CLEAN WATER

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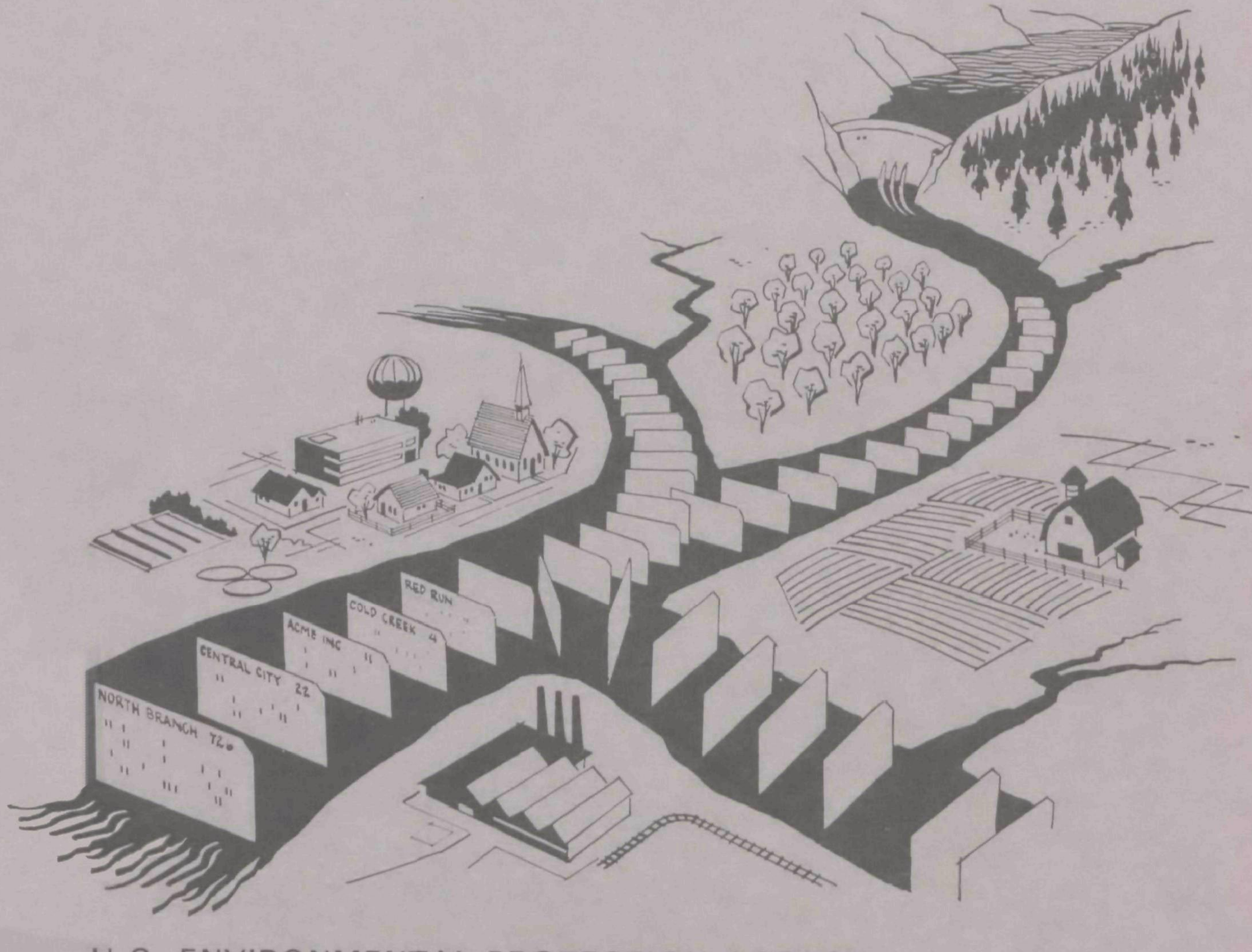
Basin Management For Water Reuse



U.S. ENVIRONMENTAL PROTECTION AGENCY

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BASIN MANAGEMENT FOR WATER REUSE

by

ALAMO AREA COUNCIL OF GOVERNMENTS

Three Americas Building
San Antonio, Texas 78205

for the

OFFICE OF RESEARCH AND MONITORING

ENVIRONMENTAL PROTECTION AGENCY

Project #16110 EAX

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ABSTRACT

Computer programs were developed for the preliminary design and costing of wastewater renovation by the lime-clinoptilolite-carbon processes of advanced waste treatment; for activated sludge treatment; and for pipeline conveyance of water. These together with methods or algorithms of lesser depth for other processes were used to cost water supply and waste treatment under conditions expected in San Antonio in the year 2000 for two extreme alternatives, one importation of surface water according to the Texas Water Plan and conventional water treatment, waste treatment and disposal by discharge; the other completly closed recycle, discharging no waste water and reusing all the waste water after treating it to make it reusable. The unit costs for these two extremes were about 20¢/kilogallon of water used and the reuse scheme was only 10% more costly than the conventional scheme, i.e. well within the expected error of the estimates. It was shown that the seasonality of the water consumption in the face of non-seasonality of the sewage produced has an important bearing on the design and cost of reuse systems.

This report is submitted toward fulfillment of Grant No.16110 EAX under the partial sponsorship of the Environmental Protection Agency.

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CONCLUSIONS

In the design of municipal water reuse systems a very important factor is the seasonality of the water consumption in the face of the relative constancy of the sewage production. This situation means that there is a seasonal variation in the amount of new makeup water required in the system. This seasonality makes for a lower utilization factor and thus a higher cost than would be estimated from constant annual averages. Furthermore the seasonality brings about a continually fluctuating quality in the blend water being used or a continually fluctuating requirement for demineralization.

The magnitude and seasonal nature of these effects depend upon the makeup quantity and the relative quality of the makeup water and the required blend as well as on the characteristic impurity increment added to the water by a single municipal use. In San Antonio the conditions are such that without discharge and without demineralization the water would be better with respect to inorganic contaminants in the summer than in the winter, levelling off at about 1000 mgpl (milligrams per liter) in the winter and about 500 mgpl in the summer. To meet a typical quality standard of 500 mgpl would require no demineralization during two summer months and demineralization to the extent of removing 45 - 70% of the contaminants on all of the recycled water during two winter months.

The cost of supplying the projected San Antonio water supply and waste treatment at the quality and cost levels of 1969 and at the quantity levels estimated for the year 2000 by the conventional means of importation and sewage treatment and discharge according to the current Texas Water Plan would be within 10% of the cost of not discharging any wastes but treating all sewage by advanced waste treatment and reusing the product water. The 10% difference is well within the estimating error which means that the complete reuse cost is comparable with the conventional importation and discharge cost. (Certain alternatives to the Texas Water Plan are said to have lower costs for a conventional system.)

The San Antonio conditions are favorable for the conventional scheme because the makeup water would be partly from local ground water which is relatively inexpensive. (The conventional scheme requires more makeup than the reuse scheme.) In cities not having access to ground water the reuse scheme would have that additional advantage.

RECOMMENDATIONS

1. In their planning for future water and waste water management, municipalities should utilize preliminary estimating and comparison methods, as partly worked out herein and elsewhere to assess the relative economics of advanced treatment and recycling of waste waters in comparison with the conventional methods of seeking additional water sources and discharging waste to streams.

2. Most of the seasonality in water consumption comes from irrigation of urban and suburban lawns. It is not meant to derrogate the aesthetic and the psychological value of lawns, but using the methods of this report some exemplary studies should be made to determine the dollar cost to the community of having (and irrigating) lawns. The seasonality, of course, would be reduced as well as the total water consumption and thus the community costs would be reduced. Comparison of the costs for the actual consumption pattern with the corresponding costs for a hypothetical pattern from which the lawn losses had been eliminated would provide the information on just what lawns are costing.

