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COST REDUCTION FOR WASTEWATER TREATMENT UTILIZING WATER MANAGEMENT AT HOLSTON ARMY AMMUNITION PLANT

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COST REDUCTIONS FOR WASTEWATER TREATMENT UTILIZING WATER MANAGEMENT AT HOLSTON ARMY AMMUNITION PLANT

Dennis J. Kravec
Product/Production Graduate Engineering Program
DARCOM Intern Training Center
Red River Army Depot

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Final Report

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DARCOM Intern Training Center - USALMC
Red River Army Depot
Texarkana, Texas 75501

FOREWORD

The research discussed in this report was accomplished as part of the Product/Production Engineering Graduate Program conducted jointly by DARCOM Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact: Professor T. F. Howie, DRXMC-ITC-PPE, Red River Army Depot, Texarkana, Texas 75501.

Approved:

Professor T. F. HOWIE, P.E.
Chairman, Department of Product/Production Engineering

For the Commandant

JAMES L. ARNETT, Director
DARCOM Intern Training Center

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study examines the cost reductions obtained by using water management techniques at Holston Army Ammunition Plant. It compares the cost obtained per 1000 gallons of wastewater treated to an original treatment proposal presented by Clark, Dietz and Associates Engineers, Inc. of Memphis, Tennessee.

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INTRODUCTION

During the past decade, environmental pollution has been a subject which has received much attention. Due to public pressure, various state and government agencies have passed strict environmental controls which industry must meet by the years 1977 and 1983. While in most cases the technology is available to meet the controls, the cost during the past few years has escalated to the point where it has become questionable whether or not these controls are economically feasible to the degree they were when first proposed. Due to this cost escalation, one of the prime objectives of industry is to find ways to reduce the cost of pollution abatement, while still meeting the standards which are scheduled to be implemented.

Government installations will be scrutinized as carefully as private industries. Therefore, to meet these standards, projects have been reviewed by various organizations under the leadership of Edgewood Arsenal and DARCOM.

One of the scheduled projects involves the Holston Army Ammunition Plant in Tennessee. To try and meet the 1977 standards imposed by the Environmental Protection Agency and the State of Tennessee, Clark, Dietz and Associates Engineers, Inc. of Memphis, Tennessee received contract DACA01-73-009110 in 1973. This contract was for a preliminary engineering report to propose an industrial waste treatment facility at Holston. The prepared report presents preliminary designs for pretreatment and terminal treatment systems which will result in an effluent meeting all controls which have been placed on the Holston Army Ammunition Plant.

Design parameters used by Clark, Dietz and Associates were researched through pilot plant tests conducted by Purdue University Environmental Engineering Center. Using these parameters, Clark, Dietz and Associates arrived at what they considered the best treatment facility available with present technology.

The construction philosophy proposed by the contractor is as follows. Since the plant is currently operating at 50% mobilization and it is unlikely that unless a national emergency occurs that production will go above 50%, staged construction is suggested. Staged construction will be approached by initially installing a waste treatment facility that is capable of handling wastes at 50% mobilization. Naturally at production levels greater than 50% this facility would be overloaded and would not meet with the proposed standards at all times.

Clark, Dietz and Associates arrived at a proposed total construction cost of 24 million dollars. The purpose of this report will be to see what savings are possible if a 50% in-house reduction in hydraulic or contaminant loading is used. Hydraulic loading will be the quantity of wastewater which is sent through the treatment facility. Contaminant loading will be the amount of chemical contaminants per unit of wastewater which the system must handle.

The author of this report will not change the treatment steps proposed by the contractor unless calculations show them to be unnecessary. The only assumption made will be that through in-house methods of water management control it will be possible to reduce the contaminant or hydraulic loading by 50%. The study will find the projected cost of the treatment per 1000 gallons of hydraulic loading through the first 5 years of implementation. In doing this study the author will use the staged construction procedure proposed by Clark, Dietz and Associates. The author chose this to insure that the treatment system will be in compliance with the effluent standards which have been designated.

The format of this paper will be as follows. Chapter II will present the literature information surveyed in writing this report. Chapter III will analyze the cost reductions associated with a 50% reduction in contaminant loading. Chapter IV will analyze cost reductions in the treatment system based on a 50% reduction in hydraulic loading. Chapter V will present the conclusions and recommendations of the report.

CHAPTER II

LITERATURE SURVEY

Pretreatment

According to (Zajil, 1972), pretreatment is the most important process undertaken at a treatment facility. It is in the pretreatment process that precise monitoring and small changes can play a significant role in reducing costs throughout the rest of the treatment facility. This is the result of the two very important roles played by the pretreatment process. The first is to remove as much of the contaminant load as possible by means of chemical addition. The second is to see that the proper amount of chemicals is added to maintain a consistent load on the various subsystems throughout the facility. This is quite important as significant costs will result if the system loading is allowed to fluctuate.

Neutralization

Neutralization is another very important subsystem in any wastewater treatment facility. (Nemerow, 1971) Not only can excessively acid or alkaline wastes adversely affect a receiving stream, they can also degrade the quality of biological treatment. Biological treatment is more efficient at pH values near neutrality. This is due to the fact that acidic or basic solutions restrict the growth of the microorganisms which control the biological treatment process. Therefore the addition of reagents to maintain a neutral waste stream throughout the treatment process is essential for proper biological treatment.

Biological Filters

A concise, yet complete description of biological filter units is given by (Imhoff and Muller, 1971). Biological filtration, or as it is sometimes called, trickling filtration, is a process by which biological units are coated with slime growths from zoological bacteria. These growths absorb and oxidize dissolved organic matter from the wastes applied to them.

Granite, limestone or more recently plastic rings form the surface material in the filters. These materials must have a high surface area per unit of volume in order to support a large surface of active film.

As was previously stated, the pH of the wastewaters must be closely watched as the wastewater flows into the biological filter units. This is necessary if the biological filter units are to perform to their design capacities.

Anaerobic and Aerobic Digestion

(Nemerow, 1971) provides a good insight into anaerobic and aerobic digestion of sludge. Two main groups of organisms, hydrolytic and methane, carry out digestion. Hydrolytic microorganisms attack complex organic substances and convert them to simpler organic compounds. As a by-product the organisms produce acetic and butyric acid. Methane microorganisms then use these acids and other by-products to chemically attack the simple organic compounds producing carbon dioxide and methane. To support an effective digestive environment, a balance between population of organisms, food supply, temperature and pH is essential. As a result of sludge digestion, the total volume of sludge can be reduced by as much as 50%.

