0	25	0	25	0	25	0
26	0	26	10	26	0	26	0
27	0	27	10	27	0	27	0
28	0	28	10	28	3	28	0
29	0	29	8	29	0	29	0
30	0	30	8	30	0	30	0
31	0	31	5	31	0	31	0
32	0	32	5	32	0	32	0
33	0	33	3	33	0	33	0
34	0	34	0	34	0	34	1
35	0	35	5	35	4	35	1
36	30	36	0	36	4	36	4
37	40	37	0	37	0	37	1
38	50	38	0	38	0	38	1
39	40	39	0	39	0	39	0

Run 9		Run 10		Run 11		Run 12	
SW from Burke along Globemaster toward Eagle		NE from Globemaster along Burke		SW from Globemaster along Burke		NW from Eagle along Globemaster	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
40	30	40	0	40	0	40	0
41	0	41	0	41	0	41	0
42	0	42	4	42	0	42	0
43	0	43	4	43	5	43	0
44	0	44	5	44	5	44	0
45	0	45	0	45	0	45	3
46	0	46	0	46	0	46	0
47	0	47	0	47	0	47	0
48	0	48	0	48	0	48	0
49	0	49	0	49	0	49	0
50	0	50	0	50	0	50	0
51	0	51	0	51	0	51	0
52	0	52	0	52	0	52	0
53	0	53	0	53	0	53	5
54	0	54	0	54	8	54	5
55	10	55	0	55	10	55	0
56	0	56	0	56	0	56	0
57	0	57	4	57	0	57	0
58	1	58	4	58	0	58	0
59	1	59	0	59	0	59	0
60	1	60	3	60	0	60	0
61	1	61	0	61	0	61	0
62	1	62	0	62	0	62	0
63	5	63	0	63	0	63	0
64	5	64	0	64	0	64	0
65	8	65	0	65	3	65	0
66	0	66	0	66	1	66	0
67	0	67	4	67	0	67	0
68	0	68	1	68	3	68	0
69	0	69	1	69	4	69	0
70	0	70	0	70	0	70	0
71	30	71	0	71	0	71	0
72	30	72	0	72	0	72	0
73	30	73	1	73	1	73	0
74	0	74	1	74	0	74	0
75	0	75	0	75	0	75	0
76	0	76	1	76	0	76	0
77	0	77	1	77	0	77	0
78	0	78	0	78	0	78	0

Run 9		Run 10		Run 11		Run 12	
SW from Burke along Globemaster toward Eagle		NE from Globemaster along Burke		SW from Globemaster along Burke		NW from Eagle along Globemaster	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
79	0	79	0	79	1	79	1
80	0	80	0	80	3	80	0
81	3	81	4	81	5	81	0
82	3	82	0	82	0	82	0
83	0	83	0	83	0	83	0
84	0	84	0			84	0
85	0	85	0			85	0
86	0	86	0			86	0
87	0	87	0			87	0
88	0	88	1			88	0
89	5	89	0			89	0
90	0					90	0
						91	0
						92	0
						93	0
						94	0
						95	0
						96	0
						97	0
						98	0
Average %	3.7	Average %	1.7	Average %	0.9	Average %	2.0

Run 13		Run 14		Run 15		Run 16	
NE from Globemaster along Eagle		SW from Globemaster along Eagle		NE from Airlifter along Walker		NW from Walker along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
1	3	1	5	1	5	1	0
2	3	2	5	2	5	2	0
3	3	3	5	3	0	3	0
4	3	4	0	4	0	4	0
5	3	5	0	5	0	5	0
6	3	6	0	6	0	6	0
7	3	7	0	7	0	7	0
8	3	8	0	8	1	8	5
9	3	9	0	9	0	9	5
10	20	10	0	10	5	10	5
11	25	11	0	11	10	11	0
12	25	12	0	12	10	12	0

Run 13		Run 14		Run 15		Run 16	
NE from Globemaster along Eagle		SW from Globemaster along Eagle		NE from Airlifter along Walker		NW from Walker along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
13	25	13	0	13	20	13	0
14	30	14	0	14	25	14	0
15	30	15	0	15	25	15	0
16	8	16	0	16	10	16	0
17	8	17	0	17	10	17	10
18	8	18	0	18	5	18	20
19	5	19	0	19	0	19	5
20	5	20	15	20	0	20	0
21	5	21	20	21	5	21	0
22	5	22	3	22	0	22	0
23	0	23	3	23	0	23	0
24	0	24	1	24	0	24	0
25	0	25	1	25	0	25	0
26	0	26	5	26	0	26	0
27	0	27	0	27	0	27	1
28	0	28	0	28	8	28	0
29	0	29	0	29	8	29	0
30	3	30	0	30	0	30	0
31	3	31	0	31	0	31	5
32	3	32	0	32	8	32	0
33	3	33	0	33	8	33	3
34	3	34	25	34	10	34	3
35	3	35	0	35	10	35	3
36	3	36	15	36	5	36	0
37	3	37	3	37	5	37	0
38	3	38	0	38	0	38	0
39	3	39	1	39	0	39	0
40	3	40	0	40	0	40	0
41	3	41	0	41	0	41	0
42	3	42	0	42	0	42	0
43	0	43	3	43	0	43	0
44	0	44	3	44	0	44	0
45	0	45	0	45	0	45	0
46	5	46	0	46	0	46	0
47	0	47	0	47	0	47	0
48	30	48	0	48	0	48	0
49	30	49	0	49	0	49	0
50	30	50	0	50	0	50	0
51	30	51	10	51	40	51	1
52	30	52	10	52	50	52	0