3. Work on the methodology partly developed in this project should be continued so as to provide a complete methodology that is applicable for any municipality having any particular set of conditions and possibilities. The most pressing need in the methodology is to complete the work on the recycle problem, namely the method for determining in a given system what quantity must be demineralized and what quantity discharged in order to maintain a blend which just fails to violate any of the quality constraints imposed. This project studies the two extremes, namely (1) demineralize and recycle none, discharge all, and (2) recycle all, discharge none. Actually, it is very likely that the lowest cost will be achieved somewhere between these two extremes, particularly if a conventional sewage treatment plant is already constructed and in operation.

4. In the present study lacking any other information, it has been assumed that the municipal increment, namely the concentration increment in the sewage attendant upon one municipal use, does not have seasonality. Possibly this is correct, but if it is not correct the recycle algorithm would have to be quite severely modified. Thus, before a recycle algorithm could be generally useful, it would be necessary to demonstrate whether in general the municipal increment has seasonality. This should be done by sampling and analysis program in a number of cities carried out over a complete year.

5. Because of its bearing on the total cost in reuse, a study should be made in a number of cities to determine the extent and duration characteristics of the excesses of sewage flow over water used. In a reuse scheme if there are any days on which the sewage flow is greater than the water use the excess water must either be wasted or stored. If it is to be wasted, treatment and discharge must be provided; if it is to be stored, storage must be provided; in either case representing a cost not covered in the methodology of the present study.

6. A number of other recommendations for further work are contained in the appropriate sections of Chapter I including the construction of practical design and costing computer programs for demineralization, for canal conveyance and for ground water facilities.

CHAPTER 1

SUMMARY OF PROJECT

This project explored what is required and what happens if some or all of the sewage collected from a municipality is treated by advanced waste treatment (AWT) and put back in the water distribution system. By what happens and what is required is meant the changes in the quantities of water withdrawn from the sources, passing through the city and treated by various means, the changes in the concentrations of contaminants in the water and the means taken to keep these within specified limits, the size and costs of the facilities for accomplishing this recycle system, and the annual costs of such a scheme as compared with the annual costs of the conventional once-through scheme of supplying the same demands. Portions of the results are general and usable for any municipal situation. Others are specific for San Antonio in the year 2000 which was used as a concrete case around which to frame the project.

This chapter is a summary of the remaining five chapters. Chapters 2, 4, and 5 are computer programs for designing and costing advanced waste treatment processes for renovation, pipeline conveyance, and activated sludge treatment. Chapter 3 discusses the pattern and logistics of municipal recycle showing that the design and operation is considerably more complex than hitherto revealed. An important role is played by the losses that occur between the water distribution and the sewage delivered. In addition, these losses have a high seasonality which complicates the design. Chapter 3 also supplies the numbers for the year 2000 for San Antonio for two extreme cases: discharge all and reuse none, and: discharge none and reuse all. Chapter 6 develops the investment and operating costs on an annual cost basis for these two cases, in 1969 dollars.

The outcome is that complete reuse is almost as cheap as the conventional once-through system. Indeed, the difference is only 10% which is so close that any real decision would have to await a more refined study.

In the year 2000 a design water usage of 341 mgd (million gallons per day) average is predicted for San Antonio, with either system. For the conventional system of ground water plus surface water, treatment of the surface water, conventional sewage treatment and discharge, the required investment is 264 m$ (million dollars) and the total annual production costs 24.4 m$/yr (million dollars per year), 19.5¢/Kgal (Kilogallon). For the reuse scheme involving ground water, no surface water, no water treatment, advanced waste treatment by the lime-clinoptilolite-carbon process directly on the raw sewage and recycling for reuse, the investment is 169 m$ and the annual production costs are 26.8 m$/yr, 21.6¢/Kgal.

LOGISTICS OF MUNICIPAL RECYCLE

General Pattern and the Recycle Problem

Discussions on municipal recycle customarily stop at: "Let's treat the sewage to make drinking water out of it and put it back into the mains." Chapter 3 explores in some detail what is required and what happens if this is done and reveals incidentally why so many discussions come to a stop at that point.

The generalized pattern of municipal use and reuse is shown in Figure 1.

The water in a conventional municipal water supply and waste disposal system is receiving a continual input of contaminants: the contaminants in the source water, the contaminants introduced through use, and the contaminants introduced in the course of treatment for discharge. In the typical U.S. city in addition to the increment of several hundred mgpl of organics resulting from municipal use, the water also receives an increment of the order of 300 mgpl of inorganic ions.

In the conventional once-through system these contaminants are removed in the sewage treatment, in the discharge, in the losses from the sewage collection piping and in the losses representing water that is used but not returned to the collection system, the last in a major way from the watering of lawns but also from fire fighting, street flushing, etc.

In a recycle for reuse scheme some or all of the collected sewage is diverted from discharge and treated to make it acceptable for reuse. This closing of the system introduces two hitherto untackled problems - a quantity problem and a concentration problem which are themselves individually complicated and which besides are inter-related with each other in a complicated way.

As to the quantity problem it is not possible to obtain all the needed water from recycle because some of the water used does not find its way to the treatment plant but is lost in lawn losses and pipe losses. At least this much must come from makeup water, ordinarily, of course, from the source which had been in use in the conventional system. This in