Chlorination

(Shuvall, 1971) gives a description of chlorination as it pertains not only to municipal water treatment, but also industrial wastewater treatment. In an industrial situation such as the manufacture of munitions, ammonia nitrogen levels from a biological filter necessitate the addition of chlorine to convert the ammonia nitrogen into nitrogen gas and hydrochloric acid.

Carbon Adsorption

While many compounds can be removed or treated by the preceding systems, the Environmental Protection Agency suggested that no toxic materials could be discharged in the effluent from the Holston Army Ammunition Plant. Therefore activated carbon adsorption was proposed. (Zajil, 1972) says that the granular carbon used is made from bituminous coal. As the waste stream pass through a bed of carbon granules, compounds are adsorbed to the surface of the carbon granules.

While the above references are useful as background material, (Grady and Etzel, 1973) and (Deininger, 1974) are essential to determine design parameters and equations necessary to calculate equipment size in this report. (Grady and Etzel, 1973) also outlines the findings of laboratory-scale reactor studies conducted at Purdue University for Clark, Dietz and Associates. The original recommendations and cost data associated with this proposal are contained in (Clark, Dietz and Associates-Engineers, Inc. Vol.II, 1974). Chapter III presents a cost analysis for the treatment facility based on a 50% reduction in the contaminant loading of the treatment unit at Holston Army Ammunition Plant.

CHAPTER III

ANALYSIS BASED ON 50% REDUCTION IN CONTAMINANT LOADING

Background

Clark, Dietz and Associates have proposed the treatment facility depicted in Figure I. The system they designed should meet the effluent standards listed in Table 1. These effluent standards are the standards proposed by the Environmental Protection Agency and the State of Tennessee.

The cost estimates given by Clark, Dietz and Associates are listed in Table 2. These estimates were based on 1974 dollars and were increased by 30 per cent to reflect an anticipated construction cost increase of approximately 10 per cent per annum (bid dollars), assuming that the construction year would be 1977. All unit prices compiled by Clark, Dietz and Associates were based on manufacturers' quotations, standard cost estimate manuals and 1974 unit price data compiled by their firm. Clark, Dietz and Associates used the following equation to determine the staged construction (50% mobilization) cost.

$$Y_2 = Y_1 \left(\frac{a}{b} \right)^k \qquad \text{EQUATION 1}$$

where:

Y_2=total construction cost
Y_1=staged construction cost
a=design capacity (11.5 MGD)
b=half design capacity (5.75 MGD)
k=cost capacity factor (.65)

Figure I. Layout of wastetreatment plant

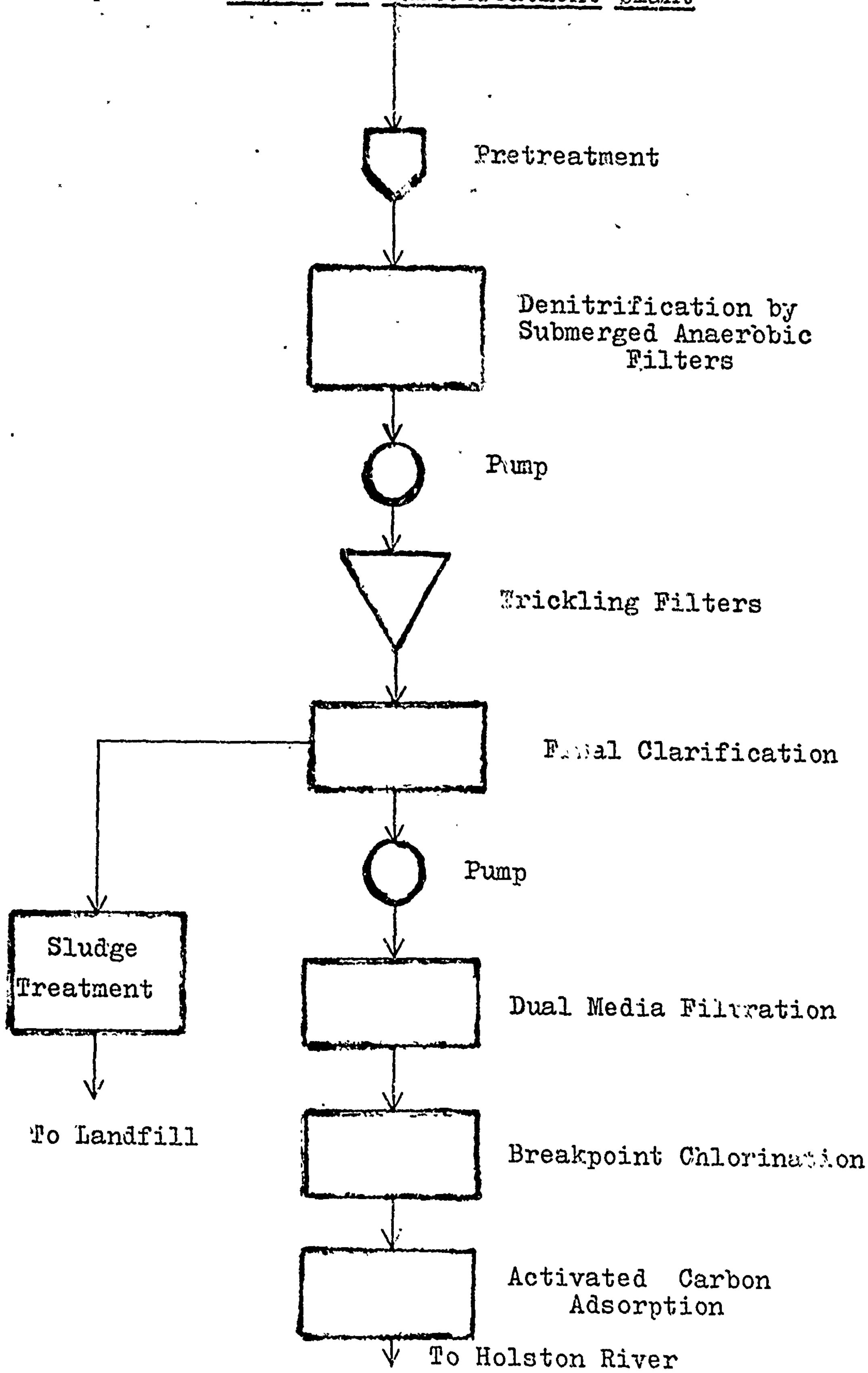


Table 1

Design Effluent Standards
Holston Army Ammunition Plant - Area B

Parameter	Maximum Daily Discharge (lbs/day)
BOD_5*	1430
Total Kjeldahl Nitrogen	76
Total Nitrogen	315
NH_3 Nitrogen**	76
NO_2-NO_3-Nitrogen***	230
Phosphorus	213
Suspended Solids	3370

