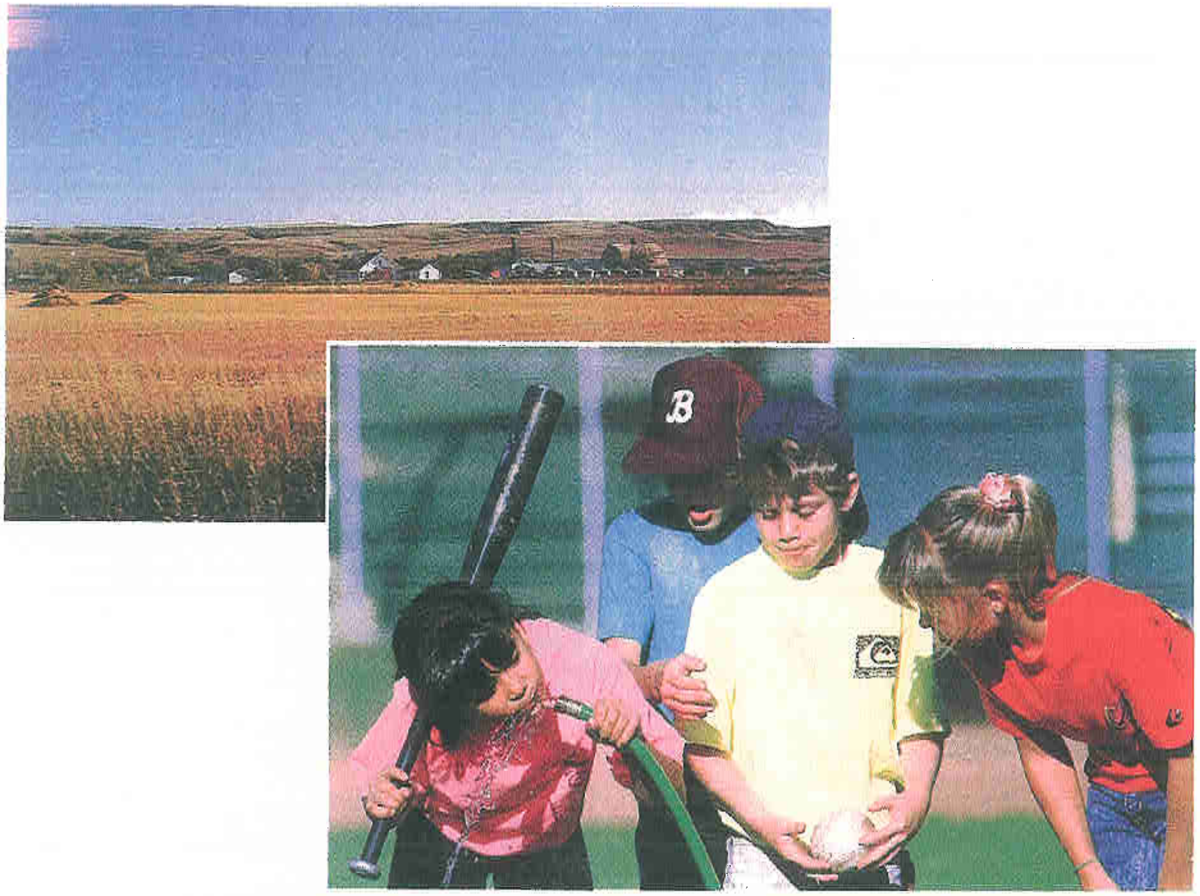

North Dakota State Water Commission
and the
Garrison Diversion Conservancy District

Northwest Area Water Supply Project
Pretreatment System Predesign
Evaluation

February 2003

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February 24, 2003

Mr. Jim Lennington
North Dakota State Water Commission
State Office Building
900 East Boulevard
Bismarck, North Dakota 58505

Subject: Draft Pretreatment System Predesign Evaluation

Dear Mr. Lennington:

Enclosed is three copies of the Pretreatment System Predesign Evaluation for your review. This letter report evaluates available chlorine and ammonia feed technologies to disinfect the NAWS water supply at the Booster Pump Station near Max, North Dakota. The evaluation also includes an evaluation of a pressurized pipe chlorine contactor and use of the pump station wet well to serve as the contact basin. The pretreatment facilities will be integrated into the Booster Pump Station facilities.

Based on the evaluation, a chlorine gas feed system, aqueous ammonia feed system and use of the wet well for the chlorine contact chamber are recommended. The evaluation looked at capital costs, operation and maintenance costs, operation and maintenance issues and safety and handling issues.

The estimated predesign level cost estimates for the pretreatment facilities total $1,624,700. Approximately one-half of the construction cost of the wet well/contactor was assigned to the pretreatment operation. The other half was assigned to the Booster Pump Station function. A summary of the construction costs are presented in the following:

Chlorine gas feed system	$864,600
Aqueous ammonia feed system	$440,900
Chlorine contactor (50 percent)	$319,200
TOTAL	**$1,624,700**

The estimated annual operation and maintenance cost of the pretreatment system is $103,600 per year.

If you have any questions or comments during your review, please contact us.

Respectfully submitted,

MWH

William G. Lynard

Houston Engineering, Inc.

Roger C. Hagen

/ps

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INTRODUCTION

The objective of the Pretreatment System Predesign Evaluation is to finalize the facility design criteria for disinfection treatment of the NAWS raw water supply. Disinfection design criteria were established in the Chloramine Challenge Study – Final Report (December 1995) to meet inactivation requirements using both ozone and chlorine/chloramines.

This evaluation is designed around the use of chlorine/ chloramines as the pretreatment disinfectant applied to meet a minimum 99.9% (3-log) inactivation of *Giardia* and 99.99% (4-log) inactivation of virus from the Lake Sakakawea raw water supply. Criteria for the pretreatment facility configuration, chlorine and ammonia feed systems, disinfectant contacting system, and chemical dose monitoring and control are developed and discussed. This report is organized in the following sections:

- Background
- Chlorine Feed System Evaluation
- Ammonia Feed System Evaluation
- Recommended Chemical Feed System Layout
- Disinfection Contactor Evaluation
- Pretreatment System Control

BACKGROUND

The Chloramine Challenge Study – Final Report (December 1995) identified both chlorine/chloramine and ozone as effective disinfection strategies to achieve inactivation requirements for the project. The Biota Transfer Control Measure (September 1998) report assumed that ozone would be carried forward as the method of pretreatment, pending additional water quality evaluations.

Since that time, additional evaluations have been conducted and issues of potential ozone byproduct formation have been investigated, including AOC's (Assimilable Organic Carbon). Based on these issues, the current recommended method to achieve that 3-log *Giardia* and 4-log virus inactivation is to use chlorine (Biota Transfer Control Measures – Update (April 2001)). Ammonia would be added after the necessary chlorine contact time to form a chloramine residual in the pipeline.

The basic process criteria derived from the Chloramine Challenge Study testing indicates that a free chlorine dose at 4.5 mg/l with a five-minute contact time followed by ammonia addition exceeded the inactivation goals for both virus and *Giardia*. The five minute contact time resulted in safety factors of over 5 for virus and approximately 2 for *Giardia*. Free chlorine residuals after initial demand, prior to ammonia addition are in the range of 3.5 to 4.0 mg/l. The experimental chlorine to ammonia ration used in the studies was 4:1.

The results of the studies also indicated that contact times exceeding ten minutes on Lake Sakakawea water did not significantly increase disinfection byproduct (DBP) formation beyond the five minute contact time levels. Therefore, the minimum contact time will be set at five minutes, with an acceptable range between five to ten minutes.

CHLORINE FEED SYSTEM EVALUATION

Several types of chlorine feed system are available for use in the NAWS water supply project. These included:

- Gas Feed System: Chlorine Gas Cylinders
- Liquid Feed System: On-Site Generation of Sodium Hypochlorite
- Liquid Feed System: Sodium Hypochlorite 12% Solution

An evaluation of the advantages and disadvantages of each of the available systems for storing and feeding chlorine is presented in the following. The evaluation parameters include delivery cost, storage constraints, feed system cost, maintenance implications, safety, and handling.

This evaluation summarizes the results of the cost and feasibility evaluations of the above systems and provides design criteria and a preliminary schematic layouts of the recommended facilities.

A summary of the system operating criteria, used to size the chlorine feed facilities is presented in Table 1.

TABLE 1

PRETREATMENT DISINFECTION SYSTEM DESIGN CRITERIA

Description	Units	Criteria
Design Flow		
Minimum	MGD	5.2
Average	MGD	10.5
1st Phase Peak	MGD	18
Ultimate Peak	MGD	26
Disinfection Requirements		
Free chlorine Dosage	mg/l	4.5
Residual Target	mg/l	3.5 to 4.0
Contact Time (minimum)	minutes	5
Contact time (maximum	minutes	10
Chlorine/Ammonia Ratio		4:1

Chlorine Gas Feed System

A chlorine gas feed system typically utilizes one-ton cylinders, chlorinators, and associated equipment and piping to inject chlorine solution into the flow. Chlorine gas feed systems are used widely in water treatment operations and represents a standard technology. Chlorine gas, however, is hazardous, and special design provisions are required. This includes separation and isolation of rooms containing chlorine equipment, monitors and alarms and the provision of a chlorine gas scrubber.

For the NAWS Pretreatment Facility, Table 2 presents the criteria used to size the chlorine gas feed system.