PROCESS ELEMENT SEQUENCE IN MUNICIPAL RECYCLE

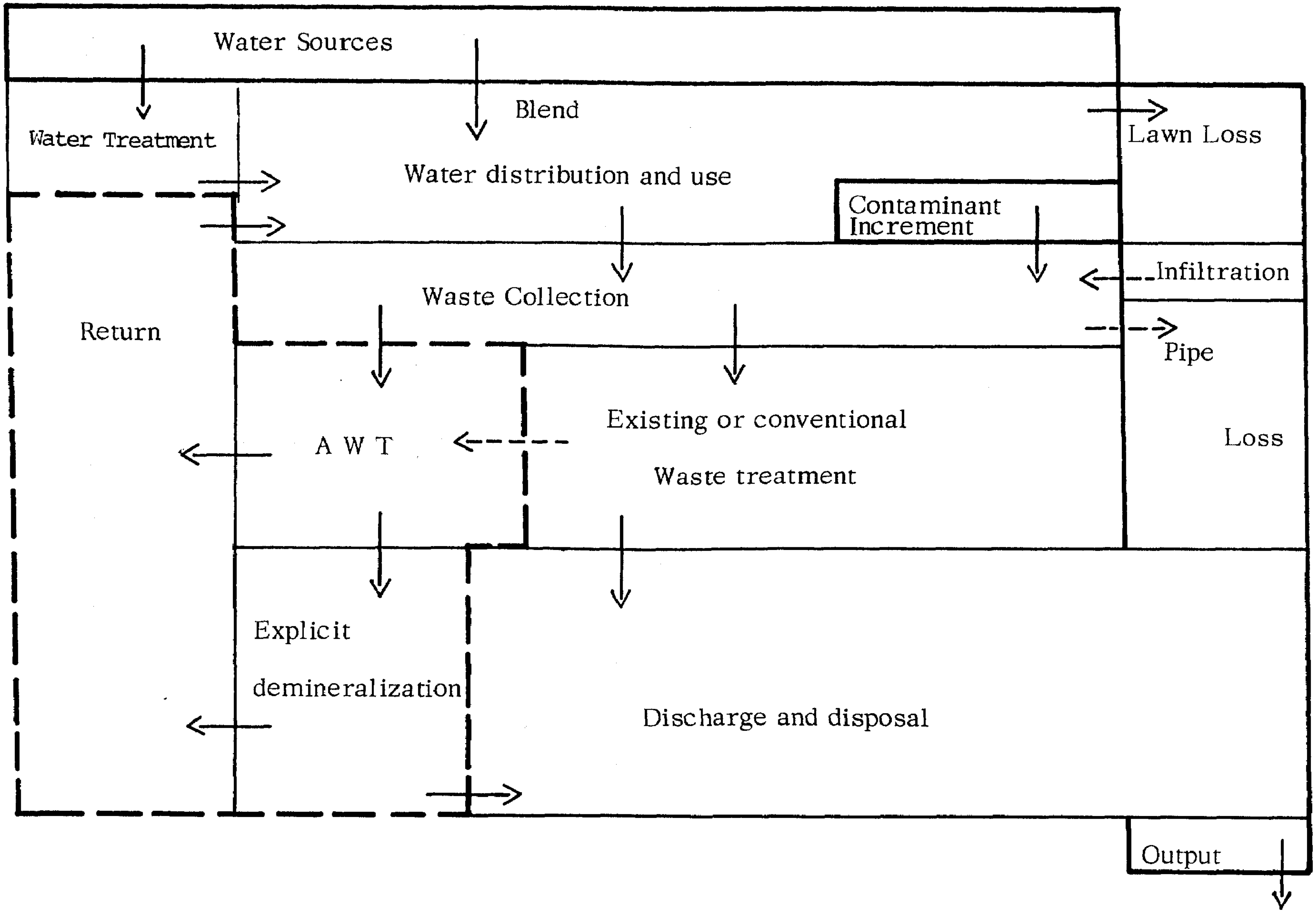


Figure 1

itself would not be much of a complication except for the unfortunate fact that while the quantity of sewage collected is almost constant throughout the year the quantity of water used has a high seasonality which obtains almost soley because of the high seasonality of lawn irrigation, high in the summer and low in the winter. This means that the system for supplying the makeup water must face a highly variable load and therefore must operate under the disadvantage of a low utilization factor, that is it must have the capability to meet a high maximum day demand but must in the year's average spread the costs over a much smaller quantity. Indeed where the present supply, now in the recycle scheme to be used for makeup, is close to its physical constraint limit it means that the new additional makeup system must be installed simply to supply a peak demand during a few months of the year.

This makes for a complicated and expensive system but this complication is nothing compared with the concentration complication.

One of the objectives that must be satisfied in reuse is to have the blend of the makeup and the return be suitable for use; that is, there is some specified constraint on each contaminant in the blend. If the return water had zero contaminants and if the makeup concentrations were all lower than the blend constraints then any quantity of return would be allowed. However, if some of the makeup concentrations are higher than the blend constraints then the return must be considered as "dilution water" for that contaminant and the blend constraint could only be met if the quantity of return water were sufficient. But the quantity of return water is limited. In San Antonio in the summertime the return water cannot amount to more than about 40% of the water used. This means that it would not be feasible to reduce the contaminant level in the makeup to half of its value. Of course, this is not a situation that would occur very often. In most cases presumably the municipality would be willing to accept a slightly lowered quality in the blend water compared to the makeup which they had historically been using. However, the circumstance could arise if it were necessary to seek a supplemental source if that source were highly mineralized.

But it would be very expensive to produce a return water with zero contaminants. Instead one would attempt to remove from the sewage only so much contaminants as is required to meet the blend constraint. In that case it is usually rather the makeup water which serves as the dilution water for the return. If all of the sewage collected is used as return water then in the summertime when the use of makeup water is high the return water would not have to be purified to the degree that it must be in the wintertime when the makeup water for dilution is low. Indeed, as actually happens in the San Antonio case it might not be necessary to demineralize at all in some of the summer months. Thus not only is the makeup water system faced with a low utilization factor but also the demineralization system is similarly disadvantaged.

Some demineralization processes may be adjusted so that they only partially remove some of the contaminants to the extent desired. Other demineralization processes remove some contaminants to a high degree and cannot efficiently be made to do less. Where the inherent removal in a demineralization process is greater than needed not all of the return need be demineralized. If such is true for all of the contaminants then for one contaminant the quantity that has to be demineralized has to be greater than for any other and only this quantity need to be demineralized. The rest can be bypassed.

Some demineralization processes remove certain contaminants very poorly. For such contaminants or indeed for any contaminants, those for which the input quantities are greater than the sum of the output quantities in the lawn loss, the pipe loss, and the demineralization process will build up in the recycling water and eventually exceed any blend constraint. Of course, one might shift to a demineralization process such as distillation and mixed bed ion exchange polishing which would remove virtually all of the contaminants. However, in general, presumably a cheaper way to handle this contaminant build up is to purge some of the sewage by discharge. While the conventional scheme involves "discharge all and reuse none," and the complete reuse scheme involves "reuse all and discharge none," this represents a compromise between the two, in the interests of ultimately achieving a cost lower than for either extreme.

There may, however, be constraints on the discharge also. There are already constraints on discharges with respect to organic contaminants and total suspended solids. In some places there are constraints on the discharge with respect to phosphates which in general appear to be handled not by phosphate removal processes but by prohibiting phosphate from appearing in the municipal increment.

For the common water minerals, NaCl, Ca(HCO3)2, etc., it is unlikely that any discharge constraint would be violated by a municipal sewage if the municipal water itself was fit to drink in the first place. However, if demineralization is practiced and one is attempting to dispose of the demineralization residue in the discharge then it is quite possible that discharge constraints could be violated. In this case there would be still another constraint on the amount that could be demineralized.

The foregoing discussion has been presented to assist the reader to visualize the complexity of the problems involved in municipal recycle and to recognize that the problem is far more complex than usually associated with the carefree philosophy "let's treat the sewage to make drinking water out of it and put it back into the mains." The formal statement of the logical problem is as follows:

> In a system of recycle for reuse having water for use as a blend of makeup water and recycled water, having a contaminant increment attendant upon use, having losses in use not returned to the treatment plant (lawn losses), having losses in transit of waste not returned to the treatment plant (pipe losses), having conventional sewage treatment, having advanced waste treatment with some attendant demineralization, having explicit demineralization and allowing some by-pass thereof and having discharge and disposal,
>
> GIVEN:
>
> makeup water quality in N contaminants, criteria (maxima) for water quality in use in N contaminants, municipal concentration increment in N contaminants, quantity of pipe losses, quantity of lawn losses, any set of treatment and advanced treatment processes, any set of explicit demineralization processes, criteria for water quality of the discharge in N contaminants, and any set of disposal processes,

DETERMINE:

for any given quantity of effluent discharged what quantity of the recycle must be demineralized (and what quantity by-passed) in order to maintain in the blend water and the discharge a steady state concencration meeting the criteria in N contaminants.

The answers to this problem comprise the quantity to be demineralized and the quantities to be discharged. For any given set of conditions, water use quantity, losses, municipal concentration increment, characteristics of treatment and demineralization processes, etc., there may be or there may not be a feasible solution. If there is a feasible solution there is a set of discharge quantities that will allow a solution which just fails to violate the criteria. For any of the allowed discharge quantities there are two demineralization quantities which will satisfy the criteria. Of these two demineralization quantities the higher one will give a total cost for the system which is higher than the cost for the lower one. (For any given demineralization quantity there is also a pair of discharge quantities which will satisfy the criteria but a simple statement cannot be made as to which of the two will be cheaper.) These pairs of economic discharge-demineralization quantities provide a set of solutions which will meet the criteria. One of these pairs will have a cost lower than all others and this is the optimum solution.

This optimum point may lie anywhere from one extreme to the other. The one extreme is to discharge all the sewage collected and reuse none and therefore demineralize none. The other extreme is to discharge none of the sewage collected and reuse all in which case of the amount reused the amount demineralized may be none, some, or all. In between the extremes lie the various combinations of discharge some, return some, and of that returned demineralize none, some, or all.

Mathematically the possibilities for the solution are represented as follows:

$$D = \text{Quantity discharged}$$

$$D = \frac{\text{Quantity discharged}}{\text{Quantity collected}} = 1 - R$$

$$R = \frac{\text{Quantity returned}}{\text{Quantity collected}} = 1 - D$$

$$Z = \frac{\text{Quantity demineralized}}{\text{Quantity retruned}}$$

$$Z = f(R, \text{------})$$

$$1 \geq R \geq 0$$

$$1 \geq Z \geq 0$$

R is the fraction of the quantity collected that is returned, Z is the fraction of the quantity returned that is demineralized. Z is a function of R and the constraints and other quantity parameters. R and Z may lie in the range between zero and one but such that the pair satisfy the functional relation.