*5 Day Biological Oxygen Demand
**Ammonia Nitrogen
***Nitrate - Nitrite Nitrogen

Table 2

Cost Estimate - Summary

Item	100% Mobilization Construction Cost	50% Mobilization Construction Cost
A. Pretreatment	734,043	467,791
B. Neutralization	122,238	122,238
C. Submerged Anaerobic Filters	1,987,728	1,266,170
D. Biological Filter Pump Station	214,073	214,073
E. Biological Filters	1,478,138	943,052
F. Final Clarifiers	750,062	478,540
G. Dual Media Filters	915,888	584,337
H. Breakpoint Chlorination	184,745	184,745
I. Carbon Adsorption	2,058,169	1,938,169
J. Miscellaneous Items and Roadway	236,088	142,230
K. Buildings	1,733,875	1,164,691
L. Instrumentation	170,500	150,000
M. Electrical	150,000	150,000
Sub-total cost (current $)	10,735,547	7,808,036
Sub-total cost (bidding $)	13,956,211	9,369,643
Sub-total cost (Volume I)	10,022,193	10,022,193
Total Cost (bidding $)	23,978,404	19,391,836

Assuming that a 50% reduction in contaminant loading could be realized through methods of wastewater management, a cost analysis was performed on the original proposal. The following areas were found to be affected and the projected costs were calculated from the available information. The costs used were those calculated by Clark, Dietz and Associates (current dollars), but these were adjusted by the use of index graphs obtained from the November 1975 edition of Chemical Engineering. The costs were then increased by 20% to reflect the anticipated construction date which is currently being considered for 1977 (bid dollars). A summary of these costs is given in Table 3.

Pretreatment System

The only system which Clark, Dietz and Associates found feasible for pretreatment was based on wet-oxidation for the conversion of organic-nitrogen to ammonia nitrogen. The principal nitrogen compound is hexamine (hexamethylene tetramine) and comes from the Ammonia Recovery Column. Assuming that a 50% reduction can be obtained in the column bottoms still necessitates the wet-oxidation procedure to eliminate the organic nitrates. Therefore the only reduction in cost obtained would be savings associated with chemicals, their storage and transfer. A summary of the pretreatment costs is given in Table 4.

Neutralization

The estimated phosphorous content of the wastewaters at Holston indicate that phosphorous addition will be needed before biological treatment. In addition, gross pH-control must be handled. For this, sodium hydroxide was suggested as the alkaline reagent and sulfuric acid as the acidic reagent. A summary of these costs is given in Table 5.

Table 3

Cost Estimate - Summary

Item	100% Mobilization Construction Cost	50% Mobilization Construction Cost
A. Pretreatment	842,967	537,206
B. Neutralization	103,651	103,651
C. Submerged Anaerobic Filters	1,690,143	1,077,095
D. Biological Filter Pump Station	274,152	274,152
E. Biological Filters	1,465,933	943,208
F. Final Clarifiers	453,787	289,189
G. Dual Media Filters	1,001,243	641,822
H. Breakpoint Chlorination	116,762	116,762
I. Carbon Adsorption	2,097,989	1,329,016
J. Miscellaneous Items and Roadway	285,666	182,049
K. Buildings	2,073,265	1,337,007
L. Instrumentation	206,305	186,305
M. Electrical	181,500	181,500
Sub-total cost (current $)	10,793,360	7,198,962
Sub-total cost (bidding $)	12,952,032	8,638,754
Sub-total cost (Volume I)	10,122,414	10,122,414
Total Cost (bidding $)	23,074,446	18,761,168

Table 4

Cost Analysis Area B, Pretreatment
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Wet Oxidation System	---	---	450,000
Chemical Storage Tanks	1	11,000	11,000
Rapid Mixing Basin	---	---	750
Pumps	1	---	3,500
Chemical Feeding Pumps	1	1,500	1,500
Chemicals	---	---	1,800
Ammonia Stripping Tower	1	2,500	2,500
Electrical Power Substation	---	---	5,000
Building	1	40,000	40,500

Sub-Total	516,050
Jan 74/Nov 75 index cost-21%	108,370
Construction Contingency-10%	62,442
Overhead and Profit-25%	156,105
Capital Cost Total	842,967

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital Cost (at bidding) 842,967 X 1.2 = 1,011,560

Table 5

Cost Analysis Area B, Neutralization Basin

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
20 HP Mixer	1	5,600	5,600
Concrete Structure	31	200	6,200
Sluice Gate	2	2,500	5,000
Chemical Storage Tanks	3	11,000	33,000
Chemical Feeding Pumps	2	1,500	3,000
Chemicals	---	---	500
Concrete Pad	60	150	9,000

Sub-Total	62,300
Jan 74/ Nov 75 index cost-21%	13,083
Construction Contingency-10%	7,538
Overhead and Profit-25%	20,730
Capital Cost Total	103,651

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 103,651 X 1.2 = 124,381

Submerged Anaerobic Filters

Normally, denitrification is used as a terminal treatment process in systems where nitrate is generated through the oxidation of ammonia and organic nitrogen. Due to the high level of nitrate-nitrite nitrogen in the wastewater at Holston, it is feasible to employ denitrification as the first treatment step.

Organic contaminants will serve as the substrate for the reduction of NO_3-NO_2-N to nitrogen gas and thus eliminate the necessity of adding synthetic substrates which would be necessary if terminal denitrification was used.

As a result of laboratory studies done at Purdue University (Grady and Etzel, 1973), a fixed film denitrification system known as a submerged anaerobic filter was recommended. A performance prediction model was developed for this filter from laboratory data:

$$N=N_0 e^{-\frac{\lambda Z}{\nu \eta}} \qquad \text{EQUATION 2}$$

where:

N=effluent NO_3-N level, mg/L
N_0=influent NO_3-N level, mg/L
Z=filter depth, ft.
ν=hydraulic application rate, ft^3/ft^2-hr
η= .5

λ is the media specific surface area which for a synthetic filter media produced by B. F. Goodrich is 1.15. Since this λ is temperature dependent, it must be adjusted to meet the minimum operating temperature of 18° centigrade at Holston. The following equation can be used to correct for the temperature dependency of λ.

$$\lambda_t = \lambda_{25^\circ}\, \theta^{t-25^\circ} \qquad \text{Equation 3}$$

where:

θ=temperature correction factor
t=minimum operating temperature
λ_{25°= 1.15

θ has been found from various studies to range from 1.14 - 1.16. Therefore 1.15 was used. This results in a λ_{18^o} of .38.

