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FEASIBILITY OF RECYCLING LAUNDRY WASTEWATERS AT MILITARY QUARTERMASTER LAUNDRIES

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Final Report

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An economic analysis of recycling Army installation laundry wastewater is detailed. Usage, costs, designs, comparisons and assumptions are presented in detail with explanatory narrative. The findings are that the cost for treatment to renovate laundry wastewater to a quality to permit its reuse is not cost effective under present conditions.

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FEASIBILITY OF RECYCLING LAUNDRY WASTEWATERS
AT
MILITARY QUARTERMASTER LAUNDRIES

1.0 INTRODUCTION

1.1 Subject.

The purpose of this study was to determine the economic practicality of reclaiming quartermaster laundry wastes at major installations for recycle.

1.2 Scope.

Using literature data from previous studies in recycling and treating laundry wastewaters, a tentative design for a recycling process will be made. Capital investment, and operating costs of the design will be compared against current water and sewage treatment rates at major installations using a breakeven analysis. The practicality of recycling laundry wastes will be discussed.

1.3 Background and Previous Investigation.

Laundry water waste extraction has been extensively looked at for a number of years. The basic concern in laundry waste treatment has been removal of laundry detergents and phosphates. Prior to 1965 the most common synthetic detergent used in laundry soaps was alklbenzenesulfonate, or ABS. ABS and its complexes were only biologically oxidated over an extended period of time. Consequently synthetic detergent build-up in certain highly populated areas became a serious problem. Concentrations higher than 12 mg/l imparted to the water disagreeable tastes, odors, and high turbidities. Chemical and physical methods of extracting the synthetic detergents from the laundry waters were investigated. Chemical treatment investigations included coagulation by aluminum sulfate, activated powdered carbon with a polyelectrolyte and combination of the two. Physical methods of removal were conducted using induced air flotation. A summary of the data obtained and flow diagrams for the processes are shown in Tables 1-1 to 1-5 and Figures 1-1 to 1-3.

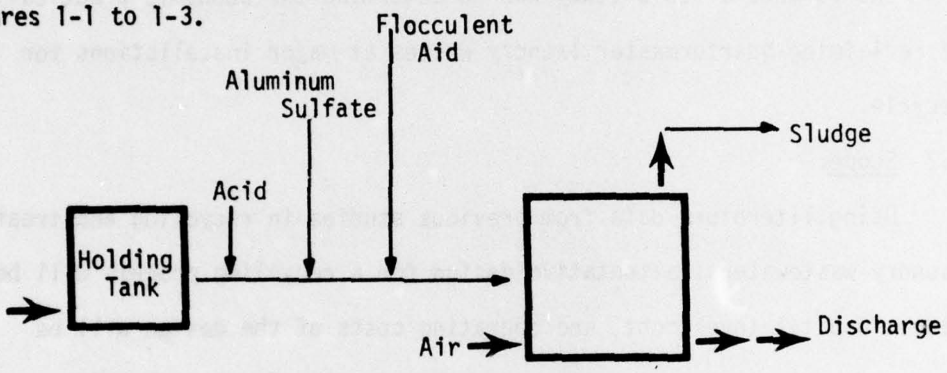


Figure 1-1.

Flow Diagram for Air Flotation.[1]

Table 1-1.

Operating Results from Flotation Process.[2]

	Influent	Effluent	Percent Removal
Ph	8.96*	5.06	--
ABS (mg/lit)	58.2	35.8	38
Suspended solids (mg/lit)	167	111	33
Dissolved solids (mg/lit)	1044	1380	--
COD (mg/lit)	591	374	37
Phosphates (mg/lit)	123	39.2	68

*Eleven (11) samples taken from pilot plant having 8,000 to 10,000 gpd flow rate. Family laundry comprised majority of wash.

Chemical dosages for air flotation were 200 mg/lit of sulphuric acid, 400 mg/lit of aluminum sulfate, 50 mg/lit soda ash and 25 mg/lit of tallow. The detention period within the flotation chamber was approximately nine minutes. Extraction of laundry wastes by air flotation was unacceptable. As seen in Table 1-1 the percent removal of wastes was generally poor. Other major problems associated with the procedure were erratic waste removal and the high percentage of water retention in the sludge.

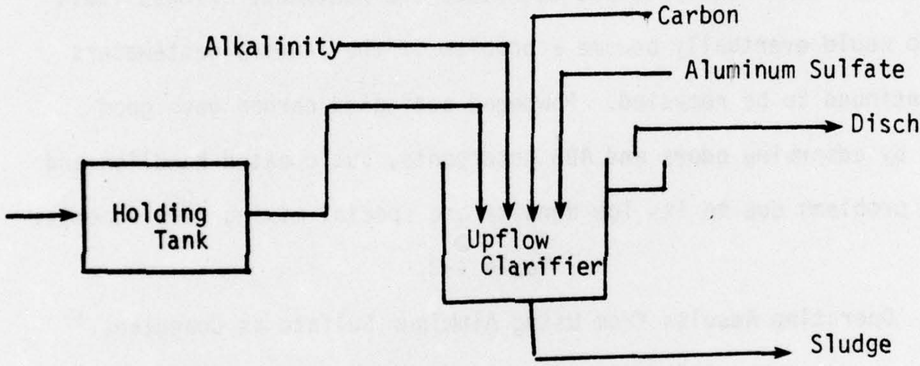


Figure 1-2.

Flow Diagram Using Aluminum Sulfate and Powdered Activated Carbon as the Coagulant.[3]

Table 1-2.

Operating Results from Using Aluminum Sulfate & Powdered Carbon as Coagulants.[4]

	Influent	Effluent	Percent Removal
Ph	7.62	9.0	--
ABS (mg/lit)	31.8	14	56
Suspended solids (mg/lit)	216	12	94
Dissolved solids (mg/lit)	669	1109	--
COD (mg/lit)	403.2	140	65
Phosphates (mg/lit)	190	4	98

Upflow clarification using aluminum sulfate as a coagulant and powdered activated carbon for adsorption and coagulation provided better results than air flotation. Chemical dosages for aluminum sulfate and powdered carbon varied between 560 mg/lit and 750 mg/lit. Tallow, as a flocculent aid was used in trace amounts. Problems occurred in the upflow clarifier operation due to the temperature fluctuations in the entering laundry wastewaters. Temperature gradients within the clarifier from the cyclic nature of the washers decreased the settleability of the floc, increased the detention time required, and decreased the wastewater flows. Salt build-up would eventually become a problem if the laundry wastewaters were continued to be recycled. Powdered activated carbon gave good results by adsorbing odors and ABS detergents, but created handling and feeding problems due to its low density and special mixing requirements.

Table 1-3.

Operating Results from Using Aluminum Sulfate as Coagulant.[5]

	Influent	Effluent	Percent Removal
Ph	11	5.4	--
Volatile suspended solids (mg/lit)	1170	190	83.8
Suspended solids	860	160	83.4
Total solids	1940	1130	--
COD	2496	292	88.6
Phosphates	4.42	.3	93.2

Similar results seen in Table 1-3 were determined using a high chemical dosage of aluminum sulfate versus aluminum sulfate and powdered carbon. Approximate chemical dosage of aluminum sulfate was 1000 mg/lit followed by a two hour detention period. The major drawbacks to using aluminum sulfate alone were the increased rate of salt build-up within the wastewater recycling process, and heat gradients affecting the settability of the floc within the clarifier.