The problem is akin to a linear programming problem but departs from linearity in a number of ways such that linear programming cannot be used for solving it. The project did not have sufficient time to work out the computer algorithm for solving the problem and the completion of the work on the problem remains as a recommendation for further investigation.

Instead, the project investigated the two extremes which are:

1. Conventional supply primarily by import and conventional waste treatment and discharge with no reuse and no demineralization, and

2. Complete reuse with required demineralization and with no discharge.

Chapter 3 develops the quantity pattern for these two extremes. Chapter 6 summarized beyond developes the costs thereof.

Numbers for San Antonio, Year 2000

Figure 2 shows a long term trend in water use in Bexar County as represented by withdrawals from the Edwards. There appears to be an upward trend for the first 20 years but after the drought in 1957 the per capita consumption falls back to the 1940 level. It is projected that the usage in the target year 2000 A.D. (anno Domini) will not differ greatly from the usage in the 60-70 decade.

Figure 3 shows the long term trend for sewage collected and the difference between water used and sewage collected, being the total loss. Over the past 15 years it appears that the gpcd (gallon per capita per day) for sewage collected has been increasing and the loss has been decreasing. Indeed, one could draw trend lines showing that in four or five years the sewage collected would amount to more than the water used. Such a trend, although not impossible and resulting from heavy infiltration or gradual inclusion of storm flows in the sewer system, is thought to be spurious and as will be seen the bases for the 2000 design are the figures from the 61-65 seasonal study to be described.

The decrease in the loss does not come from any change in rainfall. The annual rainfall over the period of interest has not been increasing particularly and the seasonal study to be described showed that the monthly loss ratio has only a second order correlation with the monthly rainfall, the main predictive parameter being the monthly temperature.

For the design basis the maximum day for water use and the maximum day for sewage collected were taken in ratio to the maximum month, both expressed as mgd (million gallons per day). The 90 percentile values for these ratios are 1.30 and 1.85, respectively. This means that there is only a 10% chance that the ratio in any single year might be greater than these values and these were used in the system design.

A study was made of the monthly per capita water withdrawal and sewage delivered in San Antonio for 1961-1965 which some of the results are presented in Figure 4. It is seen that the sewage flow has little seasonal variation but the water use has an extreme peak in July and August. As the basis for the 2000 design the monthly average per capita water withdrawal was taken as approximately the upper envelope of the water curve in Figure 4, and the makeup was similarly taken from a curve showing the excess of per capita water withdrawal over sewage delivered.