Run 13		Run 14		Run 15		Run 16	
NE from Globemaster along Eagle		SW from Globemaster along Eagle		NE from Airlifter along Walker		NW from Walker along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
53	30	53	0	53	50	53	0
54	10	54	0	54	50	54	0
55	10	55	0	55	50	55	0
56	3	56	30	56	50	56	0
57	3	57	0	57	0	57	0
58	3	58	0	58	0	58	0
59	25	59	0	59	0	59	0
60	25	60	0	60	5	60	0
61	25	61	0	61	0	61	0
62	40	62	0	62	0	62	0
63	40	63	40	63	10		
64	40	64	50	64	10		
65	25	65	50	65	10		
66	25	66	0	66	10		
67	25	67	0	67	0		
68	30	68	0	68	0		
69	30	69	0	69	0		
70	30	70	10	70	0		
71	30	71	20	71	0		
72	40	72	20	72	0		
73	40	73	30	73	0		
74	50	74	30	74	0		
75	40	75	10	75	0		
76	40	76	0	76	0		
77	30	77	0	77	0		
78	35	78	0	78	0		
79	50	79	0	79	0		
80	50	80	0	80	0		
81	50	81	0	81	0		
82	0	82	0	82	0		
83	0	83	0	83	0		
84	0	84	0	84	0		
85	0	85	0	85	0		
86	10	86	0	86	0		
87	5	87	0	87	0		
88	0	88	0	88	0		
89	0	89	0	89	0		
90	0	90	0	90	0		
91	0	91	0	91	0		
92	0	92	0	92	15		

Run 13		Run 14		Run 15		Run 16	
NE from Globemaster along Eagle		SW from Globemaster along Eagle		NE from Airlifter along Walker		NW from Walker along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
93	0	93	0	93	20		
94	5	94	0	94	0		
95	5	95	0	95	2		
96	0	96	0	96	2		
97	0	97	0	97	0		
98	0	98	0	98	0		
99	0	99	0	99	0		
100	8	100	0	100	0		
101	8	101	0	101	0		
102	8	102	0	102	0		
103	8	103	0	103	0		
104	8	104	0	104	0		
105	8	105	0	105	0		
106	8	106	0	106	0		
107	8	107	0	107	0		
108	8	108	0	108	0		
109	8	109	0	109	0		
110	8	110	0				
111	8	111	0				
112	8	112	0				
113	8	113	0				
114	10	114	0				
115	8	115	0				
116	8	116	0				
117	8	117	0				
118	8	118	0				
119	5	119	0				
120	0	120	0				
121	0	121	0				
122	0	122	0				
Average %	12.1	Average %	3.5	Average %	5.2	Average %	1.1

Run 17		Run 18		Run 19		Run 20	
SE from Walker along Airlifter		West from Airlifter along Galaxy		SE from Galaxy along Airlifter		South from Bldg. 5600 along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
1	1	1	0	1	0	1	0
2	2	2	0	2	0	2	0

Run 17		Run 18		Run 19		Run 20	
SE from Walker along Airlifter		West from Airlifter along Galaxy		SE from Galaxy along Airlifter		South from Bldg. 5600 along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
3	2	3	0	3	0	3	0
4	2	4	0	4	0	4	0
5	2	5	0	5	5	5	0
6	1	6	0	6	2	6	0
7	0	7	0	7	2	7	0
8	0	8	0	8	8	8	0
9	0	9	0	9	8	9	0
10	1	10	0	10	8	10	0
11	0	11	5	11	8	11	0
12	0	12	0	12	2	12	0
13	0	13	0	13	2	13	0
14	0	14	0	14	2	14	0
15	0	15	0	15	2	15	0
16	0	16	0	16	2	16	0
17	0	17	0	17	10	17	0
18	0	18	10	18	10	18	0
19	0	19	0	19	0	19	0
20	0	20	0	20	3	20	0
21	0	21	0	21	3	21	0
22	0	22	0	22	0	22	30
23	0	23	0	23	0	23	30
24	0	24	0	24	0	24	30
25	0	25	0	25	0	25	30
26	0	26	0	26	0	26	30
27	0	27	0	27	0	27	30
28	0	28	0	28	0	28	30
29	0	29	0	29	0	29	0
30	0	30	0	30	0	30	0
31	0	31	0	31	0	31	0
32	0	32	0	32	3	32	0
33	0	33	0	33	0	33	0
34	0	34	0	34	0	34	0
35	0	35	0	35	1	35	0
36	0	36	0	36	0	36	0
37	0	37	1	37	0	37	0
38	0	38	0	38	0	38	0
39	0	39	0	39	2	39	0
40	2	40	0	40	2	40	7
41	2	41	0	41	2	41	7
42	0	42	0	42	0	42	7

Run 17		Run 18		Run 19		Run 20	
SE from Walker along Airlifter		West from Airlifter along Galaxy		SE from Galaxy along Airlifter		South from Bldg. 5600 along Airlifter	
Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)	Position (ft)	Coating Loss (%)
43	0	43	0	43	0	43	0
44	0	44	0	44	0	44	0
45	1	45	0	45	0	45	0
46	0	46	0	46	0	46	0
47	0	47	0	47	0	47	0
48	0	48	0	48	0	48	0
49	0	49	0	49	0	49	0
50	0	50	0	50	0	50	25
51	0	51	0	51	0	51	25
52	0	52	0	52	3	52	25
53	0	53	0	53	3	53	25
54	0	54	0	54	3	54	25
55	0	55	0	55	3	55	25
56	1	56	0	56	3	56	25
57	0	57	0			57	25
58	1	58	0			58	25
59	1	59	0			59	0
60	2	60	0			60	15
61	0					61	15
62	1					62	15
63	0					63	15
64	0					64	15
65	0					65	15
66	0					66	15
						67	15
						68	15
						69	0
						70	4
						71	4
						72	4
						73	0
						74	0
Average %	0.3	Average %	0.3	Average %	1.8	Average %	8.1