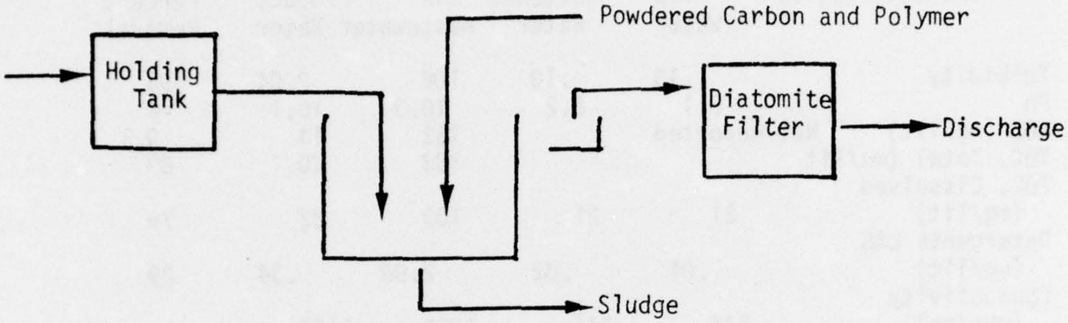


Figure 1-3.

Flow Diagram for Wastewater Treatment Using Powdered Activated Carbon A Polyelectrolyte as the Coagulant and Diatomaceous Earth for Filtration.

Sanitary Sciences Division of MERADCOM used the standard military water purification unit (ERDLATOR) to reclaim laundry wastewater.[6] The process initially used an upflow clarifier followed by filtration through a diatomaceous earth pressure filter. Coagulation was produced by powdered activated carbon and a cationic polyelectrolyte. The powdered carbon dosage was 1000 mg/lit with trace solutions of the polymer.

Table 1-4.

Operating From Coagulation of Wastewater
By Powdered Carbon and a Polyelectrolyte.

Characteristics*	Tap Water	Softened Water	Raw Wastewater	Product Water	Percent Removal
Turbidity	.13	.10	106	2.04	98
Ph	8.1	8.2	10.3	10.1	--
BOD (mg/lit)	Not Reported		152	14	9.1
TOC, Total (mg/lit			183	20	89
TOC, Dissolved (mg/lit)	21	21	103	22	79
Detergents LAS (mg/lit)	.04	.02	2.98	.34	89
Conductivity (mho/cm)	234	234	1024	1177	--
Suspended solids (mg/lit)	3	3	116	9	97
Hexane Solubles (mg/lit)	0.0	0.0	52	18	65
Hardness as $CaCO_3$ (mg/lit)	102	4	Not Reported		--

*Fifty-four (54) samples taken over a 5 month period.

As seen in Table 4 the percent removal from raw wastewater using powdered carbon was similar to previous methods discussed. Use of powdered carbon instead of aluminum sulfate had some advantages. Coagulation by powdered carbon did not form the large flocculant particles alum formed. Consequently powdered carbon was not affected as much by heat fluctuations of the water. Faster flowrates for similiar sized equipment could be used with powdered carbon as the coagulant. The detention time for powdered carbon was twenty minutes versus two hours for aluminum sulfate. The use of powdered carbon resulted in handling and feeding problems. Powdered carbon was unable to extract phosphates from the wastewater.

The problem of extracting phosphates and other salts was partially solved by Sanitary Sciences Division using reverse osmosis after filtration by diatomaceous earth. Table 1-5 is a summary of the results.

Table 1-5.

Summary of Wastewater Characteristics Using Reverse Osmosis, Coagulation, and Diatomaceous Earth Filtration

	Equalization Tank		Product Tank		RO Product Tank	
Characteristics	Average	Range	Average	Range	Average	Range
Turbidity, JTU	25.6	.5-55	1.5	.2-4.8	.2	.07-.6
pH	8.9	8.2-9.5	8.3	4.2-9.2	5.3	2.9-8.7
LAS	39	6-108	1.74	1-40	--	--
Total Hardness	71.3	44-120	60.2	32-122	56	56
Total Alkalinity	336	50-520	289	178-420	--	--
COD	422	206-1028	173	44-326	55	32-92
TOC	95.8	51-180	54	17-112	25	9-47
Suspended solids	39	1-61	9.6	0-29	--	--
Conductivity micromhos/cm	1022	480 - 2200	940	96 - 1390	274	64 - 1050

All units mg/lit except as noted.

Disadvantages to using reverse osmosis were: high cost of equipment, short membrane life, and a high brine to product water ratio.

After 1965 LAS, linear alkylate sulfonate, a biodegradable detergent, replaced the ABS detergent complexes. The majority of investigations into detergent removal were discontinued after LAS gained market acceptance. This was because LAS complexes broke down rapidly enough not to pose a build-up or pollution/source problem. Laundry wastewater investigations continued in the removal and/or replacement of phosphorus compounds in laundry soap mixes. Phosphorus removal from detergents continued to be considered because phosphorus stimulated algal growths and under some circumstances could produce nuisance conditions. NTA (nirilotriacetic acid) for a while was considered the most promising substitute for phosphorus and its compounds, but was later dropped.[7] NTA, a chelating agent had the property of making many heavy metal ions more soluble in water. This interfered in the formation of insoluble salts used to coagulate heavy metal ions. Replacement of phosphorus by NTA would have caused a more serious problem, that of heavy metal build-up in ground waters. Much of the problems encountered from using phosphorus in detergent mixes have been solved by modern methods of sewage treatment. Current sewage treatment processes are now able to remove up to 99 percent of the phosphorus in the wastewater.

Consequently further study using NTA or other chemicals to substitute for phosphorus have been discontinued. Because the problem of laundry wastewater pollution has effectively been solved it is doubtful that any further study will be made in detergent removal unless the cost of water, and sewage charges become high enough to make recycling of laundry waters profitable.

2.0 ECONOMIC ANALYSIS

2.1 Laundry Water Usage and Costs at Major Army Installations in CONUS

Laundry water usage at military installations depicted in Table 2-1 were estimated by examining the Schedule X's from the installation quartermaster laundries. The Schedule X is used to record the amount of work conducted during the year for use in a manpower survey.

Work levels are recorded by the number of laundry pieces washed each month. Water usage was estimated from pieces of laundry washed by the correlation of three gallons water required for each piece of laundry washed.[8]

Comparing the installation's total water consumption during the year to the estimated laundry water usage for the six installations in Table 2-1, would indicate that approximately 1.03% of the total water consumed at the installation is used by the installation quartermaster laundry.

Table 2-1.

Estimates for Laundry Water Consumption at Army Installations.[9]

Installation*	Year	Number of Laundry Pieces Washed In Year (10^3)	Estimated Yearly Water Consumption at Quartermaster Laundry (kGal)	Total Water Consumption at Installation(kGAL)	Percent Water Used for Laundry Purposed
Ft. Hood	FY74	7065.7	21.197	2,386,835	.88
Ft. Bragg	FY74	6406.4	19.219	1,932.887	.99
Ft. Carson	FY74	5613.2	16.840	1,097,722	1.5
Ft. Campbell	FY74	5014	15.042	1,640,694	.91
Ft. Lewis	FY73	5882	17,646	2,725,871	.64
Ft. Belvoir	FY75	3469.3	10,408	774,057	1.3

*Schedule X data no older than calendar year 1972.

Table 2-2.

Estimated Costs and Consumption Rates for Water Used at Installation Quarter Master Laudnry.