BEXAR COUNTY ANNUAL WATER USE
ex IRRIGATION

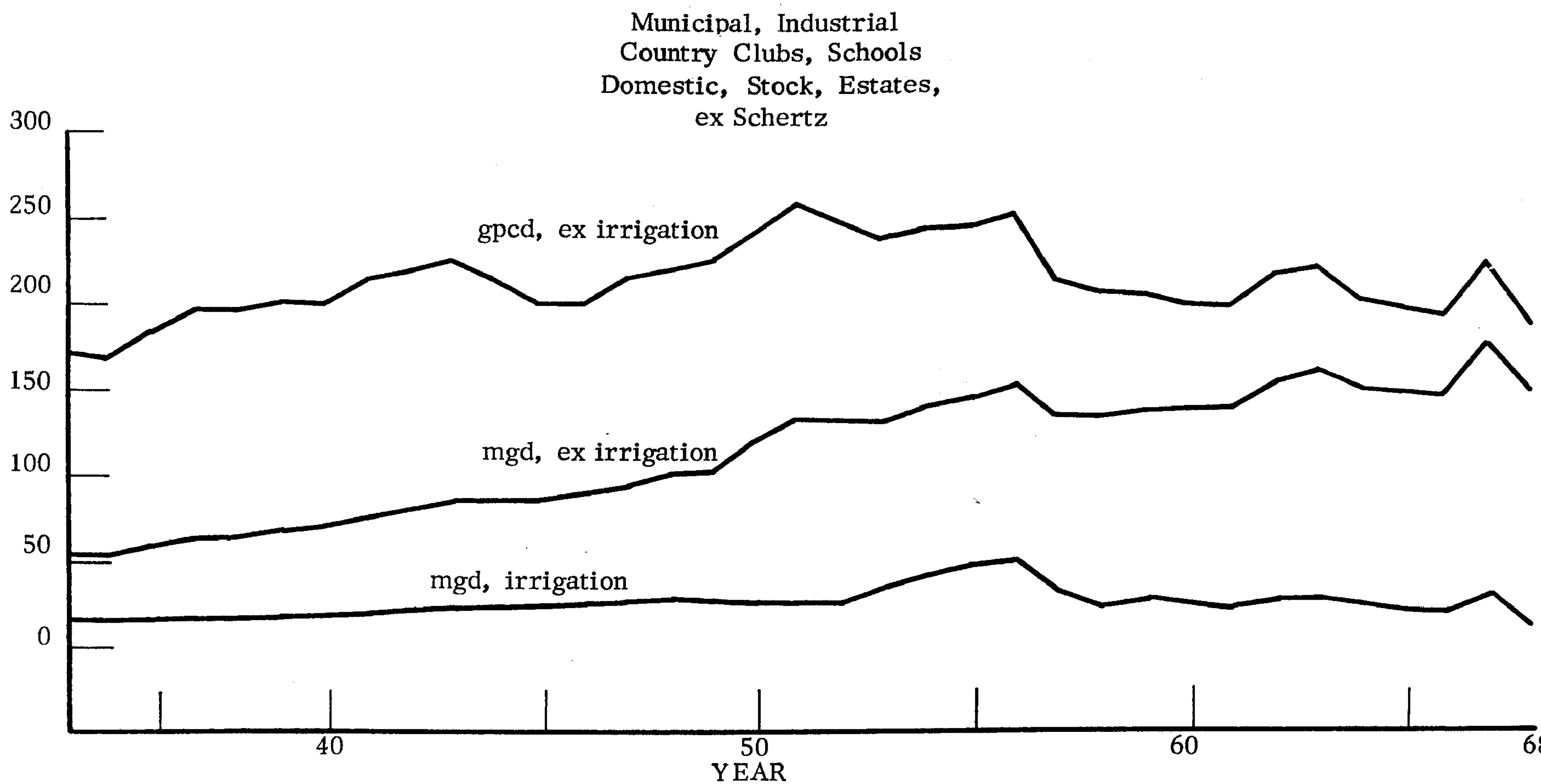


Figure 2

LONG TERM WATER AND SEWAGE RELATIONS

SAN ANTONIO

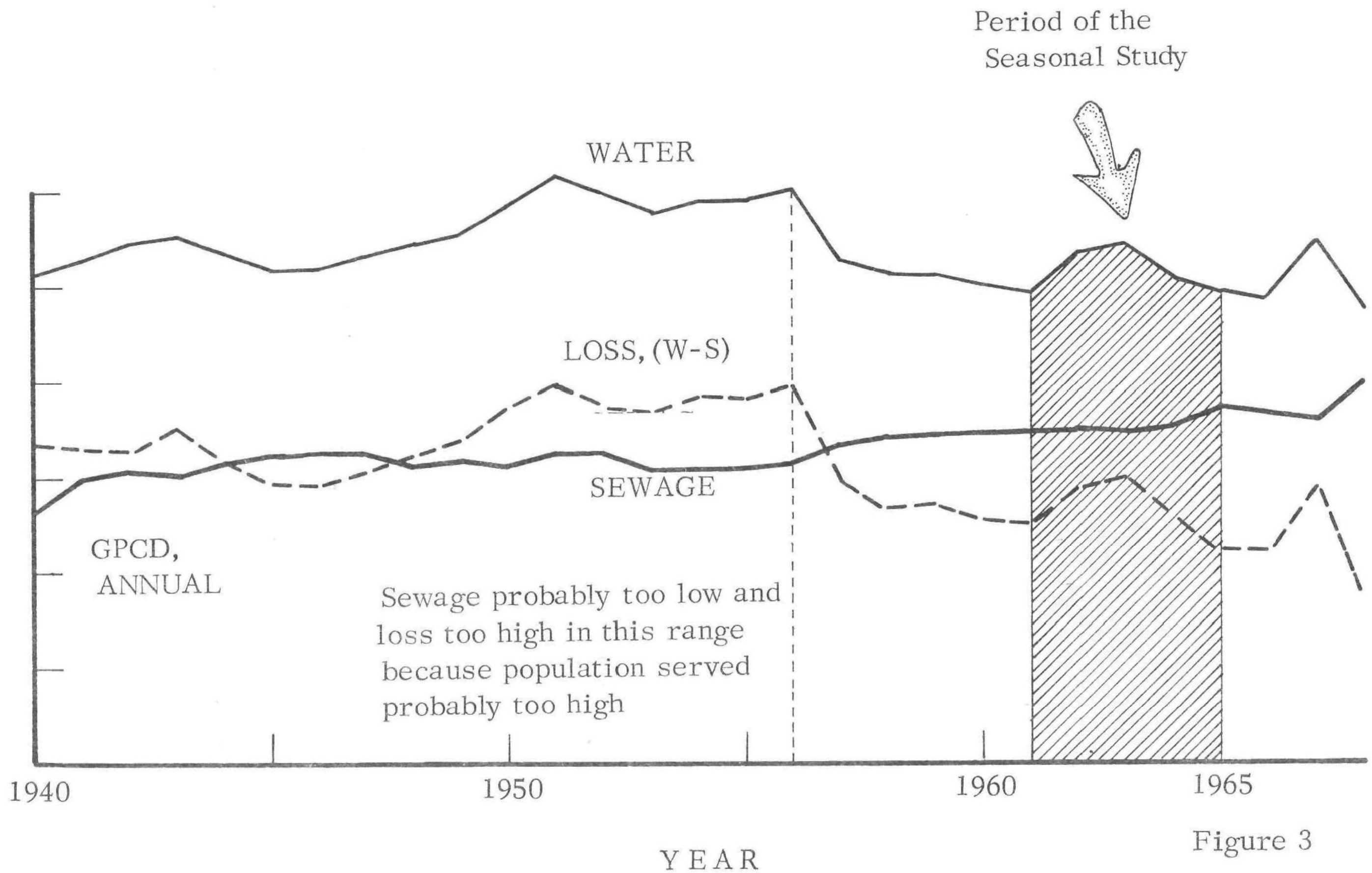


Figure 3

MONTHLY AVERAGE PER CAPITA WATER WITHDRAWAL AND SEWAGE DELIVERED - SAN ANTONIO 1961-65

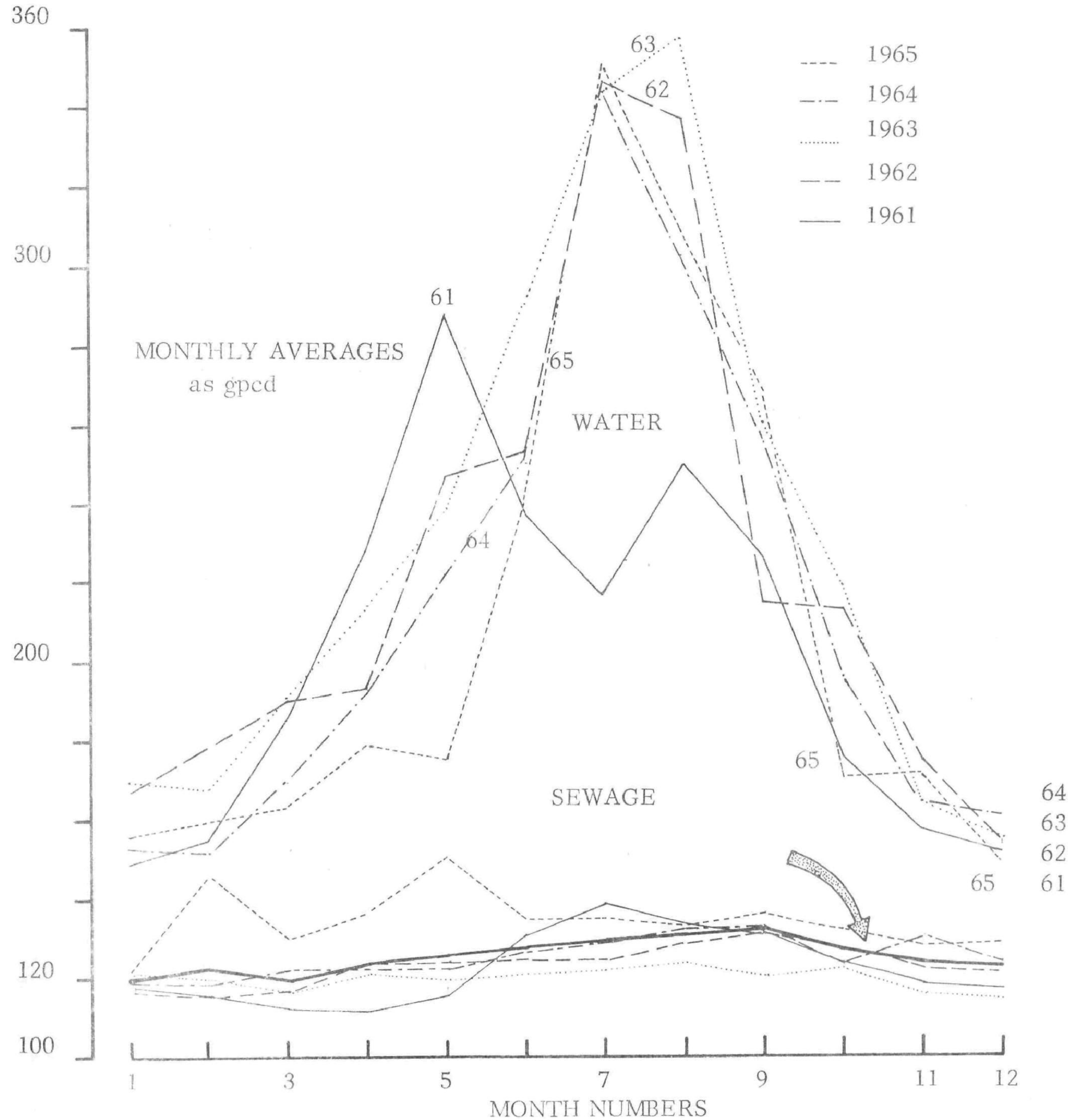


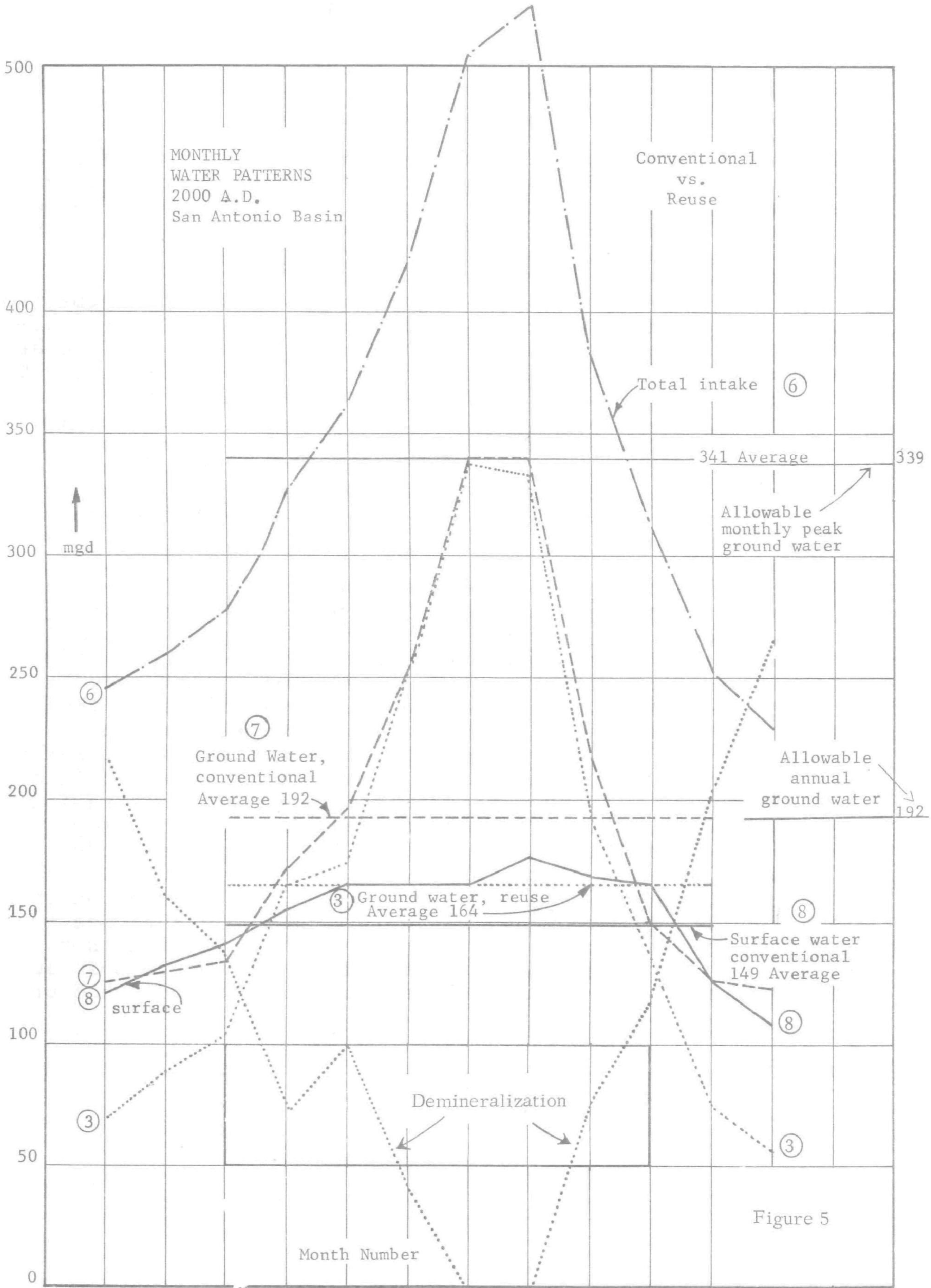
Figure 4

The existing facilities in San Antonio which will be part of the 2000 system are the three existing or under construction sewage treatment plants and the existing well stations. The latter have a firming factor, that is an average ratio of installed capability to firm capability, of 1.4.

The municipal increment is the difference in concentration between the water used and the sewage delivered. Figures for the apparent increment in San Antonio were available for five of the major ions and 13 of the minor elements. The rest of the major components in the municipal increment were filled in by the averages of figures in other western cities.

Figure 5 taken from the data just described shows the monthly water patterns in 2000 in San Antonio. It should be remembered that the design data are approximately the upper envelopes of a five year monthly series. On this basis the top curve labeled 6 shows the monthly water usage peaking at 515 mgd in August and averaging 341 mgd. The next lower curve, labeled 7, shows the ground water withdrawal under the conventional supply scheme peaking at 339 mgd which is the allowable limit on monthly withdrawal for the aquifer, and averaging 192 mgd which is the allowable limit for annual ground water withdrawal from the aquifer. To make up the difference, surface water would be required as shown in the curve