TABLE 2

CHLORINE GAS FEED SYSTEM DESIGN CRITERIA

Description	Units	Value/Criteria
Chlorine Dose Rate	mg/l	4.5
Design Consumption		
Ultimate Peak Flow	lb/d	976
Design Peak Flow	lb/d	676
Average Day Flow	lb/d	394
Minimum Flow	lb/d	195
Chlorinators	No.	3
Type	-	V-notch
Capacity, each	lb/d	500
Chloride, storage	Type	One ton cylinder
On-line	No.	2
Storage	No.	6
Days at Average Flow	Days	30
Emergency Scrubber	Type	Dry

System Configuration. A gas chlorination system is comprised of gas cylinders and weighing scales, chlorinators (two duty and one standby) gas stainer, gas pressure regulation valves and gauges, expansion tanks, eductors and associated transport water supply, gas leak detectors, and residual analyzers.

Chlorine one-ton cylinders would be contained in a cylinder storage room. This room would have two sets of scales of two cylinders each. One set of scales and cylinders would be on-line with the other set in standby mode. After emptying one set of one-ton cylinders, an automatic switch over device would bring the standby cylinder on-line.

In the cylinder storage room, four cylinders would be provided on trunnions and two empty trunnions would be reserved for cylinder change out.

With two cylinders on-line and six in storage, a total of 30 days storage capacity at average day flows would be provided.

In a separate room, three 500-lb/day chlorinators would be provided. The chlorinators are sized such that at ultimate peak flow, two chlorinators would be on-line with one unit serving as a spare.

Both the chlorine storage room and the chlorinator room would be isolated from the balance of the booster pump station area with access form the exterior of the building. A chlorine scrubber would be provided and plumbed to the storage area and chlorinator area ventilation. Should a chlorine leak occur in either area, the scrubber would be used to neutralize the chlorine.

Chlorine will be injected into the water prior to the chlorine contactor at a dose of approximately 4.5 mg/l.

The chlorine facilities have an estimated construction cost of approximately $864,600. This includes an allocation of building space utilized by the chlorination facilities. A summary of the estimated construction costs are presented in Table 3.

Operations and Maintenance. Chlorine gas, delivered in one-tone cylinders is one of the least expensive forms of chlorine delivery. Chlorine may be delivered in loads of up to 14 cylinders which is in excess of the requirements for the pretreatment facilities. Chlorine delivery is readily available in the project area. As the last two to four cylinders are on the scales, a delivery order will be placed for chlorine. Assuming two full cylinders, this represents approximately 10 days of operation at average day flows. On the average, approximately 12 deliveries per year are expected. The average annual consumption of chlorine is approximately 144,000 lbs. Based on delivery quotes from local suppliers, chlorine costs, at $595/ton are expected to be in the range of $43,000/year.

Labor costs include daily inspection, chlorine cylinder changes, chlorine delivery and equipment maintenance. A two-person crew is assumed for safety reasons. A total of about 600 hours are projected for the labor requirements for operation and maintenance of the facility at an annual cost of approximately $18,000.

Other annual expenses will be incurred for equipment supplies and maintenance. A summary of the estimated annual operation and maintenance costs are presented in Table 4.

TABLE 3

CHLORINE GAS SYSTEM CONSTRUCTION COST ESTIMATE

Item	Cost
Building Allocation	$144,000
Loading Dock (50%)	10,000
Mechanical Systems	
Chlorinators	36,000
Trunnions, Scales, Overhead Hoist	49,000
Piping, Valves, Misc. Equipment	56,000
Equipment Installation	100,000
Injector Vault	20,000
Chlorine Emergency Scrubber	130,000
Electrical/Instrumentation	100,000
Site Work/Yard Piping	10,000
Subtotal	$655,000
Construction Contingency at 20%	$131,000
Subtotal	$786,000
Mobilization/Demobilization at 10%	$78,600
TOTAL CONSTRUCTION COST	**$864,600**

TABLE 4

CHLORINE GAS SYSTEM OPERATION AND MAINTENANCE COST ESTIMATE

Item	Annual Cost, $/yr.
Chlorine	$43,000
Labor (600 hrs at $30/hr)	18,000
Scrubber O&M	2,000
Maintenance Parts/Equipment	4,000
Power/HVAC	1,000
TOTAL O&M	**$68,000**

Safety and Handling Issues. Chlorine is classified as a poisonous gas and handling procedures for gas cylinders piping systems and equipment must be considered. Safety precautions and facilities are designed and provided with the chlorine gas systems that include leak detection systems, alarms, chlorine gas scrubber and access/safety procedures. Chlorine gas systems require containment areas for both the gas cylinder storage and the chlorinator equipment rooms. Separate ventilation and access are required from the main operations area of the booster pump station.

EPA rule, 61 CFR 31668 (June 20, 1996) requires that any facility that stores certain quantities of specific gases must prepare an risk management plan (RMP). As listed in 40 CFR Part 68, the threshold quantity for chlorine is 2,500 lbs. Consequently, any facility that employs more than one ton container is required to submit an RMP to the EPA.

The Ten State Standards have set forth specific requirements for chlorine gas storage. A number of requirements are set forth for design and construction of containment areas for chlorine gas handling and storage. Key requirements include:

- Provide a shatter resistant inspection window installed in an interior wall
- Construct in such a manner that all opening between the chlorine room and the remainder of the plant are sealed
- Provide a door equipped with panic hardware, assuring ready means of exit and opening outward only to the building exterior
- Full and empty cylinders of chlorine gas should be isolated from operating areas, restrained in position to prevent upset, stored in rooms separate from ammonia storage, and stored in areas not in direct sunlight or exposed to excessive heat
- Each room shall have a ventilating fan with a capacity that provides one complete air change per minute when the room is occupied,
- Louvers for chlorine room air intake and exhaust shall facilitate airtight closure,
- Separate switches for the fan and lights shall be located outside of the chlorine room and at the inspection window. A signal light indicating fan operation shall be provided at each entrance when the fan can be controlled from more than one point.

Onsite Generation

Onsite generation produces a solution of hypochlorite that is used to disinfect water supplies with chlorine. Onsite generation is used widely today on small sources of supply, such as wells, to reduce the requirements for hazardous chlorine gas handling systems. There are several different types of onsite disinfectant generators available. Most involve applying electromagnetic energy (direct current electricity) to salt water, producing a dilute sodium hypochlorite solution (0.4 to 0.8 percent sodium hypochlorite solution). These dilute solutions are all below the concentration threshold for hazardous materials and are therefore, exempt from hazardous materials regulations.

For the purpose of this analysis, costs for the OSEC system (US Filter/Wallace & Tiernan) were utilized. The OSEC systems are modular and therefore have inherent redundancy in the system. For the NAWS Pretreatment Facility, Table 5 presents the criteria used to size the onsite generation equipment.

TABLE 5

SODIUM HYPOCHLORITE ONSITE GENERATION DESIGN CRITERIA

Description	Units	Criteria
Electrolytic Cell	No.	3
Capacity	lb/day	600
DC Rectifiers	No.	3
Bulk Solution Storage	days	4
No. of Tanks	-	2
Capacity, each	gals	20,000
Meter Pumps (one standby)	No.	3
Capacity, each	gph	100 to 300
Salt Consumption, average	lbs/day	1,200
Salt Storage	days	120
Capacity	tons	70
Peak Softened Water Supply	gpd	15,000
Average Softened Water Supply	gpd	6,000

System Configuration. The main bulk material for the generation of sodium hypochlorite is salt, which would be delivered by truck to the site and blown into a 70-ton silo. Once water is added, the saturated brine solution is stored in a specially designed tank. Softened water is required to make the saturated brine. The brine is fed to the electrolyzer where electricity is used to form and concentrate the sodium hypochlorite solution. The concentrated solution is stored in a day tank and then pumped to the intended injection point in the system.

Vendor quotes for the hypochlorite generation equipment (three package units) totaled about $630,000, including the salt storage silo and equipment. The total construction cost for the facility is approximately $1,482,000 including the building allocation, equipment installation, process piping and equipment and electrical/instrumentation work. Construction costs are presented in Table 6.

TABLE 6

ONSITE HYPOCHLORITE SYSTEM CONSTRUCTION COST ESTIMATE

Item	Cost
Building Allocation	$113,000
Mechanical Systems	
Hypochlorite Generators	350,000
Salt Storage/Brine Feed System	70,000
Hypochlorite Storage Tanks, Pumps, Piping	65,000
Piping, Valves, Misc. Equipment	85,000
Rectifiers	25,000
Water Softeners/Piping & Equipment	20,000
Control Cabinet	15,000
Equipment Installation	200,000
Injector Vault	20,000
Electrical/Instrumentation	150,000
Site Work/Yard Piping	10,000
Subtotal	**$1,123,000**
Construction Contingency at 20%	$224,600
Subtotal	**$1,347,600**
Mobilization/Demobilization at 10%	$134,760
TOTAL CONSTRUCTION COST	**$1,482,360**

Operation and Maintenance. The primary operating costs for onsite generation of hypochlorite is salt purchase, power and labor. The power consumption for onsite generations is approximately 2.5 kWh per pound of chlorine generated. On an annual basis, 144,000 lbs. of chlorine are required, resulting in a power cost of about $10,800. This is based on a power cost of $0.03/kwh. Approximately 252 tons of salt will be consumed per year. At $85/ton, this equates to a cost of about $21,400/year.