Run 21	
North from Bldg. 5600 along Airlifter	
Position (ft)	Coating Loss (%)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	4
29	4
30	4
31	4
32	4
33	4
34	4
35	5
36	5
37	10
38	10
39	0
40	0
41	0
42	0
43	0
44	5
45	5
46	5
47	0
48	0
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	0
59	0
60	0
61	0
62	0
63	0
64	10
65	20
66	25
67	10
68	10
69	0
70	0
71	0
72	0
73	0
74	0
75	0
76	0
77	0
78	0
79	0
80	0
81	0
82	0
83	0
84	0
85	0
86	0
87	0
Average %	1.7

Run 22			Run 23			Run 24		
SE from behind Bldg 1601 along Hanger Ave.			NW from behind Bldg 1601 along Hanger Ave.			NW from Gym along Patriot towards Pittsburgh		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
1	0		1	0		1	7	
2	0		2	0		2	5	
3	0		3	0		3	10	
4	0		4	0		4	10	
5	3		5	0		5	5	
6	0		6	5		6	5	
7	0		7	5		7	3	
8	10		8	0		8	3	
9	10		9	0		9	5	
10	10		10	0		10	0	
11	0		11	10		11	0	
12	0		12	10		12	0	
13	0					13	0	
14	0					14	0	
15	0					15	0	
16	5					16	0	
17	3					17	0	
18	0					18	0	
19	0					19	0	
20	0					20	0	
21	0	sediment				21	5	
22	0	sediment				22	0	
23	0	sediment				23	0	
						24	0	
						25	0	
						26	0	
						27	0	
						28	0	
						29	10	
						30	10	
						31	0	
						32	0	
						33	0	
						34	0	
						35	0	
						36	0	
						37	3	
						38	0	
						39	0	
						40	0	

Run 22			Run 23			Run 24		
SE from behind Bldg 1601 along Hanger Ave.			NW from behind Bldg 1601 along Hanger Ave.			NW from Gym along Patriot towards Pittsburgh		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
						41	0	
						42	3	
						43	0	
						44	0	
						45	3	
						46	3	
						47	3	
						48	3	
						49	3	
						50	3	
						51	3	
						52	3	
						53	0	
						54	0	
						55	0	
						56	0	
						57	0	
						58	0	
						59	3	
						60	5	
						61	5	
						62	5	
						63	5	
						64	5	
						65	5	
						66	3	
						67	3	
						68	3	
						69	3	
						70	3	
						71	0	
						72	0	
						73	0	
						74	0	
						75	0	
						76	1	
						77	1	
						78	0	
						79	0	
						80	0	

Run 22			Run 23			Run 24		
SE from behind Bldg 1601 along Hanger Ave.			NW from behind Bldg 1601 along Hanger Ave.			NW from Gym along Patriot towards Pittsburgh		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
						81	1	
						82	7	
						83	0	
						84	0	
						85	0	
						86	20	
						87	25	
						88	30	
						89	30	
						90	0	
						91	0	
						92	0	
						93	4	
						94	0	
						95	0	
						96	10	
Average	1.8%		Average	2.5%		Average	3.0%	

Run 25			Run 26			Run 27		
SE from Gym along Patriot			SE from Eagle along Hanger Drive Towards Pittsburgh			NW from Eagle along Hanger Drive		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
1	0		1	0		1		
2	0		2	0		2		*
3	0		3	5				
4	0		4	5		*Plastic Wedged in Pipe		
5	0		5	5				
6	0		6	5				
7	0		7	3				
8	0		8	0				
9	10		9	0				
10	10		10	0				
11	10		11	3				
12	0		12	0				
13	0		13	3				
14	0		14	0				
15	0		15	0				
16	0		16	0				
17	0		17	4				

Run 25			Run 26			Run 27		
SE from Gym along Patriot			SE from Eagle along Hanger Drive Towards Pittsburgh			NW from Eagle along Hanger Drive		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
18	0		18	5				
19	0		19	5				
20	0		20	8				
21	0		21	10				
22	0		22	0				
23	0		23	0				
24	0		24	8				
25	0		25	10				
26	0		26	30				
27	1		27	0				
28	1		28	0				
29	1		29	0				
30	1		30	0				
31	1		31	0				
32	1		32	0				
33	0		33	0				
34	0		34	50				
35	0		35	50				
36	0		36	0				
37	0		37	3				
38	0		38	0				
39	0		39	3				
40	0		40	0				
41	0		41	0				
42	0		42	0				
43	0		43	0				
44	0		44	0				
45	0		45	8				
46	0		46	10				
47	0		47	15				
48	0		48	3				
49	0		49	0				
50	0		50	0				
51	0		51	0				
52	0		52	3				
53	0		53	3				
54	0		54	0				
55	0		55	0				
56	0		56	7				
57	0		57	7				

Run 25			Run 26			Run 27		
SE from Gym along Patriot			SE from Eagle along Hanger Drive Towards Pittsburgh			NW from Eagle along Hanger Drive		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
58	0		58	0				
59	0		59	5				
60	0		60	5				
61	0		61	5				
62	0		62	5				
63	0		63	5				
64	0		64	8				
65	0		65	10				
66	0		66	10				
67	0		67	0				
68	0		68	0				
69	0		69	0				
70	0		70	5				
71	0		71	0				
72	0		72	0				
73	0		73	75				
74	0		74	75				
75	0		75	50				
76	2		76	30				
77	2		77	10				
78	2		78	0				
79	2		79	0				
80	2		80	0				
81	2		81	3				
82	3		82	0				
83	2		83	0				
84	2		84	0				
85	2		85	0				
86	2		86	0				
87	2		87	0				
88	2		88	0				
89	2		89	0				
90	0		90	0				
			91	5				
			92	8				
			93	10				
			94	15				
			95	10				
			96	10				
			97	10				

