RECLAMATION

Managing Water in the West

Final Report

Phase II Aluminum Bronze Piping Assessment for the Yuma Desalting Plant

U.S. Department of the Interior
Bureau of Reclamation
Yuma Area Office
Yuma, Arizona

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Final Report

Phase II

Aluminum Bronze Piping Assessment for the Yuma Desalting Plant

Prepared for

U.S. Bureau of Reclamation

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Executive Summary

Phase II of the aluminum bronze piping assessment at the Yuma Desalting Plant (YDP) involved an extensive evaluation of the existing piping system and associated future implications. Tasks consisted of testing and examination of pipe samples, evaluation of the pressure capacity and estimated remaining useful life, and development of alternative mitigation strategies for dealing with aluminum bronze pipe.

Phase II tasks were designed to follow Phase I, which developed an inventory of the aluminum bronze piping and defined methods for evaluation. The inventory of aluminum bronze pipe at YDP includes approximately 11,400 linear feet of cast and wrought pipe in sizes ranging from 2 to 78 inches in diameter. Representative sections of pipe that were identified for testing during Phase I were studied during Phase II.

Methods of Examination

During Phase II, representative segments of aluminum bronze piping were visually examined and tested using non-destructive methods. The test methods included ultrasonic thickness gauging, shear-wave ultrasonic flaw detection, and radiography. Because of the history of problems involving aluminum bronze welds at YDP, pipe welds were studied in depth. Aluminum bronze welds were examined and tested at 53 locations, 33 of which were inside the RO building and including all of the various process streams. The remaining sections were located in other areas throughout the plant.

Aluminum bronze piping was visually examined to look for evidence of leaks, corrosion, weld defects, deposits, or other abnormal conditions. A visual survey was made of the aluminum bronze piping in the Desalting Building to identify and count obvious locations of prior repairs or indications of water seeping from unusual locations on the piping.

All pipe sections that were tested were examined from the exterior, and some were examined from the interior. Pipes 54 inches and larger were entered, where possible, for examination. Interior inspections of smaller pipe were made by disassembling mechanical joints and temporarily displacing the pipe to permit observation of the interior from the ends of the pipe.

Metallographic analysis was conducted on a spare section of aluminum bronze pipe that had previously failed. This section of pipe included both cast and wrought forms of aluminum bronze, and it displayed exactly the same types of weld defects that were found on installed pipe. The scrap pipe provided representative samples and avoided the need for cutting and repairing installed pipe. The samples were used to study the metallurgy of the base metal and weld under original and repair conditions. Radiographs of the study areas were also made for comparison with radiographs of installed pipe.

Results of Examinations

Examinations of the aluminum bronze pipe showed significant defects that will affect its reliability and expected service life. The major defect is the poor quality of welds made during original construction of the plant, and these are found throughout the inventory of installed aluminum bronze pipe.

Radiography results showed that an average 90 percent of the welds had defects sufficient for rejection according to ASME B31.3, Code for Pressure Piping. Weld defects include porosity, cracks, incomplete penetration, and lack of fusion. Only 10 percent of the welds meet the reference standard for quality. YDP was not required to be constructed in accordance with ASME B31.3; however, it is the code that is most applicable for the design of process piping at YDP.

Visual inspection of exposed pipe in the Desalting Building confirms the prevalence of problems at the welds of aluminum bronze piping. At least 54 locations were found with actively seeping leaks or with evidence of prior leak repairs. All of these locations occurred at welds made during original construction of the plant. Leaks are visible because they have mounds of blue-green corrosion products characteristic of copper alloys. Previous pipe repairs are obvious because of extensive weld beads.

Samples of the base metal of the aluminum bronze piping were analyzed, and it was verified that composition of the alloy met the requirements of the specifications.

Results of ultrasonic thickness gauging of the pipe wall thickness show that 71 percent of the aluminum bronze pipe sampled currently meets the specification requirements of the original construction documents. Pipe wall thickness was below the required values at 12 percent of the tested locations and 17 percent had mixed results. These results indicate that wholesale thinning of the pipe wall by corrosion has not generally occurred. However, localized corrosion at welds will lead to leaks and reduced reliability of the piping even if the majority of the pipe surface is not substantially affected by corrosion.

Metallographic examination of aluminum bronze pipe samples disclosed the reason that welding repairs have met with mixed success at YDP. Repair welding can create a brittle microstructure, known as beta phase, in portions of the weld. Unless the beta phase is completely removed, re-welding will not form the desirable alpha phase microstructure, and cracking or other defects will result in the weld repairs. The beta phase is hard to identify under field conditions, and removal is arduous, so the success of weld repairs is not assured.

Visible evidence of weld defects in the aluminum bronze piping is also found in other areas of the plant. For example, a 72-inch-diameter discharge header of the intake pumping station has a crack in every girth weld, with evidence of localized corrosion at the crack. During the inspection, one cracked weld was found that was sufficiently wide that groundwater and silt had leaked into the pipe and required prompt repair using a Weko-Seal®.

Cracked and seeping welds are also present on the aluminum bronze wye in the discharge pipelines to the Main Outlet Drain Extension (MODE). These pipes are 48 inches in diameter and are installed in a large, deep vault. Aluminum bronze pipes with similar conditions can be observed in other areas of YDP.

The reasons are not clear for the extensive defects in the original welds of the aluminum bronze pipe. The contract specifications required visual inspection and hydrostatic testing of the constructed piping system, but they did not require any other non-destructive testing such as radiography of welds. Construction records showed that the required hydrostatic test pressures at YDP were reduced when problems in the welds of aluminum bronze piping appeared at higher test pressures. The actual final test pressures were not found in the construction records.

Pipe Condition Assessment

After completion of the pipe examination and testing, an assessment was made of the aluminum bronze piping to gauge its fitness for service under current design conditions at YDP. The primary consideration is hoop stress, or the ability of the pipe to withstand bursting from water pressure in the pipe.

The original process design at YDP was based on cellulose acetate membranes, which required high-pressure and low pH feed water for efficiency. The original design pressure for this process was 425 to 450 psi. Low-pressure service was designed for 150 psi. Other pipes, such as RO products and plant drains, are designed for gravity flow.

The assessment of pressure piping was made using methods defined in ASTM B31.3, Code for Pressure Piping. ASTM B31.3 is the most applicable code for YDP, even though YDP was not originally designed to conform to it. The analysis assumed a weld quality factor of 0.60, which represents the strength of a welded joint relative to solid plate, and is appropriate for piping systems that have not been tested and verified during construction. The analysis showed that substantial portions of the high-pressure aluminum bronze piping do not have the pressure capability that would have been required by ASME B31.3 for the original design service conditions at YDP. Higher pressure ratings would have resulted if YDP had been constructed with higher standards for welds, so that a higher weld quality factor (0.85 to 1.00) could be applied.

Analysis showed that the maximum pressure capacities of straight lengths of aluminum bronze piping generally decrease with increasing pipe diameter when calculated according to the ASME B31.3 code. Only smaller pipe sizes meet the code requirements for RO feed piping at the current YDP design pressure of 450 psi. Existing tee fittings and mitered bends also do not meet code requirements for 450 psi service. The greatest discrepancy was shown for a 30-inch mitered bend in the Hydranautics RO feed pipe, which had calculated maximum allowable pressure of 118 psi.

The demonstration testing of YDP was conducted at a maximum pressure of 300 psi, which is lower than the original design pressure. During the testing, a total of 9 leaks occurred in the aluminum bronze piping system, but bursting or structural failures of pipe did not occur. Several leaks were found on the bottom of the pipes. Also, laboratory results indicated that the copper concentration in the water was fairly high. These findings indicated that corrosion was occurring on the aluminum bronze piping during demonstration testing.

Although the current wall thickness of most of the aluminum bronze piping is within the manufacturing tolerance for new pipe, thinning of the pipe wall by general corrosion will be an issue in the future. Based on tests conducted in Phase I, corrosion rates of aluminum bronze are expected to be 15 mils per year for RO feed and reject piping, and 5 mils per year for product piping, with YDP in its present operational configuration. The high corrosion rate in the RO feed and reject piping will reduce the pipe wall thickness by 50 percent in about 8 years.

Mitigation

Mitigation alternatives were considered for high-pressure piping, and ultimately two alternatives were selected: monitor and repair as needed; or replace with Type 316 stainless steel. The replacement alternative would correct all deficiencies in the existing piping, but the cost would be substantially greater and the piping would require special operation to prevent corrosion from ruining the pipe when the plant is not operating. The repair alternative would present more risk for plant reliability and safety of personnel. While this approach would defer the mitigation associated with plant piping, CH2M HILL does not recommend this approach because of safety considerations and the likelihood of higher overall cost.

Certain large buried aluminum bronze pipes in the plant operate at low-pressure or gravity flow. Mitigation is required, but replacement would be complex and expensive. A suitable and reasonable alternative is to conduct a manned inspection or pressure testing of the pipe and implement repairs or installation of a structurally independent liner if indicated by the results of the inspection.

Any repairs involving welds will require that detailed procedures, qualifications, and quality control measures be incorporated so that repairs are effective and reliable.

No specific recommendations are made regarding the aluminum bronze piping. This is because it is not clear how the YDP will be operated in the future. YDP might operate as presently authorized by Congress; that is, MODE water as feedwater, with conventional pretreatment, RO with cellulose acetate membranes, and product water discharged to the Colorado River for inclusion in water deliveries to Mexico.

Another alternative that might be considered is operation of YDP using Yuma area groundwater, piped to the plant as feedwater, particle/micro/ultrafiltration pretreatment, RO with polyamide membranes and interstage boost, post treatment stabilization, and potable product water delivered to the City of Yuma for municipal use. These scenarios have different implications for some of the aluminum bronze piping.

It was concluded jointly with the U.S. Bureau of Reclamation that, instead of making a final singular recommendation, the report should simply list the various alternatives based on the pressure of the piping and present costs for each of them. This approach will allow the U.S. Bureau of Reclamation to select the best alternative based upon the circumstances that exist when decisions are made regarding the aluminum bronze piping at YDP.

Therefore, the recommendations of the Phase II aluminum bronze piping assessment are fundamental in scope:

1. Existing aluminum bronze piping in the high-pressure piping system should be replaced with stainless steel pipe, or the membranes should be changed to polyamide so that the required operating pressure is substantially reduced. Stainless steel has been shown to be a suitable material at the YDP. It has been used successfully at PS-1 for nearly 20 years. In addition, spot replacement of components in the main plant have been made with stainless steel and the results have been acceptable. *CH2M HILL specifically recommends against operation of the existing aluminum bronze piping systems with cellulose acetate membranes because this scenario requires high operating pressures that exceed the pressure capacity of the pipe as determined by ASME B31.3, Code for Pressure Piping.*
2. Existing, buried, low-pressure or gravity piping should be inspected or tested to determine the type and extent of repairs required. There is no practical alternative for this piping.

Estimated costs were developed for implementation of recommended mitigation alternatives. The cost estimate is Class 3, which is appropriate to a basic engineering phase in which the general scope of construction is understood but not defined in a set of plans and specifications. This level of engineering is considered 10 to 40 percent complete. A Class 3 estimate has an expected accuracy range of -10 to -20 percent on the low side and +10 to +30 percent on the high side.

Estimated costs are shown in Table ES-1. Pipe replacement assumes that aluminum bronze pipe will be removed and replaced with Type 316L stainless steel pipe, and fittings of the same diameter and wall thickness. Type 316L is used for costing purposes only. The U.S. Bureau of Reclamation will make the final selection of piping materials. Valves and appurtenances will be removed and re-installed but not replaced with new items. Electrical and instrumentation connections to piping will be temporarily removed from the old pipe and attached to the new pipe. All existing pipe supports will be reused and no new supports will be required. The quantities and sizes of fittings were taken from the U.S. Bureau of Reclamation record drawings. Because the drawings do not show all views of the piping, quantities for straight pipe sections that could not be derived from the drawings were increased by 25 percent to account for undetermined items.

TABLE ES-1
Total Cost of Remediation for Aluminum Bronze Piping
Yuma Desalting Plant

Pipe Group		Estimated Cost, Millions[a]
Replacement with Stainless Steel[b]	(9,331 LF)	$15.0
Rehabilitation of Unique Piping	(1, 856 LF)	$0.6 - 2.1
Total	(11, 187 LF)	$15.6 - 17.1

Notes:

[a] Pricing is based on the November 2007 Engineering News Record (ENR) Construction Cost Index (CCI) for Los Angeles of 8871. Market for stainless steel is currently very volatile and subject to rapid escalation.

[b] Stainless steel replacement pipe will meet the code requirements of American Society of Mechanical Engineers (ASME) B31.3.

LF = linear feet

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Acronyms and Abbreviations

ASME	American Society of Mechanical Engineers
ASNT	American Society for Non-Destructive Testing
ASTM	American Society for Testing and Materials
CA	cellulose acetate
CIPP	cured-in-place-pipe
DSB	Desalting Building
FRP	fiberglass-reinforced plastic
ksi	kilo pound(s) per square inch
LF	linear feet
mgd	million gallon(s) per day
MIC	microbial-induced corrosion
MODE	Main Outlet Drain Extension
mpy	mils per year
NDT	non-destructive testing
OPC	opinion of probable cost
PA	polyamide
ppm	parts per million
psi	pound(s) per square inch
Reclamation	U.S. Bureau of Reclamation
RO	reverse osmosis
SCR	Solids Contact Reactor
UT	ultrasonic thickness
WQIC	Water Quality Improvement Center
YDP	Yuma Desalting Plant

SECTION 1.0

Introduction

1.1 Scope of Project

This report presents the results of Phase II of the aluminum bronze piping assessment at the Yuma Desalting Plant (YDP). The project was conducted by CH2M HILL under contract to the U.S. Bureau of Reclamation (Reclamation).

Subcontractors to CH2M HILL for this project included Phoenix National Laboratory for non-destructive testing and Mr. James Jenkins, P.E., metallurgist and consultant.

Project activities occurred over an 18-month period in 2006 through 2007 and included the following tasks:

- Inspection and non-destructive testing of 60 sections of pipe previously selected for study
- Preparation of a condition assessment of the piping based on inspection and test results
- Identification and evaluation of alternative approaches to address the piping condition
- Preparation of cost estimates for the alternatives considered
- Preparation of this report

Results of the inspection and testing are described in Section 2.0 of this report. The condition assessment is presented in Section 3.0. Alternatives are addressed in Section 4.0. Cost estimates are presented in Section 5.0. A construction cost estimate for replacement of all aluminum bronze piping within the desalting building (DSB) was submitted in advance of this report in response to a request by Reclamation.

Phase I of the aluminum bronze piping assessment was documented in a separate report by CH2M HILL in 2005. The results of Phase I are relevant to Phase II and are summarized in this section.

In 2007, YDP was operated at partial capacity for 90 days to perform demonstration testing of the facility. The testing was intended to assess the performance of components of the plant including the aluminum bronze piping. The behavior of the piping system was monitored during the demonstration testing, and results are included in this report.

1.2 History of Yuma Desalting Plant

YDP is a reverse osmosis (RO) desalting plant that has the capability to produce 73 million gallons per day (mgd) of desalted water. Its purpose is to save water for beneficial use, while desalting sufficient drainage returns from the Welton-Mohawk Irrigation and Drainage District in Arizona to maintain salinity levels at Morelos Dam on the Colorado

River. As part of the Minute 24 of International Boundary Water Commission, a joint commission between the U.S. and Mexico, the average annual salinity of the water arriving at Morelos Dam cannot exceed 115 parts per million (ppm) over the average annual salinity level of water arriving at the Imperial Dam.

Construction of YDP was completed in 1992; however, the facility has not actually been placed into service except for a 9-month period during 1992 and 1993, and the 3-month period of demonstration testing in 2007, when the plant was operated at approximately one-third capacity. Plant operation has not been necessary because the salinity in the lower Colorado River water has not reached the threshold level that triggers the need to desalinate irrigation return flows from the Welton-Mohawk Irrigation and Drainage District. Although, at present, the salinity of water in the Colorado River is below this threshold concentration, the plant is maintained in a "state-of-readiness" should the salinity level rise above the regulated limit. With the current drought and reduction in the amount of water in the Colorado River, salinity levels are increasing, causing a greater potential for plant operation in the future. As a consequence, Reclamation is working to correct deficiencies and make improvements so the facility is available to be placed into operation on short notice, should it become necessary.

Reclamation also operates pilot facilities at the Water Quality Improvement Center (WQIC), a test facility on the grounds of the desalting plant. Piloting has been used to simulate and optimize the original process designed for YDP.

1.3 Aluminum Bronze Piping Problems

Aluminum bronze was used for a substantial portion of process water piping at YDP. According to the design summary (Reclamation, 1986), aluminum bronze was selected because of its unique combination of features: resistance to corrosion by saline water; mechanical properties similar to steel; and cost comparable to stainless steel. When YDP was designed and constructed, aluminum bronze was widely used in applications with similar requirements, for example, cooling water systems for nuclear power plants. Other pipe materials used at YDP include reinforced concrete, fiberglass-reinforced plastic (FRP), ductile iron, and plastics.

The majority of the aluminum bronze piping at YDP was constructed from alloy C61300, which is a wrought form that is manufactured in plates. The plates are rolled into cylinders and the edges are joined by welding. Welded pipe was used for pipe sizes larger than 12 inches in diameter. Pipes diameter sizes 12 inches and smaller were generally made of cast aluminum bronze, and alloy C95200 was used for casting.

After construction was completed, several problems were discovered with the aluminum bronze pipe. Welding defects were present in a significant portion of the installed piping. These defects created weak points at the weld and prevented the achievement of a full-strength pipe. In addition, crevices were created in the pipe along the welds resulting in favorable conditions for corrosion. It was determined that the field repair welding was difficult because complete fusion of the base material, old weld, and new weld electrode could not be achieved on a consistent basis.

Weld failures caused by original defects and repair defects made it difficult to test pressure of the installed piping. Some valves and fittings leaked for a variety of reasons, making it difficult to conduct a valid pressure test. As result of these conditions, the high-pressure piping was apparently never tested to the specified test pressure. Furthermore, the test pressures were reduced several times in an effort to get sections of piping to pass. Because of a lack of records from this process, it is not clear what test pressures were actually used to test the piping sections.

Valves continued to leak, and additional piping problems were found following startup operations in 1992 through 1993. Severe corrosion problems were detected on aluminum bronze pump impellers, piping, and other wetted parts exposed to low pH and/or high velocity. Since that time, the aluminum bronze valves and pump impellers are gradually being replaced with stainless steel.

Changes in process chemistry have also been made since the original construction. In particular, the use of sulfuric acid to reduce the pH of the water and the use of ammonia for chloramination have changed the corrosion potential of the water since the original plant design. Additionally, the source water quality has changed; it has lower salinity than when YDP was designed.

1.4 Summary of Phase I Evaluation

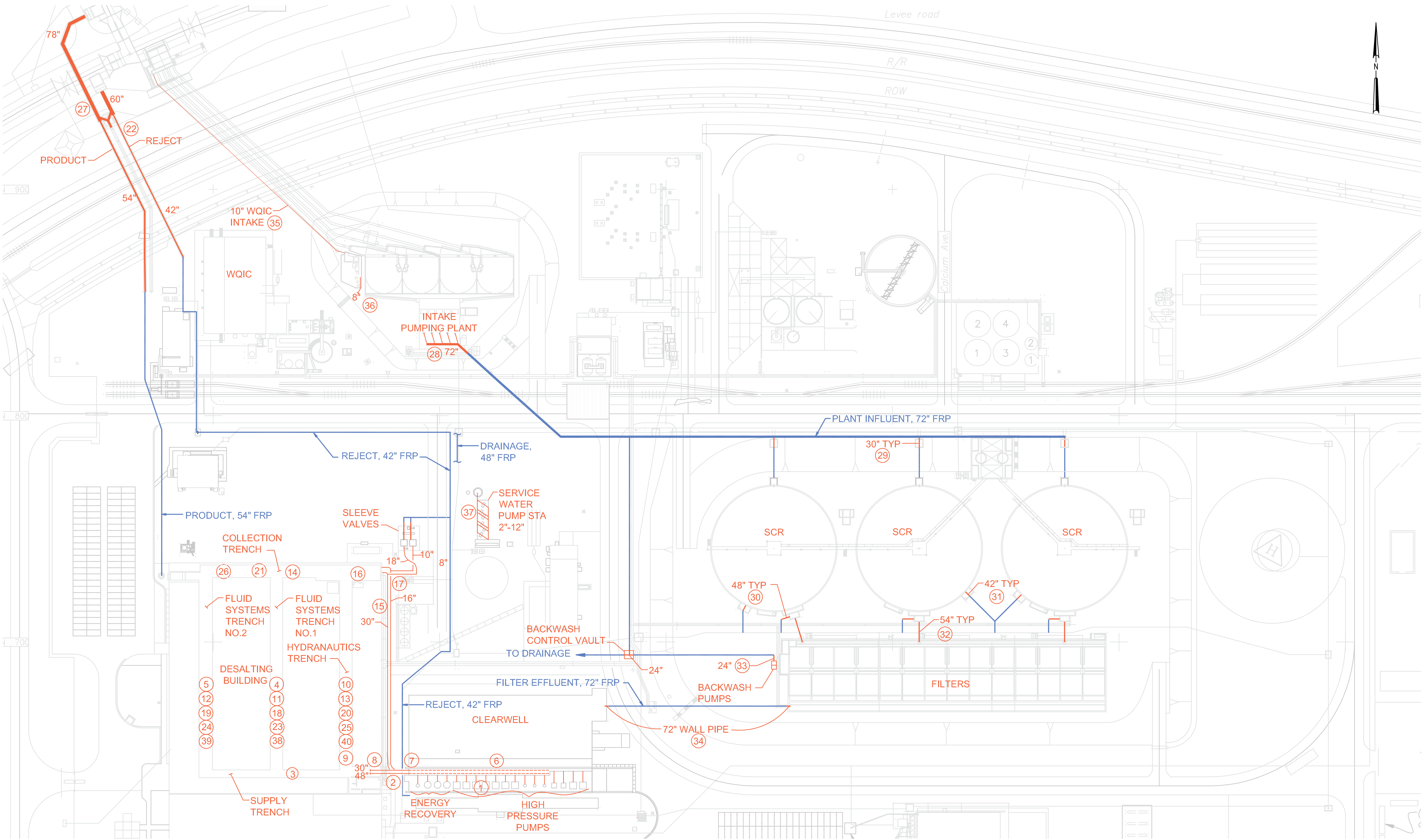
Phase I of the aluminum bronze piping assessment at YDP included development of an inventory of the pipe and characterization of the service conditions. A test plan for inspection and non-destructive evaluation was developed for Phase II.

It was determined that the total installed length of aluminum bronze pipe at YDP is approximately 11,187 linear feet. The general locations of the aluminum bronze piping are shown on Figure 1-1 (found at the end of this section). The length of aluminum bronze pipe was identified using record drawings, construction drawings, change orders, and other information available at the time.

YDP has 20 sizes of installed aluminum bronze pipe ranging from 2 to 78 inches in diameter. The greatest lengths of pipe are for 3-, 16-, and 30-inch pipe diameters. The pipe wall thickness ranges from 3/16-inch to 3/4-inch. Most of the pipe has a wall thickness of 1/4-inch. Details on the piping can be found in Table 1-1 (found at the end of this section).

Corrosion testing was performed by Reclamation using aluminum bronze coupons exposed to the water quality conditions at the WQIC. The WQIC uses the same processes as the full production facility but with smaller capacity. The tests showed that the corrosion rate of aluminum bronze is approximately 15 mils per year (mpy) for RO feed and reject water flowing at a velocity of 3.5 feet per second. The corrosion rate in RO product water was determined to be approximately 6 mpy.

The aluminum bronze piping designated for testing represented approximately 5 percent of the total length of aluminum bronze pipe at YDP. The test locations were chosen based on process stream, flow velocity, physical setting, history of weld failure, consequence of failure, and preliminary estimates of pipe stress at operating pressure.