Maintenance labor includes a two-person crew that would be responsible for daily inspection of equipment at 0.5 hours, equipment maintenance at 8 hours/week and materials delivery estimated at five times per year. A total of about 860 hours are estimated for operation and maintenance of this facility. Other costs include hydrogen vent O&M, brine disposal from water softeners, maintenance parts and equipment, and miscellaneous power for lights, heating and ventilating, etc. The total estimated O&M costs are presented in Table 7.

TABLE 7

ONSITE GENERATION OPERATION AND MAINTENANCE COST ESTIMATE

Item	Annual Cost, $/yr.
Salt Consumption	$21,400
Power, C12 Generation	10,800
Labor (860 hrs at $30/hr)	25,800
Hydrogen Vent O&M	5,000
Brine Disposal	5,000
Maintenance Parts/Equipment	2,000
Power/HVAC	1,200
TOTAL O&M	**$71,200**

The stability of the sodium hypochlorite solution is a function of the initial hypochlorite concentration temperature of storage, length of storage, impurities present in the finished product and exposure to light. However, a 0.8% sodium hypochlorite solution is very stable with little off-gasing and deterioration. Therefore, storage of dilute hypochlorite solution would not present any O&M issues for the onsite generation option.

Safety and Handling Issues. Dilute hypochlorite solution (0.8%) is much safer to handle than chlorine gas or 12% hypochlorite solution. Safety requirements for gas systems would not be required for the onsite generation option, such as the gas scrubber, leak detection and alarm equipment.

However, sodium hypochlorite solutions may react violently with acids and organics. Also, hypochlorite solutions will react with ammonia to produce chloramines, and other compounds. Ammonia and chlorine must be separated at all times. The potential for hydrogen gas buildup in piping systems present a significant safety issue that must be addressed in the system design.

Spill containment would be required around the brine tank and the day tanks. There are very few safety risks in handling because of the dilute concentrations.

Liquid Sodium Hypochlorite Solution (12%)

Direct feed of liquid sodium hypochlorite solution is another option for chlorine disinfection of the NAWS water supply. Sodium hypochlorite may be imported at higher concentrations than what can be generated onsite. A standard and somewhat stable solution of 12 percent is readily available. This chlorine alternative requires less capital than the other two alternatives since only storage tanks and feed pumps are required. However, the cost of the solution is much higher than the other two alternatives. The degradation of sodium hypochlorite at concentrations above five- percent solution is an issue. A 12 percent solution will lose up to 25 percent of its strength within 20 days during the summer months. Several options are available to compensate for strength loss. These can include dilution of 12 percent solution to below five percent after delivery. This would require large tank volumes. Other options would include smaller, more frequent deliveries, air conditioning to keep the temperature in the storage room near 50°F, or over purchase of solution to compensate for strength loss. Air conditioning and frequent deliveries are assumed for this option.

The design criteria for liquid sodium hypochlorite feed facilities is presented in Table 8.

TABLE 8

LIQUID SODIUM HYPOCHLORITE (12%) SYSTEM DESIGN CRITERIA

Description	Units	Criteria
Hypochlorite Solution Strength	percent	12
Available Chlorine	lbs. Cl_2/gal	1.0
Dose Requirements		
Ultimate Peak Flow	gal/d	976
Design Peak Flow	gal/d	676
Average Flow	gal/d	394
Minimum Flow	gal/d	195
Metering Pumps (one standby)	No.	3
Pump Capacity, each	gal/d	100-500
Storage Tanks	No.	2
Tank Capacity, each	gallons	6,000
Total Days Storage	days	30

System Configuration. A 12% solution, sodium hypochlorite chemical feed system has the same components as the onsite generation system, minus the generation equipment. This approach basically consists of storage tanks and chemical feed pumps. Each tank will require containment barriers, fill piping and valves and level monitoring and positive hydrogen off-gasing blowers.

A summary of the estimated construction cost of a hypochlorite feed system is presented in Table 9. This alternative represents the least capital cost of the chlorine feed options, however, hypochlorite supply will be expensive.

TABLE 9

LIQUID HYPOCHLORITE SYSTEM CONSTRUCTION COST ESTIMATE

Item	Cost
Building Allocation	$90,000
Containment Walls and Access	15,000
HVAC in Storage Room	20,000
Mechanical Systems	
Hypochlorite Storage Tanks, Fill Piping	45,000
Meter Pumps, Piping and Valves	45,000
Misc. Equipment	40,000
Equipment Installation	90,000
Injector Vault	20,000
Electrical/Instrumentation	80,000
Site Work/yard Piping	10,000
Subtotal	**$455,000**
Construction Contingency at 20%	$91,000
Subtotal	**$546,000**
Mobilization/Demobilization at 10%	$54,600
TOTAL CONSTRUCITON COST	**$600,600**

Operation and Maintenance. Liquid hypochlorite solution was quoted at $1.18 per gallon delivered to the project site. At the average annual demand of 144,000 gallons, this equates to approximately $170,000. This does not include any adjustments resulting from the degradation of the strength over time as a result of heat and light. This cost alone exceeds the total annual cost of chlorine gas and onsite generation by a factor of 2.

Operation and maintenance labor was estimated at 450 hours per year and includes daily inspection of the operating equipment, receiving an estimated 40 deliveries per year of hypochlorite solution (4,000 gallons per delivery) and general maintenance of the facility. Also, increased HVAC costs were included to maintain cool temperatures in the hypochlorite storage area and in off-gas/vent maintenance. A summary of the annual O&M costs for this alternative is presented in Table 10. The total annual cost of this disinfection option is $197,000 per year.

TABLE 10

LIQUID HYPOCHLORITE SYSTEM OPERATION AND MAINTENANCE COST ESTIMATE

Item	Annual Cost, $/year
Hypochlorite (144,000 gal @ $1.18/gal)	$170,000
Labor (450 hrs @ $30/hr)	13,500
Hydrogen Vent O&M	5,000
Maintenance Parts/Equipment	5,000
Power/HVAC	3,500
TOTAL O&M	**$197,000**

Safety and Handling Issues. The same safety and handling issues outlined for the onsite generation alternative also apply to this alternative. However, a 12% solution has higher safety risks associated with it than does a 0.8% solution. Spill containment and separation of the hypochlorite and ammonia feed facilities are critical. Hydrogen gas buildup in piping potential requires special valves and fittings and significant safety protection procedures.

Chlorine Feed System Evaluation

Chlorine gas feed systems are widely used in the water treatment industry throughout the United States. However, since chlorine gas is a hazardous substance, special precautions, handling operations, and emergency equipment are required. With the provision of these emergency systems, chlorine gas is a viable option, although it is more hazardous than either an 0.8 percent onsite generation hypochlorite system vs. a 12 percent liquid hypochlorite feed system.

Based on capital construction costs, the 12 percent liquid hypochlorite feed system would have the lowest front end capital cost ($600,600), followed by the chlorine gas system at $864,600, and the onsite generation system at over $1.48 million.

From an annual O&M cost standpoint, however, the liquid hypochlorite system at approximately $197,000 per year is twice the cost of either chlorine gas ($68,000 per year) or onsite generation ($71,000 per year). These costs are shown in Table 11 in the form of an annual cost analysis. Annualized capital costs were calculated using a seven- percent rate of return over a 20-year period.

TABLE 11

ANNUAL COST EVALUATION OF CHLORINE FEED SYSTEMS

System Alternative	Capital Cost	Equivalent Annual Capital Cost	Annual O&M Cost	Total Annual Cost
Chlorine Gas System	$864,600	$81,600	$68,000	$149,600
Onsite Hypochlorite Generation	$1,482,360	$139,900	$71,200	$211,100
Liquid Hypochlorite System	$600,600	$56,700	$197,000	$253,700

Based on the annual life cycle costs, the chlorine gas system represents the lowest cost alternative. Since this alternative includes safety features for handling chlorine gas, it is rated equivalent to hypochlorite solution systems. However, it should be noted that the chlorine gas alternative will require preparation of a Risk Management Program with a one-time cost of about $20,000. This plan will require updating every five years.

Recommended Chlorine Feed System

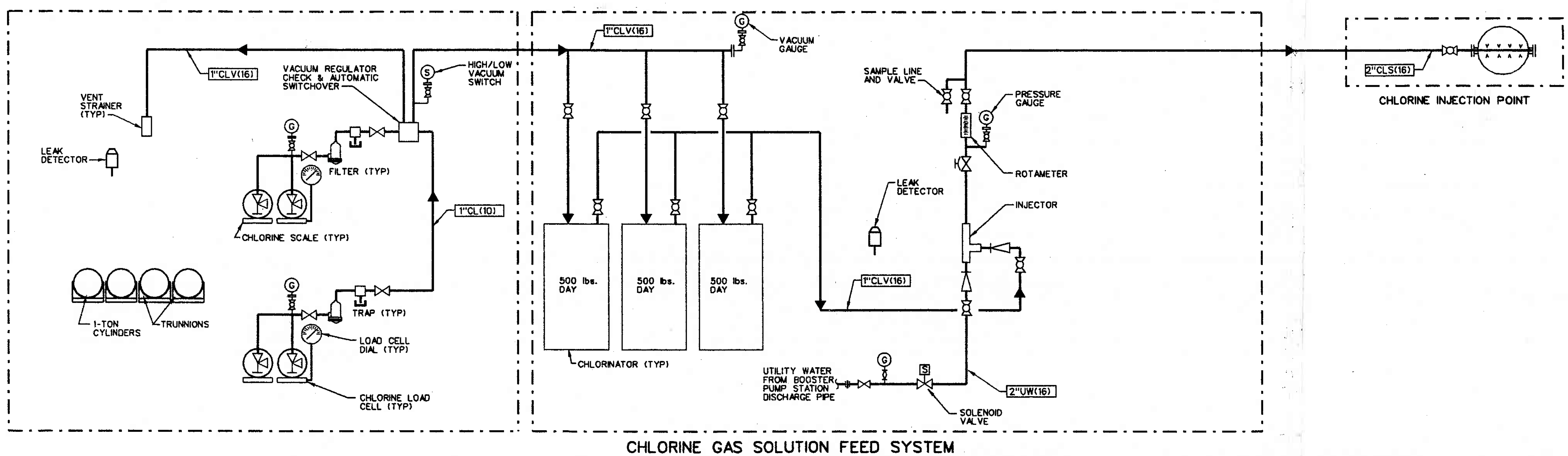
Based on the evaluation of costs, operation and maintenance requirements and safety and handling issues, the chlorine gas system is the recommended alternative for disinfecting the NAWS water supply. The cost of chemicals is the least expensive and the system is relatively easy to operate. A schematic of the recommended chlorine gas feed system is shown in Figure 1. This facility would be integrated into the Booster Pump Station building together with the ammonia feed facilities.