Run 25			Run 26			Run 27		
SE from Gym along Patriot			SE from Eagle along Hanger Drive Towards Pittsburgh			NW from Eagle along Hanger Drive		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
			98	15				
			99	20				
			100	25				
			101	25				
			102	20				
			103	20				
			104	15				
			105	10				
			106	10				
			107	10				
			108	10				
			109	0				
			110	0				
			111	0				
			112	0				
			113	0				
			114	0				
			115	3				
			116	3				
			117	3				
			118	0				
			119	0				
			120	0				
			121	0				
			122	0				
			123	0				
			124	0				
			125	0				
			126	0				
			127	0				
			128	0				
			129	0				
			130	3				
			131	0				
			132	0				
			133	0				
			134	3				
Average	0.7%		Average	6.2%		Average	0.0%	

Run 28			Run 29			Run 30		
SE from Eagle along Patriot toward Pittsburgh			NW from Eagle along Patriot			SW from Far Hydrant along Re-call		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
1	0		1	0		1	0	
2	0		2	0		2	0	
3	0		3	0		3	0	
4	0		4	0		4	0	
5	0		5	0		5	0	silt/gravel
6	0		6	0		6	0	silt/gravel
7	0		7	0		7	0	silt/gravel
8	0		8	0		8	0	silt/gravel
9	0		9	0		9	0	silt/gravel
10	0		10	0		10	0	silt/gravel
11	0		11	0		11	0	silt/gravel
12	0		12	0		12	0	silt/gravel
13	10		13	0		13	0	silt/gravel
14	10		14	0		14	0	silt/gravel
15	15		15	0		15	0	silt/gravel
16	15		16	0		16	0	silt/gravel
17	10		17	0		17	0	silt/gravel
18	10		18	0		18	0	silt/gravel
19	10		19	0		19	0	silt/gravel
20	15		20	0		20	0	silt/gravel
21	3		21	0				
22	0		22	0				
23	0		23	0				
24	0		24	0				
25	0		25	0				
26	10		26	0				
27	0		27	0				
28	0		28	0				
29	0		29	0				
30	0		30	0				
31	0		31	0				
32	0		32	0				
33	0		33	0				
34	0		34	0				
35	0		35	0				
36	0		36	0				
37	0		37	0				
38	0		38	0				
39	0		39	0				
40	0		40	0				

Run 28			Run 29			Run 30		
SE from Eagle along Patriot toward Pittsburgh			NW from Eagle along Patriot			SW from Far Hydrant along Re-call		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
41	0		41	0				
42	0		42	0				
43	0		43	0				
44	0		44	0				
45	0		45	0				
46	0		46	0				
47	0		47	0				
48	3		48	0				
49	0		49	0				
50	0		50	0	gravel/silt			
51	10		51	0	gravel/silt			
52	10		52	0	gravel/silt			
53	10		53	0	gravel/silt			
54	10		54	0	gravel/silt			
55	15		55	0	gravel/silt			
56	0		56	0				
57	0		57	0				
58	0		58	0				
59	5		59	0				
60	0		60	0				
61	0		61	0				
62	0		62	0				
63	0		63	0				
64	0							
65	0							
66	0							
67	0							
68	0							
69	0							
70	0							
71	0							
72	0							
73	0							
74	0							
75	0							
76	0							
77	0							
78	0							
79	0							
80	0							

Run 28			Run 29			Run 30		
SE from Eagle along Patriot toward Pittsburgh			NW from Eagle along Patriot			SW from Far Hydrant along Re-call		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
81	0							
82	0							
83	0							
84	0							
85	0							
86	0							
87	0							
88	0							
89	0							
90	0							
91	0							
Average	1.9%		Average	0.0%		Average	0.0%	

Run 31			Run 32			Run 33		
NE from Far Hydrant along Recall			NW from Patriot up the Hill along Sanders toward Recall			SE from Patriot along Sanders toward Hanger		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
1	0		1	0		1	0	
2	0		2	0		2	0	
3	0		3	0		3	0	more silty
4	0		4	25		4	0	more silty
5	0		5	0		5	0	more silty
6	0		6	0		6	0	more silty
7	0		7	0		7	0	more silty
8	0		8	0		8	0	more silty
9	0		9	0		9	0	more silty
10	0		10	0		10	0	more silty
11	25		11	0		11	0	more silty
12	25		12	0		12	0	more silty
13	25		13	10		13	0	more silty
14	35		14	0		14	0	more silty
15	35		15	0		15	0	more silty
16	40		16	0		16	0	more silty
17	40		17	0		17	0	more silty
18	40		18	0		18	0	more silty
19	40		19	0		19	0	more silty
20	0		20	0		20	0	more silty
21	0		21	0		21	0	more silty
22	0		22	0		22	0	more silty