LEGEND:

- ALUMINUM BRONZE PIPE
- FIBERGLASS-REINFORCED PLASTIC (FRP) PIPE
- ㉔ PIPELINE IDENTIFICATION NO. (SEE TABLE 1)

FIGURE 1
ALUMINUM BRONZE PIPING

YUMA DESALTING PLANT

CH2MHILL

Fig RB11x17.dwg Scale: 1"=40'

TABLE 1-1

YDP Aluminum Bronze Pipe Inventory

Date: October 23, 2007

			Length (mm) of Pipe Size																														
		Nominal Diamete	2	3	4	6	8	10	12	12	14	16	18	18	18	20	20	24	24	30	30	30	36	36	42	48	48	48	54	60	72	78	
		Indicated size	2-7/8 OD	3-1/2 OD	4-1/2 OD	6-5/8 OD	8-5/8 OD	10-3/4 OD	12-3/4 OD	12-3/4 OD	14 OD	16 OD	18 OD	18 OD	18 OD	20 OD	20 OD	24 OD	24 OD	30 ID	30 ID	30 ID	36 ID	36 ID	42ID	48 ID	48 ID	48 ID	54 ID	60 ID	72 ID	78 ID	
			3/16	1/4	3/16	1/4	1/4	1/4	1/4	5/16	1/4	1/4	1/4	5/16	7/16	1/4	5/16	1/4	3/8	1/4	3/8	7/16	1/4	9/16	1/4	1/4	5/16	3/4	1/4	1/4	5/16	5/16	
No.	**Pipeline**	**Ref Dwg No.**																															**Total**
		1292-D-xxxx																															feet
	1st St. Feed & 2nd St. Reject																																
	Fluid Systems																																
1	High Pressure Pump Discharge	4498, 4499, 4500							29	11					127				7									203					377
2	From Pump Manifold to DSB	4501																										34					34
3	DSB Supply Trench upstream of valves	1533, 1534																						115				171					286
4	DSB Control Block Trench No. 1 (East)	1536				60	218	52	49					111					71			48		54									664
5	DSB Control Block Trench No.2 (West)	1536				52	88	32	16					111					71			48		54									473
	Hydranautics																																
6	High Pressure Pump Discharge	4498, 4499, 4500							29	29				23	40				6			251											377
7	From Pump Manifold to DSB	4501																			34												34
8	DSB Supply Trench upstream of valve	1533, 1534																				10											10
9	DSB Sup Trench dnstrm of valve to 90 ben	1533, 1534																				64											64
10	DSB Control Block Trench	1545, 1546					49	95	26			137							88			52											446
	1st St. Reject & 2nd St. Feed (Interstage)																																
	Fluid Systems																																
11	DSB Control Block Trench No. 1 (East)	1537				126	136	96	27								30		91			68											572
12	DSB Control Block Trench No.2 (West)	1537				18	32	43	11								30		91			68											291
	Hydranautics																																
13	DSB Control Block Trench	1543, 1544					96	47	109		44		112																				407
	Interstage to Energy Recovery																																
	Fluid Systems																																
14	DSB Collection Trench	4505																	17			246											264
15	Outside DSB to Sleeve Valve & Turbines	4259, 4498, 4501, 4579											31	6	57						344												439
	Hydranautics																																
16	DSB Collection Trench	4505										66																					66
17	Outside DSB to Sleeve Valve & Turbines	4259, 4498, 4501, 4579						82				393																					475
	Low-pressure Reject																																
	Fluid Systems																																
18	DSB Control Block Trench No. 1 (East)	1542, 4510, 4511		336								282																					618
19	DSB Control Block Trench No. 2 (West)	1542, 4510, 4511		210								282																					492
	Hydranautics																																
20	DSB Control Block Trench	1549		154								282																					436
	Combined																																
21	DSB Collection Trench	4505										264																					264
22	Levee Crossing to Disposal exluding wye	1494																							177					89			266
	Product																																
	Fluid Systems																																
23	DSB Control Block Trench No. 1 (East)	1539				46	23	70			44		30					44		91			53										402
24	DSB Control Block Trench No. 2 (West)	1539				32	17	50			44		30					44		91			53										361
	Hydranautics																																
25	DSB Control Block Trench	1547					169	15			62					62				167													475
	Combined																																
26	DSB Collection Trench	4503																		83					116				62				260
27	Levee Crossing to MODE including all wye	1494, 4270																									33		244			196	473
	Pretreatment																																
28	Intake PS Disch Manifold & Pipeline	1489						50				50								79											71		249
29	SCR Influent	4260																		49													49
30	SCR Drain	4266																								16							16
31	SCR Drain	4267																							37								37
32	SCR Effluent/Filter Influent	1518, 1892, 1894																											147				147
33	Backwash Manifold	4258																80															80
34	Filter Outlet/Clearwell Inlet Wall Sleeves	1893 + est.																													20		20
	Other																																
35	WQIC Intake/Supply Pipe	1495, 1499, 4274					15	264																									279
36	WQIC Supply Pipe	6262					7																										7
37	Plant Service Water Pump Manifolds	4527, 4528	12		24	55	34		96																								221
	Cleaning Product Return																																
	Fluid Systems																																
38	DSB Control Block Trench No. 1 (East)	5090		365																													365
39	DSB Control Block Trench No. 2 (West)	5090		245																													245
	Hydranautics																																
40	DSB Control Block Trench	5090		150																													150
	Totals (ft)		12	1,461	24	389	883	894	390	40	195	1,754	202	251	224	62	59	169	443	559	379	854	105	223	331	16	33	409	453	89	91	196	11,187

SECTION 2.0

Results of Pipe Inspection and Testing

2.1 Introduction

This section presents the results of inspection and testing of aluminum bronze piping at YDP. The investigation comprises one part of Phase II of the aluminum bronze piping assessment conducted by CH2M HILL under contract to the Reclamation. During this part of the study, representative segments of aluminum bronze piping were visually examined and tested. The test methods included ultrasonic thickness gauging, shear-wave ultrasonic flaw detection, radiography, and metallography.

Phase I of the aluminum bronze piping assessment was completed in 2005. During Phase I, an inventory of installed piping was created. Pipelines were characterized by various attributes including size, diameter, thickness, physical setting, and process service. The Phase I report contains complete background information regarding the overall project and the rationale for selecting the pipelines for detailed examination. A total of 51 representative pipe sections were recommended for testing in Phase II.

2.2 Test Locations

The locations of aluminum bronze pipe sections that were selected for study are listed in Table 2-1 (found at the end of this section). The left side of Table 2-1 lists the identification number, process service, diameter, and wall thickness of the test pipes. Columns on the right side of Table 2-1 are discussed under Test Results. The locations of the test sections are shown on Figures 2-1A through 2-1C (found at the end of this section).

A total of 53 locations were examined and tested. These included 47 of the 51 pipe sections that were originally selected for testing, and 6 additional sections of pipe that were added to the test plan based on initial findings. Pipe sections designated for testing were marked with white paint and the letters "CH" followed by the test section identification number.

The test locations were distributed as follows:

- 33 pipe sections in the DSB, including all RO process streams with aluminum bronze pipe
- 14 pipe sections at or near the high-pressure pumps and energy recovery units, including both feed and interstage pipes made of aluminum bronze
- 3 pipe sections near solids contact reactor (SCR) No. 3, including influent and effluent pipes made of aluminum bronze
- 3 pipe sections at the intake pumping station, consisting of raw water pipes made of aluminum bronze

There were four sections of pipe that were originally selected for testing but were not tested. These were the RO product and reject pipelines near the Welton-Mohawk Main Outlet Drain Extension (MODE). They were not inspected or tested because they are buried and filled with water and, therefore, are not readily accessible.

2.3 Test Methods

Methods for inspection and testing the aluminum bronze pipe sections are described below. Nondestructive tests using ultrasonic and radiographic methods were conducted by Phoenix National Laboratories of Phoenix, Arizona, under contract to CH2M HILL. These tests conformed to American Society for Non-Destructive Testing (ASNT) standards for test methods and technician qualifications.

2.3.1 Visual Examination

Aluminum bronze piping was visually examined for evidence of leaks, corrosion, weld defects, deposits, or other abnormal conditions. The following two types of visual examinations were made:

- A visual survey was made of the aluminum bronze piping in the DSB to identify and count obvious locations of prior repairs or indications of water seeping from unusual locations on the piping. This survey was made by viewing the piping from the walkways.
- Sections of aluminum bronze piping were closely examined on the exterior and interior. Pipe sections that were tested were examined from the exterior, and some were examined from the interior. Pipelines 54-inch in diameter and larger were entered, where possible, for examination. Interior inspections of smaller pipe were made by disassembling mechanical joints and temporarily displacing the pipe to permit observation of the interior from the ends of the pipe.

Tools and measurement instruments used in conjunction with the visual inspection included high-intensity lighting, magnifying glasses, dye penetrant, and pit gauges. Digital photographs were taken to record features of interest.

2.3.2 Ultrasonic Thickness Gauging

The thickness of the pipe wall was measured with a digital ultrasonic thickness gauge calibrated to the aluminum bronze alloys at YDP. Ultrasonic thickness gauging uses high-frequency sound from an instrument and a transducer placed on the pipe surface. The instrument indicates the measured thickness based on the time required for the ultrasound to pass through the metal.

Scrap pieces of wrought (UNS C61300) and cast (UNS C95200) aluminum bronze pipe from YDP were used for calibration. A micrometer-caliper was used for physical measurement of the calibration samples to assure accuracy of the ultrasonic gauge.

At each test location, multiple measurements of wall thickness were made at regular intervals around the circumference of the pipe. Two rings or bands of measurements were made for all but the smallest pipe. Ultrasonic thickness tests were also made at bends in the pipeline to test for uneven erosion or corrosion associated with high-velocity flow. Measured pipe wall thicknesses were compared with those specified or shown on the drawings.

2.3.3 Shear-wave Ultrasonic Flaw Detection

Shear-wave or angle-beam ultrasonic testing was used to examine the welds of some pipe samples for the presence of defects that are not visible to the eye. Defects that can be detected in this manner include discontinuities, voids, incomplete fusion, porosity, and similar flaws.

This type of ultrasonic testing is conducted using small, shaped blocks to place ultrasonic transducers at optimal angles of 45 and 70 degrees to the pipe surface. Flaws are indicated by irregularities in the reflected ultrasound as displayed on the instrument.

The original test plan called for shear-wave ultrasonic testing to be used for all welded pipe sections, because this method can be a relatively fast method of scanning all welds that are present. However, the instrumentation was not optimized for aluminum bronze, and the results of initial tests were uncertain. Radiography (described below) was used to examine the first few pipe sections that had been previously examined by shear-wave ultrasonic testing. Radiography showed that shear-wave ultrasonic testing did not detect all defects that were present. Therefore, shear-wave ultrasonic testing was discontinued and was replaced by radiography for subsequent test sections.

2.3.4 Radiography

Radiography was used to examine welds and surrounding areas of the pipe wall for evidence of defects not visible to the eye. These defects can include cracks, lack of penetration, incomplete fusion, porosity, and similar conditions related to original construction or repairs.

Radiography uses a radioactive source to penetrate an object and produce an image on photographic film placed on the other side of the object. Pipeline radiography is similar to medical radiography, except that less powerful gamma rays are used instead of x-rays for safety in the industrial workplace. Water pipelines must be empty for testing by radiography, because the gamma rays do not have sufficient energy to pass through liquids and produce a legible image on the film.

Pipeline radiography is calibrated to produce a clear image of the metal wall of the pipe on the side of the pipe nearest the film. In most cases, the source can be placed outside the pipe on the opposite side. Defects are indicated by relatively light or dark areas on the film and are interpreted by trained technicians based on recognized standards. Procedures were in accordance with American Society of Mechanical Engineers (ASME) Section V, Article 2, and interpretations were in accordance with ASME B31.3. The films were 4.5 inches in width and varied in length from 10 to 28 inches.

Radiographs were taken at selected areas of welds, including longitudinal and circumferential welds. At least one of each type of weld was radiographed at each test section where both types were present. Weld junctions, or intersections of welds in different directions, were radiographed for most test sections.

2.3.5 Metallography

Metallographs or magnified photographs of polished and etched samples of aluminum bronze were made and examined to characterize the defects identified by non-destructive testing. Because the pipe welds were found to have numerous defects, metallographs were made of the weld areas.

Samples for metallography were taken from a section of aluminum bronze pipe that had been previously removed from the DSB and stored in the scrap yard. This section of pipe included both cast and wrought forms, and displayed exactly the same types of weld defects that were found on installed pipe. Therefore, the scrap pipe provided representative samples and avoided the need for cutting and repairing installed pipe.

Three metallographic samples were taken from the scrap pipe section. One sample consisted of a circumferential weld between cast and wrought pipe that had been previously repaired based on appearance. The other two samples were taken from longitudinal welds in wrought material. At our request, portions of these welds were ground out and repair welded by Burns and Roe staff. Wide and narrow repair weld beads were made on the samples to reflect two types of repairs observed on installed piping in the plant. The purpose of this modification was to allow study of the metallurgy of the base metal and weld under original and repair conditions. Radiographs of the metallographic samples were made prior to shipment to the laboratory.

2.4 Test Results

2.4.1 General

A summary of test results and description of notable pipe sections are discussed in this section. Selected photographs of the testing and observations are presented in Appendix A. Detailed test results and related documents are presented in Appendices B through G. Results for individual pipe sections are presented in Appendix H.

The results of ultrasonic and radiographic tests of the pipe sections are summarized in the columns on the right side of Table 2-1. Results are shown for the ultrasonic thickness (UT) gauging of each band or ring of tests using American Society for Testing and Materials (ASTM) B608 standards.

A passing grade is indicated if the measured thickness was greater than the minimum allowed by the standard, considering manufacturing tolerances. A failing grade is indicated if the measured wall thickness was less than the minimum allowed by the standard. Results show that 71 percent of the tested locations currently meet the pipe wall thickness requirements of the original construction documents. Twelve percent of the tested locations failed the thickness requirement, and 17 percent had mixed results.

Shear-wave ultrasonic test results are presented for information only, because this test method was discontinued as described in Section 2.1, Test Methods.

Radiography results showed that an average 90 percent of the welds had defects sufficient for rejection according to ASME B31.3 (Process Piping Section of ASME B31, Code for Pressure Piping). Only 10 percent of the welds meet the reference standard for quality. YDP was not required to be constructed in accordance with ASME B31.3. However, during previous discussions on this project, Reclamation indicated that ASME B31.3 may be the most applicable reference code for assessment of the aluminum bronze piping in the plant.

2.4.2 Results of Ultrasonic Thickness Gauging

Results of ultrasonic thickness gauging are shown in Appendix B, Table B-1. For each test location, the nominal plate thickness is shown along with the fabrication tolerance according to ASTM B608, Standard Specification for Welded Copper-Alloy Pipe (Appendix C). This standard was referenced in the YDP construction specifications and provides requirements for fabrication including pipe wall thickness and tolerances.

Locations where the ultrasonic transducer was placed are shown as positions beginning with the letter A for the top of the pipe, and progressing alphabetically in a clockwise direction around the pipe circumference as viewed in the direction of flow. The number of tests made around the circumference varied with the size of the pipe. Photo No. 1 (Appendix A) shows a typical ultrasonic thickness test.

Pipe wall thickness did not exhibit any particular trends. Some pipes were thicker than the minimum specified while others were thinner. The thinner wall pipes might have been that way since construction of YDP was completed because the measured thicknesses were consistent. Thinning by internal corrosion, if it occurred, would be expected to produce more variation in measured thickness.

A few pipe sections appeared to exhibit some areas of thinning from internal corrosion, or because of variations in the original thickness of the plates. As shown in Table 8 of ASTM B608, the manufacturing tolerance for pipe has a relatively wide range. Pipe made with 0.250- to 0.500-inch nominal plate can vary by plus or minus 0.023-inch in thickness at the time of fabrication.

2.4.3 Results of Radiography

Detailed results of the radiographic tests are presented in Appendix D, Table D-1. A total of 120 radiographs were produced, 83 of which were at circumferential welds and the remainder at longitudinal welds.

Radiographed welds were identified by the test section, weld orientation (C for circumferential; L for longitudinal), and the number of the weld within the test section (number 1 indicates the upstream end of the test section). For example, weld CH-1 C2 is the second circumferential weld from the upstream end of the pipe in test section CH-1.

The “View” column indicates the length of the radiographic image in inches as measured from the top of the pipe (for circumferential welds) or the end of the weld (for longitudinal welds). The remaining columns in Table D-1 indicate whether the weld passed or failed the quality requirement and the reason(s) for the determination.

The basis of judgment for weld quality was Chapter VI of ASME B31.3 (Appendix E). The text covers inspection, examination, and testing of pressure piping. Table 341.3.2 provides acceptance criteria for welds.

The last page of Table D-1 provides a summary of the causes of failure of the quality requirement:

- 71 percent of welds failed because of "porosity" (i.e., porous areas in the weld)
- 63 percent failed because of "incomplete penetration" (i.e., the weld does not span the full thickness of the pipe wall)
- 42 percent failed because of "lack of fusion" (i.e., the edges of the plate were not fully fused together by the weld)
- 8 percent failed because of "cracks" (i.e., the weld or adjacent plate are cracked)
- 2 percent failed because of inclusions, lack of fill, or flaws in the base metal

The only radiographs that passed the quality requirement were those without any of evidence of defects along the weld. A total of 14 radiographs passed inspection, and these were equally divided between longitudinal and circumferential welds.

Photo No. 2 shows the radiographic equipment in place at YDP. Photo Nos. 3 through 6 show the major types of weld defects found on the aluminum bronze piping.

The lower part of the last page of Table D-1 shows the results of radiographs on the scrap pipe from which the metallographic samples were taken. The welds on the scrap pipe failed inspection for the same principal reasons as the other welds on the installed pipe.

2.4.4 Results of Shear-wave Ultrasonic Flaw Detection

As described in Section 2.3.1, Shear-wave Ultrasonic Flaw Detection, shear-wave ultrasonic testing was discontinued when the technique could not detect all defects that were disclosed by radiography. Shear-wave ultrasonic testing was performed on 12 test sections, of which 7 were checked by radiography. The shear-wave ultrasonic method correctly detected defects in 4 of the 7 test sections but not in the other 3 test sections. Therefore, testing by the shear-wave ultrasonic method was discontinued. Photo No. 7 shows a typical shear-wave ultrasonic test.

2.4.5 Results of Metallographic Analysis

The results of the metallographic analysis are presented in Appendix F. This also includes a chemical analysis of the cast and wrought alloys. The chemical analysis verifies that the aluminum bronze pipe supplied is as specified. It also confirms that the wrought iron is suitable for welding. The metallographic analysis found normal microstructure in the cast and wrought base materials of the pipe sample. However, many defects were evident in the original welds. These defects included lack of fusion, voids with associated cracking, lack of penetration, and internal corrosion with de-alloying at cracks. All of these defects, with the exception of de-alloying, were evident on the radiographs of the samples before metallographic analysis.

The metallographic analysis also showed that repair welding was not completely successful in eliminating the defects found at the locations of the repairs. Repair welding did not correct the original lack of fusion or cracks. Significant amounts of beta phase alloy were found in one "butter" or wide weave-pattern weld. The beta phase is undesirable because it indicates that the elements of the alloy are not uniformly distributed, causing loss of mechanical properties unless the affected area is completely replaced.

The repair welding defects occurred even after repairs were made by certified and experienced welders using established practices at YDP, illustrating the difficulty of welding aluminum bronze.

For a historical perspective, two related documents from YDP records are included in Appendix G. The first is a letter from Brinderson Corporation (the construction contractor for Project DC-7610) to Reclamation, stating that visual inspection and hydrostatic pressure testing were the only conditions of acceptance for the installed piping in the contract specifications. The letter is dated November 13, 1987.

The second document in Appendix G is a letter report dated April 21, 1988, from Emtec Corporation regarding weld procedures and quality of aluminum bronze weld joints at YDP. The report concluded that, "some of the factory produced longitudinal welds and some of the circumferential field welds have grossly inadequate penetration and/or fusion." The report recommended hydrostatic testing of all sections of piping, even low-pressure piping, at "well above operating pressures," to qualify them for service.

It is not known if the issue of weld integrity was finally resolved during construction; however, it was an area of concern when YDP was built. Previous CH2M HILL review of construction records furnished by YDP did not yield a clear indication of the hydrostatic test pressures used for final acceptance. CH2M HILL test results for this task conclude that there are significant issues with weld integrity today.

2.4.6 Results of Visual Examination

The observation common to all visual examinations was that the welds in the aluminum bronze piping are the primary locations of trouble spots caused by construction welding defects or corrosion. Results of the visual examination are summarized in this section.

2.4.6.1 Desalting Building

Complete repair records for the aluminum bronze piping were not available. A cursory visual survey was made to assess the extent of obvious weld repairs and seeping leaks in the DSB, where the majority of the aluminum bronze piping is located. Seeping leaks are visible because they have mounds of blue-green corrosion products characteristic of copper alloys. Only leaks and repairs along welds were included, and not those that occurred at other joints such as flanges and flexible couplings. Results are summarized as follows:

- 22 prior weld repairs were observed that exhibited no evidence of seepage. Most of these were on the first stage feed and interstage piping. A few repairs were observed on the product piping.
- 14 prior weld repairs were observed that currently exhibit signs of seepage (Photo 8). The majority of these were on the product and low-pressure reject piping. One seeping repair was noted on the interstage piping.
- 18 welds were observed that currently show signs of leakage without repair (Photo 9). Fourteen of these occurred on the product piping and 4 on the interstage piping.

Because this survey was made by looking down at the piping from the walkways, it does not include all repairs or leaks that could be present on the lower part of the piping or in areas that are otherwise obscured from view.

2.4.6.2 Service Water Pumping Station

A visual survey was also made of the aluminum bronze piping at the service water pumping station to assess the extent of obvious weld repairs and seeping leaks. This portion of the piping system has been in continuous operation since YDP was constructed.

The pump suction and discharge pipes are exposed to view. The visual survey showed that there have been four prior weld repairs, one of which is seeping. There are two other small locations of seepage at welds.

2.4.6.3 Intake Pumping Station

The discharge header of the intake pumping station is a 72-inch-diameter aluminum bronze pipe that is approximately 100 feet in length. The discharge header is buried and encased in reinforced concrete, but it has an access manway at grade. The manway was used to enter the pipe for visual inspection of its interior surfaces. The pipe was found to be full of water and required pumping out and ventilation prior to entrance.

Upon entering the 72-inch-diameter pipeline, CH2M HILL staff observed that it was constructed from 10-foot-long sections of pipe that were welded together. The welds were readily visible because they had areas of blue-green corrosion products characteristic of copper. In contrast, the longitudinal welds within each pipe section showed very little evidence of corrosion. Examination of the circumferential welds showed that there were visible cracks in each one (Photo 10). The locations of the cracks generally aligned with the corrosion products.

One location was found near the bottom of the pipe where sediment had accumulated. Close inspection showed that the joint was not welded, and a putty knife could be placed in the gap between sections of pipe (Photo No. 11). From the sediment and condition of the joint, Burns and Roe staff surmised that groundwater had leaked into the pipe at this “open” joint over a period of years, and that this was the reason that the pipe was full of water. Subsequent to CH2M HILL inspection, plans were made to seal the joint using a Weko-Seal®, which consists of metallic expanding rings and a heavy rubber inflatable ring.

2.4.6.4 Wye Vault

The Wye Vault is located northwest of the plant and adjacent to the MODE. The 54-inch-diameter piping and valves in this vault allow the plant drain flow to be combined with either the reject or product water (or both). All of the piping in the vault is constructed from aluminum bronze.