Installation*	Population (10^3)	Estimated Water Usage for QM Laundry Purposes During Year (kGAL)	Estimated Daily Plant Capacity to Process Laundry Wastewater (GAL)	FY75 Price for Purchased Water & Waste Treatment ($/1000 gal)	Total Estimated Cost Per Year For Purchased Water & Sewage Treatment Used By The QM Laundry
Ft. Hood	61.9	23,300	89,600	.11	3,560
Ft. Knox	44	20,500	78,800	1.56	31,980
Ft. Bragg	41.7	20,00	78,100	1.60	32,480
Ft. Carson	41.1	16,800*	64,600	.61	10,250
Ft. Lewis	38	17,600*	67,700	1.05	18,480
Ft. Benning	37	22,000	84,600	.71	15,620
Ft. Bliss	36.6	22,800	87,700	.38	8,660
Ft. Campbell	35.1	17,500	67,300	.76	13,300
Ft. Ord	34	17,500	67,300	.45	7,900
Ft. Leonard Wood	31.3	16,900	65,000	.82	14,700
Ft. Sill	29	10,500	40,400	.22	2,310
Ft. Riley	29	13,000	50,000	.85	11,050
Ft. Jackson	26	11,900	45,800	.86	10,230
Ft. Polk	25	8,210	31,600	.17	1,400
Ft. Amador	22.3	17,900	68,800	.35	6,270
Ft. Rucker	21	7,900	30,400	1.21	9,560
Ft. Sam Houston	20	13,200	50,800	.62	8,180

*Values for Ft. Carson and Ft. Lewis were taken from Table 5 instead of the FY75 Facilities Engineering Annual Summary of operations.

Using 1.03% as an indicator of laundry water consumption, Table 2-2 represents the water consumed by the installation quartermaster laundry for the 17 largest installations by population. Water and sewage charges are the FY75 price paid by the installation and supplied by outside utilities. The assumption was made that any decrease in water consumption or sewage treatment for laundry wastewater recycling would be subtracted from the more expensive services supplied by off post utilities. The last column in Table 2-2, the total estimated cost per year for purchased water and sewage treatment used by the quartermaster laundry is the breakeven point for the installation's laundry recycle plant. The total yearly cost of operation and amortization of equipment costs of a laundry wastewater recycling plant must be under those estimated installation costs to be economically feasible.

2.2 Preliminary Design.

Figure 2-1 represents the major process areas that would be involved in laundry waste treatment plant indicated by the literature previously discussed.

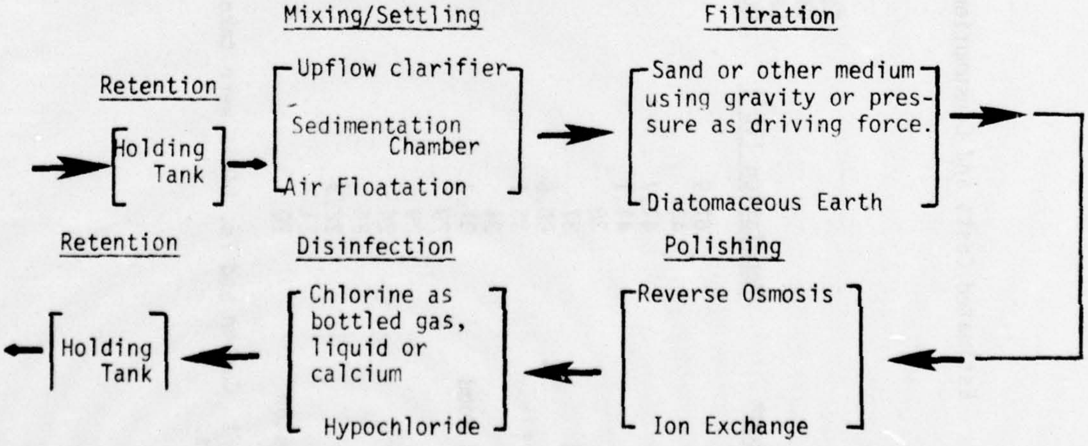


Figure 2-1.
Flow Diagram of Possible Process Equipment Used in Recycling Laundry Wastes.

Estimated equipment costs were made using Figure 2-1 as a guide for the possible process equipment that would be used in recycling wastewater. A plant capacity of 70,000 gpd of wastewater was chosen as being representative of the laundry water consumption at installations where reuse of laundry water was feasible. Equipment sizing and cost estimation was completed for coagulation by alum, and powdered carbon with a polyelectrolyte to determine if coagulation by either process amounted to any savings. The lowest value between the two was used to determine the total cost of equipment. Installation costs for the equipment were determined by using a cost proposal by a private contractor for a laundry waste treatment plant to have been located at Ft. Jackson. Operating costs include the cost of chemicals using literature dosages and the cost of an operator maintaining the equipment two to four hours daily or $5,000 per year. Electrical charges & other maintenance expenses were not added into the operating charge.

2.2.1 Mass Balance.

The basis for the treatment facility is 70,000 gallons of wastewater per operating day. Table 2-3 is representative of the typical quality of laundry water wastes found in literature.

Table 2-3.

Average Quality of Laundry Wastes.[11]

Parameter	Average (mg/lit)	Range (mg/lit)	Process Flow (Average lbs/hr)
Ph	7.13	5.0-7.6	--
BOD	120	50-185	8.75
COD	315	136-455	22.98
ABS	33	15-144	2.4
TDS	700	290-1450	51.07
Phosphate (PO^{-3}_4)	146	84-199	10.67
Acidity as $CaCO_3$	91	73-124	6.6
Alkalinity as $CaCO_3$	368	340-420	26.8

Process flows are determined from the basis. The system is expected to be operated 8 hours per day.

2.2.2 Mixing/Settling.

Air flotation because of the poor reliability i.e., the large amount of liquid entrapment within the foam overflow and poor separation, will not be considered as a suitable method of wastewater recovery. Assumptions used in the preliminary design of the upflow clarifier and sedimentation chamber are listed below.

2.2.2.1 Assumptions for design of upflow clarifier and sedimentation chamber.

2.2.2.1.1 Approximate loadings for aluminum floc are shown in Table 2-4.

Table 2-4.

Tank Loading.[12]

Nature of Solids	Specific Gravity	Settling Velocity (cps)	Surface Loading* (gpd per ft^2)	Detention Period (for 10 ft tank)
Sand, slit & clay	2.65	7×10^{-3}	146	12.3
Aluminum floc	1.002	8.2×10^{-2}	1800	1

*gpd is for 24 hour period.

2.2.2.1.2 Powdered activated carbon absorbs within 15 to 20 minutes approximately 95% of the removable COD. Inordinate times are required to remove the other 5%.[13]

2.2.2.1.3 Powdered carbon has a rise rate of 1.1 gal/min/ft^2 and a detention time of 20 minutes.[14]

2.2.2.1.4 Average depth of upflow clarifier is from 8 to 12 feet.[15]

2.2.2.1.5 Sedimentation tanks are designed with length to width ratios of 3:1 to 5:1, are almost twice as long as the estimated settling velocity would require and have a depth of approximately 8 feet.[16]

2.2.2.1.6 Average clarifier diameters range from 35 to 200 feet, 100 feet being the average. Cost of clarifiers range from \$28,000 to \$470,000. Cost estimates are from 1972.[17]

2.2.2.1.7 Aluminum floc will remove by clarification 75% ABS and 94% phosphates at a pH between 4 and 5. Concentration of $Al_2(SO_4)_3 \cdot 18\ H_2O$ used is 1000 mg/lit.[18]

2.2.2.1.8 Nomenclature.

Q: Volumetric flow rate

C: Volumetric capacity of the settling zone

t_o: Detention period

V_o: Settling velocity or surface loading

h: Height of settling zone

W: Width of settling zone

L: Length of settling zone

A: Surface Area

2.2.2.2 Calculation for Upflow Clarifier.

2.2.2.2.1 Using Alum as the coagulant.

Surface loading: 1800 gpd/ft²

Tank height: 10 feet

Surface loading 1800 gpd/ft^2 = 10.025 $ft^3/hr/ft^2$

$$\text{(a)}\quad A = Q/V_o = \left(1170 / 10.025\right) = 117\ ft^2$$

(b) Detention time $= V/Q = \dfrac{(117\ \text{ft}^2)\ (10\ \text{ft})}{1170\ \text{ft}^3/\text{hr}} = 1$ hour

(c) Doubling size to account for entrance and rapid mixing effects give a tank whose surface area is 234 ft^2, diameter is 18 ft, and height is 10 ft.