AMMONIA FEED SYSTEM EVALUATION

Ammonia will be fed to the chlorinated water at the Booster Pump Station after a minimum of five minutes of free chlorine contact time. The addition of ammonia to the chlorinated flows forms chloramines.

Three alternatives for ammonia feed systems were initially investigated. These included anhydrous ammonia (gas), aqueous ammonia (liquid) and ammonium sulfate (solid form). A summary and comparison of the handling, safety and special materials requirements for type of system is presented in Table 12.

Use of ammonium sulfate has been limited to small installations. Also, because of relatively high costs, difficult handling conditions and the requirements for significant solids handling equipment coupled with low support from equipment manufacturers to handle this material, this option will be dropped from further consideration. The analysis of ammonia feed systems will focus on anhydrous and aqueous ammonia facilities.



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Northwest Area Water Supply Project
Chlorine Gas Feed System Schematic
Figure 1

Ammonia will be fed to chlorinated water after the contactor in the ratio of 4:1 chlorine to ammonia. The feed will be based on the residual chlorine which is expected to range between 3.5 to 4 mg/l. The expected dosage of ammonia will therefore range between 0.875 to 1.0 mg/l. A 1.0-mg/l dose will be used to size the ammonia facilities.

TABLE 12

COMPARISON OF AMMONIA SUPPLY BY GAS, LIQUID AND SOLID

Item	Anhydrous Ammonia (Gas Form)	Aqueous Ammonia (Liquid Form) NH_4OH	Ammonium Sulfate (Solid Form) $(NH_4)_2SO_4$
Handling	Minimal Handling. Change over of cylinders.	Minimal Handling.	Makeup tank required. Handling of ammonium sulfate bags.
Safety	Ammonia gas is hazardous, especially by inhalation. It is also flammable. Must be kept separate from chlorine gas.	Storage premises need to be well ventilated and cool. Vapor risk. Solution weakly alkaline protection of skin and eyes required.	Lifting of bags, dust (use respirators and protective clothing). Solution acidic – protection of skin and eyes required.
Special Materials or Requirements	Softening of carrier water required. Heating required.	Avoid copper and copper zinc alloys. Design needs to take into account the risk of vapor locking. Potential spillage risks on delivery/transfer.	Epoxy lined, stainless steel, fiberglass or plastic tanks. Acid resistant diaphragm dosing pumps, plastic dosing lines. Powdered ammonium sulfate must be kept dry.

Anhydrous Ammonia Feed System

An anhydrous ammonia feed system is analogous to a chlorine gas feed system. Ammonia gas is withdrawn from 800-lb storage cylinders and routed to ammoniators (similar to chlorinators). A softened solution water feed is required to reduce scaling at the injection point. The following design criteria presented in Table 13 was used to size the anhydrous ammonia feed system:

TABLE 13

ANHYDROUS AMMONIA (GAS) FEED SYSTEM DESIGN CRITERIA

Description	Units	Value/Criteria
Ammonia Dose Rate	mg/l	1.0
Design Consumption		
Ultimate Peak Flow	lbs/d	217
Design Peak Flow	lbs/d	150
Average Day Flow	lbs/d	88
Minimum Flow	lbs/d	43
Annunciators (one standby)	No.	3
Type	-	V-notch
Capacity, each	lbs/d	150
Ammonia Storage	type	800 lb cylinders
Online	No.	1
Storage	No.	4
Days storage at average flow	days	36

The storage system consists of two scales with one cylinder on each scale. One cylinder is online and the other is in standby with an automatic switchover device. Three cylinders are on trunnions, for a total storage of four cylinders (including the standby).

System Configuration. Ammonia gas (NH3) will be supplied in 800-lb cylinders. The gas in the cylinder is liquefied since it is under pressure (at least 250 lb working pressure). Each cylinder is equipped with one liquid outlet and two vapor outlets, automatic shutoff valve, safety relief valves and vent line with a moisture trap. The cylinder storage system consists of two load cells and trunnions for storing three full cylinders and two empty slots. Dosing control is via an automatic regulator with the cylinders being capable of auto duty changeover.

Like chlorine, ammonia gas is dosed under vacuum using a solution-feed ammoniator, an injector and make-up water. Ammoniators are identical in design to chlorinators, except for minor differences in materials of construction. The ammoniators are located in a separate room. To supply the exact ratio of ammonia to chlorine, the ammoniators would be regulated by the measured chlorine residual valve.

The ammonia system also includes water softening for the carrier water. Injector water must be softened to below 30 mg/l as CaCO3. Calcium and magnesium hardness will form a precipitate that will plug the injector. Multiple injectors and diffusers are recommended so one can be removed and cleaned while continuously injecting ammonia.

Both the ammonia storage area and the ammoniator room are isolated from the rest of the Booster Pump Station facilities, and in particular, the chlorine facilities. Ammonia and chlorine will result in a violent reaction if allowed to mix in the stored concentrations.

The anhydrous ammonia feed system has an estimated construction cost of $567,600. This includes an allocation of building space which would have a separate ventilation system. A summary of the estimated construction costs are presented in Table 14.

TABLE 14

ANHYDROUS AMMONIA SYSTEM CONSTRUCTION COST ESTIMATE

Item	Cost
Building Allocation	$90,000
Loading Dock (50%)	10,000
Mechanical Systems	
Ammoniators	30,000
Trunnions, Scales, Overhead Hoist	45,000
Piping, Valves, Misc. Equipment	50,000
Equipment Installation	90,000
Water Softening System	15,000
Electrical/Instrumentation	100,000
Subtotal	**$430,000**
Construction Contingency at 20@	86,000
Subtotal	**$516,000**
Mobilization/Demobilization at 10%	51,600
TOTAL CONSTRUCITON COST	**$567,600**

Operation and Maintenance. Operation and maintenance of an anhydrous ammonia system is similar to the chlorine gas system. The largest annual cost will be the ammonia. Delivered in 800-lb cylinders, anhydrous ammonia will cost approximately $0.97/lb. At an average annual use of 32,120 lbs, this equates to about $31,200 per year.

Annual labor costs are based on about 420 hours of labor per year, assuming a two-person crew. This would include daily inspection, ammonia delivery, cylinder change-out and general maintenance.

General maintenance would include cleaning of the injectors/diffusers as a result of precipitation and buildup of calcium and manganese. The water softening system will reduce the level of buildup, but some maintenance is still expected. The water softening system will require brine and regeneration wastewater disposal.

A summary of the anticipated operation and maintenance costs are presented in Table 15.

TABLE 15

ANHYDROUS AMMONIA SYSTEM OPERATION AND MAINTENANCE ESTIMATE

Item	Annual Cost, $/yr
Ammonia	$31,200
Labor (420 hrs at $30/hr)	12,600
Maintenance Parts/Equipment	4,000
Water Softening Brine Disposal	5,000
Power/HVAC	1,000
TOTAL O&M	**$53,800**

Safety and Handling. Ammonia is a colorless gas with a very pungent, irritating odor. Ammonia is highly soluble in water and will create a white fog when released to the atmosphere. Ammonia gas is lighter than air; so leaking vapor will rise.

A dedicated, specially designed room/building is required. Ammonia is toxic by inhalation, may cause chemical burns to the skin and may react violently with acids and with oxidants such as chlorine gas. For this reason, the ammonia system is contained in separate rooms with separate ventilation systems.

Aqueous Ammonia Feed System NH_4OH

Aqueous ammonia is a clear colorless liquid consisting of 29.4 percent ammonia in water. Aqueous ammonia feed systems are used by many water utilities as the preferenced method of ammonia addition to form chloramines. Aqueous ammonia systems are simple to operate and maintain, and have the ability to meter and pump solution from bulk storage directly into the flow stream. Sizing of the bulk storage tank will depend on the period of storage required and the delivery tanker capacity. Delivery can be made by 4000-gallon trucks, 375 and 750-gallon carboys or 30-gallon drums.

The design criteria for aqueous ammonia feed system is presented in Table 16.