Based on a 50% reduction in the influent, the NO_3-N level will be 11.5 mg/L. The Environmental Protection Agency has established an effluent NO_3-N level of 1.2 mg/L.

By assuming various filter depths, the allowable hydraulic application rate can be calculated from Equation 3. Trial and error results are presented in Table 6.

Z, ft. filter depth	ν, ft^3/ft^2-hr application rate	total media vol. ft^3
10	3.37	190,500
12	4.05	190,000
14	4.73	190,000

Table 6. CALCULATED HYDRAULIC APPLICATION RATES

Since the total reactor volume and media volume represent the major costs of the unit, the application rate must be chosen to provide the best filter depth. It has been found that a ν greater than 4.35 ft^3/ft^2-hr caused reduced biological growth on the media and impaired the performance of the system. (Grady and Etzel, 1973) Therefore a depth of 12 feet was selected. At a filter depth of 12 feet, the surface area of the denitrification filters would be 15,800 ft^2.

The new layout would provide 24 individual filter units each 12 feet in depth, 18 feet high and 3 feet wide. Four banks of 6 filters each would be connected so as to handle 25% of the full mobilization design flow. A summary of the cost associated with these submerged anaerobic filters is given in Table 7.

Table 7

Cost Analysis Area B, Submerged Anaerobic Filters

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Plastic Media	190,000	2.25	427,500
Concrete Structure	1	314,000	314,000
Media Support system	2,940	15	44,100
Fiberglass Collecting Troughs	49	1,500	73,440
Piping	----	----	31,837
Control Valve Assemblies	24	5,000	120,000
Master Controller	2	2,000	4,000
Distribution Structure	2	4,900	9,800
Sluice Gates	4	2,500	10,000

Sub-Total	1,034,677
Jan 74/Nov 75 index cost-21%	217,282
Construction Contingency-10%	125,195
Overhead and Profit-25%	312,989
Capital Cost Total	1,690,143

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital Cost (at bidding) 1,690,143 X 1.2 = 2,028,177

Biological Filters

Studies conducted at Purdue University indicated that the use of conventional activated sludge to remove organics was technically unfeasible. (Grady and Etzel, 1973) This was due to the presence of filamentous organisms in the wastewater. Therefore, an aerobic fixed film reactor system was recommended.

The mathematical model used for predicting the performance of the reactor system was developed from laboratory data obtained by Purdue University.

$$S_b = S_{bo} e^{-\frac{\lambda Z}{\nu N}} \qquad \text{EQUATION 4}$$

where:

S_b=effluent T_{BOD}, mg/L *
S_{bo}=influent T_{BOD}, mg/L
Z=filter depth
ν=hydraulic application rate, gal/min-ft^2
λ=.0796 (overall reaction coefficient)
N= .5 (media characteristic)

Assuming a 50% reduction in T_{BOD} yields a T_{BOD} value of 87.5 mg/L. The minimum acceptable hydraulic application rate to insure wetting of the media is .8 gallons/min/ft^2. The maximum allowable concentration in the effluent set by the Environmental Protection Agency is 18 mg/L. Using these parameters, the following calculation shows the height of the filter media reguired. Z from Equation 4 equals 17.7 feet, or a filter depth of 18 feet at the hydraulic application rate of .8 gal/min/ft^2. A total surface area of 10,000 square feet would be required for a design flow of 11.5 million gallons per day. To provide flexibility, 4 fixed film reactors could be used. Each reactor would have a diameter of 57 feet. The total volume of the media required would therefore be 180,000 cubic feet. A summary of the costs for this system is listed in

* T_{BOD}=Total Biological Oxygen Demand

Tables 8 and 9.

Clarifiers

From the biological filters, the wastewater travels through clarifiers to remove suspended solids. Assuming that the suspended solids level will be reduced by 50% will allow the flow to be increased through the clarifiers while still maintaining the effluent quality suggested by the Environmental Protection Agency. A summary of the costs associated with this sub-system is in Table 10.

Dual Media Filtration

In the proposed design, the suspended solids level from the clarifiers (20 mg/L) is less than the effluent standard (35 mg/L). In spite of this, removal of the suspended solids is necessary to insure that the organic nitrogen contained in the biological solids is removed. In other words, at a suspended solids level of 20 mg/L and a design average flow of 11.5 million gallons per day, the projected organic nitrogen content of the solids would be 150 pounds per day. This is in excess of the 76 pounds per day total Kjeldahl nitrogen discharge standard. To eliminate this, a dual media filtration system was used in the original proposal.

Assuming a 50% reduction in the suspended solids, gives an initial load of 10 mg/L of suspended solids. Using the design average flow of 11.5 million gallons per day, an a loading of .078 mg N per mg of suspended solids, gives a projected organic nitrogen content of 75 pounds per day. Even though this is less than the allowable 76 pounds per day, in this preliminary report it can not justifiably be eliminated. A cost summary for the dual media filtration sub-system is given in Table 11.

Table 8

Cost Analysis Area B, Biological Filter Pump Station
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Structure	1	66,780	66,780
3 mgd variable speed pumps	6	13,000	78,000
12" Butterfly Valve	14	500	7,000
12" Swing Check Valve	6	750	4,500
Sump Pump	2	3,000	6,000
Misc. Fittings	---	---	2,500

Sub-Total	164,780
Jan 74/ Nov 75 index cost-21%	34,604
Construction Contingency-10%	19,938
Overhead and Profit-25%	54,830
Capital Cost Total	274,152

Cost Escalation
Construction cost index projected to increase an average of 10% annually.

Capital Cost (at bidding) 274,152 X 1.2 = 328,982

Table 9

Cost Analysis Area B; Biological Filters
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Plastic Media	180,000	2.25	405,000
Distributor Arm	4	20,000	80,000
Structure	4	92,100	368,400
Stairs	2	6,200	12,400
Distribution Structure	2	4,900	9,800
Sluice Gate	2	2,500	5,000

Sub-Total	881,100
Jan 74/ Nov 75 index cost - 21%	185,031
Construction Contingency - 10%	106,613
Overhead and Profit - 25%	293,186
Capital Cost Total	1,465,930

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital Cost (at bidding) 1,465,930 X 1.2 = 1,759,116

Table 10

Cost Analysis Area B, Final Clarifier

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Clarifier Mechanism	2	50,000	100,000
Weirs	2	1,650	3,300
Misc. Equipment, Piping, Fittings etc.	---	---	169,450

Sub-Total	272,750
Jan 74/ Nov 75 Index Cost--21%	57,277
Construction Contingency-10%	33,003
Overhead and Profit-25%	90,757
Capital Cost Total	453,787

Cost Escalation

Construction cost projected to increase an average of 10% annually.