Run 31			Run 32			Run 33		
NE from Far Hydrant along Recall			NW from Patriot up the Hill along Sanders toward Recall			SE from Patriot along Sanders toward Hanger		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
23	0		23	0		23	0	more silty
24	0		24	8		24	0	more silty
25	0		25	0		25	0	more silty
26	0		26	0		26	0	more silty
27	0		27	0		27	0	more silty
28	0		28	0		28	0	more silty
29	0		29	0		29	0	more silty
30	0		30	0		30	0	more silty
31	0		31	0		31	0	silty
32	0		32	25		32	0	silty
33	0		33	20		33	0	silty
34	0		34	20		34	0	silty
35	0		35	20		35	0	silty
36	0		36	15		36	0	silty
37	0		37	15		37	0	silty
38	0		38	10		38	0	silty
39	0		39	0		39	0	silty
40	0		40	0		40	0	silty
41	0		41	0		41	0	silty
42	0		42	0		42	0	silty
43	0		43	5		43	0	silty
44	0		44	0		44	0	silty
45	0		45	0		45	0	silty
46	0		46	0		46	0	silty
47	0		47	0		47	0	silty
48	0		48	0		48	0	silty
49	0		49	0		49	0	silty
50	0	gravel	50	0		50	0	silty
51	0	gravel	51	0		51	0	less silty
52	0	gravel	52	0		52	0	less silty
53	0	gravel	53	0		53	0	less silty
54	0	gravel	54	0		54	0	less silty
55	0	gravel	55	0		55	0	less silty
56	0	gravel	56	0		56	0	less silty
57	0		57	0		57	0	less silty
58	0		58	0		58	0	less silty
59	0		59	8		59	0	less silty
60	0		60	10		60	0	less silty
61	0		61	0		61	0	less silty
62	0		62	0		62	0	less silty

Run 31			Run 32			Run 33		
NE from Far Hydrant along Recall			NW from Patriot up the Hill along Sanders toward Recall			SE from Patriot along Sanders toward Hanger		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
63	0		63	0		63	0	less silty
64	25		64	0		64	0	less silty
65	25		65	10		65	0	less silty
66	0		66	0		66	0	
67	0		67	0		67	0	
68	0		68	0		68	0	
69	0		69	10		69	0	
70	0		70	0		70	0	
71	0		71	0		71	0	
72	0		72	0		72	0	
73	0		73	0		73	5	
74	0		74	0		74	0	
75	0		75	0		75	0	
76	0		76	0		76	0	
77	0		77	0		77	0	
78	0		78	0		78	0	
79	0		79	0		79	0	
80	0		80	0		80	0	
81	0		81	0		81	0	
82	0		82	0		82	0	
83	0		83	0		83	0	
84	0		84	0		84	0	
85	0		85	0		85	0	
86	0		86	0		86	0	
87	0		87	0		87	0	
88	0		88	0		88	0	
89	0		89	0		89	0	
90	0		90	0		90	0	
91	0		91	0		91	0	
92	0		92	0		92	0	
93	0		93	0		93	0	
94	0		94	0		94	0	
95	0		95	0		95	0	
96	0		96	0		96	0	
97	0		97	0		97	0	
98	0		98	0		98	0	
99	0		99	0	silt	99	0	
100	0		100	0	silt	100	0	
101	0		101	0	silt	101	0	
102	0		102	0	silt	102	0	

Run 31			Run 32			Run 33		
NE from Far Hydrant along Recall			NW from Patriot up the Hill along Sanders toward Recall			SE from Patriot along Sanders toward Hanger		
Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness	Location (ft)	Loss (%)	Cleanliness
103	0		103	0	silt	103	0	
104	0					104	0	
105	0					105	0	
Average	3.4%		Average	2.0		Average	0.05	

Run 34		
NE from Sanders along Patriot		
Location (ft)	Loss (%)	Cleanliness
1	0	moderately silty
2	0	moderately silty
3	0	moderately silty
4	0	moderately silty
5	0	moderately silty
6	0	moderately silty
7	0	moderately silty
8	0	moderately silty
9	0	moderately silty
10	0	moderately silty
11	0	moderately silty
12	0	moderately silty
13	0	moderately silty
14	0	moderately silty
15	0	moderately silty
16	0	moderately silty
17	0	moderately silty
18	0	moderately silty
19	0	moderately silty
20	0	moderately silty
21	10	moderately silty
22	10	moderately silty
23	10	moderately silty
24	0	moderately silty
25	0	moderately silty
26	0	moderately silty
27	0	moderately silty
28	0	moderately silty
29	0	moderately silty

Run 34		
NE from Sanders along Patriot		
Location (ft)	Loss (%)	Cleanliness
30	0	moderately silty
31	0	moderately silty
32	25	moderately silty
33	25	moderately silty
34	30	moderately silty
35	35	moderately silty
36	0	moderately silty
37	0	moderately silty
38	0	moderately silty
39	0	moderately silty
40	0	moderately silty
41	0	moderately silty
42	0	moderately silty
43	0	moderately silty
44	0	moderately silty
45	0	moderately silty
46	0	moderately silty
47	0	moderately silty
48	0	moderately silty
49	0	moderately silty
50	0	moderately silty
51	0	moderately silty
52	0	moderately silty
53	0	moderately silty
54	0	moderately silty
55	25	moderately silty
56	30	moderately silty
57	35	moderately silty
58	0	moderately silty

Run 34		
NE from Sanders along Patriot		
Location (ft)	Loss (%)	Cleanliness
59	0	moderately silty
60	0	moderately silty
61	0	moderately silty
62	0	moderately silty
63	0	moderately silty
64	0	moderately silty
65	0	moderately silty
66	0	moderately silty
67	0	moderately silty
68	0	moderately silty
69	0	moderately silty
70	0	moderately silty
71	0	moderately silty
72	0	moderately silty
73	0	moderately silty
74	0	moderately silty
75	0	moderately silty
76	0	moderately silty
77	0	moderately silty
78	0	moderately silty
79	0	moderately silty
80	0	moderately silty
81	0	moderately silty
82	0	moderately silty
83	0	moderately silty
84	0	moderately silty
85	0	moderately silty
86	0	moderately silty
87	0	moderately silty
88	0	moderately silty
89	0	moderately silty
90	0	moderately silty
91	0	moderately silty
92	0	moderately silty
93	0	moderately silty
94	0	moderately silty
95	0	moderately silty
96	0	moderately silty
97	0	moderately silty
98	0	moderately silty
99	0	moderately silty