System Configuration. The aqueous ammonia feed system consists of a liquid ammonia storage tank, meter pumps, piping and injection diffusers into the pipeline. A single 6,000-gallon storage tank is provided. A standard delivery tank truck has a volume of 4,000 gallons. Once the tank volume falls below 2,000 gallons, an order for delivery of aqueous ammonia will be made. The 6,000-gallon tank is more than adequate to provide a minimum 30-day stored supply (1,200 gallons) before re-ordering the next 4,000-gallon delivery. Redundancy in the storage tank is not viewed as an issue. Should the tank need repair, 350 lb or 750 lb carboys could be brought in and plumbed into the metering pumps. Space is provided for delivery of carboys or drums.

TABLE 16

AQUEOUS AMMONIA (LIQUID) FEED SYSTEM DESIGN CRITERIA

Description	Units	Valve/Criteria
Ammonia Dose Rate	mg/l	1.0
Available Ammonia	lbs/gal	2.2
Design Consumption		
Ultimate Peak Flow	gal/hr	4.1
Design Peak Flow	gal/hr	2.8
Average Day Flow	gal/hr	1.7
Minimum Flow	gal/hr	0.8
No. of Meter Pumps (1 standby)	no.	2
Meter Pump Capacity, range	gal/hr	0.5 to 5
Storage Tanks	no.	1
Capacity	gal	6,000
Days Storage at Average Flow		
Full (6,000 gpm)	days	150
At 1,500 gallons (pre-delivery)	days	38

The storage tank will be provided with a barrier to contain spills or leaks from the storage tanks or piping.

The ammonia feed system consists of chemical feed pumps which deliver metered ammonia solution directly to the injection diffusers. No make-up or carrier water is required. Two injector/diffusers will be provided to permit cleaning of one unit while the other is in operation.

An HVAC system will be provided to keep the temperature in the liquid ammonia storage area cool. This will reduce potential off-gasing, pressure build-up and ammonia vapor production.

The aqueous ammonia feed system has an estimated construction cost of $440,900. The construction costs of the various system components are presented in Table 17.

Operation and Maintenance. The cost of aqueous ammonia is inexpensive and is readily available. At about 2.2 lbs ammonia per gallon of 29.4 percent solution, the annual consumption of ammonia liquid will be approximately 14,600 gallons. At a quoted delivery price of $1.08/gallon, the annual chemical cost is about $15,800.

Labor requirements were estimated at 410 hours per year. This includes daily inspection of the system, handling four aqueous ammonia deliveries each year, general equipment maintenance at four hours per month and injection/diffuser cleaning at four hours per month.

TABLE 17

AQUEOUS AMMONIA FEED SYSTEM CONSTRUCITON COST ESTIMATE

Item	Cost
Building Allocation	$76,000
Loading Dock (50%)	10,000
Containment Walls and Access	5,000
HVAC in Storage Room	10,000
Mechanical Systems	
Ammonia Storage Tank, Fill Piping	33,000
Meter Pumps, Piping and Valves	25,000
Misc. Equipment, Diffusers	20,000
Equipment Installation	75,000
Electrical/Instrumentation	80,000
Subtotal	$334,000
Construction Contingency at 20%	$66,800
Subtotal	$400,800
Mobilization/Demobilization at 10%	$40,080
TOTAL CONSTRUCTION COST	**$440,880**

Other annual costs include chemicals for cleaning the injector/diffuser, general maintenance parts and equipment and power/HVAC costs. A summary of the Operation and Maintenance costs are presented in Table 18.

TABLE 18

AQUEOUS AMMONIA OPERATION AND MAINTENANCE COST ESTIMATE

Item	Cost
Aqueous Ammonia (14,600 gal at $1.08/gal)	$15,800
Labor (410 hrs at $30/hr)	12,300
Injector/Diffuser Cleaning Chemicals	500
Maintenance Parts/Equipment	4,000
Power/HVAC	3,000
TOTAL O&M	**$35,600**

Safety and Handling. Aqueous ammonia is much safer to handle than ammonia gas. However, the solution is weakly alkaline. Contact with chlorine or hypochlorites must be avoided due to the explosion hazard. Rubber or PVC gloves, boots and apron and gas tight goggles should be worn when handling. Suitable gas masks, eyebath and safety shower should be readily accessible. There is a risk to operators of ammonia vapor and this vapor is flammable.

Steps must be taken to insure that ammonia hydroxide does not come into contact with sodium hypochlorite. Signs or placards should be posted at the tank fill locations to insure that aqueous ammonia is not pumped into sodium hypochlorite tanks and vice versa.

Ammonia Feed System Evaluation

Two alternative ammonia feed systems are considered for the NAWS project. These include the anhydrous ammonia (gas) and the aqueous ammonia feed systems. From a cost standpoint the aqueous ammonia feed system is less expensive than the anhydrous ammonia system in both capital and annual costs. These costs are summarized below in Table 19.

TABLE 19

COST COMPARISON OF AMMONIA FEED SYSTEMS

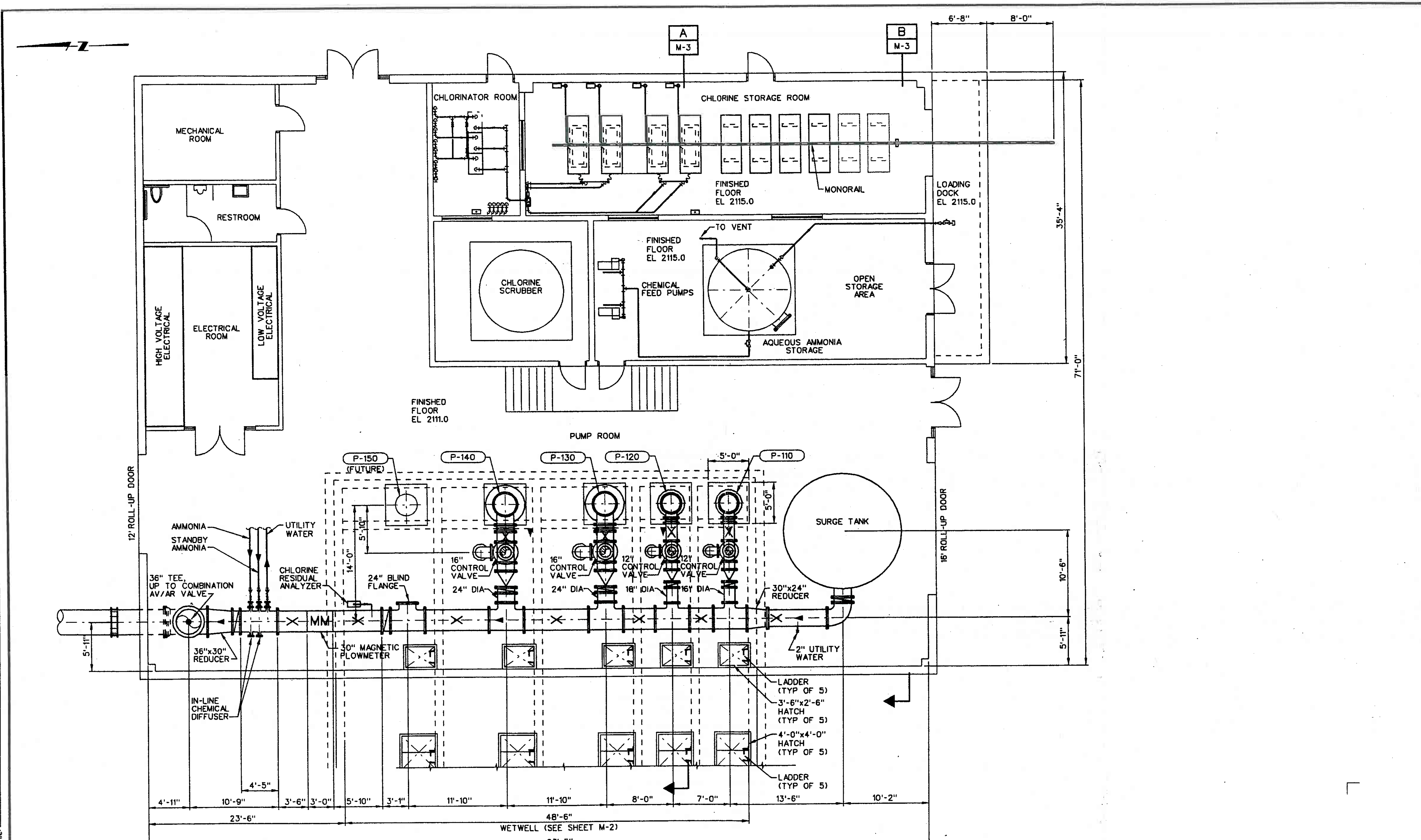
Alternative	Construction Cost	Annual Cost, $/yr
Anhydrous Ammonia (gas)	$567,600	$53,800
Aqueous Ammonia (liquid)	440,900	35,600

The aqueous ammonia is easier to operate and control, is least expensive and is considered safer than an ammonia gas feed system. Therefore, the aqueous ammonia feed system is recommended for use with the chlorine gas feed system to form chloramines in the pretreated water supply. Figure 2 presents a schematic layout of the aqueous ammonia feed system.

RECOMMENDED CHEMCIAL FEED SYSTEM LAYOUT

The recommended chemical feed systems include chlorine gas and aqueous ammonia. These chemical feed systems will be constructed as an integral part of the Booster Pump Station facility. A layout of these systems relative to the Booster Pump Station building is shown in Drawing M-1. Both the chlorine and the ammonia facilities will be constructed on an elevated floor with a loading dock.

Access to the chlorine facilities will be from the exterior of the building. Access to the ammonia facilities and the chlorine scrubber will be from the interior of the building. All chemical feed areas will be isolated in individual rooms, with individual heating and ventilation systems.