labeled 8 peaking at 176 mgd in August and averaging 149 mgd. Under the reuse scheme the ground water withdrawal would be as shown in curve 3 peaking at 336 mgd and averaging 164 mgd which may be compared with the 163 mgd now being withdrawn in 1970. No surface water would be required.

Projection of the population to years beyond 2000 indicates that in the reuse scheme the peak month constraint is just barely met since it would be violated about the year 2005. The annual constraint would be exceeded about the year 2017. Starting in 2005 there would have to be provided some surface storage for ground water pumped in the winter and spring months and stored to avoid exceeding the peak allowable in July and August. The storage period and quantity would have to become larger and larger as the population grew. Beginning in 2017 no amount of storage would suffice and it would be necessary to supplement the ground water supply. However, the target year in this project is 2000 and in this design no constraints are violated in that target year.



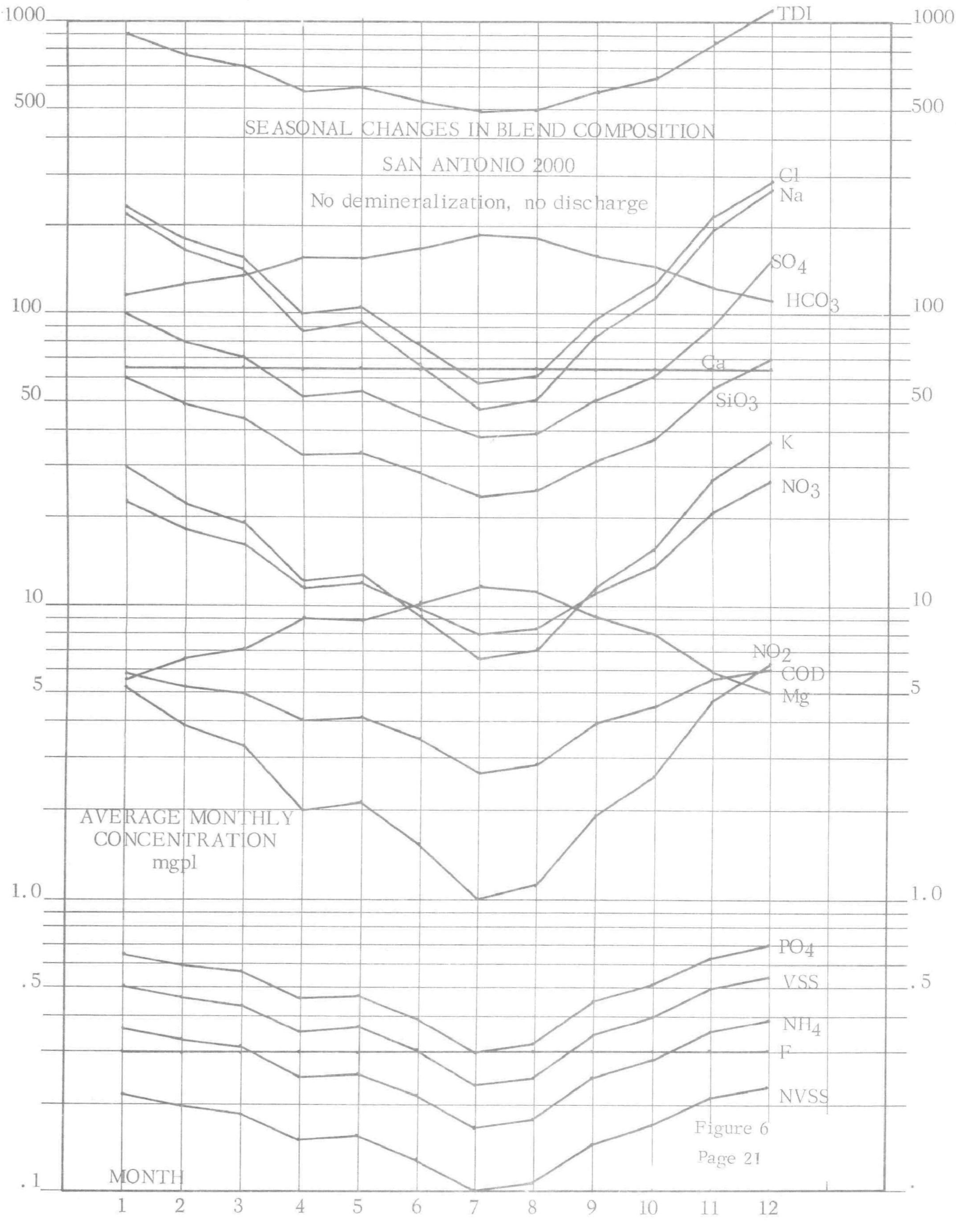
MONTHLY
WATER PATTERNS
2000 A.D.
San Antonio Basin
Conventional
vs.
Reuse
Total intake
341 Average
339
Allowable
monthly peak
ground water
mgd
Ground Water,
conventional
Average 192
Allowable
annual
ground water
192
Ground water, reuse
Average 164
Surface water
conventional
149 Average
surface
Demineralization
Month Number
500
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5

Of course, these projections depend upon the constancy of the gpcd water use and sewage delivered. Under a reuse scheme any steps taken to reduce the gpcd water intake and increase the gpcd collected would be favorable toward postponing these critical dates.