2.2.2.2.2 Using powdered carbon as the coagulant.

Surface loading: 1./ gal/min/ft^3

Tank height: 10 feet

Surface loading 1.1 gal/min/ft^2 = 8.8 ft^3/hr/ft^2

(a) $A = Q/V_o \left(1170 /_{8.8}\right) = 132.9 = 133\ \text{ft}^2$

(b) Detention time $= V/Q = \dfrac{133\ (10)}{1170} = 1.1$ hour

(c) Doubling size to account for entrance, and rapid mixing effects, gives a tank whose surface is 266 ft^2, diameter is 19 ft, and height is 10 feet.

2.2.2.3 Cost of clarifiers.

Clarifiers range in price from \$28,000 to \$470,000 for clarifiers with diameters from 35 to 200 ft. Chemical feed systems for clarifiers having diameters below 35 ft are the major cost. Consequently clarifiers with diameters of 18 to 19 feet would cost approximately the same or \$28,000. Using economic indicators from Chemical Engineering, cost of clarifiers bought in Dec 1975 would be as follows:

$$(\$28{,}000)\ \frac{(186.6)}{(137.2)}\ \frac{\text{Dec 1975}}{1972} = \$38{,}100$$

2.2.2.4 Calculations for Sedimentation Chamber using Aluminum Sulfate as Flocculate Aid.

Let $h = 8$ ft and $L = 4W$.

(a) Settling velocity $= \left(8.3 \text{ X } 10^{-2} \frac{\text{cm}}{\text{sec}}\right) \left(\frac{3600}{30.48}\right) = 9.8$ ft/hr.

(b) $V_o = h/t_o$. $t_o = 8 \text{ ft}/9.8\text{ft/hr} = .81$ hr detention time $4W^2/h/Q$

(c) $t_o = C/Q$

$$W = \left[Q/4V_o\right]^{\frac{1}{2}} = \left[1170/4 \quad (9.8)\right]^{\frac{1}{2}} = 5.5 \text{ ft}$$

$$L = 22 \text{ ft.}$$

(d) Doubling sedimentation volume to account for freeboard, and entrance and exit effects gives a tank width 6 ft, length 40 ft, and height of 8 ft.

(e) Cost of sedimentation tank

Current prices for sedimentation tanks could not be found in literature at this writing. Chemical feed and mixing systems for clarifiers would be similar to sedimentation units. Construction of the settling basin of a sedimentation tank should be similar but less expensive than an upflow clarifier because of its shape. The price should then be somewhere less than a clarifier of similar capacity or $38,000. Without knowing the degree difference for estimation purposes the cost of the sedimentation basin is $38,000.

2.2.5 Filtration.

2.2.5.1 Sand or Mixed Media Filter.

2.2.5.1.1 Assumptions.

(a) Hydraulic loading on surface of sand bed is 24.07 $\text{ft}^3/\text{hr}/\text{ft}^2$.[19]

(b) Backwash when loss of head is 5 psi. Backwash at rates between 12-15 $\text{gal}/\text{ft}^2/\text{min}$ for sand filtration. Continue backwashing for 5-10 minutes.[20]

(c) Bed depth is between 2 to 3 feet deep.[21]

(d) Bed can contain between ¼ to ½ cubic feet of suspended solids prior to backwashing.[22]

(e) Approximate cost of sand filter is \$80 per square foot loading area.[23]

2.2.5.1.2 Calculations.

(a) Surface area of filter.

$$\text{Surface area} = \frac{(\text{Volumetric flow rate})}{(\text{Hydraulic loading})} = \frac{1170 \text{ ft}^3/\text{hr}}{20.07 \text{ ft}^3/\text{hr}/\text{ft}^2} = 48.6 \text{ ft}^2 = 50 \text{ ft}^2$$

(b) Cost is then; (50 ft^2) $(\$80/\text{ft}^2)$ = \$4000 for 1970 without pump.

(c) Updating the cost to December 1975 is $(\$4000) \left(\frac{186.6}{125.7} \begin{matrix}\text{Dec 1975}\\ \text{1970}\end{matrix}\right)$ \$6000 for sand filter.

(d) Pump sizing.

Backwash rate is 13.5 gal/ft^2/min or (13.5) gal/ft^2/min (50 ft^2) = 675 gal/min. Total water requirement for backwashing is (675 gal/min) (7.5 min) = 5100 gal. Backwashing requires pump with suction pressure of 15 psi (34 ft of water). Using chart in Reference 17, cost of a cast iron centrifugal in line pump with motor is \$650 for 1971 costing. Updating cost to Dec 1975; $\$650 \, \frac{(186.6)}{(132.2)} \begin{matrix}\text{Dec 1975}\\ \text{1971}\end{matrix} = \$900$

(e) Total cost of sand filter is then; \$6000 + \$900 = \$6,900.

2.2.5.2 Diatomaceous Earth Filtration.

2.2.5.2.1 Assumptions.

(a) Bodyfeed at constant rate of 29 mg/lit.[24]

(b) Precoat filter are at rate of .1 lb/ft^2.[25]

(c) Hydraulic loading of filter area is 4.16 gal/ft^2/min.[26]

(d) Head loss at end of run between 35-100 psi. Backwash at 50 psi.[27]

2.2.5.2.2 Calculations.

(a) Filter area

$Q = 1170 \text{ ft}^3/\text{hr} = 8753 \text{ gal/hr}$.

L_o = 4.16 gal/ft^2/min (60 min/hr) = 249.6 gal/ft^2/hr

Q/L_o = A: $\frac{8753}{249.6}$ = 35 ft^2 of filter area.

(b) Cost using Figure 19-108 in Perry's Handbook for a continous vacuum precoat filter is $9,000 for 1968. Cost includes pumping charges.

(c) Updating cost to Dec 1975 total cost of uninstalled diatomaceous earth filter is $9000 $\frac{(186.5)}{(113.7)}$ $\frac{\text{Dec 1975}}{1968}$ = $14,800

2.2.6 Polishing.

2.2.6.1 Reverse Osmosis.

2.2.6.1.1 Assumptions.

(a) Membrane life is 6 to 9 months. This membrane life is currently longer than the actual life expectancy of the current model but membrane life can be expected to increase as technology improves. Membrane life will also vary due to the following: construction of membrane, percent influent recovered to brine exhausted, and initial clarity of influent waste.[28]

(b) Using a spiral wound RO unit and 90% recovery of pretreated wastewater, the power requirement is 9.8 kw-hr/1000 gal and the flux is 12 gpd/ft^2 of membrane at 530 psi and 70^{o}F.[29]

(c) Membrane cost is between $3 and $8 per sq ft. Cost of equipment is $30/ft^2 of installed membrane.[30]

2.2.6.1.2 Calculations.

(a) Membrane size.

Q/L_o = A 70,000 gpd/ft^2 = 5,833 ft^2

(b) Membrane Cost.

($5.5/ft^2) (5,833 ft^2) = $32,081 each 6 to 8 months depending on length of membrane life.

(c) Cost of equipment; ($30/ft^2) (5,833 ft^2) - $32,081 = $142,909.

(d) Total cost. Fixed costs for a reverse osmosis unit is $143,000 plus an operating cost of $32,000 each 6 to 9 months for membrane replacement. Economic indicators were not used to update the unit cost since reverse osmosis units are expected to drop in price eventually.

2.2.6.2 Ion Exchange.

2.2.6.2.1 Assumptions.

(a) Use two bed system for demineralization with sodium hydroxide and sulfuric acid as regenerates.