PLAN

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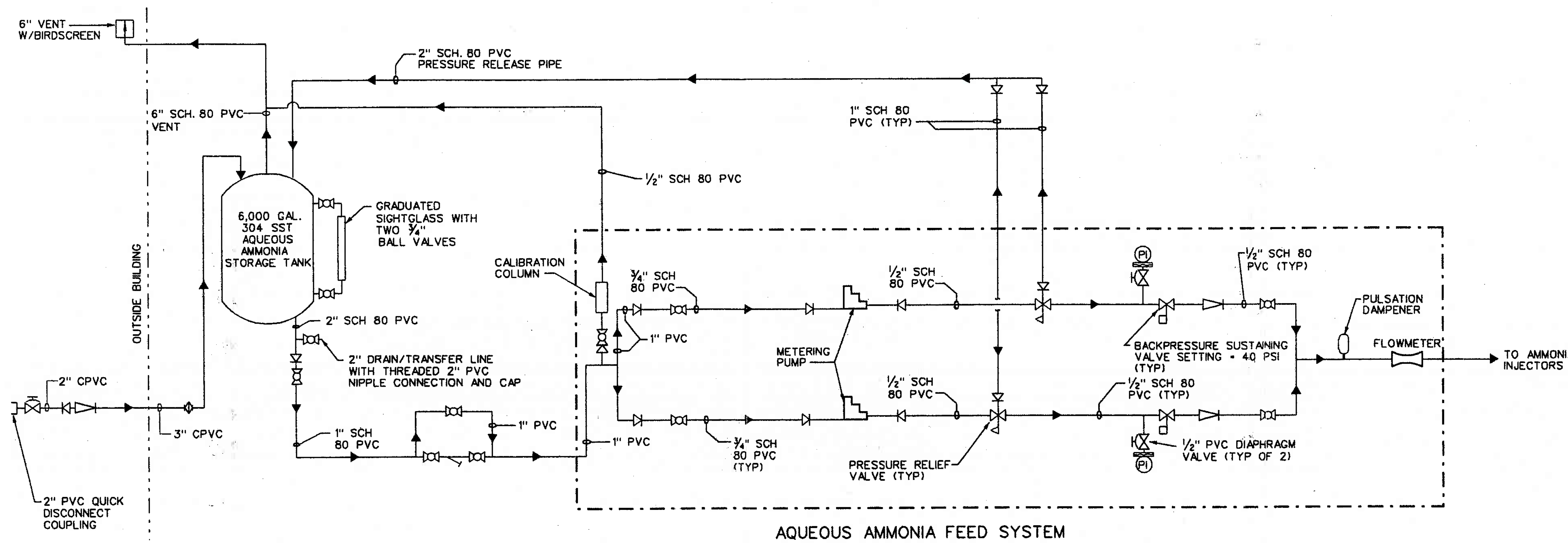
DESIGNED P. NAYLOR

DRAWN P. HUNTER

CONTRACT 4-1A

NORTHWEST AREA WATER SUPPLY PROJECT
BOOSTER PUMP STATION/PRETREATMENT FACILITY

SHEET BPS/PTE M-1



Northwest Area Water Supply Project
Aqueous Ammonia Feed System Schematic
Figure 2

DISINFECTION CONTACTOR EVALUATION

Two alternative chlorine contactor systems were evaluated to achieve the design five-minute free chlorine contact time. One of these options included the use of the pipeline on the discharge side of the pump station. This alternative was adapted from the intake pump station contactor concept. The second option involves use of the booster pump station influent wet well. A description of each of these alternatives is presented in the following sections.

Pipeline Contactor

Utilization of the discharge piping system from the booster pump station (up to 150 psi) will require a multi-pipe contactor system with control valves to achieve a minimum five minute contact time and not exceeding a ten minute contact time. The multi-pipe system represents an optimization of the number of pipes, size, length and configuration over the expected range of project flows. The range of flows was specifically keyed to pump selection and combinations of operation. Four 48-inch diameter pipes, approximately 240 feet long will be required. Motor operated valves will be used to select the number of pipes in operation depending on the flow rate. The system will include vaults for the ammonia injectors and chlorine residual analyzer, the motor operated valves, and flow meters for each pipe. A layout of the pipeline disinfection contactor is presented in Figure 3.

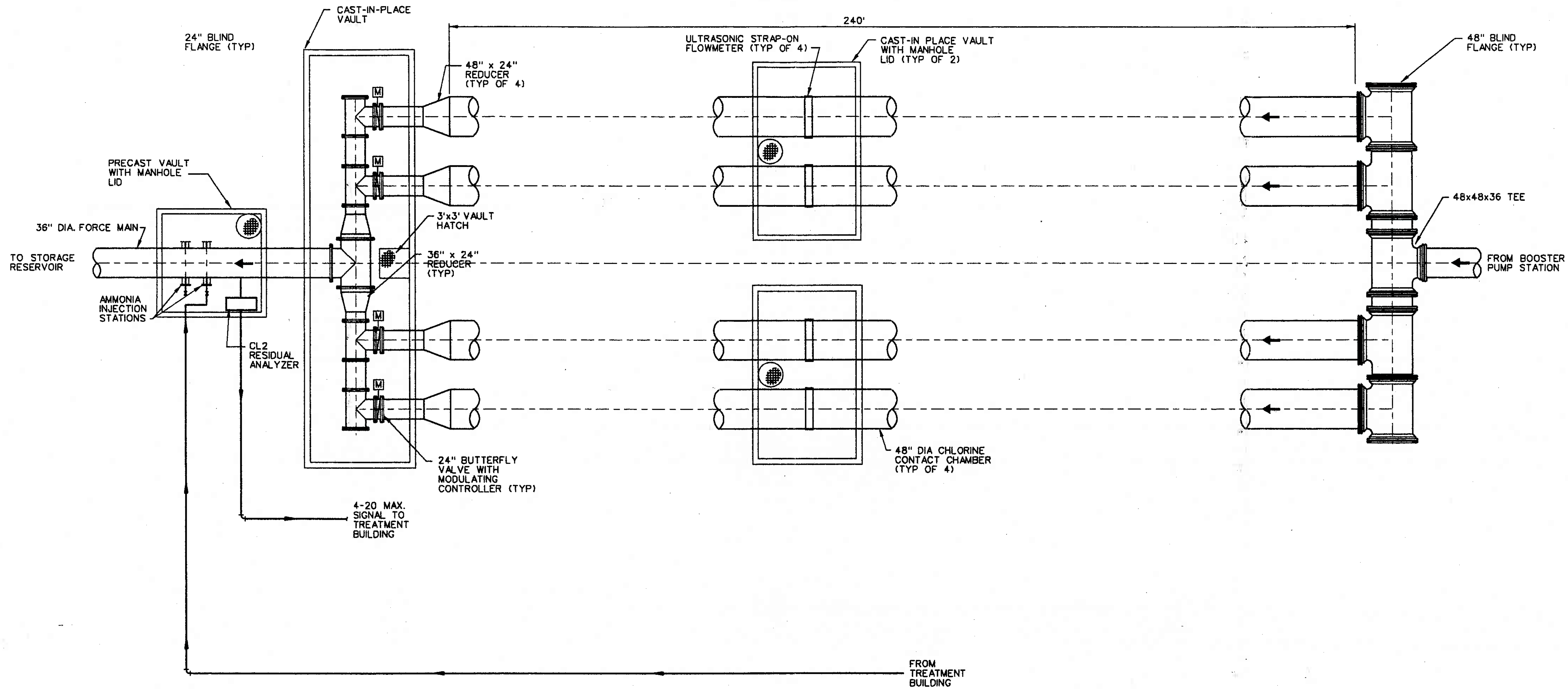
The flow meters are provided to regulate the motor operated valves such that flows in the operating contactor pipes are distributed equally.

Operation of this contactor will require both ammonia and chlorine be pumped into the discharge side of the booster pumps. Discharge pressures will range up to 150 psi. However, use of the pipeline contactor will limit the pipeline pressure to 150 psi or less. Higher pressure will result in significant cost increases in pressure class valves and fittings. Chlorine will be dosed at constant 4.5 mg/l. The minimum free chlorine contact time is five minutes. However, based on the combination of pipes in use corresponding to the pumped flow, contact times up to ten minutes will be experienced at some flow combinations.

An estimate of construction costs for the pipeline contactor alternative is presented in Table 20.

Booster Pump Wet Well Contactor

This alternative modifies and reconfigures the wet well to the Booster Pump Station to also serve as the chlorine contact chamber. This modification results in the wet well volume being channelized for each individual pump. The operating volume and dimensions are designed to provide a minimum five minute contact time at each pumps maximum flow rate. The maximum flow rate of each pump is determined assuming that only that specific pump is in operation. For example, if a 9-mgd pump is operating, then that pump will only see dynamic friction loss at 9 mgd in the pipeline to the reservoir.