Figure 6 shows the seasonal changes in the blend composition in the year 2000 for the recycle scheme with no demineralization and no discharge. It is seen that with no discharge and even with no demineralization the blend would have a TDI (total dissolved ions) of less than 500 mgpl in the two summer months but would rise to higher than 1000 mgpl in the winter. In Chapter 6 summarized beyond there is worked out roughly the quantities of demineralization (by electrodialysis) that would be required to lower the TDI to 500 in every month. This is shown as the dotted lowermost curve on Figure 5.

Table 1 shows the quantities involved in the 2000 system giving the average, the peak monthly, and the peak day for each element of the system. The triple figures in the conventional column show the requirement if the peak day load is thrown entirely to the ground water, entirely to the surface water, or spread equally between them. The figures for demineralization are obtained as a rough approximation by determining the amount of demineralization that would be required to reduce the return flow from its concentration with no demineralization to a concentration which would result in a blend concentration of 500 mgpl for TDI. This somewhat overstates the quantities to be demineralized for if the blend were reduced to 500 TDI then the return liquor would not reach such a high concentration in the recycling. To determine the quantities to be demineralized under true steady state conditions not violating the blend constraints would require the solution to the recycle problem which has not been accomplished under this project.



SEASONAL CHANGES IN BLEND COMPOSITION
SAN ANTONIO 2000
No demineralization, no discharge
AVERAGE MONTHLY CONCENTRATION mgpl
MONTH
1000
500
100
50
10
5
1.0
.5
.1
1 2 3 4 5 6 7 8 9 10 11 12
TDI
Cl
Na
SO_4
HCO_3
Ca
SiO_3
K
NO_3
NO_2
COD
Mg
PO_4
VSS
NH_4
F
NVSS

Figure 6

TABLE 1

LOGISTICS OF THE NEW SUPPLY - 2000

Note: Peak day is the 90% level --i.e. expected to be exceeded in only 10% of the years.

	AWT Reuse Scheme mgd	Conventional Import Scheme mgd
Ground water withdrawal, average	164	192
Peak monthly	336	339
Peak day	435	339/440/494
Utilization factor	.377	.567/.436/.389
Surface water withdrawal, average		149
Peak monthly	none	176
Peak day	withdrawn	331/230/176
Utilization factor		.429/.649/.845
Total withdrawal	164	341
Peak monthly	336	515
Peak day	435	670
Over-all utliziation factor	.377	.510
Water treatment, average		149
Peak monthly	not	176
Peak day	used	331/230/176
Utilization factor		.429/.649/.845
Lawn and pipe losses	164	164
	(AWT)	(Conventional STP)*
Sewage treatment or AWT, average	177	177
Peak monthly	189	189
Peak day	350	350
Utilization factor	.506	.506
Demineralization, average (rough)	117	
Peak monthly	261	not
Peak day	486	used
Utilization factor	.241	
Disposal to the Gulf, average (rough)	7	
Peak monthly	--	not
Peak day	14	used
Utilization factor	.5	
Discharge to San Antonio River	none discharged	177
Storage required	yes	no

* Sewage treatment plant

When this is done the amount (of demineralization residue) to be disposed of to the Gulf will also be decreased.

The term "storage required" refers to the need for a balancing storage to store the return water on those days on which the amount of sewage collected is more than the amount of water used. This cannot yet be computed because it requires a day-by-day study of the water and sewage flows to determine the statistics and pattern of the excesses.

Table 2 shows the sewage treatment plant alternatives, conventional sewage treatment for the conventional scheme and advanced waste treatment for the reuse scheme.

TABLE 2

LOGISTICS OF THE NEW SUPPLY - 2000
Sewage Treatment Plant Alternatives

	mgd	
	AWT Reuse Scheme	Conventional Import Scheme
Existing or U.C. STP (3 plants)		
Peak day capability	not	116
Average	used	59
New capability required	(AWT)	(STP)
Peak day	350	234
Peak monthly	189	-
Average	177	118
Utilization factor	.506	.506
Discharged to San Antonio River	none	177

Table 3 shows the required ground water facilities, which do not differ much between the two schemes. Table 4 shows the conveyance alternatives. The AWT reuse scheme in the single AWT plant embodiment would require the conveyance back from the AWT plant illustratively at the Rilling site to the water distribution system illustratively taken as the Hildebrand tank in the north part of the city. The conventional scheme would require the conveyance from one of the several alternative supplemental sources here taken as the Cuero-Cibolo source. This source would require the reimbursement of the Guadalupe Basin with water from Goliad Reservoir.

TABLE 3

LOGISTICS OF THE NEW SUPPLY - 2000
Ground Water Facility Alternatives

	mgd AWT Reuse Scheme	mgd Conventional Import Scheme
Existing GW facilities		
Peak day firm capability	333	333
Average	125	145
New facility required		
Peak day, firm	102	107
Average	39	47
Utilization factor	.377	.436

TABLE 4

LOGISTICS OF THE NEW SUPPLY - 2000
Conveyance Alternatives

	mgd AWT Reuse Scheme	mgd Conventional Import Scheme
Cureo and Cibolo to Hildebrand		
Peak day	0	230
Average	0	149
Goliad to Victoria		
Peak day	0	141.4
Average	0	113.1
Rilling to Hildebrand		
Peak day	350	0
Average	177	0

COSTS OF THE TWO EXTREME ALTERNATIVES

Chapter 6 develops approximate costs for those cost elements other than AWT, pipeline conveyance and activated sludge treatment for which computer programs are developed in chapters 2, 4, and 5. Some of these Chapter 6 costs for the other elements are generally applicable though of an approximate nature without the flexibility of the full computer programs. Others of the Chapter 6 costs are simple ad-hoc costs developed specifically for San Antonio.

The assignment to these categories is as listed:

	General	Ad-hoc
Surface water reservoirs		X
Ground water facilities		X
Water treatment	(X)	
Demineralization (by electrodialysis)	X	
Sewage conveyance	X	

Table 5 gives a summary of the element and system costs for the two extreme alternatives. About three-quarters of the conventional costs are for the source water and its treatment. The differential over the comparable cost of source water for the AWT reuse case is about 17 m$/yr. However, the only additional cost in the conventional system is for sewage treatment and the cost of advanced waste treatment and associated elements slightly overbalances the differential.