The piping in the vault was inspected on the exterior surfaces only. The piping is full of water because the ends of the reject and product pipelines are under water, and the plant drain pipeline flows into them. The adjacent buried reject and product pipelines are made of aluminum bronze and are not easily accessible for inspection. Therefore, the piping in the vault was inspected.

Inspection showed that the circumferential welds immediately upstream of the valves are cracked and seeping at several locations (Photo No. 12). No defects were observed in longitudinal welds or other circumferential welds.

2.4.6.5 Other Pipes

Several other aluminum bronze pipelines were inspected on their interior surfaces. Pipelines in the hydranautics portion of the DSB were selected because they were thought to have had the most service time of the pipelines in the plant.

14-Inch-Diameter Hydranautics Product Pipeline

A section of the 14-inch-diameter hydranautics product pipeline was inspected through a 10-inch-diameter vertical tee. This section of pipe was CH-45, located between future Control Blocks 1 and 2. Inspection showed that corrosion was minor; however, corrosion products were relatively thick on some parts of the circumferential welds.

This pipeline tapers to a 10-inch-diameter pipe and terminates in a butterfly valve. The interior of the horizontal 10-inch-diameter pipe was examined after removal of the valve at the end of the pipe. Inspection showed that the pipe was crusted with deposits, and corrosion products were evident at the circumferential welds.

16-Inch-Diameter Hydranautics Low Pressure Reject Pipeline

A section of the 16-inch-diameter hydranautics low-pressure reject pipeline was temporarily removed for inspection. This section of pipe was CH-50, located between future Control Blocks 20 and 22. The pipe interior was covered with specks of white deposits uniformly distributed over the surface. The white deposits were underlain by a tenacious dark brown layer. After cleaning, the metal surface was found to have pitting that was too shallow to measure with a pit gauge. The welds were in the same condition as the pipe, with no evidence of localized corrosion or cracking.

18-Inch-Diameter Hydranautics Interstage Pipeline

A section of the 18-inch-diameter hydranautics first stage reject/second stage feed (interstage) pipeline was temporarily removed for inspection. This section of pipe was located between Control Blocks 15 and 16, and south of test section CH-29.

It appeared that the pipe had been partially full of water. There was a line of shallow pitting to a depth of 3 to 5 mils (1 mil equals 0.001 inch) at the air-water interfaces along the sides of the pipe. Pale yellow-green sediment was present on the bottom of the pipe. The longitudinal welds did not show evidence of corrosion or other construction defects.

30-Inch-Diameter Hydranautics Feed Pipeline

A section of the 30-inch-diameter hydranautics first stage feed pipeline was temporarily removed for inspection. This section of pipe was located near the south end of the trench, between the sites of future Control Blocks 1 and 2. This location was test section CH-19.

This pipeline also appeared to have stood partially filled with water for some time because a water line was evident on the sides of the pipe. Blue-green mounds of corrosion products were present, below the water line, on the circumferential welds and the longitudinal welds (Photo No. 13). The pipe wall had a few pits at the water line, and the deepest was 30 mils. When the corrosion products were removed from the welds, pits and reddish coloration indicative of de-alloying were observed (Photo No. 14). These pits were 40 to 60 mils in depth.

A repair weld was discovered on the bottom of the pipe, directly above one of the pipe stands, on the longitudinal weld. A mass of aluminum bronze from the repair weld was evident inside the pipe. The mass was covered with blue-green corrosion products. When the corrosion products were removed (Photo No. 15), the mass had a reddish color but was irregular that it could not be determined if pitting was present.

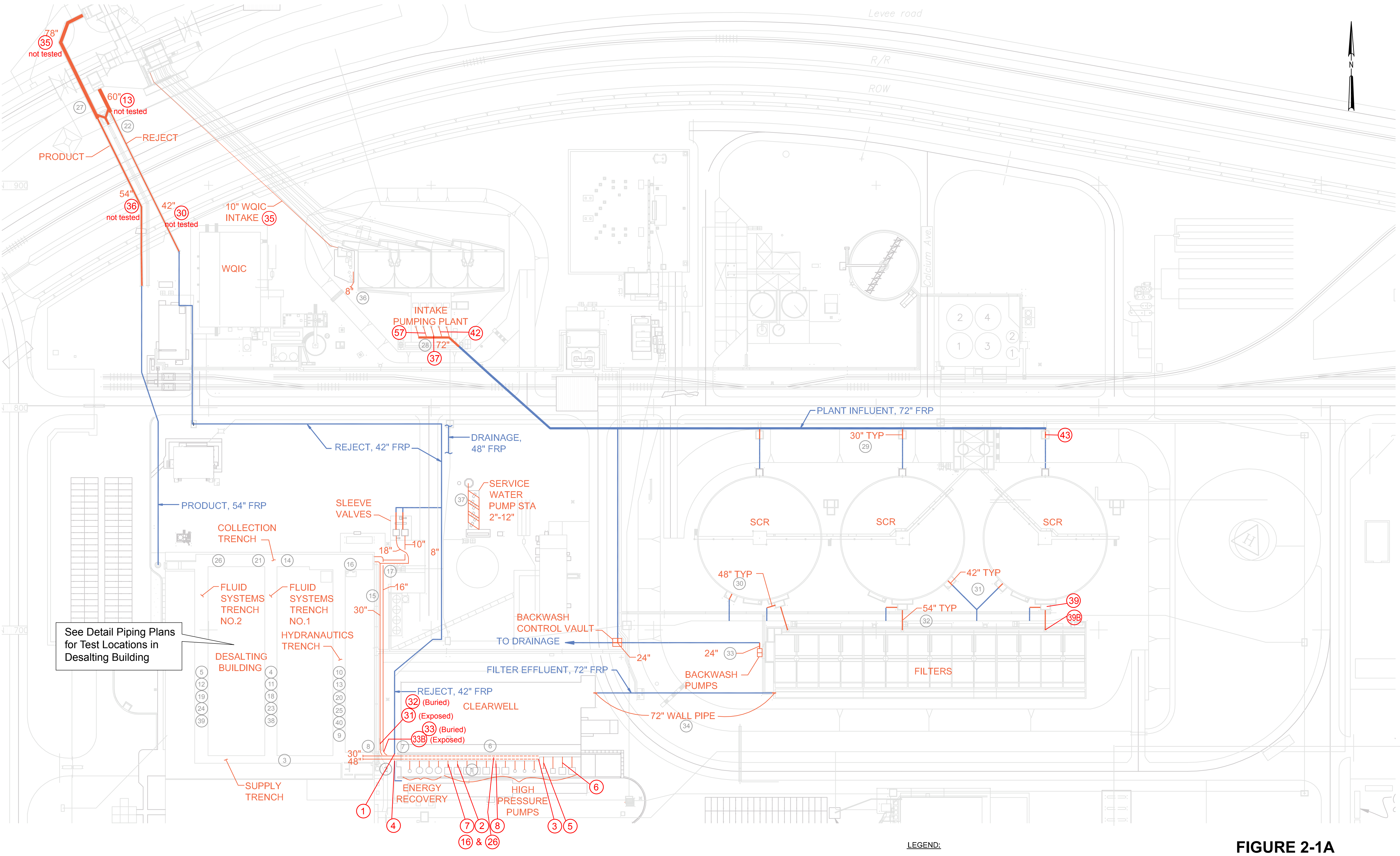
The appearance of the corrosion pits along the welds of this pipeline appear similar to those caused by microbial-induced corrosion (MIC) associated with standing water conditions. However, the pitting could also have resulted from galvanic corrosion or other localized conditions in the welds.

Date: 12/21/2007

TABLE 2-1
YDP Aluminum Bronze Piping
Summary of Test Sections

No. CH-	Process Train	Process	Pipeline Description	Ref Dwg No. 1292-D-	Pipe Diameter (in)	Wall Thickness (in)	UT Results		Shear Wave Result	Radiograph Result
							Band 1	Band 2		
1	***Hydranautics***	**Feed**	From Pump Manifold to DSB	4501	30	3/8	Pass	Pass		FC, PL
2	***Fluid Systems***	**Feed**	High-pressure Pump Discharge	4498	18	7/16	Pass	2 Fail		FL (No C)
3	***Fluid Systems***	**Feed**	High-pressurePump Discharge	4498	24	3/8	All Fail	All Fail		FL (No C)
4	***Fluid Systems***	**Feed**	From Pump Manifold to DSB	4501	48	3/4	Pass	Pass		FC, PL
5	***Combined***	**Feed**	High-pressure Pump Discharge	4498	12-3/4	5/16	Pass	Pass		FC (No L)
6	***Hydranautics***	**Feed**	High-pressure Pump Discharge	4498, 4499	18	7/16	Pass	Pass		FC, FL
7	***Hydranautics***	**Feed**	High-pressure Pump Discharge	4498	18	7/16	Pass	Pass		FC, FL
8	***Fluid Systems***	**Feed**	High-pressure Pump Discharge	4498	18	7/16	Pass	Fail		FL (No C)
9	***Hydranautics***	**Interstage (1st St. Reject & 2nd St. Feed)**	DSB Contol Block Trench	1543, 1544	18	5/16	3 Fail	Pass		FC, FL
10	***Fluid Systems***	**Interstage (1st St. Reject & 2nd St. Feed)**	DSB Control Block Trench No. 1 (East)	1537	30	7/16	NT	NT		FC, FL
11	***Fluid Systems***	**Interstage to Energy Recovery**	DSB Collection Trench	4505	30	7/16	All Fail	All Fail		FC, FL
12	***Fluid Systems***	**Low Pressure Reject**	DSB Collection Trench	4505	16	1/4	Pass	Pass		FC, FL
13	***Combined***	**Low Pressure Reject**	Levee Crossing to disposal excluding wye	1494	60	1/4	NT	NT		
14	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 1 (East)	1536	30	7/16	Pass	Pass	FC	
15	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 2 (West)	1536	30	7/16	1 Fail	Pass		FC (No L)
16	***Hydranautics***	**Feed**	Pump Manifold	4498	30	7/16	8 Fail	6 Fail		
17	***Hydranautics***	**Feed Manifold**	DSB Supply Trench Upstream of valve	1533, 1534	30	7/16	All Fail	All Fail	FC	FC (No L)
18	***Hydranautics***	**1st St. Feed & 2nd St. Reject**	DSB Supply Trench Downstream of valve to 90 bend	1533, 1534	30	7/16	Pass	Pass	FC, FL	FC, FL
19	***Hydranautics***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench	1545, 1546	30	7/16	All Fail	All Fail		FC, FL
20	***Hydranautics***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench	1545, 1546	16	1/4	Pass	Pass		FC, FL
21	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 1 (East)	1536	24	3/8	Pass	Pass	P	
22	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 2 (West)	1536	24	3/8	Pass	Pass		FC, FL
23	***Fluid Systems***	**Feed Manifold**	DSB Supply Trench upstream of valves	1533, 1534	36	9/16	1 Fail	Pass		FC, FL
24	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 1 (East)	1536	36	9/16	Pass	Pass	P	FC, FL
25	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 2 (West)	1536	36	9/16	Pass	Pass		FC (No L)
26	***Fluid Systems***	**Feed**	Pump Manifold	4498	48	3/4	All Fail	All Fail		
27	***Fluid Systems***	**Feed Manifold**	DSB Supply Trench upstream of valves	1533, 1534	48	3/4	4 Fail	Pass	P	FC, PL
28	***Fluid Systems***	**1st St. Feed & 2nd St. Reject**	DSB Control Block Trench No. 1 (East)	1536	18	5/16	Pass	Pass	FC, FL	FC, FL
29	***Hydranautics***	**Interstage (1st St. Reject & 2nd St. Feed)**	DSB Contol Block Trench	1543, 1544	12-3/4	1/4	Pass	Pass		FC (No L)
30	***Combined***	**Low Pressure Reject**	Levee Crossing to disposal excluding wye	1494	42	1/4	NT	NT		
31	***Fluid Systems***	**Interstage to Energy Recovery**	Outside DSB to Sleeve Valve & Turbines	4501	30	3/8	Pass	Pass		FC, FL
32	***Fluid Systems***	**Interstage to Energy Recovery**	Outside DSB to Sleeve Valve & Turbines	4501	30	3/8	Pass	Pass	FC, PL	FC, FL
33	***Hydranautics***	**Interstage to Energy Recovery**	Outside DSB to Sleeve Valve & Turbines	4501	16	1/4	Pass	Pass	P	FC, FL
33B	***Hydranautics***	**Interstage to Energy Recovery**	Outside DSB to Sleeve Valve & Turbines	4501	16	1/4	Pass	Pass		FC, FL
35	***Combined***	**Product**	Levee Crossing to MODE including all wye	1494	78	5/16	NT	NT		
36	***Combined***	**Product**	Levee Crossing to MODE including all wye	1494	54	1/4	NT	NT		
37	***Combined***	**Pretreatment**	Intake PS Disch Manifold & Pipeline	1489	72	5/16	Pass	Pass		
38	***Combined***	**Product**	DSB Collection Trench	4503	42	1/4	Pass	Pass		FC, FL
39	***Combined***	**Pretreatment**	SCR Effluent/Filter Influent	1518, 1892, 1894	54	1/4	Pass	Pass		FL (No C)
39B	***Combined***	**Pretreatment**	SCR Effluent/Filter Influent	1518, 1892, 1895	54	1/4	NT	NT		FC (No L)
40	***Fluid Systems***	**Low Pressure Reject**	DSB Control Block Trench No. 1 (East)	1542	3-1/2	1/4	Pass	Pass	P	FC (No L)
41	***Fluid Systems***	**Low Pressure Reject**	DSB Control Block Trench No. 2 (West)	1542	3-1/2	1/4	Pass	Pass		FC (No L)
42	***Combined***	**Pretreatment**	Intake PS Disch Manifold & Pipeline	1489	30	1/4	Pass	Pass		FC, FL
43	***Combined***	**Pretreatment**	SCR Influent	4260	30	1/4	Pass	Pass		FL (No C)
44	***Fluid Systems***	**Product**	DSB Control Block Trench No. 2 (West)	1539	24	1/4	Pass	Pass		FL (No C)
45	***Hydranautics***	**Product**	DSB Control Block Trench	1547	14	1/4	Pass	Pass	FC, FL	FC (No L)
46	***Hydranautics***	**Product**	DSB Control Block Trench	1547	8-5/8	1/4	Pass	Pass		FC (No L)
46B	***Hydranautics***	**Product**	DSB Control Block Trench	1547	8-5/8	1/4	All Fail	All Fail		F tee
47	***Fluid Systems***	**Product**	DSB Control Block Trench No. 1 (East)	1539	24	1/4	Pass	Pass	FC	FC, FL
48	***Hydranautics***	**Interstage (1st St. Reject & 2nd St. Feed)**	DSB Contol Block Trench	1543, 1544	18 to 14	5/16 to 1/4	All Fail	Pass		FC, FL
49	***Hydranautics***	**Product**	DSB Contol Block Trench	1547	30	1/4	Pass	Pass		FC, FL
50	***Hydranautics***	**Low Pressure Reject**	DSB Control Block Trench	1549	16	1/4	Pass	Pass		FC, FL
51	***Combined***	**Product**	DSB Collection Trench	4503	54	1/4	Pass	Pass		FC, FL
52	***Fluid Systems***	**Product**	DSB Control Block Trench No. 2 (West)	1539	36	1/4	Pass	Pass		FC, FL
53	***Fluid Systems***	**Interstage (1st St. Reject & 2nd St. Feed)**	DSB Control Block Trench No. 2 (West)	1537	20	5/16	Pass	Pass		FC, FL
54	***Hydranautics***	**Product**	DSB Collection Trench	4503	30	1/4	Pass	Pass		FC, FL
55	***Fluid Systems***	**Interstage to Energy Recovery**	DSB Collection Trench	4505	30	7/16	1 Fail	1 Fail		FC, FL
56	***Fluid Systems***	**Low Pressure Reject**	DSB Collection Trench	4505	16	1/4	Pass	Pass		FC, FL
57	***Combined***	**Pretreatment**	Intake PS Disch Manifold & Pipeline	1489	30	1/4	NT	NT		FC, PL

LEGEND
Y = YES
NT = NOT TESTED
N = NO
FC = FAILED CIRCUMFERENTIAL WELD
PC = PASSED CIRCUMFERENTIAL WELD
FL = FAILED LONGITUDINAL WELD
PL = PASSED LONGITUDINAL WELD



LEGEND:

- ALUMINUM BRONZE PIPE
- FIBERGLASS-REINFORCED PLASTIC (FRP) PIPE
- ㉔ PIPELINE IDENTIFICATION NO. (SEE TABLE 1-1)
- ① PIPE TEST LOCATION

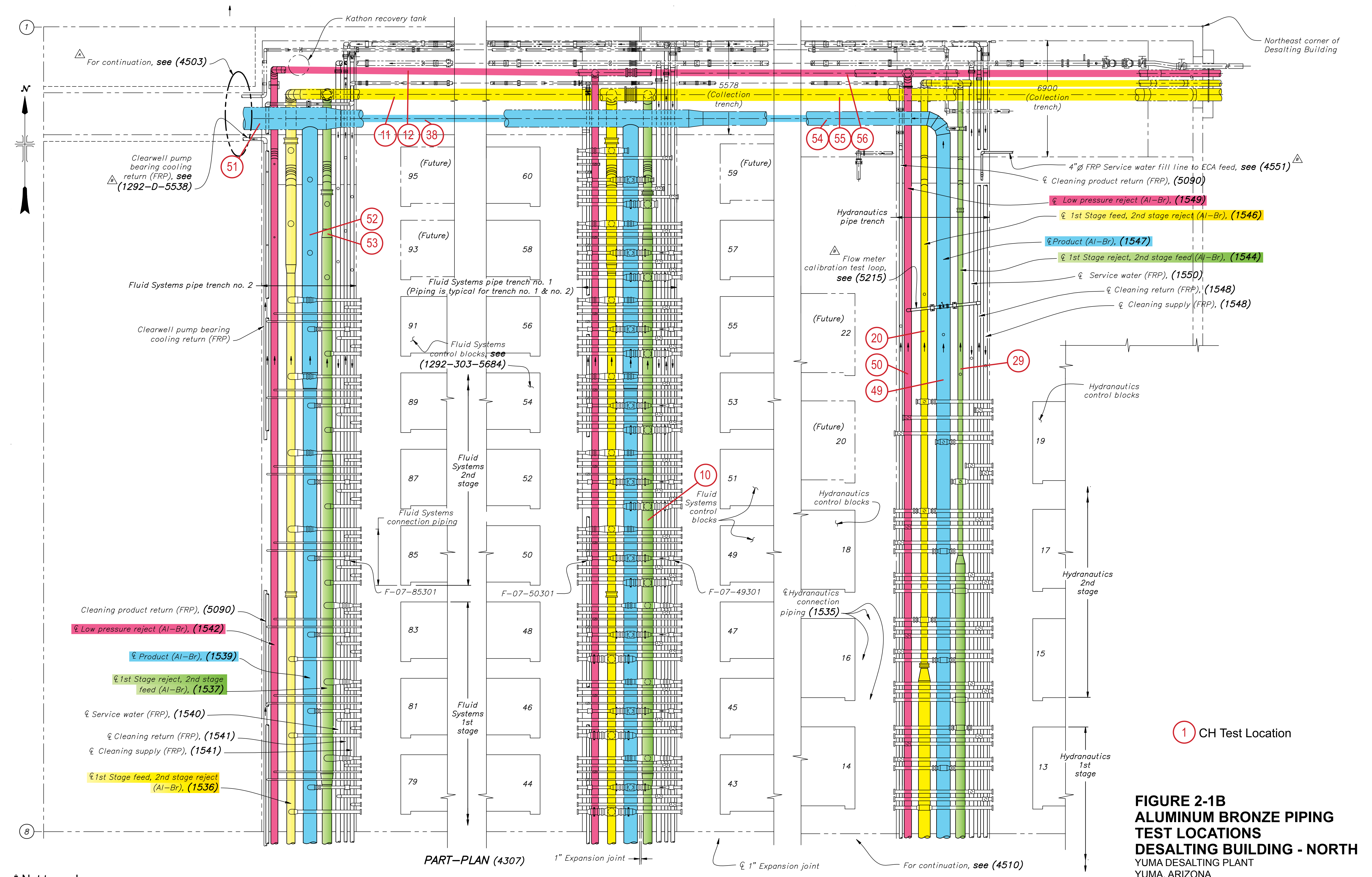
FIGURE 2-1A
ALUMINUM BRONZE PIPING TEST LOCATIONS

YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

Fig RB11x17.dwg Scale: 1"=40'

ES112007004SAC Figure_2-1A.ai 11/15/07 afint



* Not to scale

FIGURE 2-1B
ALUMINUM BRONZE PIPING TEST LOCATIONS DESALTING BUILDING - NORTH

YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

ES112007004SAC Figure_2-1B.ai 11/20/07 afint

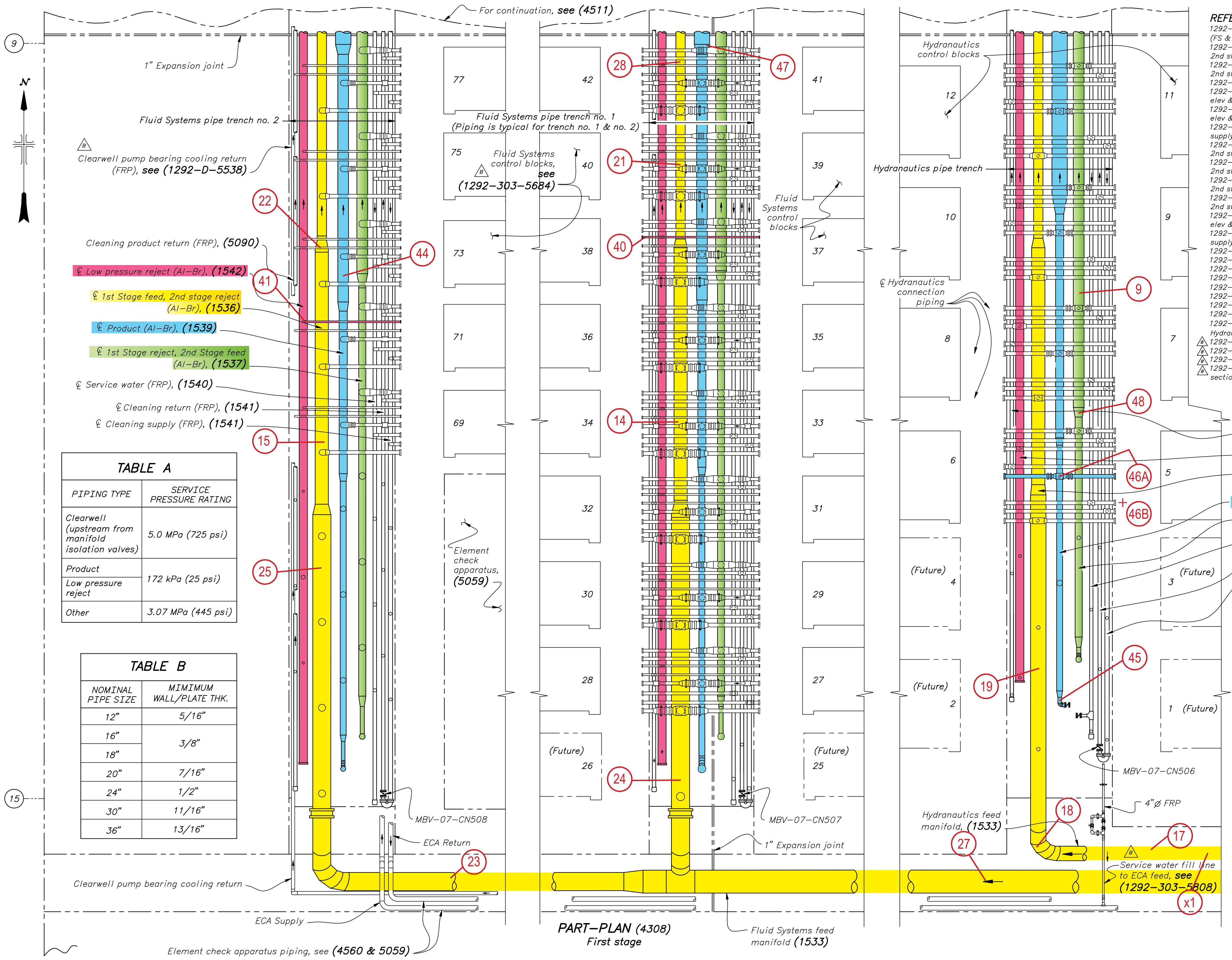


TABLE A

PIPING TYPE	SERVICE PRESSURE RATING
Clearwell (upstream from manifold isolation valves)	5.0 MPa (725 psi)
Product Low pressure reject	172 kPa (25 psi)
Other	3.07 MPa (445 psi)