(b) Exhaustion and regeneration reactions are as follows*:

$$H_2R + MgCl_2 \xrightleftharpoons[\text{Exchange}]{\text{Cation}} RMg + 2HCl$$

$$AOH + HCl \xrightleftharpoons[\text{Exchange}]{\text{Anion}} ACl + H_2O$$

$$RMg + H_2SO_4 \xrightleftharpoons[\text{Regeneration}]{\text{Cation}} H_2R + MgSO_4$$

$$ACl + NaOH \xrightleftharpoons[\text{Regeneration}]{\text{Anion}} AOH + NaCL$$

*R&A are cation and anion exchange resins respectively.

(c) Hydraulic loading per square foot of bed area is between 8 and 12 gallons per minute.[31]

(d) Average bed depth is between 2 to 8 feet.[32]

(e) Cation has a resin life expectancy of 10 years. Anion resins have a life expectancy between 2 and 8 years.[33]

(f) Resins are regenerated every 4 hours.[34]

(g) Cation resin can adsorb 1 to 3 pounds of ions per cubic foot of bed. Anion resin can adsorb 1.5 to 2.5 pounds of ion per cubic foot of bed.[35]

(h) Between 2 and 5 lbs of H_2SO_4 are required to regenerate each cubic foot of cation resin. Approximately 4 lbs of NaOH are required to regenerate each cubic foot on anion resin.[36]

(i) Rinsing and backwashing of resin beds requires 40 to 60 gallons per cubic foot of bed.[37]

(j) Chemical regenerate consumption (percent of stoichiometric) is between 120 and 200 percent.[38]

(k) Resin costs are $20 per cubic foot for cation resin and $60 to $100 per cubic foot for anion resin at 1970 cost.[39]

(l) The solubility of $Al(OH)_3$ in solution is very low (2.62×10^{-9} mole/lit at 25°C). For design purposes $AlOH_3$ does not add to salt build-up.

2.2.6.2.2 Calculations.

2.2.6.2.2.1 Surface area of resin bed (tanks are cylindrical).

$Q/L_o = A$

$Q = 70{,}000$ gpd $= 146$ gal/min

$L_o = 10$ gal/ft^2/min

$A = 146/10 = 14.6$ ft^2 bed

2.2.6.2.2.2 Resin Volume.

(a) Cation resin.

1) Cation resin adsorbs 2 lbs ion/ft^3 resin/4 hr.

2) From Table 2-3, 26.8 lbs alkalinity as $CaCO_3$/hr is 107.2 lbs of alkalinity as $CaCO_3$ added each four hour period to the wastewater system.

3) Required cation resin is then; (107.2 lbs as $CaCO_3$)/(2 lbs as $CaCO_3/ft^3$/resin).

(b) Anion Resin.

1) Anion resin adsorbs 2 lbs ion/ft^3 resin.

2) From Table 2-3, 6.6 lbs acidity as $CaCO_3$/hr/4 hr is 26.4 lbs of acidity as $CaCO_3$ added each four hour period to the wastewater system.

3) Powdered activated carbon if added to the system will not increase the ion content. Aluminum sulfate will add the sulfate ion to the wastewater mix. If 1000 mg/lit of aluminum sulfate ($Al_2(SO_4)_3 \cdot 18\ H_2O$) is used, 250 lbs of SO_4 ion will be added each day.

4) Required anion resin when using aluminum sulfate as coagulant is then (151.4 lbs acidity as $CaCO_3$) (2 lbs as $CaCO_3/ft^3$ resin) = 76 ft^3 of anion resin.

5) Required anion resin using powdered carbon is (26.4/2) = 13 ft^3 anion resin.

2.2.6.2.2.3 Tank Volume.

Freeboard is 70% of bed volume.

(a) Cation resin.

1) 1.7 (54 ft^3 resin) = 92 ft^3 volume.

2) Dimension of tank.

Height = Volume/Surface area = 92/14.6 = 6.3 (height of tank is then 6.3 ft and diameter is 4.3 ft).

(b) Anion resin.

1) Aluminum sulfate as coagulant.

Volume = (1.7) (76 ft^3) = 129 ft^3

Dimension of tank. ht = 129/14.6 = 8.8 ft and diameter is 4.3 ft

2) Powdered carbon as coagulant.

Volume = (1.7) (13 ft^3) = 22.1 ft^3

Dimension of tank. Let diameter be 3 ft due to small volume. Height is then 22 ft^3/7 ft^3 = 3 ft.

2.2.6.2.2.4 Chemical dosage for regeneration.

(a) Cation resin.

1) 3.5 lbs H_2SO_4/ft^3 resin are required for regeneration.

2) The pounds of H_2SO_4 required to regenerate cation bed is;

(3.5) (54) = 189 lbs of H_2SO_4 required for regeneration every four hours.

3) Sulfuric acid is transported at 66% strength in 55 gallon drums. The amount used in one regeneration cycle is;

$$(1.842 \text{ sp.g.}) (62.4 \text{ lb/ft}^3 \text{ H}_2\text{O}) \frac{35.31 \text{ ft}^2}{264.2 \text{ gal}} = 15.36 \text{ lb/gal } (189 \text{ lbs}) (1/15.36$$

lbs/gal) (1/.66) = 18.6 gal of stock solution.

(b) Anion Resin

1) 4 lbs NaOH/ft^3 resin are required for regeneration.

2) Pounds of NaOH required for regeneration using aluminum sulfate is (4 lbs/ft^3) (76 ft^3) = 304 lbs of NaOH every four hours for regeneration. Using Powdered Carbon; (4 lbs/ft^3) (13 ft^3) = 52 lbs of NaOH every four hours for regeneration.

3) Sodium hydroxide is transported at 50% strength in 55 gallon drums. The amount used in one regeneration cycle is then:

$$(2.13 \text{ sp.g.})\ (62.4 \text{ lbs/ft}^3\ H_2O)\ \frac{35.31 \text{ ft}^3}{264.2 \text{ gal}} = 17.76 \text{ lbs/gal}$$

Using Aluminum Sulfate:

(304 lbs) (1/17.76 lbs/gal) (1/.5) = 5.8 gal of solution

2.2.6.2.2.5 Regenerant usage during day.

Assume that the last half of the regenerant volume is saved for next backwash (concentration is 200 percent of theoretical). Daily chemical usage of regenerate chemicals would then be amounts calculated in 2.2.4.2.2.4.

2.2.6.2.2.6 Water required for backwash and rinse.

(a) Half of regeneration cycle water is supplied from previous wash. If two backwashings are required each day, the daily water requirement is the water used for one regeneration cycle.

(b) Rinse and backwash requires 50 gallons per cubic foot of resin bed.

(c) Cation resin rinse and water requirements are:

(50 gal/ft^3) (54 ft^3) = 2700 gal.

(d) Anion resin rinse and water requirements are:

1) Using Aluminum as coagulant: (50 gal/ft^3) (76 ft^3) = 3000 gal

2) Using Powdered Carbon as coagulant: (50 gal/ft^3) (13 ft^3) = 650 gal.

2.2.6.2.2.7 Resin bed cost.

(a) Cation resin.

1) Resin cost is $\$20/ft^3$ in 1970.

2) Cost using economic indicators for Dec 1975 is;

$$(\$20/ft^3)\ (54\ ft^3)\ \frac{(186.6)}{(125.7)}\ \begin{matrix}\text{Dec 1975}\\ \text{1970}\end{matrix}\ = \$1600$$

(b) Anion resin

1) Resin cost is $\$80/ft^3$ in 1970.

2) Costs using economic indicators for Dec 1975 is; using aluminum as coagulant:

$$(\$80/ft^3)\ (76\ ft^3)\ \frac{(186.6)}{(125.7)}\ \begin{matrix}\text{Dec 1975}\\ \text{1970}\end{matrix}\ = \$9000$$

Using Powdered Carbon as coagulant:

$$(\$80/ft^3)\ (13\ ft^3)\ \frac{(186.6)}{(125.7)}\ \begin{matrix}\text{Dec 75}\\ \text{1970}\end{matrix}$$

= $1,550.