Capital cost (at bidding) 453,787 X 1.2 = 544,545

Table 11

Cost Analysis Area B, Dual Media Filtration

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Horizontal Dual Media Pressure Filter	8	60,000	480,000
Vessels Support	112	200	22,400
Filter Pump Station Structure	1	10,000	10,000
3 mgd Pumps	3	13,000	39,000
Piping	---	---	11,800
Backwash Holding Tank	1	35,100	35,100
Methanol Storage Tank	1	2,500	2,500
Methanol Feeding Pump	1	1,000	1,000

Sub-Total	601,800
Jan 74/ Nov 75 index cost-21%	126,378
Construction Contingency-10%	72,817
Overhead and Profit-25%	200,248
Capital Cost Total	1,001,243

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 1,001,243 X 1.2 = 1,201,491

Breakpoint Chlorination

Organic nitrogen level control will result from a combination of pretreatment plus ammonia nitrogen uptake in the biological treatment units through the synthesis of biological solids. Since 2 mg/L is necessary for the biological treatment unit to operate, a savings can only be realized in the amount of chlorine necessary to achieve breakpoint chlorination. Based on a 50% reduction in contaminant loading, the amount of chlorine necessary would be 14 mg/L. This will result in savings in chemicals as well as their storage and transportation. The costs associated with this sub-system are given in Table 12.

Activated Carbon Adsorption

Although activated carbon adsorption could be used for the purpose of removing materials which exert BOD*, the principle purpose of carbon adsorption is to remove residual organic materials which could exert a toxic effect on biological life in the receiving stream.

Tests conducted by Purdue University indicated that explosives such as TNT and HMX would be removed by activated carbon treatment. (Grady and Etzel, 1973) The applicable carbon adsorption equation came from the Freundlich Isotherm:

$$X/M=(2.3 \times 10^{-5})\ C^{2.4} \qquad \text{EQUATION 5}$$

where:

X/M=ultimate capacity, g COD**/g Carbon
C=influent COD concentration, mg/L

Assuming a 50% reduction gives an influent COD level of 29-34 mg/L, this yields an ultimate capacity for activated carbon of .074 to .11 pounds COD per pound of Carbon.

*Biological Oxygen Demand
**Carbon Oxygen Demand

Table 12

Cost Analysis Area B, Chlorination Facilities
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Chlorination Feeding System	----	----	10,000
Monorail System	----	----	2,500
2 - ton Hoist	1	3,500	3,500
Chlorine Contact Basin	----	----	45,000
Piping	----	----	6,680
3' Throat Parshall Flume	1	2,500	2,500

Sub-Total	70,180
Jan 74/ Nov 75 index cost-21%	14,738
Construction Contingency-10%	8,492
Overhead and Profit-25%	23,352
Capital Cost Total	116,762

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 116,762 X 1.2 = 140,115

Experience has shown that a design capacity of 80% of that demonstrated by the carbon adsorption equation can be assumed. For the purpose of this design .06 pounds COD per pound of Carbon will be used. From Figure II, it is apparent that the minimum residual COD level is approximately 15 mg/L. At a design flow of 11.5 million gallons per day and using .06 pounds COD per pound of Carbon, the carben exhaustion rate will be 22,341 pounds of Carbon per day.

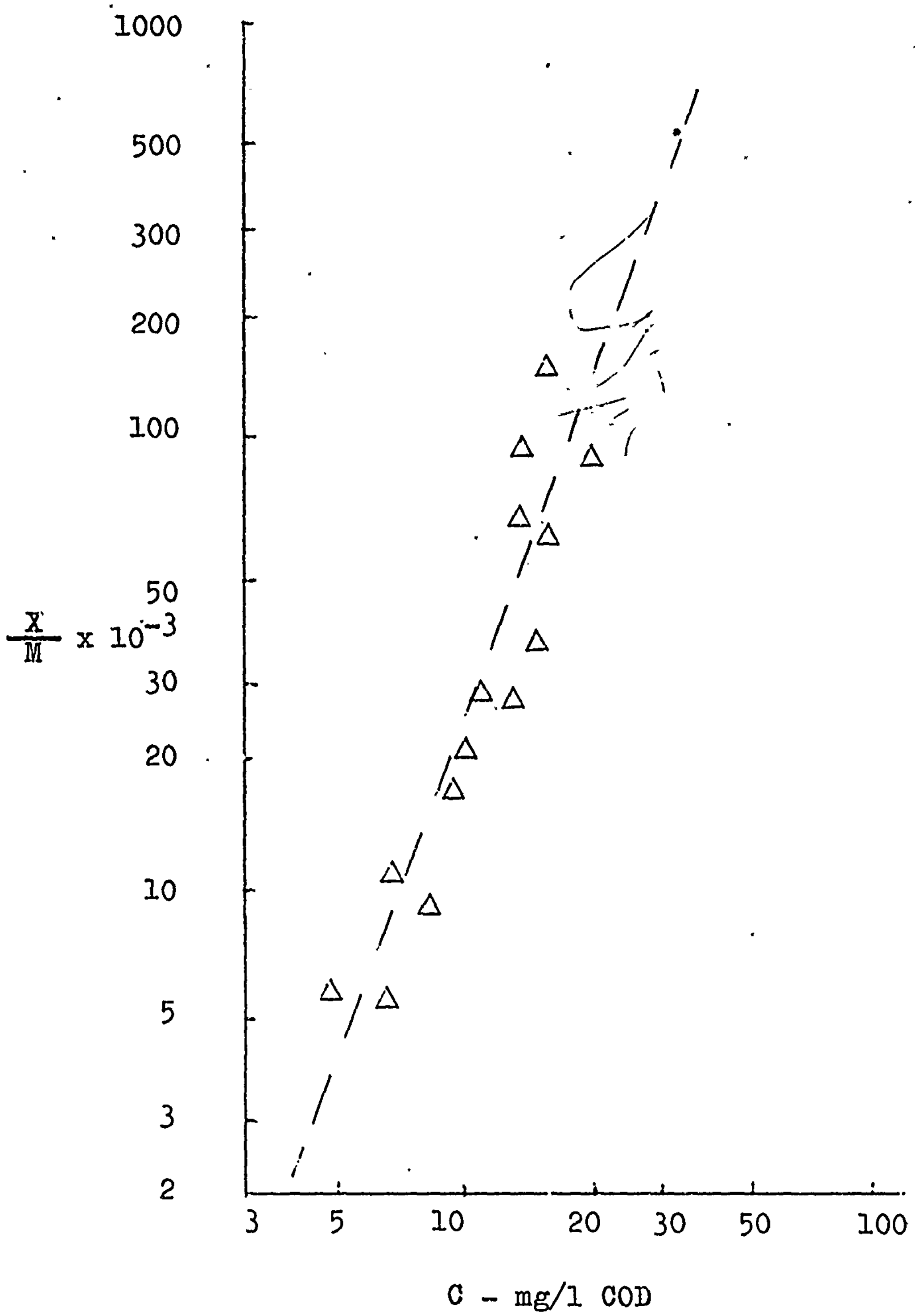
From tests conducted at Purdue University, the hydraulic application rate was estimated to be 5 gallons per minute foot squared. (Grady and Etzel, 1973) The contact time for a 50% reduction in contaminants could be estimated to be 11 minutes based on the Purdue figures. Under these conditions the total carbon bed depth required can be found from the following:

$$Z=(f\cdot Z_a)+\frac{(C_o)\ (G_1)\ (t_b)\ (8.33\text{x}10^{-6})}{\sigma_a\ (X/M)} \qquad \text{EQUATION 6}$$

where:
- $f\cdot Z_a$=fractional ability of the adsorption zone times height of the adsorption zone
- Z=bed height
- C_o=influent COD, mg/L
- G_1=hydraulic application rate, gpm/ft^2
- t_b=breakthrough time, minutes
- σ_a=packed density of Carbon, 26 lb/ft^3
- X/M=lbs COD/lb Carbon

Since the time to breakthrough (t_b) is dependent on the product ($f\cdot Z_a$), it is impossible to predict the exact bed height unless a pilot study would be conducted to determine ($f\cdot Z_a$). This is due to the fact that C_o, $f\cdot Z_a$, t_b and X/M all differ from the original proposal. At this point the author assumes that a bed height of 4 feet will be adequate since the retention time and contaminant loading have decreased.

Figure II. mg/l Removed by Carbon Adsorption VS Inout COD Concentration



To maintain the hydraulic application rate of 5 gallons per minute, a total surface area of 3200 square feet would be needed as was proposed in the original design. Therefore, the design proposed by this author would include 8 carbon adsorption beds each 10 feet by 10 feet with a depth of 4 feet. A summary of the cost associated with this sub-system is listed in Table 13.

Buildings, Roadway, Instrumentation and Electrical

Very little information is given in the original proposal concerning costs associated with buildings, roadways and electrical instrumentation. Since these will be necessary if the facility is built, the costs used in this report are those calculated by Clark, Dietz and Associates. These costs were increased by 1% which represents the cost index change minus the 10% for which Clark, Dietz and Associates allowed. The following chapter considers what cost savings will result if a 50% in-house reduction in hydraulic loading can be realized.

Table 13

Cost Analysis Area B, Carbon Adsorption Facilities
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Carbon Adsorbers (concrete)	270	200	54,000
Stainless Steel Hoppers	4	25,000	100,000
Carbon Media	780	600	468,000
Collecting Troughs	12	1,000	12,000
Process Water, Piping and Valves	---	---	32,360
Pump Station	1	78,280	78,280
Carbon Transport System	---	---	76,500
Regeneration System	---	---	425,000

Sub-Total	1,246,140
Jan 74/ Nov 75 index cost-21%	261,689
Construction Contingency-10%	150,783
Overhead and Profit-25%	414,653
Capital Cost Total	2,073,265

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 2,073,265 X 1.2 = 2,487,918

CHAPTER IV

ANALYSIS BASED ON 50% REDUCTION IN HYDRAULIC LOADING

A summary of the costs associated with a 50% reduction in hydraulic loading is given in Table 14. Below, each of the treatment areas are individually investigated.

Pretreatment and Neutralization

Due to the fact that these systems are primarily concerned with the chemical addition necessary to change the pH of the wastewater, a 50% reduction in hydraulic loading will not affect the amount of chemicals needed in this procedure. Cost summaries are given in Tables 15 and 16.

Submerged Anaerobic Filters

Reducing the hydraulic loading by 50% will result in a design flow of 5.75 million gallons per day. This will cause the influent (N_o) NO_3-N level to equal 46 mg/L. Using Equation 2 (Page 15) which was described in the previous chapter, the following results can be found:

Z, ft. filter depth	ν, ft^3/ft^2-hr application rate	total media volume ft^3
16	2.52	159,000
20	3.94	150,000
22	4.75	132,000

Table 17. CALCULATED HYDRAULIC APPLICATION RATES

At a filter depth of 20 feet, the surface area of the denitrification filters would be 7,500 feet squared. The proposed layout would provide

Table 14

Cost Estimate - Summary

ITEM	100% Mobilization Construction Cost	50% Mobilization Construction Cost
A. Pretreatment	888,192	566,027
B. Neutralization	147,907	147,907
C. Submerged Anaerobic Filters	1,319,024	840,588
D. Biological Filter Pump Station	192,629	192,629
E. Biological Filters	1,277,926	814,397
F. Final Clarifiers	907,575	578,380
G. Dual Media Filters	583,310	371,732
H. Breakpoint Chlorination	268,250	268,250
I. Carbon Adsorption	1,218,996	776,842
J. Miscellaneous Items and Roadway	238,449	151,958
K. Buildings	1,751,213	1,116,013
L. Instrumentation	172,205	152,205
M. Electrical	151,500	151,500
Sub-total cost (current $)	8,592,176	6,128,428
Sub-total cost (bidding $)	10,310,611	7,354,113
Sub-total cost (Volume I)	10,122,414	10,122,414
Total Cost (bidding $)	20,433,025	17,476,527

Table 15

Cost Analysis Area B, Pretreatment

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Wet Oxidation System	---	---	450,000
Chemical Storage Tanks	2	11,000	22,000
Rapid Mixing Basin	---	---	750
Pumps	2	3,500	7,000
Chemical Feeding Pumps	2	1,500	3,000
Chemicals	---	---	3,600
Ammonia Stripping Tower	1	2,500	2,500
Electrical Power Substation	---	---	5,000
Building	1	40,000	40,000

Sub-Total	533,850
Jan 74/ Nov 75 index cost-21%	112,108
Construction Contingency-10%	64,596
Overhead and Profit-25%	177,638
Capital Cost Total	888,192

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 888,192 X 1.2 = 1,065,831

Table 16

Cost Analysis Area B, Neutralization Basin
Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
20 HP Mixer	2	5,600	11,200
Concrete Structure	62	200	12,400
Sluice Gate	2	2,500	5,000
Chemical Storage Tanks	4	11,000	44,000
Chemical Feeding Pumps	3	1,500	4,500
Chemicals	---	---	1,000
Concrete Pad	72	150	10,800

Sub-Total	88,900
Jan 74/ Nov 75 index cost-21%	18,669
Construction Contingency-10%	10,757
Overhead and Profit-25%	29,581
Capital Cost Total	147,907

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 147,907 X 1.2 = 177,489

12 individual filter units, each 16 feet high and 2 feet wide. A summary of the cost estimated with this sub-system is in Table 18.