PIPELINE DISINFECTION CONTACTOR

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MWH MONTGOMERY WATSON HARZA

NAWS Pretreatment Facilities

Figure 3

TABLE 20

PIPELINE CHLORINE CONTACTOR CONSTRUCTION COST ESTIMATE

Item	Quantity	Units	Unit Cost	Cost
Excavation	6,500	CY	$3.50	$22,750
Bedding	200	CY	15.00	3,000
Pipe Zone Backfill	2,000	CY	13.00	26,000
General Backfill	3,900	CY	4.00	15,600
48" Pipe (Restrained Joint)	960	LF	195.00	187,200
Pipe Fittings, Misc.	1	LS	80,000.00	80,000
Motor Operated Valves – 24" (Mod)	4	Ea.	8,000.00	32,000
48" Ultrasonic Flow Meters	4	Ea.	10,000.00	40,000
Meter Vaults	2	Ea.	14,500.00	29,000
Valve Vaults	1	Ea.	35,000.00	35,000
Misc. Metals	1	LS	12,000.00	12,000
Electrical/Instrumentation	1	LS	50,000.00	50,000
Subtotal				**$532,550**
Construction Contingency at 20%				106,510
Subtotal				**$639,906**
Mobilization/Demobilization at 10%				63,906
TOTAL CONSTRUCTION COST				**$702,966**

As more pumps come online, the friction loss increases and the individual pump rate decreases. Therefore, the contact time in each wet well chamber to any specific pump will increase. The system is designed to not exceed a ten-minute contact time. However, one feature in this contactor configuration is the ability to adjust water levels to adjust contact time. For example, at a specific flow rate and water surface elevation, a contact time of 7.1 minutes is realized. By lowing the water surface elevation in the contactor by 1.6 feet, without changing the flow rate, reduces the contact time to the five-minute design criteria. This provides added flexibility for contact time/disinfection operation without the need to adjust chemical dose rates (e.g., constant dose criteria of 4.5 mg/l).

The configuration of the contactor includes separate raw water feed pipes from the influent pipeline to each pump/chamber facility. A motor operated isolation valve opens on a pump start. The flow enters the chamber and passes through a redwood baffle to equally distribute the flow over the chamber section area. This improves the plug flow regime. The floor of the contact chambers/wet wells are sloped to a center trench to provide an area to accumulate settleable solids and clean the chambers. The booster pumps will dewater the chamber to within one to two feet of the bottom. Submersible pumps will then be used to pump the remaining volume during cleaning operations.

The chambers are also connected to 6-inch valves in the chamber walls to equalize the operating water surface in the system. Since the operation of the intake pump station will be based on the level of the wet well, this reduces the need for multiple level sensors and instrumentation. Operation of the contactor will not impact the wet well booster pump operation.

Chlorine will be injected in a vault just upstream of the contactor in the 36-inch raw water pipeline.

The total construction cost of the wet well/contactor is estimated at $638,500, and is summarized in Table 21. Since the facility serves a dual purpose, wet well for the pumps and contactor for the disinfection system approximately half of the construction cost, about $319,250, is assigned to each function.

TABLE 21

WET WELL CHLORINE CONTACTOR CONSTRUCTION COST ESTIMATE

Item	Quantity	Units	Unit Cost	Cost
Excavation	3,500	CY	$3.50	$12,250
Structural Bedding	160	CY	15.00	2,400
Concrete	625	CY	370.00	231,250
General Backfill	1,125	CY	4.00	4,500
Overflow Structural Concrete, Valves	1	LS	8,800.00	8,000
Pipe Fittings, Misc.	1	LS	55,000.00	55,000
Motor Operated Valves – 24"	3	Ea.	6,000.00	18,000
Motor Operated Valves – 16"	2	Ea.	4,500.00	9,000
24" BF Valve	3	Ea.	3,000.00	9,000
16" BF Valve	2	Ea.	2,500.00	5,000
Redwood Baffles	420	SF	25.00	10,500
6" BF w/Operators	5	Ea.	1,600.00	8,000
Valve Vault	1	Ea.	40,000.00	40,000
Misc. Metals, Hatches & Ladders	1	LS	20,000.00	20,000
Electrical/Instrumentation	1	LS	50,000.00	50,000
Subtotal				**$483,700**
Construction Contingency at 20%				96,740
Subtotal				**$580,440**
Mobilization/Demobilization at 10%				58,044
TOTAL CONSTRUCTION COST				**$638,484**

Chlorine Contactor Recommendations

Based on operational considerations, the use of the wet well of the booster pump station is the recommended alternative to achieve the free chlorine contact time of five minutes. The wet well contactor provides a higher degree of operational control of the contact time over the range of flow rates that the pump station will handle, and will permit relatively precise adjustments to the contact time by adjusting water surface elevations without impacting pump operations or chemical dosing.

The wet well/contactor is also a cost-effective use of single facility. At a cost allocation of $319,000 for the chlorine contact function of the structure, this alternative is more than one-half the cost of the pressurized pipe contactor, estimated at approximately $703,000.

A layout of the wet well/chlorine contactor structure is presented in Drawing M-2. A section view of the contractor is shown in Drawing M-3, together with the booster pump station and chemical feed systems.

PRETREATMENT SYSTEM CONTROL

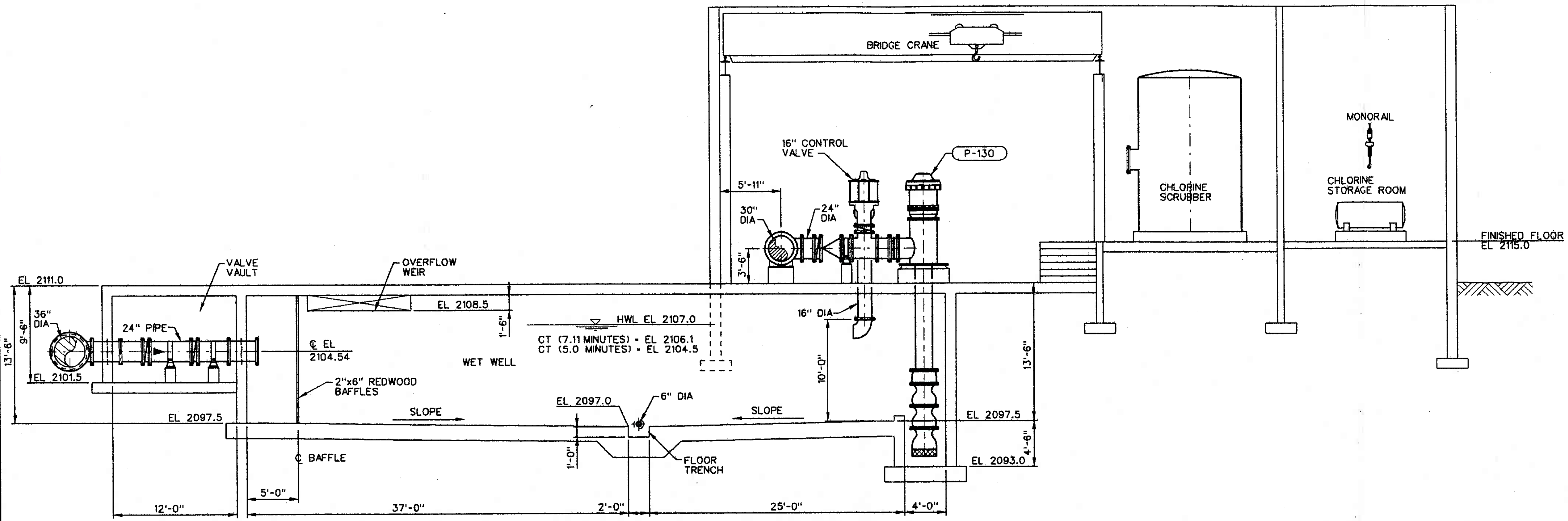
The Booster Pump Station/Pretreatment Facilities Program Logic Controller (PLC) will provide the control to the Pretreatment System Chemical Feed Systems and associated monitoring and alarming devices. A Human Machine Interface (HMI) will be used for local (at the facility) control and input of operational setpoints to the PLC. The PLC will communicate with the system wide Supervisory Control And Data Acquisition (SCADA) system via a telemetry system for remote operations, control and alarming of the Pretreatment System. The following paragraphs describe the Normal, Emergency and Fail-Safe operation of this system. The operation and control description of both the chlorine and ammonia feed systems are combined within each operation scenario because they function as interrelated systems.

Normal Operation

Normal operation of the Pretreatment System starts with operator input of the desired chlorine dosage (normal 4.5 mg/l), and chlorine to ammonia feed ratio (normal, 4:1). These values may be remotely input to the PLC through the system wide SCADA system or locally through the HMI. Chlorinator feed rate, in pounds per day, is then "flow paced" controlled based on the pump station discharge flow rate. "Flow paced" control is based on the fact that chemical feed rate is directly proportional to the discharge flow rate times the operator input dosage.

The ammonia dosage (mg/l) is proportionally controlled to the operator input chlorine to ammonia ratio based on the free chlorine residual value (mg/l) measured by a free chlorine residual analyzer. The ammonia feed rate, gallons per hour (gph), is then "flow paced" based on the pump station discharge flow rate. The free chlorine residual analyzer is located on the pump station discharge header, upstream from the ammonia injection point.