2.2.6.2.2.8 System Cost.

Using table in Reference 1, cost for ion exchanger system is $23,000 in 1972. Cost of ion exchanger system by Dec 1975 is then;

$$(\$23{,}000)\ \frac{(186.6)}{(137.2)}\ \begin{matrix}\text{Dec 1975}\\ \text{1972}\end{matrix}\ = \$31{,}000$$

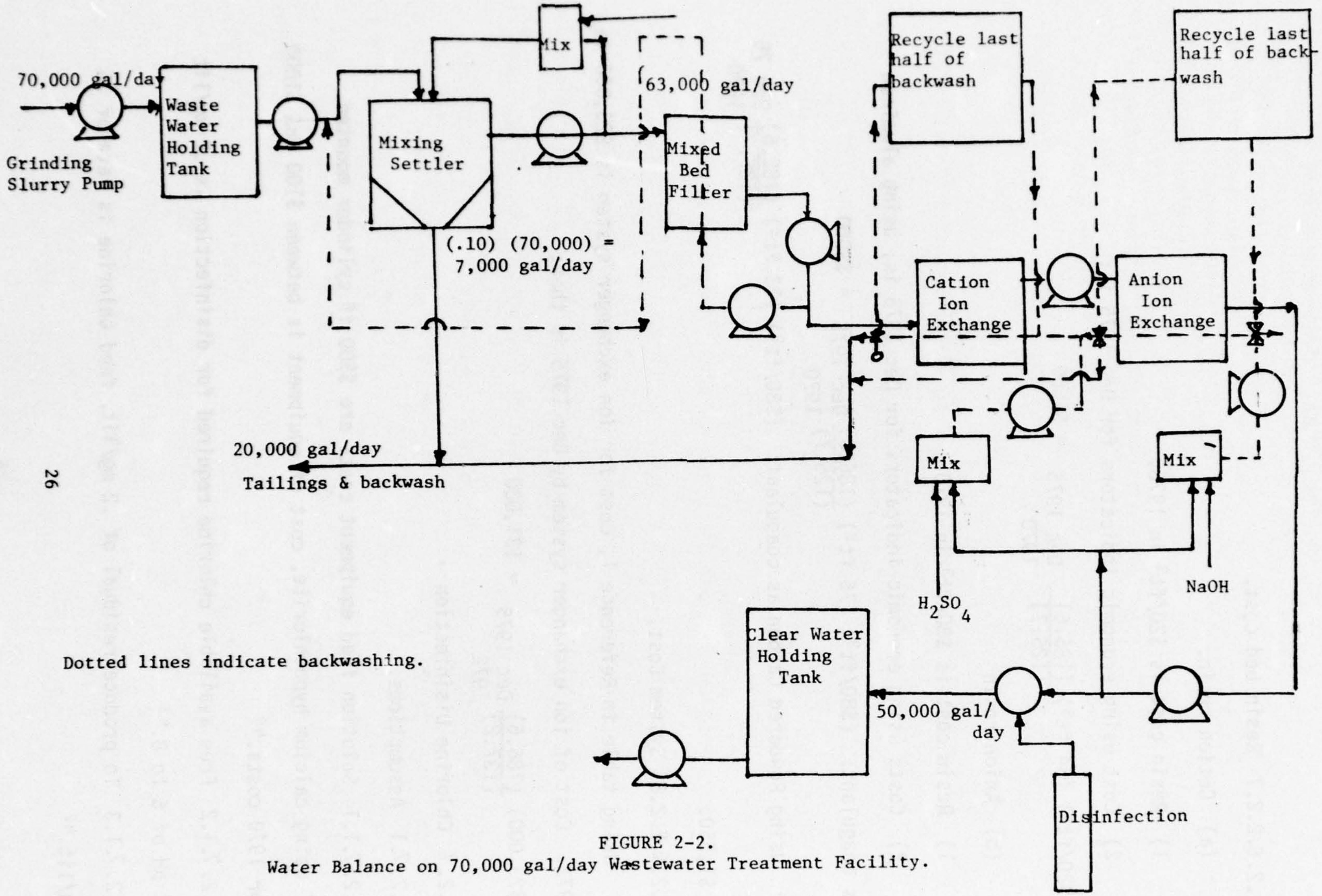
2.2.7 Chlorine Disinfection

2.2.7.1 Assumptions.

2.2.7.1.1 Solution feed equipment costs are $500 if cylinder mounted. If using calcium hypochlorite, cost of equipment is between $100 and $1000 for 1970 costs.[40]

2.2.7.1.2 Free available chlorine required for disinfection is .2 mg/lit at pH of 6 to 8.[41]

2.2.7.1.3 To produce residual of .2 mg/lit, feed chlorine is rate of .5 mg/lit.[42]



Dotted lines indicate backwashing.

FIGURE 2-2.
Water Balance on 70,000 gal/day Wastewater Treatment Facility.

2.2.7.2 Calculations.

2.2.7.2.1 Chlorine bottled gas required: (.0005 gr/lit) (3.785 lit/gal) (lbs/454 gr) = 4.1685 X 10^{-6} lbs/lit/gal) 70,000 gal/day (4.1685 X 10^{-6} lbs Cl_2/gal) = .3 lb chlorine required each day.

2.2.7.2.2 Calcium hypochlorite required: $Ca(OCl)_2 \cdot 4\,H_2O$ = 215 lb/lb-mole (normal commercial form) For 100% dissociation (.3 lbCl) $\frac{\text{lb-mole}}{\text{35.45 lb}}$ = .0084 lb-mole Cl, or (.00423 lb-mole Cl_2) (215 lb/lb-mole) (.00423 lb-mole) = 9 lb calcium hypochlorite required each day.

2.2.7.3 Cost of system.

2.2.7.3.1 Chlorine gas $\$500 \frac{(186.6)}{(125.7)} \begin{array}{l}\text{Dec 1975}\\ \text{1970}\end{array} = \$750$

2.2.7.3.2 Calcium Hypochlorite $\$700 \frac{(186.6)}{(125.7)} \begin{array}{l}\text{Dec 1975}\\ \text{1970}\end{array} = \$1{,}000$

2.2.8 Wastewater and Clear Holding Tanks.

2.2.8.1 Assumptions.

2.2.8.1.1 Total volume of tanks and process equipment should be able to retain the water used during the day over periods when laundry is not in use.

2.2.8.1.2 Wastewater holding tank should be able to retain influent waste during heaviest loading period.

2.2.8.1.3 Wastewater holding tank should be large enough so that the wastewater from different cycles are well mixed. This is required so that influent waste concentrations are constant and temperatures are constant to minimize heat gradients within the clarifier and chemical feed fluctuations.

2.2.8.2 Calculations.

2.2.8.2.1 The average washing cycle including both wash and rinse cycles takes approximately one hour. During an eight hour day no more than eight washing cycles could be done on each piece of equipment. Taking into account the amount of time required to load and prepare a cycle, the minimum number of cycles within a day would be approximately five. Consequently only 1/5 to 1/8 of a day's water supply is being used at any one time. As a conservative estimate each tank should be able to retain 1/5 of the daily water supply or 15,000 gal capacity. Detention time in wastewater holding tank would be about 1.5 hours, long enough to mix the influent wastes.

2.2.8.2.2 Using Means Handbook, cost data for 1975, a precast 15,000 gallon cement septic tank costs about $4350.[43] Total cost of holding tanks is then $8,700.