Run 34		
NE from Sanders along Patriot		
Location (ft)	Loss (%)	Cleanliness
100	0	moderately silty
101	0	moderately silty
102	0	moderately silty
103	0	moderately silty
104	0	moderately silty
105	0	moderately silty
106	0	moderately silty
107	0	moderately silty

Appendix B: Data for EPANET Calculations

```
[TITLE]
Westover Air Reserve Base Water Distribution Model
[JUNCTIONS]
;------------------------------------
;   ID  Elevation  Demand  (Pattern)
;------------------------------------
   1        0
   3        0
   4        0
   5        0
   6        0
   7        0
   8        0
   9        0
  10        0
  11        0
  12        0
  13        0
  15        0
  16        0
  17        0
  18        0
  19        0
  20        0
  21        0
  22        0
  23        0
  24        0
  25        0
  26        0
  27        0
  28        0
  29        0
```

33	0
34	0
35	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
59	0
60	0
61	0
62	0
63	0
64	0
65	0
66	0
67	0
68	0
69	0
74	0
75	0
76	0
78	0
79	0
80	0
81	0
82	0
84	0
86	0
88	0
89	0

90	0
91	0
93	0
94	0
95	0
96	0
97	0
99	0
100	0
101	0
102	0
103	0
104	0
105	0
106	0
107	0
108	0
109	0
110	0
111	0
112	0
113	0
114	0
115	0
116	0
117	0
118	0
119	0
120	0
121	0
122	0
123	0
124	0
125	0
126	0
127	0
128	0
129	0
130	0
131	0
134	0

135	0
136	0
137	0
138	0
139	0
140	0
141	0
142	0
143	0
144	0
145	0
146	0
147	0
148	0
149	0
150	0
151	0
152	0
153	0
154	0
155	0
156	0
157	0
158	0
159	0
160	0
161	0
162	0
163	0
164	0
165	0
166	0
168	0
169	0
170	0
171	0
172	0
173	0
174	0
175	0
177	0

178	0
179	0
180	0
182	0
183	0
184	0
185	0
186	0
189	0
190	0
191	0
192	0
193	0
194	0
195	0
196	0
197	0
198	0
199	0
200	0
201	0
202	0
203	0
204	0
205	0
210	0
211	0
212	0
213	0
214	0
215	0
216	0
217	0
218	0
219	0
220	0
221	0
222	0
223	0
224	0
225	0

226	0
227	0
229	0
230	0
231	0
232	0
233	0
234	0
235	0
236	0
237	0
238	0
239	0
240	0
241	0
243	0
244	0
245	0
246	0
249	0
250	0
251	0
252	0
253	0
254	0
255	0
256	0
257	0
258	0
259	0
260	0
261	0
262	0
263	0
264	0
265	0
266	0
277	0
278	0
279	0
280	0

281	0
282	0
283	0
284	0
285	0
286	0
288	0
289	0
290	0
291	0
292	0
293	0
295	0
296	0
297	0
299	0
300	0
301	0
303	0
304	0
305	0
306	0
308	0
309	0
310	0
311	0
312	0
313	0
315	0
316	0
317	0
318	0
319	0
321	0
322	0
323	0
324	0
325	0
326	0
327	0
328	0

```
 329          0
 330          0
 331          0
 333          0
 334          0
 335          0
 336          0
 344          0
 345          0
 346          0
 347          0
 348          0
 349          0
 350          0
 351          0
 352          0
 353          0
 354          0
 355          0
 356          0
 357          0
 400          0
 401          0
 402          0
 405          0
 406          0
 407          0
 408          0

[TANKS]
;-------------------------------------------------------------
;                    Initial  Minimum  Maximum           (Minimum
;  ID   Elevation    Level    Level    Level    Diameter  Volume)
;-------------------------------------------------------------
 307   100.25        153      139.5    153.5    50        78991
 358     5
   2     5

[PIPES]
;--------------------------------------------------------------------
```

; ID	Head Node	Tail Node	Length	Diameter	Roughness Coefficient	(Minor Loss Coefficient)	(Check Valve)
1	1	2	375	6	80		
3	3	4	120	4	80		
5	5	6	30	6	80		
6	11	12	690	8	80		
7	12	13	259	8	80		
10	9	18	56	3	80		
11	16	17	30	3	80		
13	21	22	30	3	80		
14	7	23	56	3	80		
15	19	26	259	8	80		
17	28	29	26	6	80		
19	34	35	94	12	80		
21	35	10	20	12	80		
29	44	45	63.75	12	80		
30	44	55	130	12	80		
31	55	56	15	6	80		
32	55	59	1042.5	12	80		
33	45	46	228.75	12	80		
34	46	47	45	6	80		
35	46	49	555	12	80		
36	59	60	401.25	8	80		
37	60	61	12	6	80		
38	60	62	97.5	8	80		
39	62	63	30	8	80		
40	63	64	15	8	80		
41	64	65	253.25	8	80		
42	64	67	157.5	8	80		
43	67	68	11.25	6	80		
44	65	66	11.25	6	80		
45	67	69	11.25	8	80		
46	59	74	393.75	12	80		
47	74	88	431.25	12	80		
48	88	75	273.75	12	80		
49	75	76	18.75	12	80		
50	76	78	525	12	80		
51	78	49	120	12	80		
52	78	79	228.75	6	80		