TABLE B

NOMINAL PIPE SIZE	MIMIMUM WALL/PLATE THK.
12"	5/16"
16"	3/8"
18"	
20"	7/16"
24"	1/2"
30"	11/16"
36"	13/16"

* Not to scale

REFERENCE DRAWINGS

1292–D–1533, Desalting building, process area, Fluid Systems, feed manifolds (FS & Hydranautics), plan & sections
1292–D–1536, Desalting building, process area, Fluid Systems, 1st stage feed, 2nd stage reject, elev & sections
1292–D–1537, Desalting building, process area, Fluid Systems, 1st stage reject, 2nd stage feed, elev & sections
1292–D–1538, Desalting building, process area, Fluid Systems control block
1292–D–1539, Desalting building, process area, Fluid Systems, product piping, elev & sections
1292–D–1540, Desalting building, process area, Fluid Systems, service water, elev & sections
1292–D–1541, Desalting building, process area, Fluid Systems, cleaning return & supply, elev & sections
1292–D–1543, Desalting building, process area, Hydranautics, 1st stage reject, 2nd stage feed, Plan
1292–D–1544, Desalting building, process area, Hydranautics, 1st stage reject, 2nd stage feed, elev & sections
1292–D–1545, Desalting building, process area, Hydranautics, 1st stage feed, 2nd stage reject, plan
1292–D–1546, Desalting building, process area, Hydranautics, 1st stage feed, 2nd stage reject, elev & sections
1292–D–1547, Desalting building, process area, Hydranautics, product piping, elev & sections
1292–D–1548, Desalting building, process area, Hydranautics, cleaning return & supply, elev & sections
1292–D–1549, Process area, Hydranautics, low pressure reject, elev & sections
1292–D–1550, Process area, Hydranautics, service water, elev & sections
1292–D–4308, General arrangement, 9–line thru 17–line, floor EL 38.250
1292–D–4503, Process area collection trench, product piping
1292–D–4511, Process area trench piping, gen. arrangement, plan (Sht 2 of 2)
1292–D–4512, Process area, Hydranautics control block
1292–D–4560, Element check & clearwell transfer piping, plan & elev
1292–D–5059, Process area, element check apparatus piping, plan & sections
1292–D–5090, Process area, cleaning product return, plan & sections (FS & Hydranautics)
B 1292–D–5538, Clearwell pump bearing cooling return, elev. & sections
B 1292–303–5215, Process area, flow meter calibration test loop, plan & sections
B 1292–303–5684, Process area, plant arrangement, FS control blocks, plan
B 1292–303–5808, Process area, service water fill line to ECA feed, plan & sections

NOTES

1. All dimensions are in millimeters unless otherwise noted.
2. All elevations are in meters.
3. All expansion anchors shall be stainless steel unless otherwise noted.
4. All control blocks not labeled "Future" shall be connected to the trench piping.
5. Trench piping connections for control blocks labeled "Future" shall be furnished with groove end–caps for Al–Br piping, and glued (cemented) caps or blind flanges for FRP piping.
6. For pipe anchor locations, see specific pipe drawings.
7. Service pressure for aluminum bronze (Al–Br) piping are shown in TABLE A.
8. Al–Br Fittings shall be forged, cast or fabricated from plate and shall be fully rated for the appropriate service pressure. Fabricated four–cut elbows shall have a minimum plate thickness from tangent line to tangent line as shown in TABLE B unless otherwise shown on drawings.

① CH Test Location

FIGURE 2-1C
ALUMINUM BRONZE PIPING TEST LOCATIONS DESALTING BUILDING - SOUTH

YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

SECTION 3.0

Condition Assessment

3.1 Factors Affecting Serviceability

3.1.1 Weld Integrity

Codes for construction of pressurized piping systems include requirements that are intended to provide an appropriate level of integrity for the pipe and joints used in the piping system. Code requirements are often specific to aspects of a piping system, including design, materials, workmanship, operation, maintenance, and monitoring.

Welds are a particular area of focus for codes because the solidified molten metal in the area of the weld can contain defects that could compromise the integrity of the fused materials. These defects might be difficult to detect. If defects are detected in a weld, the type and size of the defect will determine if its presence is acceptable for service under a particular code. However, cracked welds are not acceptable under any code.

There are established relationships between weld quality, inspection, and suitability of a piping system for service. ASME B31.3 Process Piping, Table 341. 3.2, summarizes the acceptance criteria for welds and examination methods for evaluating weld imperfections. A copy of Table 341.3.2 is included in Appendix I of this report.

3.1.2 Weld Quality Factor

A key concept of weld integrity is weld quality factor, which is the assumed weld strength relative to the strength of a comparable piece of solid metal. The quality factor that is allowed to be assumed is defined by prescribed welder qualifications, welding procedures, and examination of finished welds. This rigid control is necessary because the strength of the weld must be known relative to the metal being joined by the weld. The goal is to prevent the establishment of hidden weak points in the piping system caused by substandard welds.

The weld quality factor is also known by other names, including pipe quality factor, joint quality factor, and joint efficiency factor, especially for pipe joints. The weld quality factor has a range of 0.60 to 1.00, as shown in Table 302.3.4 of ASME B31.3 (Appendix J).

Low values of quality factor are associated with numerous weld defects or conditions lacking a high degree of quality control. Conversely, the quality factor may be increased to 0.90 if spot radiography is used, or 1.00 if 100 percent radiography is used, to prove the integrity of the welds.

For YDP, a weld quality factor of 0.60 was assumed because of the fact that aluminum bronze is an unlisted material in ASME B31.3, and that numerous defects were found in the welds as described in Section 2.0.

3.1.3 Corrosion Rate

Corrosion of metallic piping causes metal loss by thinning or pitting, or both. The form of corrosion depends on the chemical characteristics of the fluid, type of metal and surface condition, and a variety of other factors. Thinning is a reduction of wall thickness across a large area of the pipe and is most often the result of acidic or strongly corrosive conditions. The metal simply dissolves in the flow and the pipe wall becomes thinner with time.

Pitting is the loss of metal from local areas and could result from conditions that differ across the metal surface. Pits can lead to holes in the pipe even though the majority of the wall of the pipe is intact. This form of corrosion tends to cause leaks rather than breaks, although alignment of pits can create weak planes and cause a pipe to burst under pressure.

Pipe can also be weakened by corrosion if it occurs preferentially along welds. Preferential weld corrosion can occur for a variety of reasons including crevices at incomplete welds and differences in metallurgy created by the heat of welding. These conditions are believed to exist at various locations in the aluminum bronze piping at YDP.

3.1.4 Construction Details

Construction details, such as complexity of fabrication, can affect the serviceability of a piping system. Components, such as fabricated tees with sharp mitered welds, can be difficult to fabricate and examine for quality using non-destructive testing (NDT) equipment. For this reason, use of fittings, specials, reducers, and other irregularly shaped components can prove troublesome and might even be the weak points in the piping system. Uniform shapes, such as straight pipes, are easier to fabricate and test, and are often easier to use than fittings.

3.2 Approach to Estimating Service Life

The estimated service life of a piping system is the time required for the system to deteriorate to an unacceptable condition. The expected remaining service life of an existing piping system is determined by the following factors:

- Current condition of the piping system
- Service conditions for future operation
- Estimated rate of deterioration of the piping system in service
- Definition of the end of service life of the piping system

These factors determine the time required for the piping system to reach the end of its service life at the established rate of deterioration.

Deterioration could result from any number of factors, such as physical or chemical factors. At YDP, deterioration by corrosion is a significant issue. Estimation of remaining service life of the YDP piping must take into account the corrosion rate that is expected with the plant in operation. However, the service life for low- and high-pressure piping must be evaluated in different ways.

Low-pressure piping typically does not have large hoop stresses; therefore, pipe bursting is not an issue. The service life of low-pressure piping is often determined by the rigidity of the pipe in the aboveground installations. A low-pressure pipe could become thin as a result of corrosion. The pipe will reach the end of its service life when the pipe wall has become thin to the extent that it is unable to support itself or resist damage from accidental striking of the pipe. In this case, the corrosion rate directly affects the service life of the pipe.

Conversely, a high-pressure pipe must resist hoop stress and other significant stresses. High-pressure piping will reach the end of its service life when the pipe no longer meets code for the intended design pressure, or when the pipe actually fails. Either condition becomes more likely as the pipe wall becomes thin or pitted by corrosion. However, the form and rate of corrosion are only two of the variables that determine the serviceability of the pipe. In this case, the corrosion rate affects the design pressure rating, which affects the service life of the pipe.

3.2.1 Corrosion Rate

Tests were conducted to estimate the rates of corrosion of aluminum bronze in various water chemistry conditions at YDP. The tests were conducted by YDP staff at WQIC using the PS-1 train. The test was used to estimate the expected rate of thinning of the aluminum bronze pipe wall as a result of corrosion in the main plant at normal operating conditions.

The PS-1 process flow streams have chemical characteristics similar to those expected for full-scale operation at YDP under current process design conditions. The corrosion tests used coupons made of aluminum bronze alloys, C61300 and C95200, the same as those used in the main plant. The indicated corrosion rates for the coupons represent the corrosion rates for the YDP piping as if it were in full-scale operation.

The test method is described in ASTM D2688 and consists of a pipe loop with coupons (small rectangular pieces of aluminum bronze) at fixed locations in the pipe. Water flows through the pipe at a known velocity past the coupons for a known period of time and causes corrosion that reduces the weight of the metal. The coupons are accurately measured and weighed before and after exposure. The corrosion rate is calculated using the coupon surface area, weight loss, and time of exposure.

The corrosion rate is determined by the type of metal, corrosivity of the water, and the velocity of flow. For many metals including aluminum bronze, the corrosion rate increases with velocity. Other metals, such as stainless steel, have lower corrosion rates associated with high flow velocities.

Corrosion rate studies were conducted at YDP for periods of approximately 3 weeks during the summer of 2005. Two sets of tests were conducted. The results of the second test are shown in Table 3-1. The results of the second test are considered more representative than the first set, because corrosion rates tend to stabilize with time.

TABLE 3-1
Aluminum Bronze Corrosion Rate (Second Set of Coupon Test Results)

		Corrosion Rate (mils per year)		
Coupon Number	**Alloy**	**Hydranautics RO Feed**	**Hydranautics RO Reject**	**Hydranautics RO Product**
1	C95200	15.4	14.5	5.0
2	C61300	14.7	15.8	6.3
3	C95200	14.2	15.0	5.0
4	C61300	15.3	15.1	6.2

Notes:

Test period 500 hours

Flow rate 3.5 feet per second

Results show that the corrosion rates in the RO feed and reject were approximately 15 mpy. The corrosion rate in the RO product was approximately 6 mpy. Corrosion rates were slightly higher for the wrought alloy (C61300) than they were for the cast aluminum bronze alloy (C95200). These corrosion rates were produced by a water flow velocity of 3.5 feet per second, which is in the normal range for piping at YDP.

The corrosion rate for raw water was not determined by test. The corrosion rate of raw water is estimated to be somewhere between the rates for RO product and RO reject, and is probably closer to the corrosion rate for RO product.

3.2.2 Low-pressure Piping

The service life of the low-pressure piping was estimated by determining the time required for the pipe wall thickness to reach 50 percent of its original thickness at a known corrosion rate. With 50 percent of its wall thickness gone, the pipe would be too flexible or easily damaged to be useful on a practical basis.

The present wall thickness is 1/4-inch nominal for all YDP low-pressure piping. A 50 percent loss of thickness results in a practical limit of 1/8-inch for the pipe wall. The service life was calculated by subtracting the practical limit from the wall thickness and dividing it by the corrosion rate. This calculation was done for product and low-pressure reject water.

3.2.3 High-pressure Piping

The service life of the high-pressure piping was estimated by determining the time required for the pipe wall thickness to reach a value less than the minimum thickness required for a design pressure rating. The pressure rating was based on ASME B31.3 and is further described in this section. The use of ASME 31.3 calculations results in more accurate and reliable estimates, and allows for the evaluation of tees and mitered bends. Therefore, it is a more rigorous and precise method than previous methods of calculation.

3.2.3.1 Previous Estimates of Service Life

There were two previous estimates of remaining service life for the aluminum bronze piping at YDP. The first was presented in a February 2002 inspection report done by

Reclamation using internal resources (Reclamation, 2002). The second was an August 2003 CH2M HILL report, *Evaluation of pH Adjustment System at the Yuma Desalting Plant* (CH2M HILL, 2003). These two studies, which used different approaches to estimate service life, produced different estimates, which were based on pressure ratings determined by a simple hoop stress equation; whereas, the estimate in this report is based on ASME B31.3.

Reclamation (2002) used an allowable stress of 27 kilo pounds per square inch (ksi). This value was based on mill test reports, which stated that the pipe had an ultimate tensile strength of 81 ksi and a yield strength of 46 ksi. The allowable stress of 27 ksi was determined by taking 1/3 of the mill test tensile strength.

CH2M HILL (2003) used an allowable stress of 19 ksi. This value was based on the yield strength specified in the construction document. The allowable stress of 19 ksi was determined by taking slightly more than 1/2 of the specified yield strength.

Reclamation's analysis (2002) included a weld quality factor of 0.85 based on the assumption that successful hydrostatic testing had been conducted. However, construction records indicate that hydrostatic testing was conducted on YDP high-pressure piping at about 400 psi and not at the 600 psi required by the specifications.

Another difference between the CH2M HILL (2003) and Reclamation (2002) studies was the corrosion rate used to estimate the remaining life. Reclamation used a corrosion rate of approximately 6 to 7 mpy for reject and RO feed piping. However, recent tests (described above) at YDP indicated that corrosion rates were about double the rate assumed by Reclamation. CH2M HILL assumed corrosion rates similar to recent YDP test results.

Reclamation (2002) did not take into account the minus manufacturing tolerances of the pipe according to the reference standard for aluminum bronze pipe, ASTM B608. Therefore, the study attributed the differences between measured and nominal specified pipe wall thickness as loss of thickness caused by corrosion. However, our review of the test data indicates that the ultrasonic thickness gauging showed that the wall thickness was still within the manufacturing tolerance allowed by ASTM B608.

Reclamation (2002) concluded that the aluminum bronze piping at YDP could have a service life of 4 to more than 30 years, depending on size of pipe and length of service. CH2M HILL (2003) estimated the service life of the high-pressure RO feed piping to be 1.3 to 11 years, depending on size of pipe and length of service.

The method used to estimate the service life in the present study is more rigorous than the previous methods of calculating service life, and the results of the present method are considered more accurate.

3.2.3.2 Estimating Pressure Rating

The pressure capacity of the existing aluminum bronze piping at YDP was assessed using the method described in ASME B31.3. This method examines the piping in its current state, without accounting for future loss of wall thickness caused by corrosion. The assumed conditions were pressures of 450 pounds per square inch (psi) for high-pressure feed; 425 psi for interstage; 150 psi for low pressure, and 25 psi for gravity.

The piping service life estimates in this report assume a weld quality factor of 0.60 for the existing aluminum bronze piping. This is appropriate because of the uncertainty that a hydrostatic test was passed, and because of the high frequency of actual weld defects found by radiography and visual inspection. Additional support for the assumed low value of weld quality factor at YDP is provided by actual plant experience, which indicates that pipe failures have occurred mostly at welds, and those welds are sometimes very difficult to repair by further welding.

For comparison, although the ASME B31.3 code allows a weld quality factor of 0.60 to 1.00, it would be rare by today's standards for a factor of 0.60 to be used for new plant piping design.

3.3 Results of Estimating Service Life

3.3.1 Low-pressure Piping

Based on the corrosion rates, the estimated life for product, reject, and feed water piping was estimated. The results are shown in Table 3-2.

The results in Table 3-2 show that the RO product piping has an estimated remaining service life of approximately 20 years; the RO reject piping, approximately 8 years. These results assume that a 50 percent wall thickness reduction signifies the end of the service life.

TABLE 3-2
Estimated Service Life of 1/4-inch Wall Aluminum Bronze Pipe at Yuma Desalting Plant

Product Water Piping[a]	Reject Water Piping[b]
21 years	8 years

[a] Corrosion rate 6 mpy from Table 3-1.

[b] Corrosion rate 15 mpy from Table 3-1.

Note: Assumes gravity-pressure condition and end of life at 50 percent loss of thickness.

Low-pressure reject piping could experience pressure up to 150 psi when the plant is operating and flushing or when the sleeve valves are fully open. However, the low-pressure reject pipes in the DSB are normally empty except when flushing is occurring. The low-pressure reject piping would have continuous flow downstream of the sleeve valves if the plant were in operation. Because of the variable operation of the low-pressure reject piping, CH2M HILL assumed a gravity pressure condition for planning purposes.

Aluminum bronze piping in raw water and pretreatment service is assumed to have a corrosion rate somewhere between the corrosion rates for RO product and RO reject, and probably more similar to RO product. Therefore, the estimated service life is expected to be similar for planning purposes.

3.3.2 High-pressure Piping

3.3.2.1 Results of Estimating Pressure Rating

The design pressure capacity of the existing aluminum bronze piping was assessed using the methods described in ASME B31.3. This condition examines the piping in its current state, with no loss of wall thickness caused by corrosion. After the current state is established, anticipated corrosion rates can be applied to examine the reduction in design pressure rating as the pipe wall becomes thinner from corrosion.

Calculations for design pressure rating are presented in Appendix J, Mathcad Calculations, and are discussed in this section. Mathcad, a commercial software program for engineering and scientific applications, was used to perform the calculations.

The assumed conditions were pressures of 450 psi for high-pressure feed; 425 psi for interstage; 150 psi for low pressure, and 25 psi for gravity. A weld quality factor of 0.60 was assumed.

3.3.2.2 Straight Pipe Sections

Results of the analysis of calculated and allowable hoop stresses of aluminum bronze straight pipes are shown in the first table on page 2 in Appendix J. Calculated maximum permissible design pressures are shown in Table 3-3, assuming a weld quality factor of 0.60. The information in Table 3-3 was taken from pages 3 and 4 of Appendix J.

TABLE 3-3
Permissible Design Pressure of Aluminum Bronze Straight Piping
ASME B31.3 Method

Nominal Pipe Diameter (inch)	Nominal Pipe Wall Thickness (inch)	Maximum Permissible Design Pressure (psi)
3	0.25	1,419
6	0.25	730
8	0.25	557
10	0.25	445
12	0.25	374
12	0.3125	473
14	0.25	407
16	0.25	355
18	0.25	315
18	0.3125	391
18	0.4375	563
20	0.25	283
20	0.3125	351
24	0.25	236
24	0.375	356
30	0.25	185
30	0.375	277
30	0.4375	326

TABLE 3-3
Permissible Design Pressure of Aluminum Bronze Straight Piping
ASME B31.3 Method

Nominal Pipe Diameter (inch)	Nominal Pipe Wall Thickness (inch)	Maximum Permissible Design Pressure (psi)
3	0.25	1,419
6	0.25	730
8	0.25	557
10	0.25	445
36	0.25	155
36	0.5625	349
42	0.25	133
48	0.25	116
48	0.3125	144
48	0.75	354
54	0.25	103
60	0.25	93
72	0.3125	96
78	0.3125	89

Assumed weld quality factor = 0.60

Results show that operation of aluminum bronze straight pipe at 450 psi would exceed the pressure capacity of all piping except the 6- and 8-inch-diameter sizes and some of the 12- and 18-inch-diameter sizes with heavier wall thickness.

Operation at 425 psi would exceed the allowable stress for all aluminum bronze piping except the 6- through 10- and 18-inch-diameter sizes. The results are shown in the second table on page 2 of Appendix J.

Operation at 150 psi would exceed the allowable stress for all aluminum bronze straight piping in the 42- and 60-inch-diameter sizes. (These pipe sizes are used only for the low-pressure reject and product lines, respectively, and it is unlikely that these pipelines would experience 150 psi pressure except for short periods of time.) The results are shown in the first table on page 3 of Appendix J.

Operation at 25 psi would not exceed the allowable stress in any aluminum bronze straight piping under current conditions. The results are shown in the second table on page 3 of Appendix J.

The effect of weld quality factor on pressure rating of aluminum bronze straight pipe was studied. The results of the analysis are shown on page 4 of Appendix J. Results for a quality factor of 0.60 are shown on the upper portion of the page, and results for a quality factor of 0.80 are shown on the lower portion of the page. The results show that increasing the assumed weld quality factor to 0.80 reduces stresses within allowable limits for all pipes except the 30- and 60-inch-diameter pipelines. (It is unlikely that 60-inch-diameter pipelines would receive pressure approaching 150 psi.)

The effect of weld quality factor of 1.00 on pressure rating of aluminum bronze straight pipe is shown in the first table on page 5 of Appendix J. The results show that increasing the assumed weld quality factor to 1.00 reduces stresses within allowable limits for all pipes regardless of size or pressure. A quality factor of 1.00 is not realistic for YDP based on weld radiography, as described in Section 2.0.

3.3.2.3 Tee Fittings

Several types of tee fittings were studied as representative cases of the various aluminum bronze pressure pipe tees in the plant. The analysis is presented on pages 5 through 22 of Appendix J.

The 30- by 12-inch tees for hydranautics high-pressure feed were analyzed. Results are shown on pages 7 through 8 of Appendix J. These results indicate the tees can withstand only 294 psi design pressure if the weld quality factor is a realistic 0.60. These tees would be considered capable of service at a design pressure of 450 psi only if the quality factor were 0.95 or greater (Appendix J, page 8).

An analysis of the 48- by 36-inch tee that supplies Section 1 hydranautics is shown on pages 9 through 12 of Appendix J. Results shown on page 12 of Appendix J indicate that this tee cannot withstand the 450 psi design pressure regardless of weld quality factor. The calculated maximum allowable pressure of this tee is 92 psi with a weld quality factor of 0.60. Even if the weld quality factor were 1.00, the maximum allowable pressure of this tee would be only 153 psi.

Similar analyses are presented in Appendix J for the 10- by 10-inch and 12- by 12-inch high-pressure feed tees. Results are shown on page 15 of Appendix J for the 12- by 12-inch tees, and on page 18 of Appendix J for the 10- by 10-inch tees. The results indicate that neither type of tee would resist 450 psi design pressure regardless of the weld quality factor. The calculated maximum pressures of the tees with a weld quality factor of 0.60 are 163 psi for the 10- inch tees and 190 psi for the 12-inch tees. If the weld quality factor were 1.00, the calculated maximum allowable pressure would be 271 psi for the 10-inch tees and 316 psi for the 12-inch tees.

The 36- by 12-inch tees for the fluid systems high-pressure feed were analyzed. Results are shown on pages 9 through 21 of Appendix J. The results indicate that the tees cannot withstand the 450 psi design pressure unless the weld quality factor is at least 0.75. At a realistic weld quality factor of 0.60, the maximum allowable pressure is 363 psi.