2.2.9 Piping Estimate.

Using a scale drawing, the amount of piping is estimated as follows; 186 feet 6 inch diameter cast iron piping for process flow and 90 feet of 4 inch piping for secondary flows of slurried sludges. Estimated costs using Means Handbook, for 1975 is $1700 and $480 respectively. Total cost for piping is then $2,180.[44]

2.2.10 Pumping Estimate.

Volumetric flow is 146 gpm. Assumed pressure head should range between 20 and 100 feet of water. The cost of a cast iron centrifugal in line pump with motor is between $300 and $600 for comparable pressures using the Chemical Engineering Deskbook from October 1971. For estimation purposes the average pump for a laundry wastewater system will cost $400 each. A total of six major pumps are required for process flow. The cost for 1971 is then 6(400) = $2400. Using Chemical Engineering economic indicators, price in December 1975 is then: $\$2400 \frac{(209.1)_{\text{Dec 1975}}}{(132.2)_{1972}} = \$3{,}800.$

2.2.11 Building Site.

Floor space for wastewater system is estimated at 60 x 40 feet. Using 1975 Means Handbook, cost for covered area (warehouse/storage building) is $33,000.

2.2.12 Auxiliary Equipment.

Figure 2-2 is a flow diagram of the proposed wastewater treatment facility. Each day 20,000 gallons of the 70,000 gallons entering would be used to slurry away flocculants from the clarifier and the salts from the ion exchanger. Part of the waste effluent leaving the clarifier, about 3500 gallons daily could be recovered using a holding tank with a large detention period or by using a dewatering filter. Neither would be economical to install unless the operating and amortized costs were less than the recovered water and sewage charges. Recovering 3500 gal/day was not considered economically practical in this report. The other effluent waters from backwashing the ion exchangers contain large amounts of ionic salts. These are removable only by more exotic methods of waste recovery and would also not be practical. Special care would be required in monitoring the pH of the backwash water from the ion exchangers.

2.3 Cost Analysis.

2.3.1 Total equipment and installation cost.

Table 2-5 is a compilation of estimated equipment costs from the previous sections.

Table 2-5.

Estimated Costs of Chemicals for Laundry Wastewater Recovery.

Holding Tank	$ 4,350
Upflow/Clarifier	38,100
Sand/Mixed Media Filter	6,900
Ion Exchange	31,000
Chlorine disinfection	750
Holding Tank	4,350
Piping	2,200
Pump	3,800
Subtotal	91,450
Building	33,000
Total	$124,450

A private contractor in September 1973 proposed to build at Fort Jackson a 1.44 X 10^5 gpd laundry wastewater reclamation system. The cost in 1973 money for the system was $75,000 for equipment supplied by the contractor and $60,960 for installation by a different firm. Total cost of the system was then $135,960. The following is a listing of the equipment that would have been supplied by the contractor:[46]

1. Engineering drawings
2. Two air operated slow speed mixers
3. Three chemical feed systems
4. Required pumping systems
5. Vacuum filter
6. Two water softeners with regeneration tank
7. Chlorine feed system
8. Control panel

Installation charges were for the following:

1. Building and concrete work
2. Equipment installation
3. Mechanical installation, i.e., piping and bracketing required
4. Electrical wiring and installation
5. Air compressor
6. Receiving, i.e., all items received and unloaded.

The estimated charge by the contractor did not include the cost of two holding tanks. Using Means Cost Data for 1975 the equipment cost and installation cost of two 30,000 gallon cement holding tanks would be approximately $18,000.[47] Using Economic indicators from Chemical Engineering to update the estimate by the contractor gives the following for Dec 1975 prices.

Contractor equipment estimate: $$75{,}000 \frac{(186.6)}{(144.1)} \begin{matrix}\text{Dec } 75\\ 1973\end{matrix} = \$97{,}100.$$

Contractor installation estimate: $$(\$60{,}960) \frac{(186.6)}{(144.1)} \begin{matrix}\text{Dec } 75\\ 1973\end{matrix} = \$78{,}900.$$

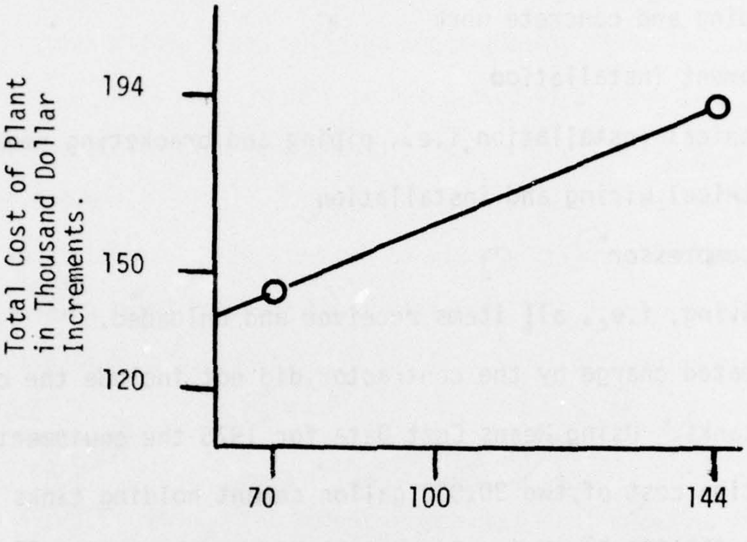
Total estimated cost is then $97,100 + $78,900 + $18,000 = $194,000.

Installation costs for the 70,000 gpd treatment facility are determined by using the ratio of contractor estimated installation costs over the total cost estimate.

Installation estimate: $$(\$91{,}450) \frac{78{,}900 + 2{,}400}{194{,}000} = \$38{,}300.$$

The additional $2,400 is for installation of the holding tanks. Adding 15% for A&E costs, the total cost for the 70,000 gpd treatment facility would be: 1.15 ($38,300 + $91,450) = $150,000

Figure 2-3 shows total cost of plant versus capacity for a laundry wastewater treatment facility.



Plant Capacity for Wastewater Treatment (10^3 gpd).

Figure 2-3.

Estimated Laundry Waste Treatment Plant Cost Versus Plant Capacity

2.3.2 Chemical Costs.

Table 2-6 is a compilation of estimated chemical costs. Chemicals are of commercial grade and bought in small quantities. Prices are twice the value of literature prices for bulk quantities in 1975 and F.O.B.[48] Prices have been doubled to account for the small quantities bought. Cost of chemicals are tabulated in increments of 1000 gallons of recovered wastewater.

Table 2-6.

Estimated Costs of Chemicals for Laundry Wastewater Recovery.

Chemical	Form	Cost[48]	Concentration Used	Cost 1000/gal
Aluminum Sulfate	100 lb bag	$7.00	8.3 X 10^{-3} lbs/gal	$ .82
Sodium Hydroxide	55 gal drum 50% strength	$53.00	34.2 gal/day for Aluminum Sulfate Coagulation	.66
			5.8 gal/day for Powdered Carbon Coagulation	.11
Sulfuric Acid	55 gal drum 60% strength	$50.00	18.6 gal/day	.34
Polymer	Liquid	--	Trace Amount	.03
Powdered Activated Charcoal	100 lb bag or Cannister	$10.00	8.3 X 10^{-3} lbs/gal	1.17

The total chemical charge using aluminum sulfate as a coagulant to treat 1000 gallons of wastewater is then $1.82. Using powdered carbon as the coagulant the total charge is $1.65 to treat 1000 gallons of wastewater.

2.3.3 Operating Costs.

Operation and maintenance is estimated to be 3% of the initial capital investment or $4,500 per year.

2.3.4 Total Cost.

Table 2-7 is a summary of estimated costs required to install and maintain a 70,000 gpd treatment facility. The yearly cost for equipment and installation was determined using a capital recovery factor, a 25 year plant life with no salvage value, and money at 10 percent.

Table 2-7.

Summary of Costs for 70,000 gpd Wastewater Treatment Facility.