53	79	80	63.75	2	80
54	80	81	7.5	2	80
55	79	82	288.75	6	80
56	82	84	146.25	2	80
58	82	86	450	6	80
59	49	50	360	8	80
60	50	51	30	6	80
63	88	86	378.75	6	80
64	86	89	603.75	6	80
65	89	96	435	8	80
66	96	97	420	6	80
67	97	99	250	6	80
68	97	101	45	6	80
70	105	104	37.5	6	80
71	104	103	476.25	8	80
72	104	106	512	8	80
73	99	74	320.5	6	80
74	99	100	45	6	80
75	106	107	78.75	12	80
76	107	74	270	12	80
77	106	126	41.25	12	80
78	107	108	333.75	8	80
79	108	109	11.25	6	80
80	108	110	367.5	8	80
81	110	111	215.5	8	80
82	111	112	11.25	6	80
83	111	113	180	8	80
84	113	114	48.75	8	80
85	114	117	37.5	6	80
86	114	115	90	8	80
87	115	116	11.25	8	80
88	115	118	123.75	8	80
89	118	119	11.25	8	80
90	118	120	217.5	8	80
91	120	121	11.25	8	80
92	120	122	123.75	8	80
93	122	123	11.25	6	80
94	122	124	88	8	80
95	126	127	67	6	80
96	126	125	228.75	12	80
97	125	124	42	8	80

98	125	128	240	12	80
99	128	129	80.5	1.5	80
100	129	130	63.75	1.5	80
101	130	131	3.75	1.5	80
105	134	135	30	6	80
106	134	136	123.75	12	80
107	136	137	202.5	16	80
108	137	138	11.25	16	80
109	136	139	251.25	12	80
110	139	140	108.75	3	80
111	139	141	50.5	12	80
112	141	142	28	6	80
113	141	143	48.75	12	80
114	143	103	273.75	8	80
115	103	102	82.5	8	80
116	102	96	270	8	80
117	143	144	115	12	80
118	144	357	300	8	80
119	357	358	187.5	8	80
120	357	355	453.75	8	80
121	355	356	100	6	80
122	355	353	382.5	8	80
123	353	354	100	6	80
124	353	351	146.25	8	80
125	351	352	30	6	80
126	351	350	255	8	80
127	350	349	75	8	80
131	345	346	39	6	80
132	345	344	180	8	80
133	344	336	2887.5	8	80
141	336	333	656.25	8	80
142	333	334	408.75	6	80
143	334	335	12	6	80
144	333	285	667.5	8	80
146	144	145	71.25	12	80
147	145	146	243.75	6	80
148	145	147	167	12	80
149	147	148	30	6	80
150	147	149	94	12	80
151	149	150	30	3	80
152	149	151	251.25	12	80

153	151	152	20	12	80
154	152	153	131.25	1	80
155	153	154	11.25	1	80
156	154	155	3.5	1	80
157	152	156	23	12	80
158	156	157	26.25	6	80
159	89	90	52.5	8	80
160	90	91	22.5	8	80
161	90	172	251.25	6	80
162	172	173	120	2	80
163	173	174	82.5	2	80
165	96	161	787.5	6	80
166	102	159	787.5	8	80
169	158	159	352.5	6	80
170	159	315	24	6	80
171	315	316	11.25	6	80
172	315	160	195	6	80
173	160	161	52.5	6	80
174	161	162	148	6	80
175	162	163	217.5	3	80
176	163	164	30	3	80
180	166	165	26.25	3	80
182	169	95	45	6	80
183	95	175	330	2	80
184	95	177	630	6	80
185	177	178	127.5	8	80
186	178	179	112.5	8	80
187	177	180	48.75	6	80
188	158	308	78.75	12	80
189	308	309	165	6	80
192	305	307	90	12	80
193	305	303	150	12	80
194	303	304	262.5	6	80
195	303	301	180	12	80
196	301	299	88	12	80
197	299	300	30	3	80
198	299	296	258.75	12	80
199	296	297	262.5	6	80
200	296	295	157.5	12	80
202	290	288	225	8	80
203	288	289	112.5	4	80

204	288	286	82.5	8	80
205	286	285	39.4	8	80
206	285	284	311.25	8	80
207	284	281	82.5	8	80
208	281	282	15	6	80
209	282	283	11.25	6	80
210	281	280	131.25	8	80
211	280	279	285	8	80
212	295	292	93.75	12	80
213	292	293	30	3	80
214	292	93	210	12	80
215	93	291	30	6	80
216	93	290	67	12	80
217	290	279	168.75	12	80
218	279	277	45	12	80
219	277	278	20	6	80
220	277	264	225	12	80
222	264	265	26.25	3	80
224	262	263	386.25	6	80
225	262	261	112.5	12	80
226	261	260	85	12	80
227	260	94	30	12	80
228	94	259	11.25	6	80
229	94	258	63.75	12	80
230	258	257	307.5	12	80
231	301	310	82.5	6	80
232	310	311	101.25	6	80
233	311	312	15	6	80
234	310	313	270	6	80
235	159	313	630	8	80
236	313	317	52.5	6	80
237	317	318	11.25	6	80
238	317	319	165	6	80
239	160	319	640	6	80
240	319	321	213.75	6	80
241	180	182	562.5	8	80
242	180	186	180	6	80
243	186	184	536.25	6	80
244	184	185	11.25	6	80
245	184	183	24.5	6	80
246	186	189	660	6	80