The effect of weld quality factor on pressure rating of the tees was analyzed, and the tabulated results of the analysis are shown on page 22 of Appendix J. The left side of the table shows the calculated permissible design pressure for tees with weld quality factors of 0.60, 0.80, and 1.00. The right side of the table shows the suitability of the tees for 450 psi design pressure service with the same three weld quality factors. The results show that the 48- by 36-inch, 12- by 12-inch, and 10- by 10-inch tees are not adequate for 450 psi design pressure service regardless of weld quality factor. None of the tees are suitable for 450 psi design service with a weld quality factor of 0.60. Some of the other tees considered would be suitable for 450 psi design pressure service only if the weld quality factor were at least 0.80.

3.3.2.4 Mitered Bends

Analyses were also conducted for two large, four-part mitered bends in the high-pressure feeds to Sections 1 and 3. The analyzed fittings included 90-degree bends in 30- and 36-inch diameters. Results, which are presented on pages 23 and 24 of Appendix J, indicate that both bends fail to meet 450 psi design pressure requirement regardless of the assumed weld quality factor. The calculated maximum allowable pressure with a weld quality factor of 0.60 is 118 psi for the 30-inch bend and 144 psi for the 36-inch bend. Even if the weld quality factor were 1.00, the calculated maximum allowable pressure would be 197 psi for the 30-inch bend and 241 psi for the 36-inch bend.

3.4 Summary of Service Life Estimate

3.4.1.1 Low-pressure Piping

The results of the service life estimate for low-pressure aluminum bronze piping are summarized below, for the scenario with the plant in operation under current conditions.

- Service life of product piping is approximately 20 years
- Service life of reject piping is approximately 8 years

These results provide an overall indication of the service life of the system based on thinning of the pipe wall caused by corrosion. The existing piping has defects (leaks) and it is likely to develop new defects in the future. A visual survey of aluminum bronze piping inside the desalting building shows leakage at numerous locations in welds in both product and reject piping. Therefore, the apparent discrepancy between calculated service life of the piping system and the current leaking pipes can be explained by the presence of weld defects as disclosed by the test program.

3.4.1.2 High-pressure Piping

Analysis of the high pressure piping according to ASME B31.3 shows that much of the aluminum bronze pipe and fittings are not capable of service at the current design pressure rating at this time. Therefore, they will not be capable of service under the same conditions in the future.

SECTION 4.0

Mitigation

4.1 Process Alternative Summary

The original process design at YDP was based on cellulose acetate (CA) membranes which required high-pressure and low pH feed water for efficiency. The original design pressure for this process was 425 to 450 psi. The water to be treated was MODE water, which is known to be corrosive to ferrous metals. Recently, Reclamation has been testing polyamide (PA) membranes for possible groundwater treatment. The PA membranes do not require high-pressure and low pH feed water. This would reduce the design pressure to approximately 150 psi. Additionally, the groundwater to be treated is thought to be less aggressive toward ferrous metals than MODE water.

4.1.1 Effect of Operating Pressure on Mitigation Alternatives

As described in Section 3.0, much of the high-pressure aluminum bronze piping does not currently meet the ASME B31.3 criteria to operate at the original design pressures. However, it is assumed that YDP will operate at approximately 300 psi in the future if the CA membranes remain in use. During the demonstration testing conducted in the spring of 2007, the piping showed that it could successfully operate at 300 psi although leaks did occur while the piping was in service.

4.2 Mitigation Alternatives

The following six alternatives for mitigation were developed and analyzed for the aluminum bronze piping at YDP:

- Monitor and Repair
- Replace with Stainless Steel
- Pressure Test and Repair
- Pressure Test and Replace
- Inspect and Repair
- Inspect and Install Cured-In-Place-Pipe (CIPP)

Only a few alternatives are feasible for any given aluminum bronze pipe, and no alternatives are feasible for all aluminum bronze piping. The feasibility of each alternative depends on several aspects associated with the aluminum bronze piping. They include operating pressure, exposure, accessibility, diameter, water characteristics, and configuration.

Partial replacement of the aluminum bronze piping was considered; however, this approach was not fully developed because of difficulty with demolition/installation and concerns with galvanic corrosion at aluminum bronze to stainless steel interfaces. A discussion of the galvanic corrosion concerns can be found in Appendix K.

4.2.1 Monitor and Repair

This alternative is essentially a continuation of the current practice at the YDP. It requires visually observing the piping. If a leak or failure is detected, it would be repaired. Failures from defects, as described in Section 2.4.3, would most likely be located at welds. These repairs could be performed by completely grinding out existing welds and repair welding the defective area. The welding should be performed by certified welders with experience welding aluminum bronze. This option would require a reliable weld repair procedure and qualified welders to ensure a weld is produced with acceptable quality.

This alternative is not valid for piping operating at high pressures; therefore, it is only appropriate for feed piping if PA membranes are used. Additionally, it would not address the general corrosion of the piping that is occurring. Depending on the operating pressure and the water being conveyed, the aluminum bronze piping has an estimated remaining useful life of approximately zero to 20 years.

4.2.2 Replace with Stainless Steel

This alternative would require the replacement of the aluminum bronze piping with Type 316 stainless steel. This would include the removal and disposal of aluminum bronze piping and the installation of the stainless steel piping. It would also include concrete removal and repair at any wall or floor penetrations. Based on preliminary calculations, the required wall thicknesses of stainless steel would be similar to the original aluminum bronze wall thicknesses.

Replacing the existing aluminum bronze piping with Type 316 stainless steel will correct the existing deficiencies in the piping, which would lead to a longer service life, reduced maintenance activities, increased reliability, fewer shutdowns, and reduced corrosion.

Experience at YDP has shown that stainless steel does not significantly corrode during flow conditions. Stainless steel pipe has been used in PS-1 for nearly 20 years with very little indication of corrosion. However, this has been under continuous flow conditions and not intermittent service. PS-1 is a 1/100 scale of the YDP production plant, and both facilities use the same treatment processes. However, standing water would be unacceptable because of the potential for devastating corrosion of stainless steel under stagnant conditions. During plant shutdowns, when the piping is not in service, the stainless steel pipes would need to be flushed with product water and completely drained. This would mitigate corrosion associated with stainless steel being submerged in stagnant water.

4.2.3 Pressure Test and Repair

This alternative would include pressure testing the piping at 25 percent over normal operating values. If the piping passes the pressure test, no further action is required and the monitor and repair approach would be adopted. If the piping fails the pressure test, repairs could be made by welding plates over the existing welds or with Weko-Seals®. Figure 4-1 shows a schematic of a Weko-Seal® (Figures 4-1 through 4-14 can be found at the end of this section). Welded plates and Weko-Seals® have been successful in the filter inlet pipes. This option would require a reliable weld repair procedure and qualified welders to ensure a weld is produced with acceptable quality.

This alternative would not address the general corrosion of the piping that is occurring. Depending on the operating pressure and the water being conveyed, the aluminum bronze piping has an estimated remaining useful life of approximately zero to 20 years.

4.2.4 Pressure Test and Replace

This alternative would include pressure testing the piping at 25 percent over normal operating values. If the piping passes the pressure test, no further action is required. If the piping fails, the pressure test the piping would be replaced with stainless steel or other suitable material (i.e., FRP).

4.2.5 Inspect and Repair

This alternative would include draining and cleaning the pipe followed by an interior inspection of the welds and pipe wall. Based on the results of the inspection, repairs would be made by welding plates over the existing welds or with Weko-Seals®. This approach has been successful in the filter inlet pipes, and would require a reliable weld repair procedure and qualified welders to ensure a weld is produced with acceptable quality.

This alternative is only valid for gravity piping with large enough diameters for physical entry. This approach would not address the general corrosion of the piping that is occurring. Depending on the operating pressure and the water being conveyed, the aluminum bronze piping has an estimated remaining useful life of approximately zero to 20 years.

4.2.6 Inspect and Install CIPP

This alternative would include draining and cleaning the pipe followed by an interior inspection of the welds and pipe wall. Based on the results of the inspection, a CIPP, such as Insituform, could be installed.

CIPP consists of a fiber-impregnated, thermosetting resin tube that is inverted into the existing pipe using hydrostatic pressure. The resin is then cured in place using circulated hot water. This results in a continuous, corrosion-resistant, structurally independent pipe. This process is shown on Figure 4-2.

This alternative is valid where spot repairs are not practical or pipes are too small for physical entry. This approach would correct the existing deficiencies in the piping. This would lead to a longer service life, reduced maintenance activities, increased reliability, fewer shutdowns, and reduced corrosion.

4.3 Mitigation Alternatives Comparison

A summary of the feasible alternatives for each pipe is shown in Table 4-1 (found at the end of this section). The location of each pipe is shown on Figure 1-1. Figures 4-3 through 4-14 show the various layouts of each pipe discussed below.

4.3.1 Pipes 1 through 17

These are 6-inch to 48-inch-diameter, high-pressure pipelines that carry RO feed or interstage water (Figures 4-3 through 4-5). The total length of this piping is approximately 5,278 feet. Details on these pipes are listed in Table 1-1. They were included in the previous cost estimate for replacement with stainless steel. Most of these pipes do not have any useful remaining life if operated at the original design pressure based on ASME B31.3 and the calculations performed in Section 3.0.

This group of pipes includes test locations CH 1-11, 14-29, 31-33B, 48, 53, and 55 as discussed in Section 2.

All of these pipes, except for Pipes 15 and 17, are also candidates for monitoring and repair if the CA membranes at YDP are replaced with PA membranes. The repair alternative is feasible because PA membranes can be operated at a much lower pressure and with less corrosive (non-acidified) water, so the piping would be generally safer to operate even with the possibility of failure. Pipes 15 and 17 (Figure 4-5) are buried pipelines that have had numerous prior failures and should be replaced without consideration, assuming that they will still be needed in the future.

The monitoring and repair alternative assumes that some leaks will occur and will require repair. Monitoring would be done by visual observation during operation and would not have any defined cost. Any leak detected would be repaired so that the pipeline could be returned to service.

During the demonstration run, a total of 2 leaks occurred over a 3-month period when a portion of the plant was in operation. Extrapolating this leak frequency to full-time, full-scale operation of YDP suggests that approximately 8 to 16 leaks would occur annually. An average leak repair cost of $5,000 is assumed based on information provided by YDP staff. Thus, the annual cost of leak repairs for Pipes 1 through 17 would be $40,000 to $80,000. No costs were assumed for other expenses that could be incurred such as plant shutdown, loss of product, or repair of other damage resulting from a leak.

4.3.2 Pipes 18 through 22

These pipelines carry low-pressure reject water and range in size from 3 to 60 inches in diameter (Figures 4-3 and 4-6). The total length of this piping is approximately 2,076 feet. Details on these pipes are listed in Table 1-1.

This group of pipes includes test locations CH 12-13, 30, 40-41, 50, and 56, as discussed in Section 2.

Pipes 18 through 21 (Figure 4-3) are exposed and accessible, so it is feasible to consider monitoring and repair of pipe failures when they occur. However, all of these pipes have a wall thickness of 1/4 inch, and can be expected to lose 50 percent of the pipe wall thickness in 8 years at the rate of corrosion for current reject water quality. At that time, the pipes will be considered to have failed because they will have a wall thickness of 1/8 inch, which is considered structurally unsound for exposed pipe. Because the reject water pipes in the DSB are intermingled with the high-pressure piping, replacing the reject lines would be easier and cheaper if all of the piping were replaced at the same time.

During the demonstration run, a total of 2 leaks occurred over a 3-month period when a portion of the plant was in operation. Extrapolating this leak frequency to full-time, full-scale operation of YDP suggests that approximately 8 to 16 leaks would occur annually. An average leak repair cost of $5,000 is assumed based on information provided by YDP staff. Thus, the annual cost of leak repairs for Pipes 18 through 21 would be $40,000 to $80,000. No costs were assumed for other expenses that could be incurred such as plant shutdown, loss of product, or repair of other damage resulting from a leak.

Pipe 22 (Figure 4-6) is buried and carries reject water by gravity under the levee to disposal. This pipeline is the only means of conveyance for this purpose and its condition is unknown because it is difficult to access and has not been inspected for many years. This pipeline should be drained, made safe for manned entry, and inspected for damage and deterioration. Spot repairs can be made if the damage is localized, or the pipe can be lined with CIPP if the damage is too extensive.

Based on the number of defective welds that CH2M HILL observed on other pipelines that are accessible, it is reasonable to assume that the joints of Pipe 22 are at intervals of 30 feet, and 30 percent of the girth welds are defective and require repair. Repair methods include butt-welding plates or installing Weko-Seals® over damaged welds.

It will be necessary to coordinate the evaluation of Pipe 22 with Pipe 27 because they connect at a wye vault outside of the levee. YDP’s main drain line (FRP) also connects at the wye vault and must be considered because it is in continuous operation and can carry significant flows of drainage water.

4.3.3 Pipes 23 through 27

These pipelines carry product water at gravity or low-pressure and range in size from 6 to 78 inches in diameter (Figures 4-3 and 4-6). The total length of this piping is approximately 1,971 feet. Details on these pipes are listed in Table 1-1. Considerations for mitigation are similar to those for Pipes 18 through 22 because the piping systems are generally parallel in the process and have the same wall thickness.

This group of pipes includes test locations CH 35-36, 38, 44-47, 49, 51-52, and 54, as discussed in Section 2.

Pipes 23 through 26 (Figure 4-3 and 4-6) are exposed and accessible, so it is feasible to consider monitoring and repair of pipe failures when they occur. These pipes all have a wall thickness of 1/4 inch, and can be expected to lose 50 percent of the pipe wall thickness in 20 years at the rate of corrosion determined for current product water quality. At that time, the pipes are considered to have failed because they will have a wall thickness of 1/8 inch, which is considered structurally unsound for an exposed pipe. Because the product water pipes in the DSB are intermingled with the high-pressure piping, replacing the product lines would be easier and cheaper if all of the piping were replaced at the same time.

During the demonstration run, a total of 5 leaks occurred over a 3-month period when a portion of the plant was in operation. Extrapolating this leak frequency to full-time, full-scale operation of the YDP suggests that approximately 20 to 40 leaks would occur annually. An average leak repair cost of $5,000 is assumed based on information provided by YDP staff. Thus, the annual cost of leak repairs for Pipes 23 through 26 would be $100,000 to

$200,000. No costs were assumed for other expenses that could be incurred such as plant shutdown, loss of product, or repair of other damage resulting from a leak.

Pipe 27 (Figure 4-6) is buried and carries product water by gravity under the levee to the point of discharge. This pipeline is the only means of conveyance for this purpose and its condition is unknown because it is difficult to access and has not been inspected for many years. This pipeline should be drained, made safe for manned entry, and inspected for damage and deterioration. Spot repairs can be made if the damage is localized, or the pipe can be lined with CIPP if the damage is too extensive.

Based on the number of defective welds that CH2M HILL observed on other pipelines that are accessible, it is reasonable to assume that the joints of Pipe 27 are at intervals of 30 feet and 30 percent of the girth welds are defective and require repair. Repair methods include butt-welding plates or installing Weko-Seals® over the damaged welds.

Any work on Pipe 27 will involve coordination with Pipe 22, as described in the previous section.

4.3.4 Pipe 28

This piping consists of the intake pumping station manifold and a short length of pipeline (Figure 4-7). The pump connections are exposed and have a 30-inch diameter. The manifold has a 72-inch diameter, and is underground and encased in reinforced concrete. The short length of pipe also has a 72-inch diameter and is direct buried with polyethylene encasement for corrosion protection. The pump discharge pressure is 15 to 25 psi, according to plant operators.

This pipe includes test locations CH 37, 42, and 57, as discussed in Section 2.

This piping system supplies all water to the main process plant when it is in operation and, therefore, is critical to reliable service. Inspection has shown that defects are present in all welds, and there are visible cracks in the girth welds of the manifold and pipeline. The 30-inch-diameter pump leads have complex geometry that makes them difficult to repair. For all of these reasons, demolition of the existing piping and replacement with new material is the preferred alternative for mitigation. Either stainless steel or cement mortar-lined and –coated steel could be used for the replacement material.

Another alternative is to pressure test the piping at 25 percent over normal operating values and make repairs based on the defects found. This would probably involve welding plates or installing Weko-Seals® over the existing welds as has been done successfully in the filter inlet pipes.

4.3.5 Pipe 29

This 30-inch-diameter pipeline conveys water from the intake pumping station discharge pipeline to the SCR drain pipeline (Figure 4-8). There are three short lengths of pipe, one for each SCR. Each pipe passes through a deep concrete vault and contains a valve and flowmeter. The aluminum bronze pipe connects to buried FRP piping outside of the vault.

This pipe includes test location CH 43, as discussed in Section 2.

These pipes are pressurized at 15 to 25 psi by the intake pumps. There is no record of any failures of welds in these pipes, although the welds are known to have defects based on the results of inspection and testing. Because the piping operates at low pressure, has not had prior failures, and would be difficult and expensive to replace, other alternatives were considered.

The practical alternative for Pipe 29 is to pressure test using the intake water pumping system. The valve could be closed to pressurize most of the aluminum bronze pipe. After the test, the interior of the piping would be repaired as required. This would probably involve welding plates or installing Weko-Seals® over the existing welds as has been done successfully in the filter inlet pipes.

4.3.6 Pipes 30 and 31

This pipeline consists of SCR drain lines with 42- and 48-inch diameters. The pipelines operate by gravity flow. There are several short lengths of pipe associated with each SCR (Figure 4-9). The pipes pass through deep concrete vaults and contain valves. The aluminum bronze pipe connects to buried FRP piping outside of the vaults.

These pipes do not include any CH test locations.

There is no record of any failures of welds in these pipes, although the welds are known to have defects based on the results of inspection and testing. Because the piping operates at gravity pressure, has not had prior failures, and would be difficult and expensive to replace, other alternatives were considered.

The practical alternative is to conduct an internal inspection of the piping and make repairs based on the findings. Repairs would probably involve welding plates or installing Weko-Seals® over the existing welds as has been done successfully in the filter inlet pipes.

4.3.7 Pipe 32

This pipeline has a 54-inch diameter and conveys water from the SCR's pipeline to the filters (Figure 4-10). There are three short lengths of pipe, one for each SCR. Each pipe consists of a mitered bend that is partially embedded in the concrete structure of the filter and partially exposed in the filter gallery.

This pipe includes test locations CH 39 and 39B, as discussed in Section 2.

These pipes had cracked welds and have been repaired with welded plates and Weko-Seals®. They would be difficult and expensive to replace. Therefore, the practical alternative is to inspect each pipeline on the interior and repair any welds or defects that have not already been repaired.

4.3.8 Pipe 33

This piping consists of the filter backwash pump manifold and the backwash control vault (Figure 4-11). The pipes have diameter sizes ranging from 6 to 24 inches. The pump manifold is deeply buried and embedded in concrete. The vault piping contains valves and flowmeters. The piping system operates at 30 psi or less pressure when the filters are backwashed.

This pipe does not include any CH test locations.

There is no record of any failures of welds in these pipes. Because the piping is difficult to access and has no record of failure, it is not essential to replace it until proven necessary. The practical alternative is to pressure test the piping at 25 percent over normal operating values and make repairs as indicated by the results of the test. The tee in the control vault could be replaced if it fails, but the rest of the piping is more suitable for repair. Repairs would be made by welding plates or installing Weko-Seals® over defective welds disclosed by the pressure test. Replacement of the pump manifold, if necessary, would require substantial excavation and demolition work to gain access to the existing manifold.

4.3.9 Pipe 34

This piping consists of short lengths of 72-inch-diameter aluminum bronze piping that are wall pipes that connect the filters and clearwell to a buried FRP pipeline between them (Figure 4-12). They operate in gravity flow. Metallic wall pipes are used because they have the strength to withstand embedment in the concrete walls of the structures.

This pipe does not include any CH test locations.

However, the girth welds in these pipes have previously cracked and were repaired with Weko-Seals®, according to plant operators. Replacement of the wall pipes would involve demolition of the concrete walls of the filter and clearwell structures. This would be expensive and could cause other damage to the structures. An alternative approach would be to inspect the wall pipes and prior repairs to verify that their condition is suitable for continued service. Any necessary repairs would be made based on the results of the inspection.

4.3.10 Pipes 35 and 36

These pipes are 8- and 10-inch-diameter aluminum bronze pipelines that serve the WQIC (Figure 4-13). These pipelines are the source of supply for the plant service water that is produced at the WQIC.

These pipes do not include any CH test locations.

There is no record of failure of these pipelines. However, most of the piping is buried and its condition is unknown. A reasonable approach is to pressure test the piping and replace it if it fails the test. However, Pipe 35 is located beneath the levee and might be difficult to access. A CIPP liner would be a likely alternative to replacement.

4.3.11 Pipe 37

The plant service water pumping station manifolds are already planned for replacement with stainless steel pipe by YDP and no further work is required.

4.3.12 Pipes 38 through 40

This piping is a 3-inch-diameter cleaning product return piping that is constructed from aluminum bronze pipe (Figure 4-3). The total length of this piping is approximately 760 feet. Details on these pipes are listed in Table 1-1. They are used only when the RO membranes are cleaned, and receive acidic and corrosive flows when they are in operation.

These pipes do not include any CH- test locations.

These pipes have a wall thickness of 1/4 inch, and can be expected to lose 50 percent of the pipe wall thickness in 8 years. At that time, the pipes will be considered to have failed because they will have a wall thickness of 1/8 inch, which is considered structurally unsound for exposed pipe. Because the cleaning product pipes in the DSB are intermingled with the high-pressure piping, replacing the cleaning product lines would be easier and cheaper if all of the piping were replaced at the same time.

4.3.13 Pipe 41

This piping is not aluminum bronze, has been significantly damaged by corrosion, and requires mitigation. There are 28 sections of piping, each about 10 feet in length and connecting the filters to the effluent channel (Figure 4-14). These pipes consist of cement mortar-lined steel. They are partially embedded in concrete and each pipe contains a valve. Because of the corroded condition of the pipe, replacement of the pipes with stainless steel is the only feasible alternative. Demolition and removal of the existing lines will be required.

This pipe does not include any CH test locations.