Type of Expense	Total Cost	Yearly Cost	Cost/1000 gal*
Equipment & installation	$150,000	$16,500	$1.27
Chemical cost using Aluminum Sulfate for Coagulation	--	$23,700	$1.82
Chemical cost using Powdered Carbon as Coagulation	--	$21,500	$1.65
Operation & maintenance	--	$ 4,500	$ .35

*Cost 1000 gal is determined from water that is recycled or 50,000 gal/day.

Using the lowest chemical charge, powdered carbon, the annual expense of maintaining a treatment facility recycling 50,000 gpd of laundry wastewater would be $42,500.

The breakeven point for water and sewage charges would then be $3.21 per 1000 gallons of treated wastewater.

By a similiar procedure the breakeven point for the plant size recommended by the contractor is $2.66 per 1000 gallons of treated wastewater.

Figure 2-4 is the estimated breakeven line for water and sewage charges versus daily plant capacity.

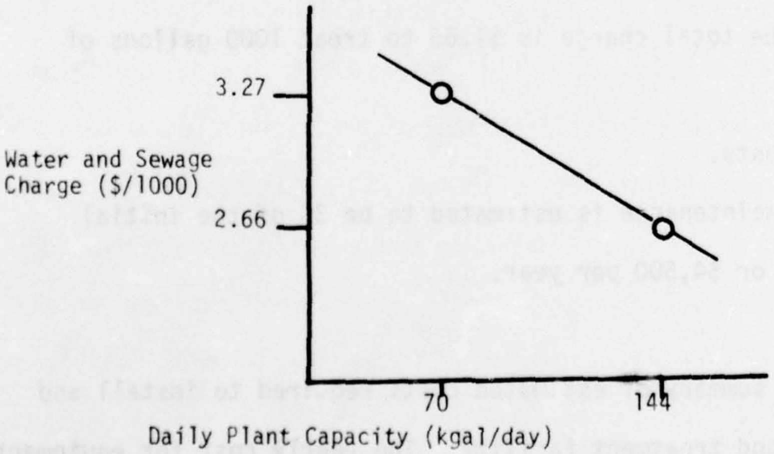


Figure 2-4.
Breakeven Line for Plant Capacity Versus Water and Sewage Charge.

3.0 DISCUSSION.

3.1 Comparison.

The breakeven point for a 70,000 gpd laundry treatment facility is $3.27/1000 gal of treated wastewater. Comparing this value against the purchased water and sewage treatment rates in Table 2-2, for the 17 largest installations by population there is no CONUS installation that warrants the use of laundry water recycle. Ft. Bragg's purchased water and sewage treatment is the nearest to the estimated breakeven point at $1.60/1000 gal. Increasing plant capacity and laundry water consumption rates will decrease the cost of wastewater treatment lowering the breakeven point. Using the Ft. Bragg laundry and $1.60/1000 gal as a breakeven point for example, approximately 270,000 gpd of laundry wastewater would have to be recycled at the laundry to attain the breakeven costs of $1.60/1000 gal. A flowrate of this magnitude amounts to four percent of Ft. Bragg's total yearly water consumption. Four percent of the yearly water consumed is much higher than what would be expected to be consumed at the Ft. Bragg laundry. About one percent or a 78,100 gpd wastewater flow had been previously estimated. Comparison of the two values would indicate that the Ft. Bragg laundry does not use the amounts of water required to be economical using the process flow described within this report. Comparing the costs and estimated wastewater flows of other installations in Table 2-2, indicates that no other installation currently has the required wastewater flow rate or purchased water and sewage rates to make the installation of a laundry wastewater recycling process economical.

A possible method of lowering the breakeven value of the laundry wastewater treatment facility would be not to use the ion exchanger and recycle only a portion of the flocculated wastewater to keep the ionic salt build-up below an acceptable limit. Figure 3-1 is a representation of the flow diagram. Using the same sized equipment and estimating procedures for a 70,000 gpd, the total installed cost would be $98,000. Letting X be the amount of wastewater to be recycled per year, $1.17/1000 gal the chemical and operating cost, $1.60/1000 gal the purchased water and sewage charge, and $10,000 the yearly fixed cost, the amount of water required to be recycled to breakeven would be as follows:

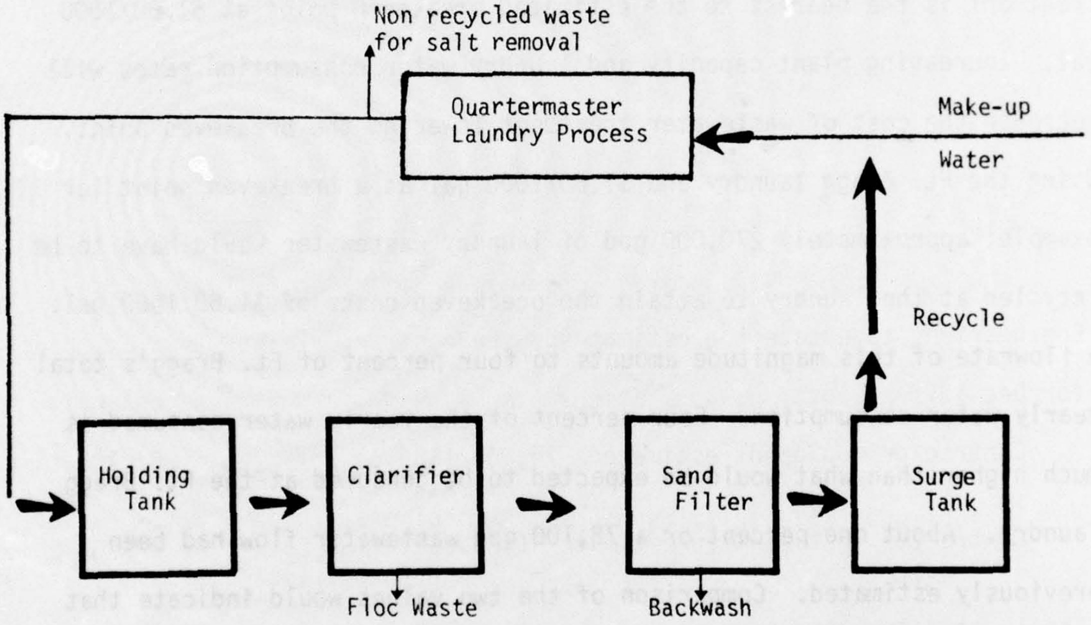


FIGURE 3-1.

Flow Diagram for Laundry Wastewater Recycling Without the Use of Ion Exchange Equipment.

Total Cost	=	Total Profit
$10,800 + ($1.17/1000 gal) (X)	=	($1.60/1000 gal) (X)

Solving for X, 25,000 kgal/yr of wastewater would have to be recycled. Ft. Bragg to breakeven would have to recycle at a rate of 125%. Any recycle rate above 100% is physically impossible. Consequently, this method is also not economically feasible. Even if the fixed cost were $5,000 annually, representing a installed plant cost of $45,000, the breakeven recycle rate is 58% and this value intuitively is still too high.

Laundry wastewater recycling for economic reasons currently does not appear to be feasible. As seen in the previous discussion the process flows are not large enough, purchased water and sewage rates are not high enough, and equipment and installation costs are too high. It is not reasonable to expect these parameters to change rapidly. Laundry wastewater recycle at the installation quartermaster laundries will remain economically infeasible until conditions and water costs increase. Future efforts should consider the economics of recover of the chemical treatment materials as this is a major cost item. If the activated carbon could be recovered and reused, substantial cost savings would occur.

4.0 CONCLUSION.

4.1 Conclusion.

Laundry wastewater recycling at CONUS installation quartermaster laundries is currently uneconomical to perform. There is no indication that present circumstances will change dramatically enough in the near future to warrant future study into recycling processes for installation quartermaster laundries.

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