247	189	190	11.25	6	80
248	189	191	34	6	80
249	191	192	352.5	6	80
250	192	193	11.25	6	80
251	192	194	412.5	6	80
252	194	195	45	6	80
253	194	196	440	8	80
254	196	197	16	8	80
255	197	198	34.5	6	80
256	197	199	363.75	8	80
257	199	200	15	8	80
258	200	201	11.25	6	80
259	200	202	221.25	8	80
260	202	210	292.5	8	80
261	202	203	13	8	80
262	203	204	11.25	6	80
263	203	205	12	8	80
264	199	213	461.25	8	80
265	213	214	11.25	6	80
266	213	215	300	8	80
267	196	211	217.5	8	80
268	211	212	11.25	6	80
269	211	219	543.75	8	80
270	191	222	32	6	80
271	222	220	281.25	6	80
272	220	221	11.25	6	80
273	220	219	112.5	6	80
274	219	218	133	6	80
275	218	216	157.5	6	80
276	216	217	11.25	6	80
277	216	215	86.25	6	80
278	215	243	558	12	80
279	243	244	11.25	6	80
280	243	245	7.5	12	80
281	245	251	300	6	80
282	245	246	7.5	12	80
283	222	249	483	6	80
284	249	250	50	6	80
285	249	223	78.75	6	80
286	218	227	595	6	80
287	227	226	262.5	6	80

288	215	240	808	12	80
289	240	241	11.25	6	80
290	240	239	283	12	80
291	239	238	30	12	80
292	238	237	56.25	12	80
293	237	234	228.75	8	80
294	237	252	204.5	12	80
295	252	253	11.25	6	80
296	252	257	22.5	12	80
297	257	254	327.5	6	80
298	254	255	11.25	6	80
299	254	256	7.5	6	80
301	295	328	540	8	80
302	328	326	52.5	8	80
303	326	327	11.25	6	80
304	326	321	480	8	80
305	321	322	75	8	80
306	322	323	11.25	6	80
307	322	324	390	8	80
308	324	325	11.25	6	80
309	324	182	221.25	8	80
310	182	183	172.5	8	80
311	183	223	288.75	8	80
312	223	224	45	8	80
313	224	225	11.25	6	80
314	224	226	378.75	8	80
315	226	229	9.5	8	80
316	229	230	11.25	6	80
317	229	231	288.75	8	80
318	231	232	131.25	3	80
319	232	233	15	3	80
320	231	234	138.75	8	80
321	234	235	60	8	80
322	235	236	11.25	6	80
323	235	329	356.25	8	80
324	329	330	78.75	4	80
325	330	331	18.75	3	80
326	329	328	120	8	80
327	41	43	30	8	80
328	42	43	11	12	80

329	43	44	182	12	80
330	33	28	205	8	80
331	28	26	142.5	8	80
332	26	27	80	8	80
333	13	15	240	8	80
334	15	16	110	4	80
335	16	9	56	4	80
336	15	20	262	8	80
337	20	19	8	8	80
338	20	21	112	4	80
339	21	7	56	4	80
340	19	24	60	4	80
341	24	25	71	4	80
342	2	3	300	16	80
343	3	5	190	16	80
344	5	34	1070	16	80
345	50	52	266.25	8	80
346	52	400	116.25	2	80
347	52	401	5.625	8	80
348	401	53	37.5	6	80
349	401	54	18.75	8	80
350	128	134	285	12	80
351	349	402	11.25	6	80
353	172	170	127.5	6	80
354	170	405	11.25	6	80
355	170	169	412.5	6	80
356	162	171	7.5	6	80
357	171	406	39.5	6	80
358	171	168	108.75	6	80
359	168	166	202.5	3	80
360	168	169	217.5	6	80
361	308	407	75	12	80
362	407	306	45	3	80
363	407	305	157.5	12	80
364	264	408	35	12	80
365	408	266	22.5	6	80
366	408	262	60	12	80
367	10	42	50	12	80
368	349	348	40	8	80
369	348	347	562.5	8	80
370	347	345	1237.5	8	80

```
 371      8     33      450         8        80
 372     33     41      345         8        80

[PUMPS]
;-------------------------------------------------------------------
;        Head   Tail
;   ID   Node   Node   Characteristics
;-------------------------------------------------------------------

[VALVES]
;-------------------------------------------------
;        Head   Tail
;   ID   Node   Node   Diameter   Type   Setting
;-------------------------------------------------

[STATUS]
;--------------------------
;  First    (Last
;   Link     Link)   Setting
;--------------------------

[CONTROLS]
;----------------------------------------------------
; LINK     ID     Setting     Condition
;----------------------------------------------------

[PATTERNS]
;------------------------------------------------------------------
;   ID   Multipliers
;------------------------------------------------------------------

[QUALITY]
;---------------------------------------
;  First     (Last
;  Node      Node)     Initial Quality
;---------------------------------------

[SOURCES]
;--------------------------------------
;   Node    Concentration    (Pattern)
;---------------------------------------
```

```
[REACTIONS]
;---------------------------------------------
; Type     (First ID)   (Last ID)   Coefficient
;---------------------------------------------

[REPORT]
;---------------------------------------------
; Reporting Options
;---------------------------------------------
PAGE           55
STATUS         NO

[TIMES]
;---------------------------------------------
; Execution Control Information
;---------------------------------------------
DURATION               24     HOUR
HYDRAULIC TIMESTEP      1     HOUR
PATTERN TIMESTEP        1     HOUR
REPORT TIMESTEP         1     HOUR
REPORT START            0     HOUR

[OPTIONS]
;-----------------------------------------------
;  Network Properties & Simulation Options
;-----------------------------------------------
UNITS                  GPM
HEADLOSS               H-W
QUALITY                NONE
SPECIFIC GRAVITY       1.0
VISCOSITY              1.1E-5
DIFFUSIVITY            1.3E-8
TRIALS                 40
ACCURACY               0.001
SEGMENTS               100
MAP                    WESTOVER.MAP
[END]
```

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