Biological Filters

To calculate the height of the filters, Equation 4 which was described in the previous chapter was used. Assuming a 50% reduction in hydraulic loading would result in a design flow of 5.75 million gallons per day and an influent T_{BOD} level, (S_{bo}), equal to 350 mg/L. Using these parameters a bed height (Z) of 26 feet was calculated. At a hydraulic application rate of .8 gal/min/ft^2, a total surface area of 5,000 feet squared would be required. The total media volume needed would then equal 130,000 cubic feet.

To provide flexibility, 4 fixed film reactors could be employed. Each reactor would have a depth of 26 feet and a diameter of 29 feet. A summary of the costs associated with this sub-system is listed in Tables 19 and 20.

Dual Media Filtration

Based on 50% reduction in the hydraulic loading, the suspended solids level will increase to 40 mg/L. Using the design flow and a level of .078 mg N per mg of suspended solids, the projected organic nitrogen content of the solids would be 150 pounds per day. Since this is in excess of the allowable 76 pounds per day shown on Table 1 (Page 9), suspended solids removal is necessary. The only cost savings which will result will be in the size of the filters, pumping and storage costs. A summary of these costs is given in Table 21 and 22.

Breakpoint Chlorination

A 50% reduction in hydraulic loading will not result in any

Table 18

Cost Analysis Area B, Submerged Anaerobic Filters

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Plastic Media	150,000	2.25	337,500
Concrete Structure	1,240	200	248,000
Media Support System	2,322	15	34,830
Fiberglass Collecting Troughs	39	1,500	58,500
Piping	----	----	25,172
Control Valve Assemblies	13	5,000	65,000
Master Controller	2	2,000	4,000
Distribution Structure	2	4,900	9,800
Sluice Gates	4	2,500	10,000

Sub-Total	792,802
Jan 74/ Nov 75 index cost-21%	166,488
Construction Contingency-10%	95,929
Overhead and Profit-25%	263,804
Capital Cost Total	1,319,024

Cost Escalation

Construction cost index projected increase an average of 10% annually.

Capital cost (at bidding) 1,319,024 X 1.2 = 1,582,829

Table 19

Cost Analysis Area B, Biological Filter Pump Station

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Structure	1	66,780	66,780
3 mgd variable speed pump	3	13,000	39,000
12" Butterfly valve	7	500	3,500
12" Swing Check Valve	3	750	2,250
Sump Pump	1	3,000	3,000
Misc. Fittings	---	---	1,250

Sub-Total	115,780
Jan 74/ Nov 75 index cost-21%	24,314
Construction Contingency-10%	14,009
Overhead and Profit-25%	38,526
Capital Cost Total	192,629

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 192,629 X 1.2 = 231,155

Table 20

Cost Analysis Area B, Biological Filters

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Plastic Media	130,000	2.25	292,500
Distributor Arm	4	20,000	80,000
Structure	4	92,100	368,400
Stairs	2	6,200	12,400
Distribution Structure	2	4,900	9,800
Sluice Gate	2	2,500	5,000

Sub-Total	768,100
Jan 74/ Nov 75 index cost-21%	161,301
Overhead and Profit-25%	255,585
Construction Contingency-10%	92,940
Capital Cost Total	1,277,926

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 1,277,926 X 1.2 = 1,533512

Table 21

Cost Analysis Area B, Dual Media Filtration

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Horizontal Dual Media Pressure Filter	4	60,000	240,000
Vessels Support	86	200	11,200
Filter Pump Station Structure	1	10,000	10,000
3 mgd Pumps	3	13,000	39,000
Piping	---	---	11,800
Backwash Holding Tank	1	35,100	35,100
Methanol Storage Tank	1	2,500	2,500
Methanol Feeding Pump	1	1,000	1,000

Sub-Total	350,600
Jan 74/ Nov 75 index cost-21%	73,626
Construction Contingency-10%	42,422
Overhead and Profit-25%	116,662
Capital Cost Total	583,310

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 583,310 X 1.2 = 699,973

Table 22

Cost Analysis Area B, Final Clarifier

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Clarifier Mechanism	4	50,000	200,000
Weirs	4	1,650	6,600
Misc. Equipment, Piping, Fittings etc.	---	---	338,900

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 907,575 X 1.2 = 1,089,090

appreciable savings in the chlorination system. As was explained in Chapter III, this is due to the fact that for the treatment unit to operate it is necessary to maintain a minimum ammonia nitrogen level of 2 mg/L. A summary of the costs is given in Table 23.

Activated Carbon Adsorption

A 50% reduction in hydraulic loading will give an influent COD level of 116-136 mg/L. Using Equation 5 (Page 24) would then result in an ultimate capacity for activated carbon of 2.07 to 3.03 pounds COD per pound of Carbon.

Using an 80% design estimate would yield a carbon capacity of 1.66 pounds COD per pound of Carbon. Using Figure II (Page 27) and an influent level of 116 mg/L of COD, results in 19 mg/L removed by activated carbon adsorption. At the design flow of 5.75 million gallons per day the projected carbon exhaustion rate is 2,797 pounds of Carbon per day.

As was stated in Chapter III, it is impossible to accurately predict the exact bed height unless pilot studies would be conducted. Under the criteria that the retention time and the influent COD level would increase, Equation 6 (Page 26) would suggest that the bed height would increase. Based on this, the author estimates that a bed height of 10 feet would be adequate.

To maintain a hydraulic application rate of 5 gallons per minute, a total surface area of 1,600 feet squared would be needed. Therefore the author recommends 4 carbon adsorption beds; each 5 feet by 8 feet, with a depth of 10 feet. A summary of the costs associated with this sub-system is listed in Table 24. The next chapter will present the results, conclusions and recommendations put forth by this report.