YDP Aluminum Bronze Piping
Rehabilitation Alternatives

No.	Pipeline	Ref Dwg No.	Pipe Size	Operating Pressure	Total Pipe Length		Rehabilitation Alternatives						Comments
		1292-D-xxxx	Range, In.	Estimated, psi	Feet	Included In Prior Cost Estimate	Monitor & Repair [A]	Replace with SST [B]	Pressure Test & Repair [C]	Pressure Test & Replace [D]	Inspect & Repair [E]	Inspect & CIPP [F]	
	1st St. Feed & 2nd St. Reject												
	Fluid Systems												
1	High Pressure Pump Discharge	4498, 4499, 4500	12 - 48	450 or 150	377	✓	✓	✓					
2	From Pump Manifold to DSB	4501	48	450 or 150	34	✓	✓	✓					
3	DSB Supply Trench upstream of valves	1533, 1534	36 - 48	450 or 150	286	✓	✓	✓					
4	DSB Control Block Trench No. 1 (East)	1536	6 - 36	450 or 150	664	✓	✓	✓					
5	DSB Control Block Trench No.2 (West)	1536	6 - 36	450 or 150	473	✓	✓	✓					
	Hydranautics												
6	High Pressure Pump Discharge	4498, 4499, 4500	12 - 30	450 or 150	377	✓	✓	✓					
7	From Pump Manifold to DSB	4501	30	450 or 150	34	✓	✓	✓					
8	DSB Supply Trench upstream of valve	1533, 1534	30	450 or 150	10	✓	✓	✓					
9	DSB Sup Trench dnstrm of valve to 90 bend	1533, 1534	30	450 or 150	64	✓	✓	✓					
10	DSB Control Block Trench	1545, 1546	8 - 30	450 or 150	446	✓	✓	✓					
	1st St. Reject & 2nd St. Feed (Interstage)												
	Fluid Systems												
11	DSB Control Block Trench No. 1 (East)	1537	6 - 30	425 or 150	572	✓	✓	✓					
12	DSB Control Block Trench No.2 (West)	1537	6 - 30	425 or 150	291	✓	✓	✓					
	Hydranautics												
13	DSB Control Block Trench	1543, 1544	8 - 18	425 or 150	407	✓	✓	✓					
	Interstage to Energy Recovery												
	Fluid Systems												
14	DSB Collection Trench	4505	24 - 30	425 or 150	264	✓	✓	✓					
15	Outside DSB to Sleeve Valve & Turbines	4259, 4498, 4501, 4579	18 - 30	425 or 150	439	✓		✓					Numerous prior failures
	Hydranautics												
16	DSB Collection Trench	4505	16	425 or 150	66	✓	✓	✓					
17	Outside DSB to Sleeve Valve & Turbines	4259, 4498, 4501, 4579	10 - 16	425 or 150	475	✓		✓					Numerous prior failures
	Low Pressure Reject												
	Fluid Systems												
18	DSB Control Block Trench No. 1 (East)	1542, 4510, 4511	3 - 16	150	618		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
19	DSB Control Block Trench No. 2 (West)	1542, 4510, 4511	3 - 16	150	492		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
	Hydranautics												
20	DSB Control Block Trench	1549	3 - 16	150	436		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
	Combined												
21	DSB Collection Trench	4505	16	150	264		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
22	Levee Crossing to Disposal exluding wye	1494	42 - 60	25	266						✓	✓	Gravity flow
	Product												
	Fluid Systems												
23	DSB Control Block Trench No. 1 (East)	1539	6 - 36	25	402		✓	✓					20 yrs life due to corrosion rate; easier to replace at same time as HP
24	DSB Control Block Trench No. 2 (West)	1539	6 - 36	25	361		✓	✓					20 yrs life due to corrosion rate; easier to replace at same time as HP
	Hydranautics												
25	DSB Control Block Trench	1547	8 - 30	25	475		✓	✓					20 yrs life due to corrosion rate; easier to replace at same time as HP
	Combined												
26	DSB Collection Trench	4503	30 - 54	25	260		✓	✓					20 yrs life due to corrosion rate; easier to replace at same time as HP
27	Levee Crossing to MODE including all wye	1494, 4270	48 - 78	25	473						✓	✓	
	Pretreatment												
28	Intake PS Disch Manifold & Pipeline	1489	30 - 72	25	249				✓	✓			Normal operating pressure range is 15 to 25 psi
29	SCR Influent	4260	30	25	49				✓				Normal operating pressure range is 15 to 25 psi
30	SCR Drain	4266	48	25	16						✓		Gravity flow
31	SCR Drain	4267	42	25	37						✓		Gravity flow
32	SCR Effluent/Filter Influent	1518, 1892, 1894	54	25	147						✓		Gravity flow
33	Backwash Manifold	4258	24	30	80				✓	✓			Normal operating pressure is 30 psi maximum
34	Filter Outlet/Clearwell Inlet Wall Sleeves	1893 + est.	72	25	20						✓		Gravity flow; previous weld failures repaired with Weko-Seals

YDP Aluminum Bronze Piping
Rehabilitation Alternatives

No.	Pipeline	Ref Dwg No.	Pipe Size	Operating Pressure	Total Pipe Length		Rehabilitation Alternatives						Comments
		1292-D-xxxx	Range, In.	Estimated, psi	Feet	Included In Prior Cost Estimate	Monitor & Repair [A]	Replace with SST [B]	Pressure Test & Repair [C]	Pressure Test & Replace [D]	Inspect & Repair [E]	Inspect & CIPP [F]	
	Other												
35	WQIC Intake/Supply Pipe	1495, 1499, 4274	8 - 10	25	279					✓		✓	Plant service water supply
36	WQIC Supply Pipe	6262	8	25	7					✓			Plant service water supply; pressurized by pumping
37	Plant Service Water Pump Manifolds	4527, 4528	2 - 12	25	221			✓					Replacement already planned by YDP due to prior failures
	Cleaning Product Return												
	Fluid Systems												
38	DSB Control Block Trench No. 1 (East)	5090	3	10	365		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
39	DSB Control Block Trench No. 2 (West)	5090	3	10	245		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
	Hydranautics												
40	DSB Control Block Trench	5090	3	10	150		✓	✓					8 yrs life due to corrosion rate; easier to replace at same time as HP
	Special												
41	Filter Effluent Pipes (28 ea 10'L; NOT Aluminum bronz	1894	42		280			✓					Gravity flow; steel pipes are corroded and mortar lining failed
	Notes												
A	For Pipe Nos. 1 through 16, this alternative allowed is only if PA membranes are installed due to associated reduced operating pressure and lower corrosivity .												
B	This alternative allowed only if pipes are flushed with Product water and drained when not in service.												
C	If pipe fails pressure test, repair with butt-strap welds, Weko-Seals or other indicated repairs. No action required if pipe passes pressure test.												
D	If pipe fails pressure test, replace with stainless steel or other suitable material for service. No action required if pipe passes pressure test.												
E	Drain and enter pipe for inspection of welds and pipe condition. Repair with butt-strap welds, Weko-Seals or other indicated methods.												
F	Drain and enter pipe for inspection of welds and pipe condition. Install cured-in-place-pipe (CIPP) if defects are too numerous for spot repairs.												

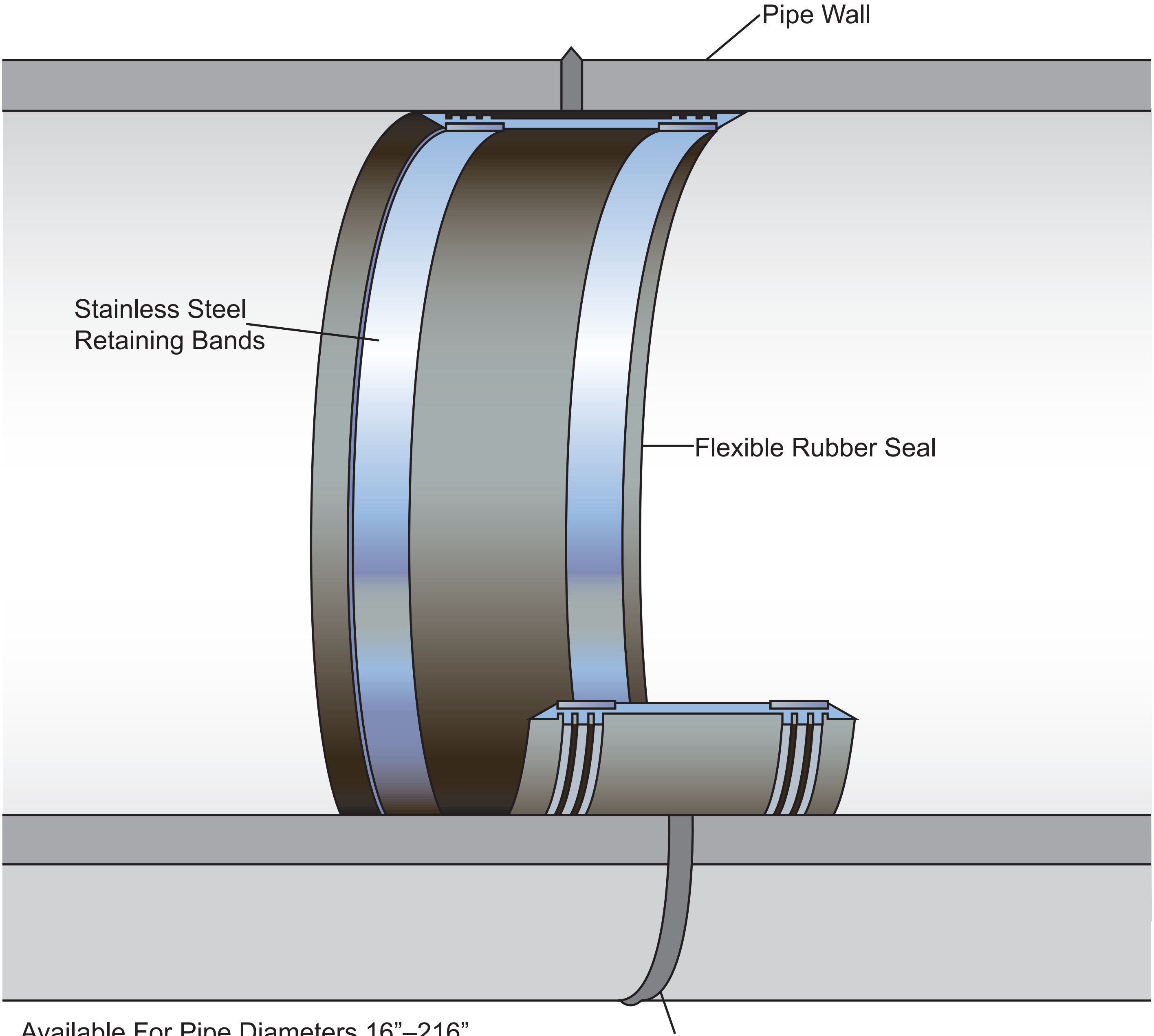
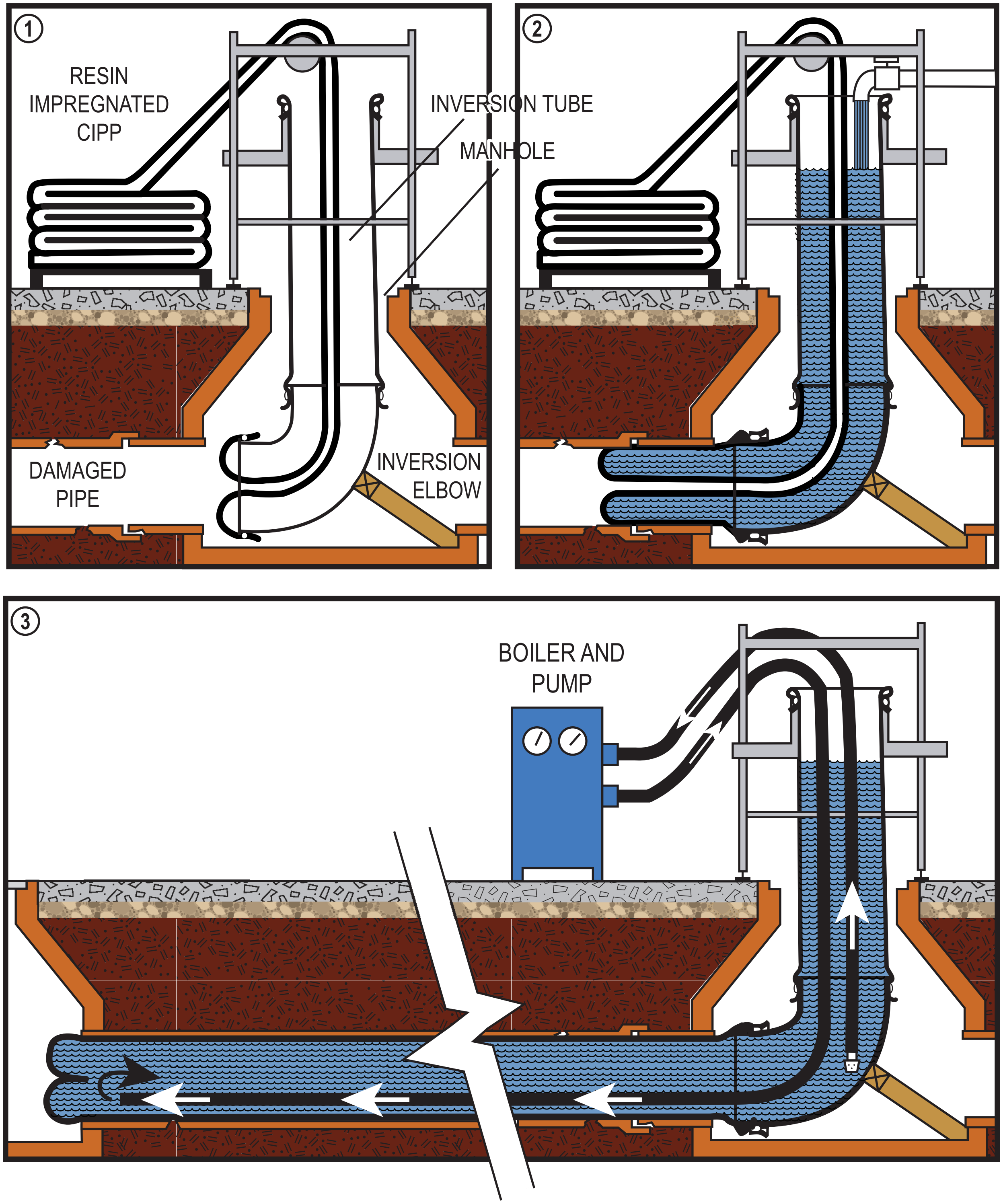


FIGURE 4-1
WEKO-SEAL®
YUMA DESALTING PLANT
YUMA, ARIZONA



① The CIPP is manufactured to fit the damaged pipe.

② The thermosetting resin tube is inverted into the pipe using hydrostatic pressure.

③ Circulating hot water cures the pipe in place.

FIGURE 4-2
CIPP INSTALLATION
YUMA DESALTING PLANT
YUMA, ARIZONA

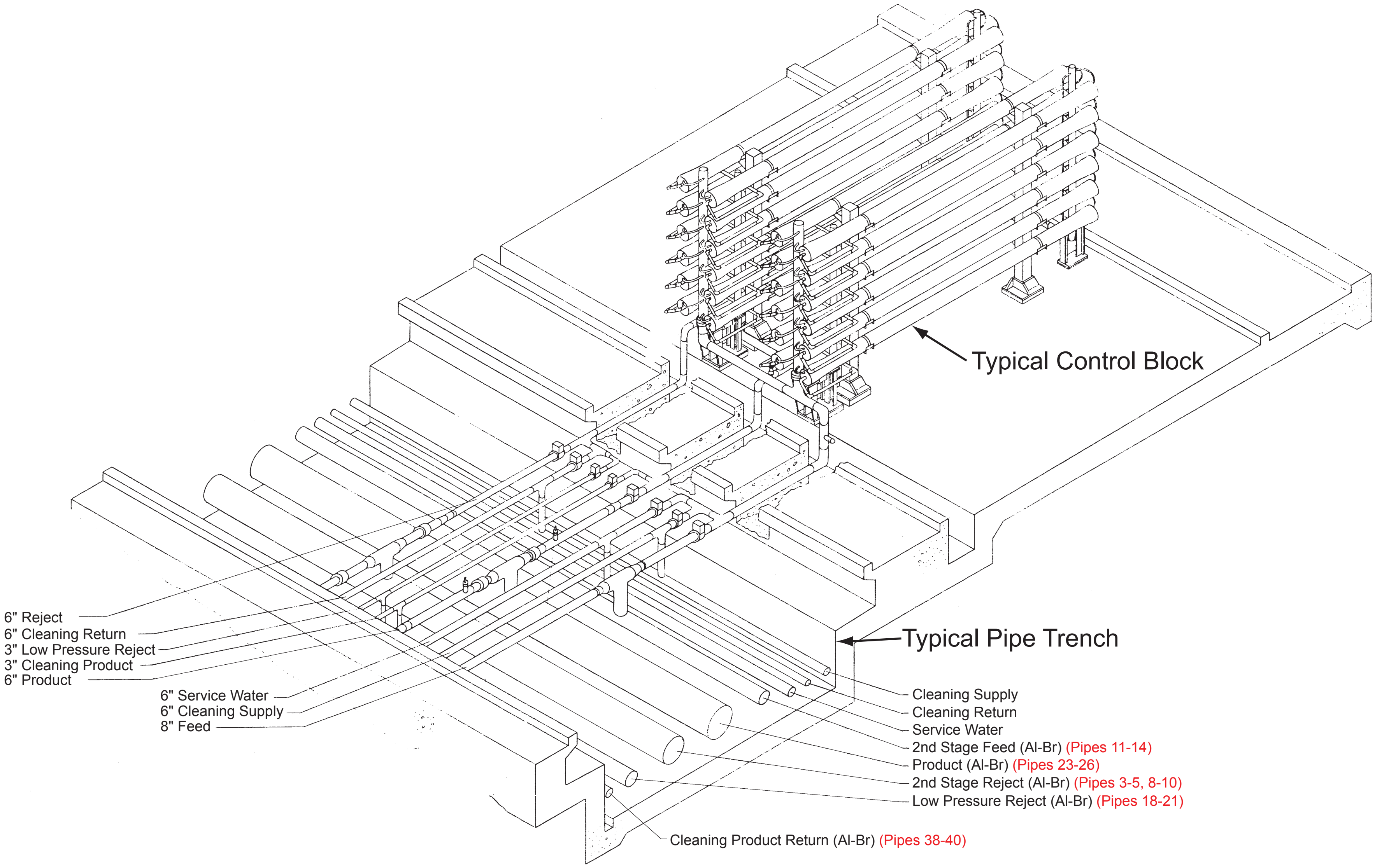
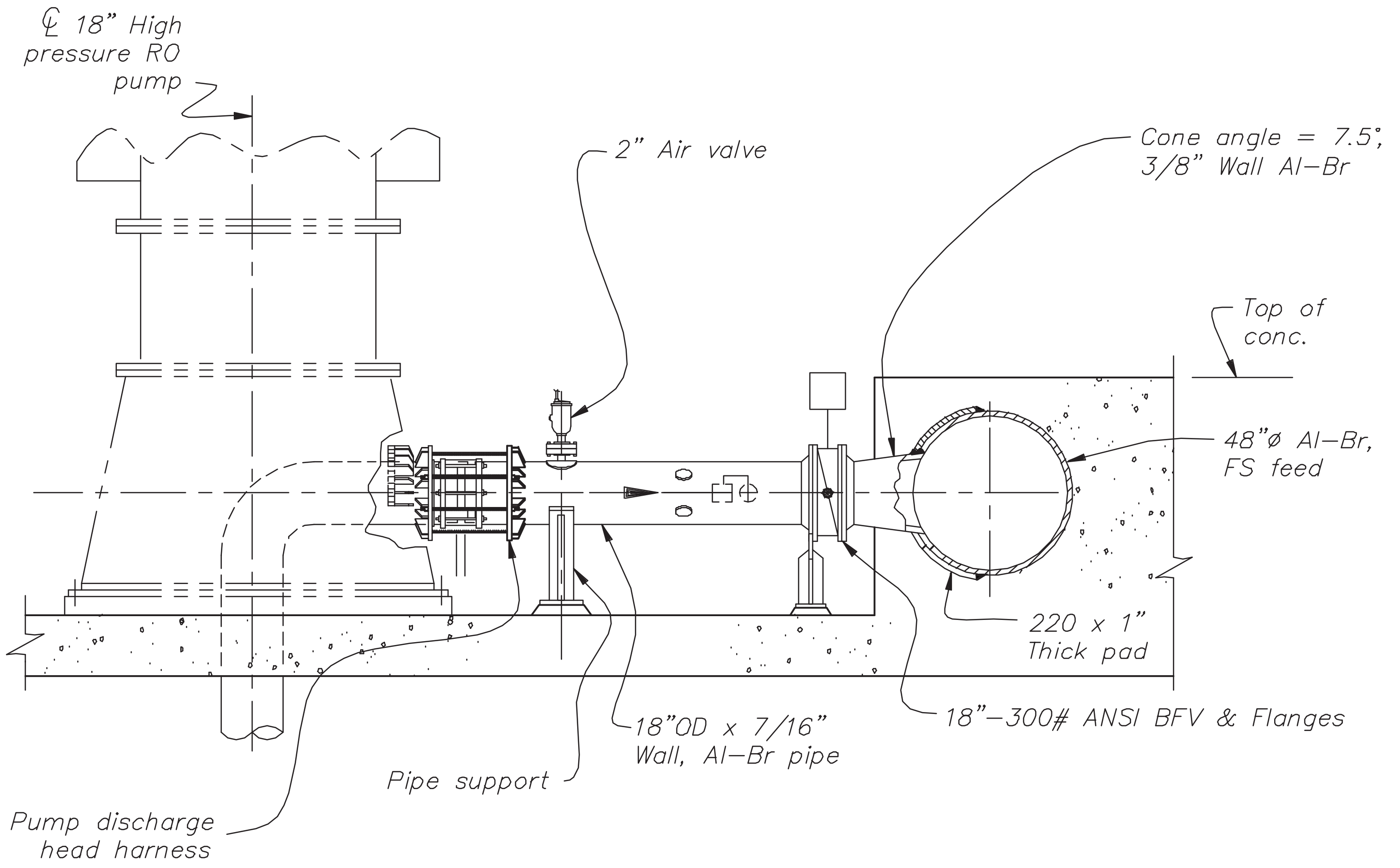


FIGURE 4-3
DESALTING BUILDING PIPING
YUMA DESALTING PLANT
YUMA, ARIZONA

Notes: 1. Not to scale
2. Excerpted from 1292-D-4512

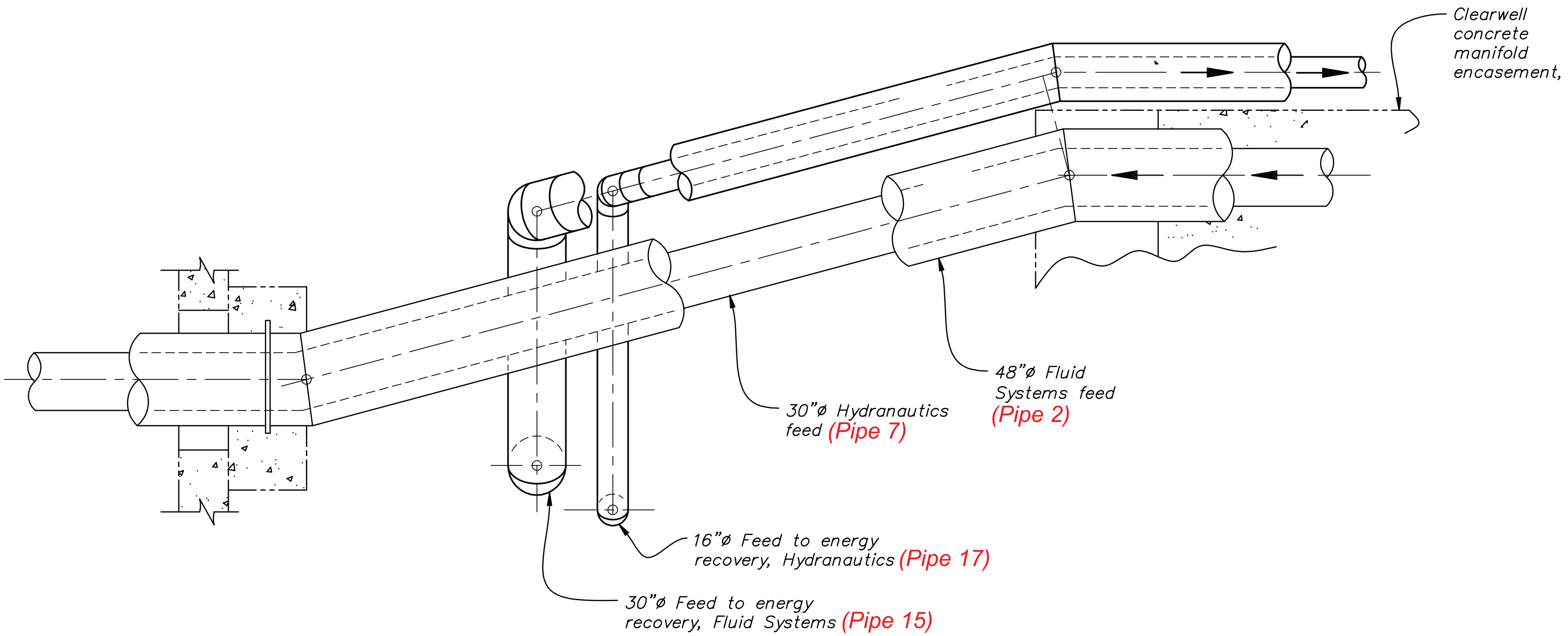


Notes:

1. Not to scale
2. Excerpted from 1292-D-4498

FIGURE 4-4
HIGH PRESSURE PUMP DISCHARGE CONFIGURATION (PIPES 1 AND 6)
YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

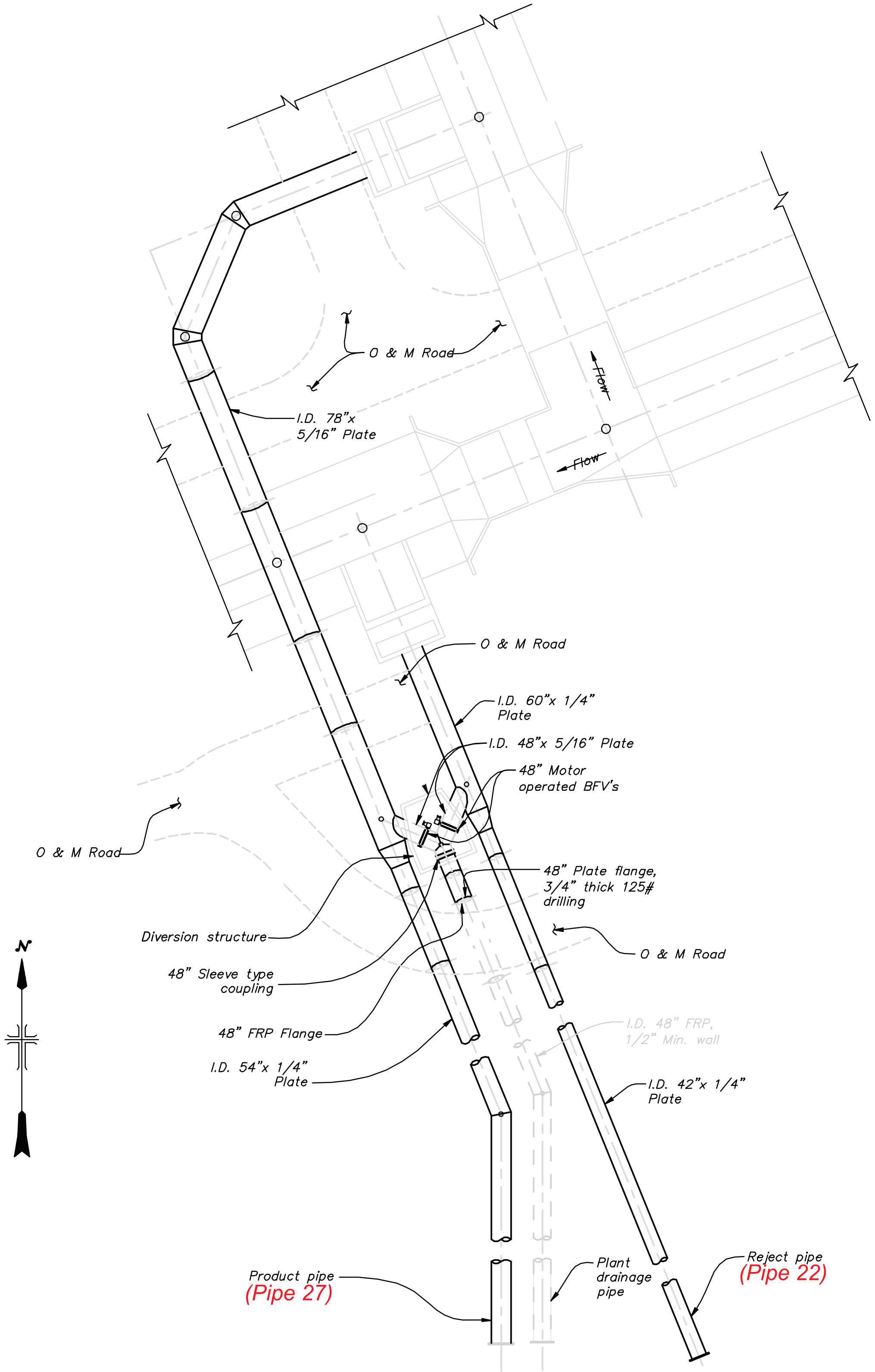


Notes:

1. Not to scale
2. All pipes shown are Al-Br
3. Excerpted from 1292-D-4501

FIGURE 4-5
DESALTING BUILDING FEED PIPING (PIPES 2 AND 7) AND ENERGY RECOVERY PIPING (PIPES 15 AND 17)

YUMA DESALTING PLANT
YUMA, ARIZONA



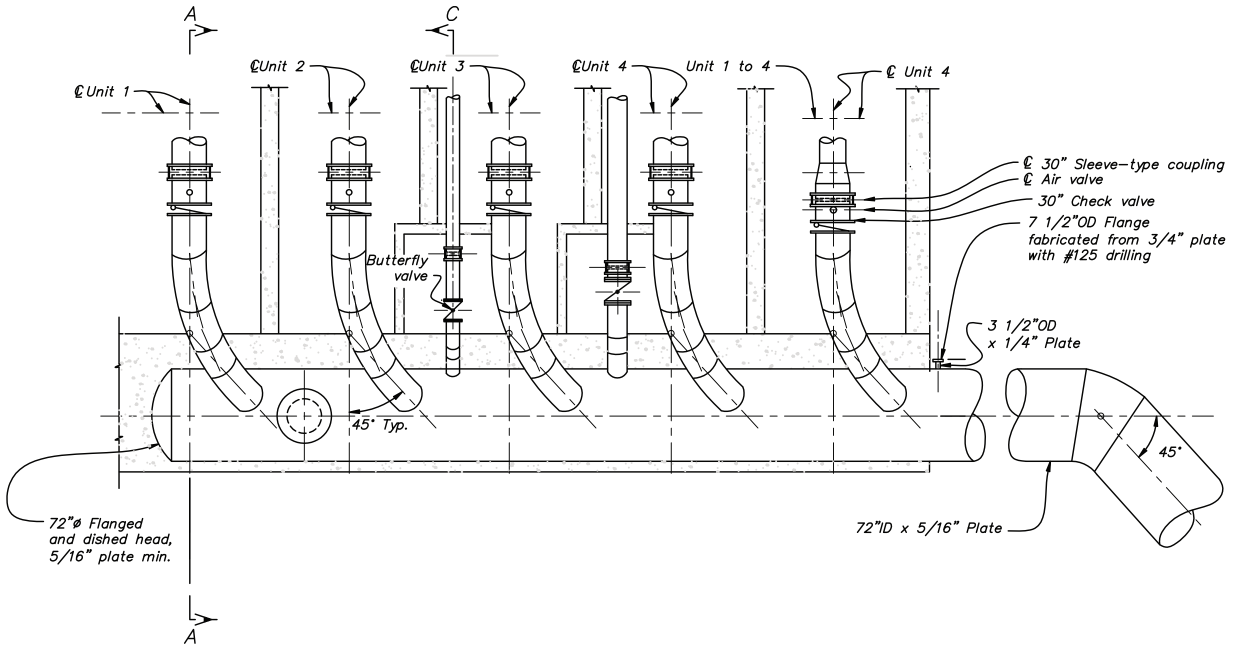
Notes:

1. Not to scale
2. All pipes shown are Al-Br
3. Excerpted from 1292-D-1494

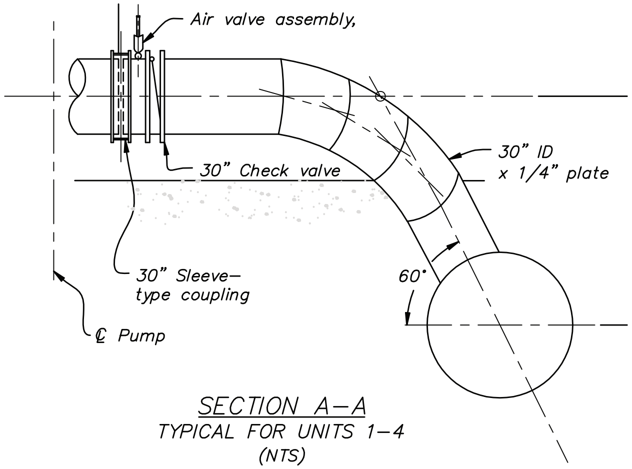
FIGURE 4-6
LEVEE CROSSING PIPELINES (PIPES 22 AND 27)

YUMA DESALTING PLANT
YUMA, ARIZONA

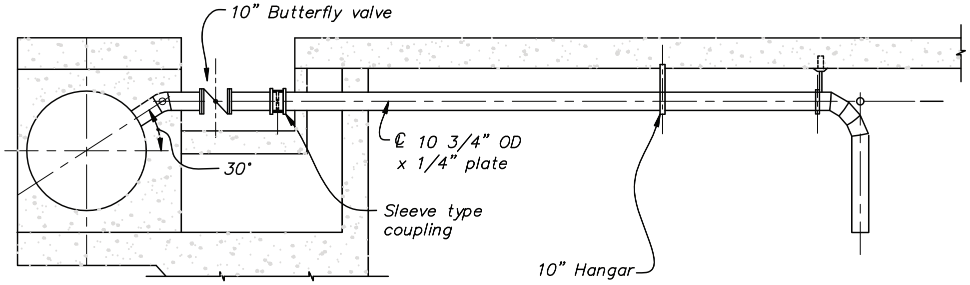
CH2MHILL



PLAN
(NTS)



SECTION A–A
TYPICAL FOR UNITS 1–4
(NTS)



SECTION C–C
(NTS)

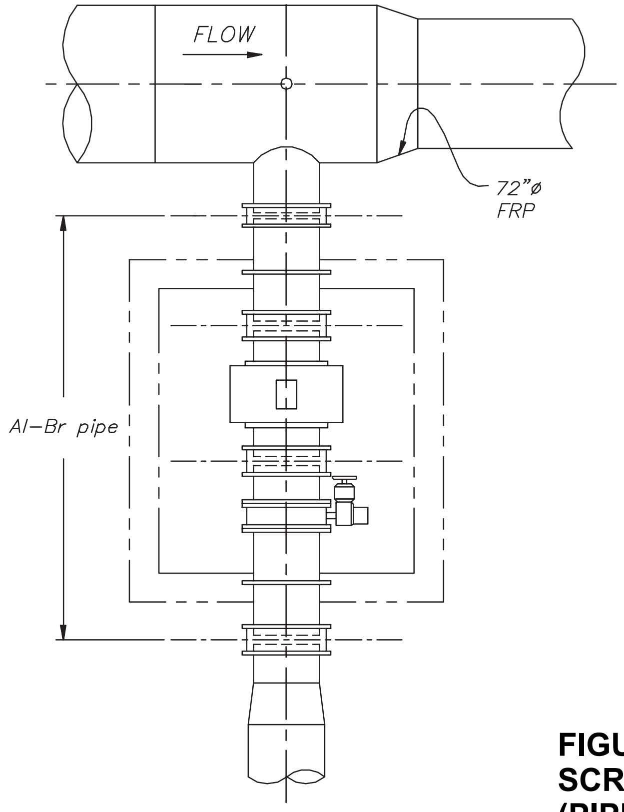
Notes:

1. Not to scale
2. All pipes shown are Al-Br
3. Excerpted from 1292-D-1489

FIGURE 4-7
INTAKE PUMP STATION MANIFOLD (PIPE 28)

YUMA DESALTING PLANT
YUMA, ARIZONA

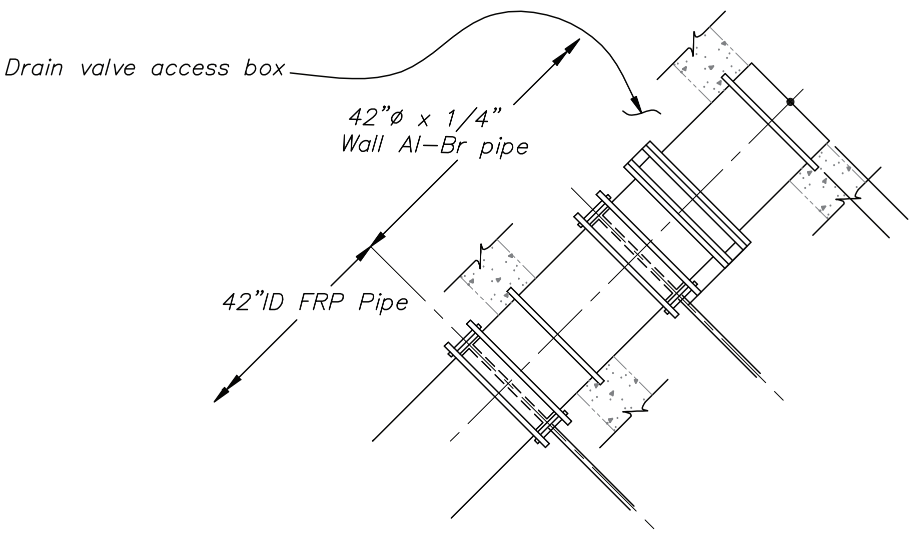
CH2MHILL



Notes:

1. Not to scale
2. Excerpted from 1292-D-4260

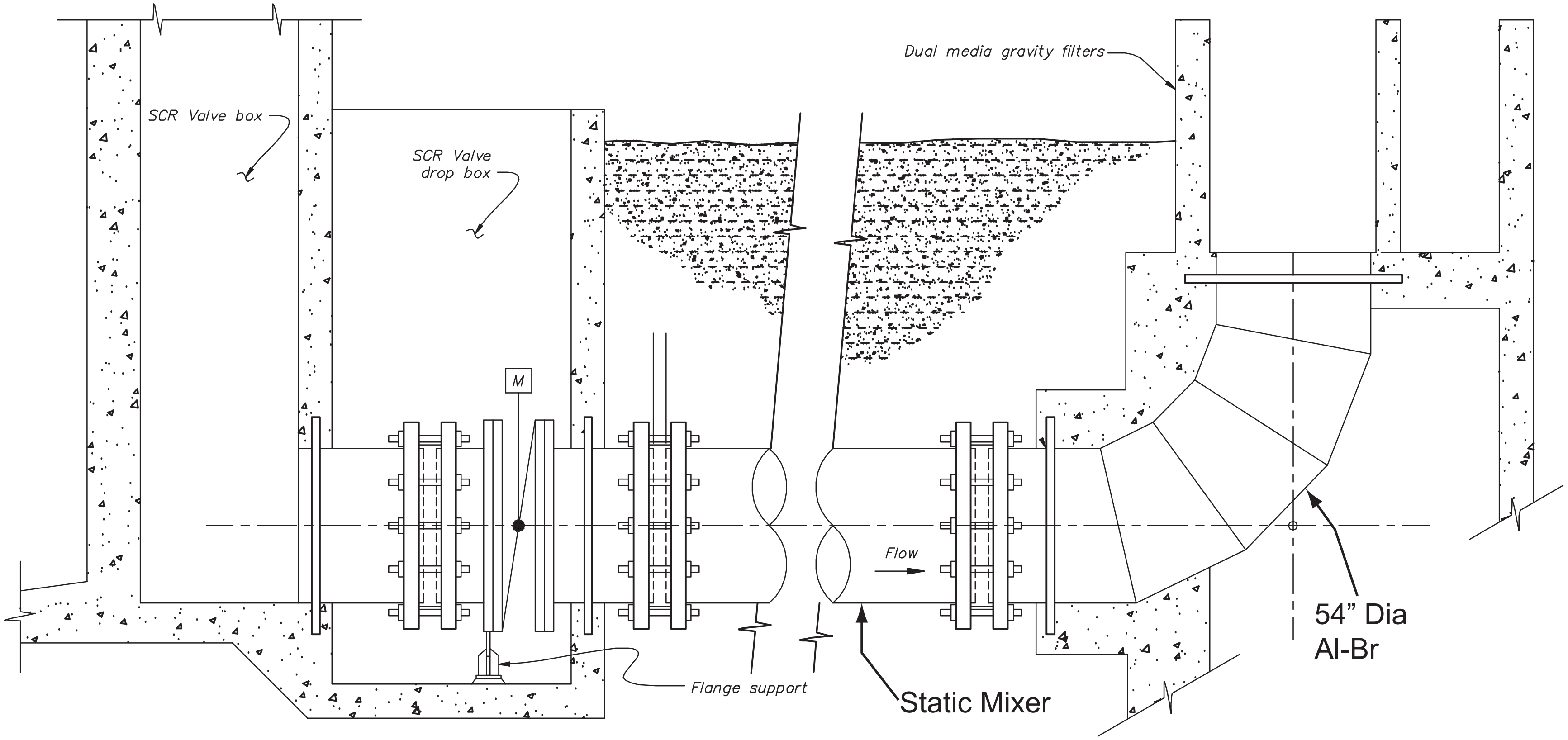
FIGURES 4-8
SCR INFLUENT PIPING
(PIPE 29)
YUMA DESALTING PLANT
YUMA, ARIZONA



Notes:

1. Not to scale
2. Excerpted from 1292-D-4266

FIGURE 4-9
SCR DRAIN PIPING
(PIPES 30 AND 31)
YUMA DESALTING PLANT
YUMA, ARIZONA

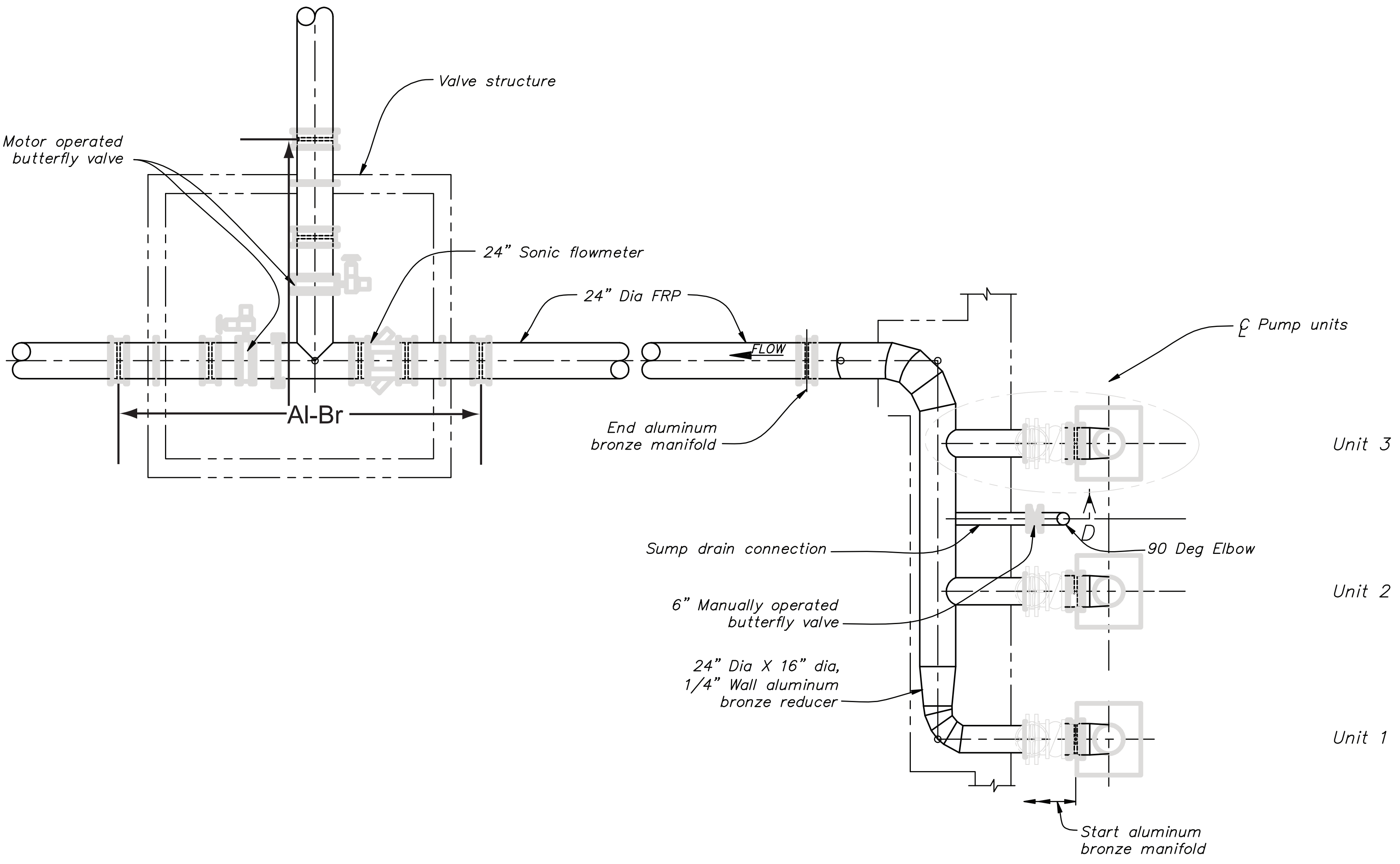


Notes:

1. Not to scale
2. All pipes shown are Al-Br
3. Excerpted from 1292-D-1518

FIGURE 4-10
SCR EFFLUENT/FILTER INFLUENT PIPING (PIPE 32)
YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL



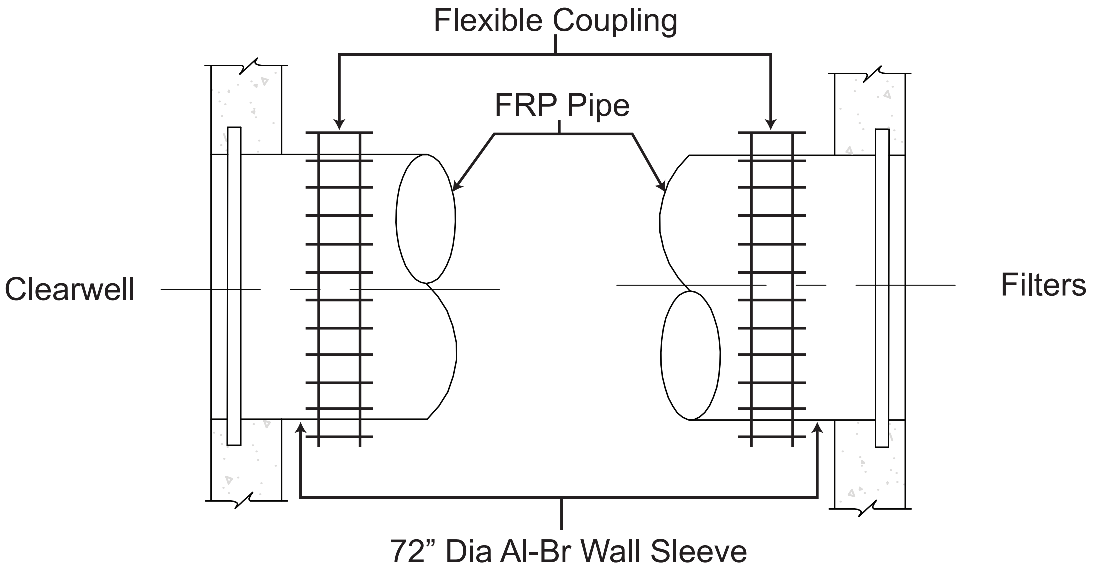
Notes:

1. Not to scale
2. Excerpted from 1292-D-4258

FIGURE 4-11
BACKWASH MANIFOLD AND PIPING (PIPE 33)

YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

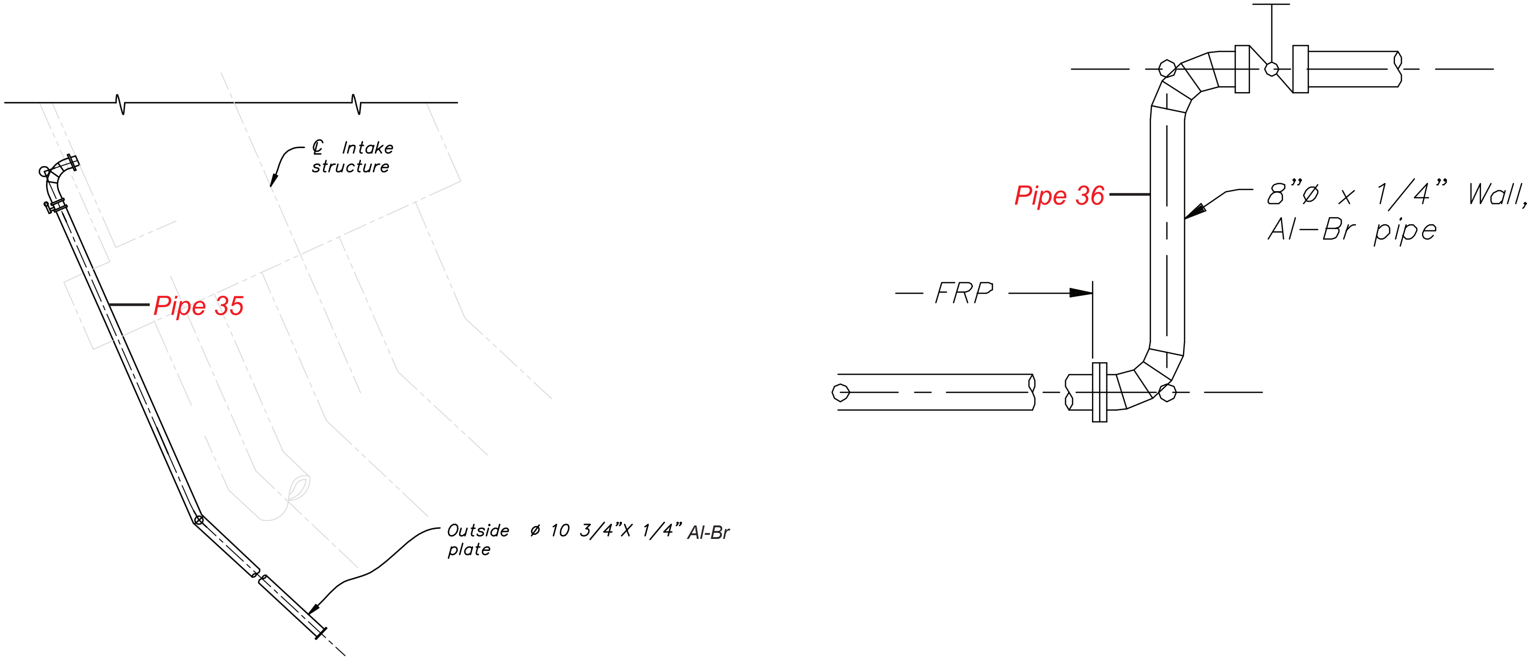


Notes:

1. Not to scale
2. Configuration assumed based on construction photographs.

FIGURE 4-12
FILTER OUTLET/CLEARWELL INLET WALL SLEEVES (PIPE 34)
YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL

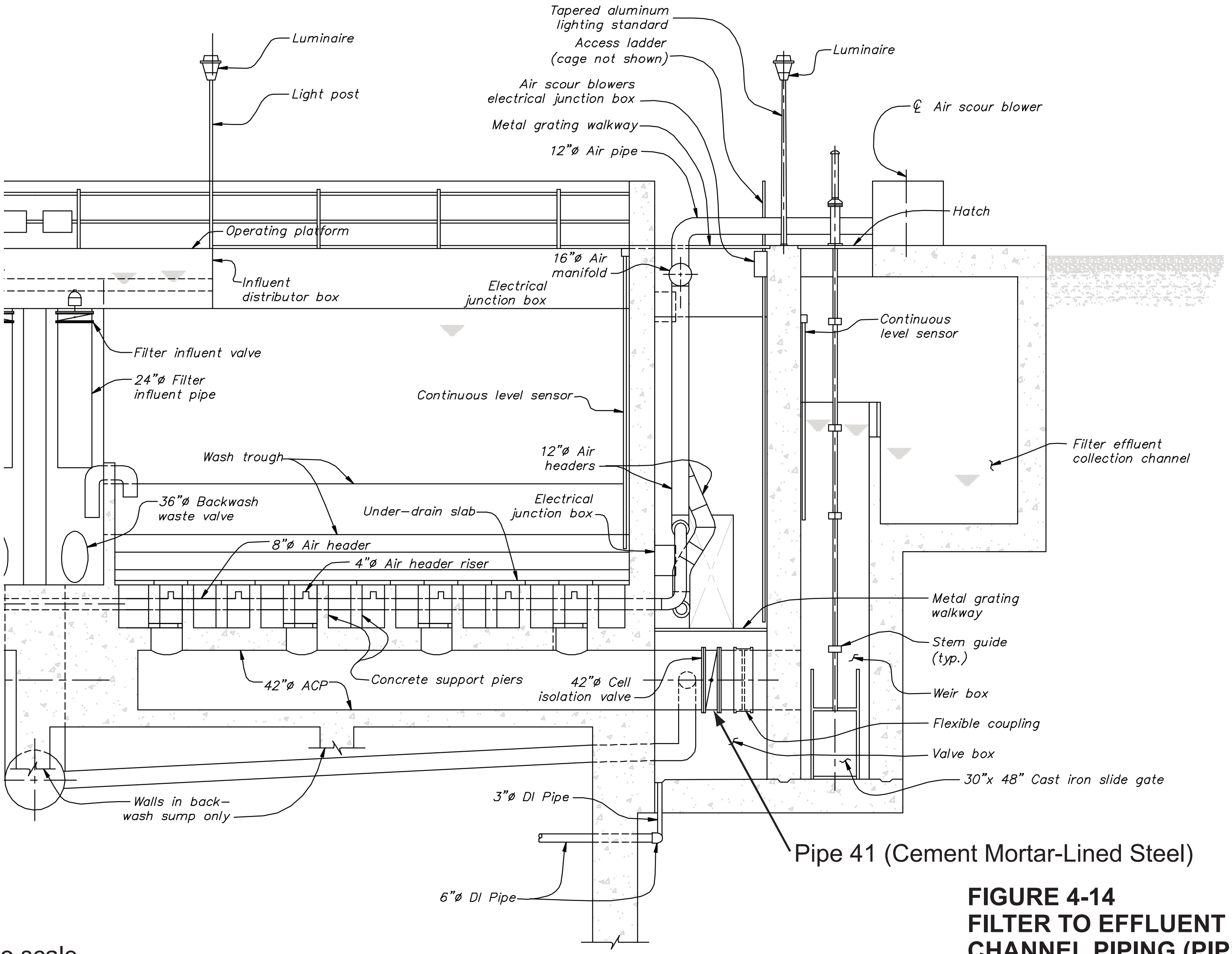


Notes:

1. Not to scale
2. Excerpted from 1292-D-1495 and 1292-303-6262

FIGURE 4-13
WQIC PIPING
(PIPES 35 AND 36)
YUMA DESALTING PLANT
YUMA, ARIZONA

CH2MHILL



Notes:

1. Not to scale
2. Excerpted from 1292-D-1894

FIGURE 4-14
FILTER TO EFFLUENT CHANNEL PIPING (PIPE 41)

YUMA DESALTING PLANT
YUMA, ARIZONA

SECTION 5

Opinion of Cost

5.1 Cost Estimating Approach

This section presents an opinion of probable costs for the remediation alternatives described in Section 4.0. Appendix L presents the details of estimated capital costs associated with piping replacement and rehabilitation. Estimated costs were itemized for each pipe identification number (Pipe No.) shown in Tables 1-1 and 4-1.

For most of the aluminum bronze piping, the alternatives are to replace with Type 316 stainless steel pipe, or to defer replacement by monitoring and repairing the existing piping until its remaining useful life is expended. The majority of this piping is located in the DSB. The major costs for implementation will be associated with construction, including demolition of existing piping and commissioning of newly constructed piping systems.

The remainder of the aluminum bronze piping at YDP is unique in that it is installed in a variety of conditions including buried service and vaults. For most of these unique pipes, replacement is not a practical option because it would involve extensive excavation, structural demolition and construction. Making the existing pipes suitable for continued service in their current settings is an appropriate course of action. Rehabilitation of these pipes will involve planning and conducting tests or inspections and implementing the required repairs based on the results.

Estimated replacement costs are also provided for the filter effluent pipes, which are not constructed from aluminum bronze but were found to have serious damage from corrosion and require remedial action for reliable service. Because of the nature of the installation, replacement with Type 316 stainless steel is the appropriate action, and this was the only alternative for which costs were estimated.

Method

Construction cost estimates were developed using CH2M HILL’s cost estimating system and the record drawings for YDP that were provided by Reclamation.

For the unique pipes that will require rehabilitation, CH2M HILL estimated the costs for planning, inspection, and repairs based on its experience at YDP and other plants.

For the deferral (monitor and repair) alternative, CH2M HILL estimated the future number of leaks and average repair cost over the remaining life of the pipes to determine the total cost associated with this scenario.

Description of Class 3 Cost Estimate

The Association for the Advancement of Cost Engineering (AACE International) has established a cost estimate classification system in Recommended Practice 18R. There are five classes of estimates with degrees of accuracy determined by the level of definition and completeness of the basis information. Class 5 estimates are the least precise, and Class 1 the most precise. A Class 3 estimate is required for this project and is described as follows:

> A Class 3 estimate is appropriate to a basic engineering phase in which the general scope of construction is understood but not defined in a set of plans and specifications. This level of engineering is considered 10 to 40 percent complete. A Class 3 estimate has an expected accuracy range of -10 to -20 percent on the low side and +10 to +30 percent on the high side.

5.1.1 Cost Estimating in Uncertain times (Rapidly escalating costs)

The cost of stainless steel and the cost of labor has been escalating and rapidly fluctuating in recent years. Because the anticipated construction schedule is unknown no attempt has been made to account for these escalating costs. This results in a present value cost estimate that may need to be adjusted in the future.

5.1.2 Assumptions

The major assumptions of the cost estimate for aluminum bronze piping mitigation at YDP are that the plant is not operational at the time of construction and there will be no cost for loss of product.

Other assumptions for pipe replacement include the following:

- Where pipe replacement is called for, aluminum bronze piping will be removed and replaced with Type 316L stainless steel pipe and fittings of the same diameter and wall thickness.
- Valves and appurtenances will be removed and re-installed, but not replaced with new items. Electrical and instrumentation connections to piping will be temporarily removed from the old pipe and attached to the new pipe.
- All existing pipe supports will be reused, and no new supports will be required.
- Quantities and sizes of fittings will be as shown on Reclamation record drawings for YDP. Because the drawings do not show all views of the piping, quantities for straight pipe sections that could be derived from the drawings were increased by 25 percent to account for undetermined items.

Assumptions for rehabilitation of unique aluminum bronze pipes include the following:

- Pressure tests can be conducted using existing pumps and valves were applicable. All other equipment needed will be rented.
- Internal inspections of large-diameter pipelines will be conducted by manned entry using proper confined space procedures.
- Inspection and repairs to the levee pipelines will require temporary dams and diversion pumping. All equipment for this will be rented.
- Each group of pipes is given an allowance for planning and preparation. This includes pipe entry planning and coordination, equipment rental, cleaning, debris removal,

inspection, pressure testing, etc. This estimate has taken into account the number of pipelines in each group, the difficulty of pipe entry, length of pipe, etc. for each group of pipes listed.

- The rehabilitation alternative estimates are based on previous experience at YDP and similar projects, the number of joints assumed to require repair, and actual contractor's estimates where applicable (Weko-Seal® and cured-in-place-pipe or CIPP).

5.2 Costs for Deferred Replacement

Costs for the monitor and repair alternative for piping in the DSB (Pipes 1-21 and 23-26) are presented in Table 5-1. These costs essentially represent the costs of deferring replacement of the aluminum bronze piping until its remaining useful life is expended. For comparison, the cost of replacement with new Type 316 stainless steel piping is shown.

The monitor and repair costs are based on the estimated number of leaks that would be expected using the demonstration testing as an indicator of the frequency that leaks would occur if the piping were in continuous operation. Based on information from YDP and other projects, it is assumed that the average cost to repair a leak in the DSB would be approximately $5,000. This estimate indicates that it would cost approximately $3.3 to $6.5 million to maintain aluminum bronze piping in the DSB for its remaining estimated life. The cost to replace the piping with Type 316 stainless steel would be approximately $11.6 million (from Table 5-3).

TABLE 5-1
Desalting Building Piping Alternative Comparison
Yuma Desalting Plant

Pipe Group	Replacement[a]	Monitor and Repair[b]
Pipes 1-17 (High Pressure)[c]	$8,251,286	$840,000 - $1,680,000
Pipes 18-21 (Low Pressure Reject)[d]	$888,987	$320,000 - $640,000
Pipes 23-26 (Product)[E]	$2,329,195	$2,100,000 - $4,200,000
Total	$11,589,612	$3,260,000 - $6,520,000

[a] Type 316 stainless steel; costs from Table 5-3, excludes mobilization.

[b] Excludes replacement of the aluminum bronze piping, which is required at the end of the service life.

[c] Based on 8 to16 forecast leaks per year, $5,000 average cost per repair, and 21 years remaining life of piping.

[d] Based on 8 to16 forecast leaks per year, $5,000 average cost per repair, and 8 years remaining life of piping.

[e] Based on 20 to 40 forecast leaks per year,$5,000 average cost per repair,and 21 years remaining life of piping.

Table 5-1 indicates that the cost of monitoring and repairing aluminum bronze piping would be approximately 28 to 56 percent of the cost of early replacement with Type 316 stainless steel. The monitor and repair option should be considered only if the operating pressures of the existing aluminum bronze piping can be substantially reduced as would occur if the existing RO membranes are replaced with polyamide membranes.

5.3 Summary of Capital Cost

Table 5-2 presents the estimated costs associated with the unique yard piping (Pipes 22 and 27-36) at YDP. The total cost for rehabilitation for each group of pipes is presented as a range, covering the lowest and highest estimated rehabilitation alternative.

TABLE 5-2
Unique Yard Piping Rehabilitation Cost Estimate
Yuma Desalting Plant

Pipe Group	Minimum	Maximum
Mobilization	$24,751	$90,281
Pipes 28 & 33 (Pretreatment)	$78,200	$981,438
Pipe 29 (Pretreatment)	$49,400	$57,400
Pipes 30-34 (Pretreatment)	$99,700	$113,700
Pipes 22 & 27 (Levee)	$158,900	$661,040
Pipes 35 & 36 (WQIC)	$163,825	$192,673
Total	$574,776	$2,096,532

See Appendix L for cost detail.

Table 5-3 presents a summary of the estimated cost for replacement of the selected aluminum bronze piping at YDP. This includes replacement of all of the aluminum bronze piping in the DSB; the plant service water pump manifold, and the steel filter effluent pipes. The estimated cost for this replacement is $15.0 million.

An overall summary of estimated cost for remedial action for the aluminum bronze piping at YDP is presented in Table 5-4.

Table 5-3
Yuma Desalting Plant
Aluminum Bronze Piping Rehabilitation
Class 3 Cost Estimate Summary

Estimate Description	**Source of Cost**	**Task Cost**	**Subtotals**	**Total**
Replacement with 316 Stainless Steel	Estimate Page Nos.			
Mobilization	1	*$625,000*		
1st St. Feed/2nd St. Reject				
Fluid Systems (Pipes 1-5)	3; 8; 9	*$3,470,088*		
Hydranautics (Pipes 6-10)	10; 14; 15	*$1,693,558*		
1st St. Reject/2nd St. Feed				
Fluid Systems (Pipes 11-12)	19	*$1,063,629*		
Hydranautics (Pipe 13)	22	*$354,200*		
Interstage to ER				
Fluid Systems (Pipes 14-15)	24	*$1,326,774*		
Hydranautics (Pipes 16-17)	26	*$343,037*		
Subtotal for Pipes 1-17			$8,251,286	
Low Pressure Reject				
Fluid Systems (Pipes 18-19)	29	*$479,823*		
Hydranautics (Pipe 20)	30	*$211,446*		
Combined (Pipe 21)	31	*$197,718*		
Subtotal for Pipes 18-21			$888,987	
Product				
Fluid Systems (Pipes 23-24)	35	*$1,072,657*		
Hydranautics (Pipe 25)	36	*$516,479*		
Combined (Pipe 26)	37	*$740,059*		
Subtotal for Pipes 23-26			$2,329,195	
Cleaning Product Return				
Fluid Systems (Pipes 38-39)	40	*$93,978*		
Hydranautics (Pipe 40)	41	*$26,166*		
Subtotal for Desalting Building			**$11,589,612**	
Other				
Plant Service Pump Manifold (Pipe 37)	38	*$143,427*		
Steel Filter Effluent Pipe (Pipe 41)	43	*$2,637,848*		
Total for Replacement with Stainless Steel				**$14,995,887**

TABLE 5-4
Total Cost for Remediation of Aluminum Bronze Piping
Yuma Desalting Plant

Pipe Group	Estimated Cost, Millions
Replacement with Stainless Steel	$15.0
Rehabilitation of Unique Piping	$0.6 - 2.1
Total	$15.6 - 17.1

Costs from Tables 5-2 and 5-3

SECTION 6.0

Conclusions and Recommendations

6.1 Conclusions

The tasks completed during Phase II of the aluminum bronze piping assessment at YDP have led to the following conclusions:

1. The existing aluminum bronze piping system has a number of defects that will affect its reliability and expected service life. The major defect is the poor quality of welds made during original construction of the plant. Testing of sample welds in pipes from a variety of locations and services showed that approximately 90 percent of the welds contained defects that would be unacceptable for pressurized service by today's standards. Weld defects include porosity, cracks, incomplete penetration, and lack of fusion.

2. It is not clear as to why YDP was constructed with so many defects in the original welds of the aluminum bronze pipe. The contract specifications required visual inspection and hydrostatic testing of the constructed piping system, but did not require any other non-destructive testing such as radiography of welds. Construction records showed that the required hydrostatic test pressures at YDP were reduced when problems in the welds of aluminum bronze piping appeared at higher test pressures. The actual final test pressures were not found in the construction records.

3. Welding repairs have been made on aluminum bronze piping where leaks have occurred, and the repairs have met with mixed success. Microscopic examination shows the reason for this situation. Repair welding can create a brittle microstructure, known as beta phase, in portions of the weld. Unless the beta phase is completely removed, re-welding will not form the desirable alpha phase microstructure, and cracking or other defects will result in the weld repairs. Because the beta phase is difficult to identify under field conditions, and removal is arduous, the success of weld repairs is not assured.

4. The wall thickness of most of the aluminum bronze piping is within the manufacturing tolerance for new pipe. Therefore, wholesale thinning of the pipe wall by corrosion has generally not occurred to any significant extent to date. However, corrosion rates of aluminum bronze are expected to be 15 mpy for RO feed and reject piping, and 5 mpy for product piping, with YDP in its present operational configuration. The high corrosion rate in the RO feed and reject piping will reduce the pipe wall thickness by 50 percent in about 8 years.

5. Samples of the base metal of the aluminum bronze piping were analyzed, and it was verified that composition of the alloy met the requirements of the specifications.

6. Visual examination of aluminum bronze piping indicates that corrosion tends to occur at welds and at seeps where the welds are cracked. This localized corrosion will lead to

leaks and reduced reliability of the piping even if the majority of the pipe segment is not substantially affected by corrosion.

7. An assessment was made of the aluminum bronze piping relative to ASME B31.3, Code for Pressure Piping. This is the most applicable code for YDP, even though YDP was not originally designed to conform to it. ASME B31.3, Code for Pressure Piping, does not address situations with a weld quality factor of 0.80 or less. However, for purposes of approximating pressure rating of installed pipe, a weld quality factor of 0.60 was assumed, because defects were found in most of the welds examined.
8. The maximum pressure capacities of straight lengths of aluminum bronze piping generally decrease with increasing pipe diameter when calculated according to ASME B31.3 code. Only smaller pipe sizes meet the code requirements for RO feed piping at the current YDP design pressure of 450 psi. Existing tee fittings and mitered bends also do not meet code requirements for 450 psi service.
9. The demonstration testing of YDP was conducted at a maximum pressure of 300 psi, which is lower than the original design pressure. During the testing, a total of 9 leaks occurred in the aluminum bronze piping system, but bursting or structural failures of pipe did not occur. Several leaks were found on the bottom of the pipes. Also, laboratory results indicated that the copper concentration in the water was fairly high. These findings indicated that corrosion was occurring on the aluminum bronze piping during demonstration testing.
10. Mitigation alternatives were developed for aluminum bronze piping. Two alternatives were considered for high-pressure piping: monitor and repair as needed, or replace with Type 316 stainless steel. The replacement alternative would correct all deficiencies in the existing piping, but the cost would be substantially greater and the piping would require special operation to prevent corrosion from ruining the pipe when the plant is not operating. The repair alternative would present more risk for reliability but would be initially less expensive would deferral of the replacement of the aluminum bronze piping for 8 to 20 years.
11. Certain large buried aluminum bronze pipes in the plant operate at low-pressure or gravity flow. Mitigation is required, but replacement would be complex and expensive. A suitable alternative is to conduct a manned inspection or pressure testing of the pipe and implement repairs or installation of a structurally independent liner if indicated by the results of the inspection.

6.2 Recommendations

This report makes few recommendations regarding the aluminum bronze piping because it is not clear as to how YDP will be operated in the future. YDP might operate as presently authorized by Congress; that is, MODE water as feedwater, with conventional pretreatment, RO with cellulose acetate membranes, and product water discharged to the Colorado River for inclusion in water deliveries to Mexico.

Another alternative that might be considered is operation of the YDP using Yuma area groundwater, piped to the plant as feedwater, particle/micro/ultrafiltration pretreatment, RO with polyamide membranes and interstage boost, post treatment stability, and potable product water delivered to the City of Yuma for municipal use. These scenarios have different implications for some of the aluminum bronze piping.

It was concluded jointly with Reclamation that, instead of making a final singular recommendation, the report should simply list the various alternatives based on the pressure of the piping and present costs for each of them. This approach will allow Reclamation to select the best alternative based on the circumstances that exist when decisions are made regarding the aluminum bronze piping at YDP.

Therefore, the recommendations of the Phase II aluminum bronze piping assessment are fundamental in scope:

- Existing aluminum bronze piping in the high-pressure piping system should be replaced with stainless steel pipe, or the membranes should be changed to polyamide so that the required operating pressure is substantially reduced. *CH2M HILL specifically recommends against operation of the existing aluminum bronze piping systems with cellulose acetate membranes because this scenario requires high operating pressures that exceed the pressure capacity of the pipe as determined by ASME B31.3, Pressure Piping code.*
- Existing, buried, low-pressure or gravity piping should be inspected or tested to determine the type and extent of repairs required. There is no practical alternative for this piping.

Alternatives for high-pressure piping are compared in Table 6-1.

TABLE 6-1
Comparison of Alternatives for High-pressure Aluminum Bronze Piping
Yuma Desalting Plant

	Advantages	**Disadvantages**
Monitor and Repair as Needed	Lower capital cost, at least initially Quicker to implement before placing the plant in service	Not recommended for cellulose acetate membranes Replacement of RO reject piping required in as few as 8 years as a result of corrosion Uncertainty of reliability of pipe Require difficult welding repairs
Replacement with Type 316 Stainless Steel	Corrects all deficiencies of existing piping Maximizes reliability of plant piping Allows either cellulose acetate or polyamide membranes to be used	High capital cost Disruption of plant operations by major construction project Requires flushing and special operations to prevent corrosion damage when the plant is not in operation

SECTION 7.0

Works Cited

CH2M HILL. 2003. *Evaluation of pH Adjustment System at the Yuma Desalting Plant*. August.

U. S. Department of the Interior, Bureau of Reclamation (Reclamation). 2002. *Yuma Desalting Plant Aluminum Bronze Pipe Inspection* (Report). February.

U. S. Department of the Interior, Bureau of Reclamation (Reclamation). 1986. *Yuma Desalting Plant Pretreatment Completion and Desalting Building* (Design Summary). June.