The free chlorine residual analyzed value is not used for "feedback" control or trim of the chlorine feed rate; but it is used for reporting and alarming. The NAWS Project Chloramine



SECTION A
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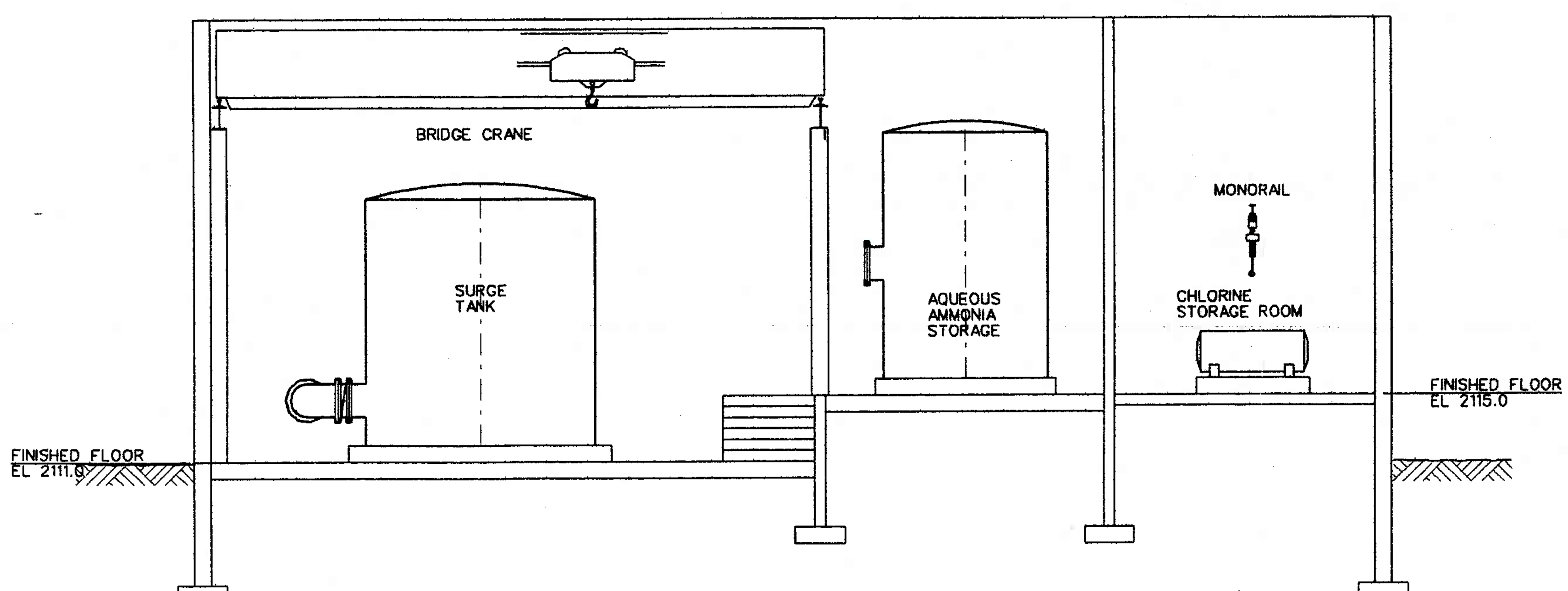

SECTION B
SCALE: 3/16" - 1'-0" M-1

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CONTRACT 4-1A	NORTHWEST AREA WATER SUPPLY PROJECT BOOSTER PUMP STATION/PRETREATMENT FACILITY SECTIONS	SHEET BPS/PTE M-3		

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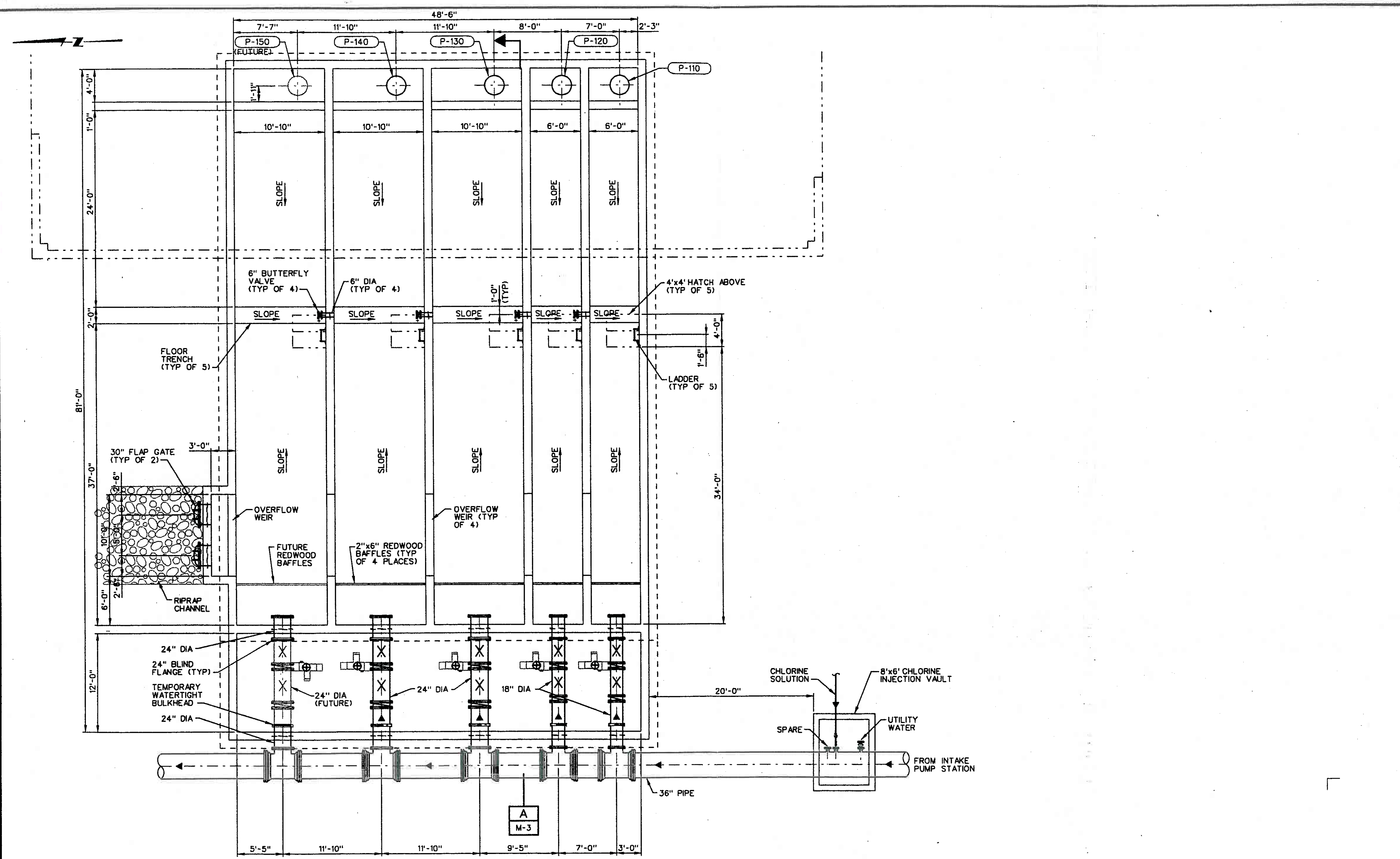

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NORTHWEST AREA WATER SUPPLY

CONTRACT 4-1A

NORTHWEST AREA WATER SUPPLY PROJECT
BOOSTER PUMP STATION/PRETREATMENT FACILITY
WET WELL PLAN

SHEET BPS/PTE M-2

Challenge Study Final Report – December 1995 verified that a chlorine feed dosage of 4.5 mg/l (recommended input dosage), with a 5 minute detention time, followed by ammonia addition to form chloramines, achieved greater than 3-log *Giardia* inactivation in less than 180 minutes. The Normal Operation control plan directly follows the guidance of the Chloramine Challenge Study.

An on-line automatic ammonia concentration analyzer has not been included in the design of the control scheme. Automatic on-line ammonia concentration analyzers have not proven to be effective to date. The accuracy and repeatability has been problematic which causes upsets in true chloramine dosage. Periodic manual sampling and testing, using an ammonia test kit, is the recommended technique for chloramine concentration verification and optimization. The ammonia feed system will have a flow meter to verify that ammonia is being injected into the pump station discharge header. This flow meter value will be used for trending and alarming function only.

Emergency Operation

Emergency operation of the Pretreatment System consists of automatic shutdown of the chemical feed systems based upon loss of SCADA/telemetry, loss of facility power, loss of facility PLC, a chlorine leak or an ammonia leak. Anyone of these conditions will force automatic shutdown of the booster pumps and the chemical feed systems. The chlorine scrubber is an emergency device that is activated by chlorine leak detectors located in the chlorine storage and chlorinator rooms. However, the chlorine scrubber will not operate if there is a loss of primary power to the Booster Pump Station facility. The possibility of a simultaneous chlorine leak and loss of primary power is considered to be extremely remote, in and of itself, to justify the need for standby power generation.

All major systems and devices such as pumps, valves and chemical feed systems will be provided with local on/off control at each device. This local control will allow operators to locally control them during maintenance and emergency conditions.

Fail-Safe Operation

Fail-Safe Operation is based on the requirement that no raw water which has not received pretreatment will be pumped to the Hudson Bay drainage basin. To prevent the possibility of this occurrence, the booster pumps must be shutdown if chlorine feed is lost to the injection point. The chlorine residual analyzer provides the primary fail-safe operation by measuring chlorine residual. A minimum chlorine residual setpoint (2.4 to 3.0 mg/l) will automatically shutdown the Booster Pump Station and the Pretreatment Facility. The chlorinators and chlorine solution transport water solenoids will each have contacts that will be used to prove chlorine feed. The ammonia feed system will have a flow meter to prove aqueous ammonia feed to the injection point. The aqueous ammonia chemical metering pumps will have on/off contacts that will also be used to prove ammonia feed. Failure of one of these contacts or conditions will shutdown the chemical feed system and the pump station and send alarms to the SCADA network.