Table 23

Cost Analysis Area B, Chlorination Facilities

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Chlorination Feeding System	----	----	20,000
Monorail System	----	----	5,000
2-Ton Hoist	1	3,500	3,500
Chlorine Contact Basin	----	----	90,000
Piping	----	----	13,360
3' Throat Parshall Flume	1	2,500	2,500

Sub-Total	134,360
Jan 74/ Nov 75 index cost-21%	28,217
Construction Contingency-10%	16,257
Overhead and Profit-25%	44,708
Capital Cost Total	223,542

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 223,542 X 1.2 = 268,250

Table 24

Cost Analysis Area B, Carbon Adsorption Facilities

Capital Cost Estimate

ITEM	QUANTITY	UNIT COST	TOTAL COST
Carbon Adsorbers (concrete)	540	200	108,000
Stainless Steel Hoppers	8	25,000	200,000
Carbon Media	72	600	43,200
Collecting Troughs	24	1,000	24,000
Process Water, Piping and Valves	---	---	64,720
Pump Station	1	132,560	132,560
Carbon Transport System	---	---	99,000
Regeneration System	---	---	61,000

Sub-Total	732,680
Jan 74/ Nov 75 index cost-21%	153,863
Construction Contingency-10%	88,654
Overhead and Profit-25%	243,799
Capital Cost Total	1,218,996

Cost Escalation

Construction cost index projected to increase an average of 10% annually.

Capital cost (at bidding) 1,218,996 X 1.2 = 1,462,796

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

To find the cost associated with treating 1000 gallons of wastewater, an assumption had to be made concerning the time span under consideration. The author chose to compare cost per 1000 gallons over a 5 year time span. A 5 year time span was chosen because while maintenance expenses will occur over this period, they should not greatly affect one comparison over another. This assumption is considered to be valid as the only equipment changes recommended have been in size and quantity. This should result in maintenance costs being fairly consistent over the early life of the equipment. After 5 years, this assumption might not hold true. The following table shows the cost associated with each alternative at 100% mobilization.

Year	Proposal by Clark,Dietz and Associates	50% Reduction in Contaminant Loading	50% Reduction in Hydraulic Loading
1	$5.87	$5.49	$4.86
2	$2.93	$2.74	$2.43
3	$1.98	$1.83	$1.67
4	$1.47	$1.37	$1.27
5	$1.17	$1.10	$ .97

Table 25. 5 YEAR COSTS AT 100% MOBILIZATION

These values were obtained by dividing the total costs in tables 2, 3, and 14 by the volume of water that has been treated up to that time. This value is then represented as cost per 1000 gallons of wastewater treated. Based on these figures, if the hydraulic loading could be reduced by 50%, the savings over the original proposal for a 5 year period would average $ .44 per 1000 gallons treated.

The reason that a reduction in hydraulic loading results in a lower cost than a similar reduction in contaminant loading, is that for a reduced hydraulic load a reduction is achieved in the equipment size. This does not hold true for contaminant loading as calculations show most of the original equipment is still necessary to meet the effluent standards.

The following table presents the costs associated with 50% mobilization or staged construction.

Year	Proposal by Clark, Dietz and Associates	50% Reduction in Contaminant Loading	50% Reduction in Hydraulic Loading
1	$9.24	$8.93	$8.32
2	$4.62	$4.47	$4.16
3	$3.08	$2.98	$2.77
4	$2.31	$2.23	$2.08
5	$1.85	$1.79	$1.66

TABLE 26. 5 YEAR COSTS AT 50% MOBILIZATION

Based on these figures, if the hydraulic loading could be reduced by 50%, the savings over the original proposal for a 5 year period would average $ .42 per 1000 gallons treated.

The results of this report show that significant cost reductions can be made over the original proposal. If the reductions in contaminant or hydraulic loading can be realized, the author feels that the treatment facility designed by Clark, Dietz and Associates will not be the most cost effective design in controlling the pollution. While the contractor has designed a system which will meet with all the effluent standards, the author feels that Clark, Dietz and Associates has failed to consider the costs and effects which would result if improvements would be made on equipment which is currently in operation within the plant. The author therefore recommends the following:

1) That a study be implemented concerning the ammonia recovery column. If significant steps can be achieved in reducing the organic load from the column bottoms, appreciable savings can be achieved through the elimination of the denitrification, dual media filters and breakpoint chlorination systems.

2) That a feasibility study be implemented to see if it is possible to recycle cooling water streams within the plant. Currently, this water is being used once. Even though it then contains no pollutants under the original design it is treated.

3) A cost analysis must be done to see what additional costs will be incurred to recycle water streams within the plant and improve the efficiency of the ammonia recovery column.

4) Finally, based on the results of studies 1 and 2, pilot-scale verifications should be made concerning the laboratory design parameters. This is necessary to eliminate any unfounded conservatism in the final design.

In conclusion, the purpose of this report was to see if estimated reductions would cause significant savings in the treatment facility. A systems analysis of the wastetreatment facility was performed and resulted in a savings of 3.5 million dollars in total construction cost. In addition, the author recommended that studies be performed on the ammunition plant itself. While these studies are beyond the scope of this report, due to lack of equipment and available information, they should be performed before the current design moves out of its preliminary stage. This is based on the opinion that conclusions from these studies will show a reduction in the amount of treatment needed. This will result in further cost reductions through the elimination of various treatment processes. The resulting system, while still meeting all effluent standards, would therefore have a significantly smaller construction cost than the design currently under consideration.

REFERENCES

1. Chemical Engineering. November 10, 1975; Vol. 82, No. 24. McGraw-Hill, Inc., New York, New York, 1975.

2. Clark, Dietz and Associates-Engineers, Inc. Industrial Waste Treatment Facilities, Holston Army Ammunition Plant. Vol. I, January, 1974.

3. Clark, Dietz and Associates-Engineers, Inc. Industrial Waste Treatment Facilities, Holston Army Ammunition Plant. Vol. II, January, 1974.

4. Deininger, Rolf A. Models For Environmental Pollution Control. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1974.

5. Grady, C.P.L., Jr. and J. G. Etzel. Development of Design Parameters for Treatment of Industrial Wastewater from the Holston Army Ammunition Plant. Purdue Research Foundation, 1973.

6. Imhoff, Karl and W. J. Muller. Disposal of Sewage and Other Waterborne Wastes. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1971.

7. Nemerow, Nelson L. Liquid Waste of Industry: Theories, Practices and Treatment. Addison-Wesley Publishing Company, Reading Massachusetts, 1971.

8. Shuvall, Hillel I. Developments In Water Quality Research. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1971.

9. Zajil, J. E. Water Pollution: Disposal and Reuse. Vol. I, Marcel Dekker, Inc., New York, New York, 1972.