TABLE 5

COST SUMMARY

	Conventional					AWT Reuse				
	Design Capability mgd	Average Production mgd	New Capital m$	Annual Cost K$	¢/Kgal	Design Capability mgd	Average Production mgd	New Capital m$	Annual Cost K$	¢/Kgal
Surface water delivered	230	149	201.3	13,989	25.7		0	0	0	
Water treatment	230	149	18.6	3,240	6.1		0	0	0	
Total SW delivered and treated		149	219.9	17,229	31.8		0	0	0	
Ground water	440	192	5.7	(1,326)	(1.9)	435	164	(5.5)	(1,173)	(2.0)
Total water delivered and treated		341	225.6	(18,555)	(14.9)		164	(5.5)	(1,173)	(2.0)
Sewage treatment	350	177	38.5	(5,707)	(9.8)		0	0	0	
Advanced waste treatment		0	0	0		350	177	86.1	15,352	23.8
Return conveyance		0	0	0		350	177	15.7	2,138	3.3
Balancing storage		0	0	0			required, not considered yet			
Demineralization (very rough)		0	0	0		327	104	42.8	7,073	18.6
Disposal to Gulf (very rough)		0	0	0		14	7	19	1,100	44
Total		341	264.1	(24,362)	(19.5)		341	169.1	(26,836)	(21.6)

( ) = Costs do not include amortization on existing plant.

COMPUTER PROGRAM FOR RENOVATION COSTS

Chapter 2 covers the development of a computer program for the design and costing of the lime-clinoptilolite-carbon process for renovating municipal waste waters for reuse. The over-all process points toward an advanced waste treatment system whereby water meeting potable standards is produced from waste waters.

The major steps are:

1. Lime clarification with recalcination of the lime...reducing the suspended solids, the organic content both suspended and dissolved, and the phosphate content of the waste.

2. Clinoptilolite ion exchange regeneration and stripping ...removing the ammonia nitrogen from the waste and concentrating it in a small volume of ion exchange regenerant from which it is air stripped.

3. Activated carbon absorption...removing the organics residual from lime clarification.

These steps are followed by a final chlorination to assure disinfection of the water.

In this process all the wash liquors generated in the later stages are returned to the lime clarification step so that no liquids leave the system other than in the product water and the only solid for disposal is the moist inert residue from the lime slaker. The organics are burned off in the lime recalcination kiln and the ammonia leaves as a gas from the stripping tower.

Selecting this process for the basis of the present study was a calculated risk. The process had been piloted on a moderate scale but as applied to secondary sewage treatment plant effluent, not to raw sewage. Applied to raw sewage the process was under study during the design period, at the Blue Plains, District of Columbia, Experimental Plant operated by EPA. It appeared, and still appears so, that this process, the so-called independent physical-chemical process, was a likely contender for water renovation as against the conventional biological processes with supplementary (tertiary) treatment, in part because it was more readily controllable for varying production rates and not subject to the erratic fluctuations that plague the biological processes. Furthermore, renovation by conventional biological treatment followed by tertiary treatment would involve exactly the same process steps, lime, clinoptilolite or other forms of ammonia removal, and carbon, and the cost of these tertiary steps would be only very slightly less than the cost of the same steps applied directly to raw sewage. In other words, the cost of renovating secondary effluent would have been only slightly less than the cost of renovating raw sewage and in addition there would have to be borne the basic cost of the conventional biological process itself. It was decided therefore to use the independent physical-chemical process even though (1) it had not been fully proven, and (2) the basic performance data were not yet complete.

Under these circumstances it is readily conceded and should be emphasized that the design and computer program is highly preliminary and is to be considered not an end in itself but only one of the steps toward answering the question: "With what we know about it now, how does reuse compare economically with a conventional system?"

Not enough is known about the equilibrium, stoichiometric, and rate processes involved to construct a true mathematical model, i.e., a model in which any parameter change will be reflected in a corresponding performance change. For example, in the activated carbon stage the COD (chemical oxygen demand) of the effluent is set by the value assigned to the parameter COD89, in the exemplary work set at 8 mg/l (milligrams per liter). The COD actually reached in the effluent for a fixed feed composition will in a real plant vary with the equipment configuration, the contact time, and the carbon loading factor. Lacking knowledge of the relationship among these the program merely provides for setting the contact time and carbon loading factor...or in other words it allows the user to make his own selection of carbon loading factor and contact time which he thinks will produce the desired COD in the effluent.

In using the program the user may select any combination of feed water quality parameters and any reasonable combinations of the other decision parameters. Using these, the program will design and cost the equipment so that the plant capability is QDOT, the design capability mgd, and will cost the operation when it is operated in that equipment at QBARE, the expected average production rate, mgd.

Such a program, of course, can be used as a research and development tool to direct research toward cost improvement. Very little of this was done with the program, however, since the present purpose was simply the costing of the process under the current technological level. In the costing the various performance parameters were set at levels expected from pilot plant work or from actual operation of similar equipment.

Economic factors were set at plant life, 20 years; tax, insurance and interest rates .01, .01, and .045 annual fraction of investment, respectively; energy price 1¢/Kwh (kilowatt hour); base labor price $3/man hr; and payroll extras factor .45 fraction of payroll. The feed liquor used is a typical San Antonio sewage composition with a COD of 500, suspended solids of 220 mg/l, and inorganic ions approximately as found in the sewage.

The next page comprises the printout of results of the AWT renovation process for San Antonio in the year 2000 considered as a single central plant. The costs are 1969, San Antonio. The QDOT capability is 350 mgd, meaning that the plant has a capability to treat as much as 350 mg in a single day. The average production is 177 mgd, for a utilization factor of .506. The entries may be explained by example as follows. For the lime stage of the process the investment is 20,454K$ which is 23.77% of the total investment. The unit investment in this lime stage facility is 5.844¢/gpd of capability or 11.556¢/gpd of actual production. The production cost for the lime stage, that is the operating costs plus the amortization is 3,479K$/yr which is 5.386¢/Kgal produced and this represents 22.67% of the total production cost. The total investment for the entire renovation plant is some 86 million dollars and the annual production cost 15.3 million dollars. Over-all amortization costs are 12.9¢/Kgal, operating costs 10.9¢/Kgal and total production cost 23.8¢/Kgal. One hundred forty-three tons per day of moist inert residue are disposed of in a sanitary landfill. The cost of this disposal is only about .5% of the total production cost.

Figure 7 shows the investment and production costs at various production rates in plants in which the capability is two times the production rate. In the high production ranges, above 100 mgd, the unit cost does not fall off very much as production rate increases, in other words the scale economy is quite small. Consideration such as this would be used in making preliminary decisions on the economics of centralized and regional plants. The graph shows that not much economy can be achieved by centralizing plants which are already as big as 100 mgd, but considerable economy can be achieved by centralizing plants of a one mgd or ten mgd size.

---- OVERALL AWT PROCESS ----

QBARE 177.00 QDOT 350.00 UBAR .50571 DISP.,TPD 143.053

INVESTMENT COSTS, K$

PROCESS	K$	PCT. OF TOTAL	CENTS/GPD OF QDOT	CENTS/GPD OF QBARE
PRELIM.	685.477	.74	.196	.387
LIME	22410.410	24.27	6.403	12.661
CLINOP.	19517.989	21.14	5.577	11.027
CARBON	37438.609	40.55	10.697	21.152
CHLOR.	690.852	.75	.197	.390
BUILDINGS	8074.334	8.74	2.307	4.562
DISPOSAL	0.	0.	0.	0.
ENGR.	3516.747	3.81	1.005	1.987
TOTAL	92334.416	100.00	26.381	52.166

PRODUCTION COSTS

PROCESS	K$/YEAR	CENTS/KGAL	PCT.
PRELIM.	123.624	.191	.76
LIME	3759.420	5.819	23.23
CLINOP.	4088.432	6.328	25.26
CARBON	6116.832	9.468	37.80
CHLOR.	342.300	.530	2.12
BUILDINGS	782.210	1.211	4.83
DISPOSAL	78.373	.121	.48
ENGR.	340.689	.527	2.11
OPR. LABOR	551.903	.854	3.41
TOTAL	16183.783	25.050	100.00

COST SUMMARY, CENTS/KGAL

AMORT. = 13.846, OPER. = 11.205, TOTAL = 25.050

STOP.

CPU SECONDS 12.735
BYE

K600001 LOG OFF. 17.32.51.

COST OF AWT BY THE LIME-CLINOPTILOLITE-CARBON PROCESS

San Antonio Sewage 1968 Utilization Factor, UBAR = 0.5

FCODAC = 0.8

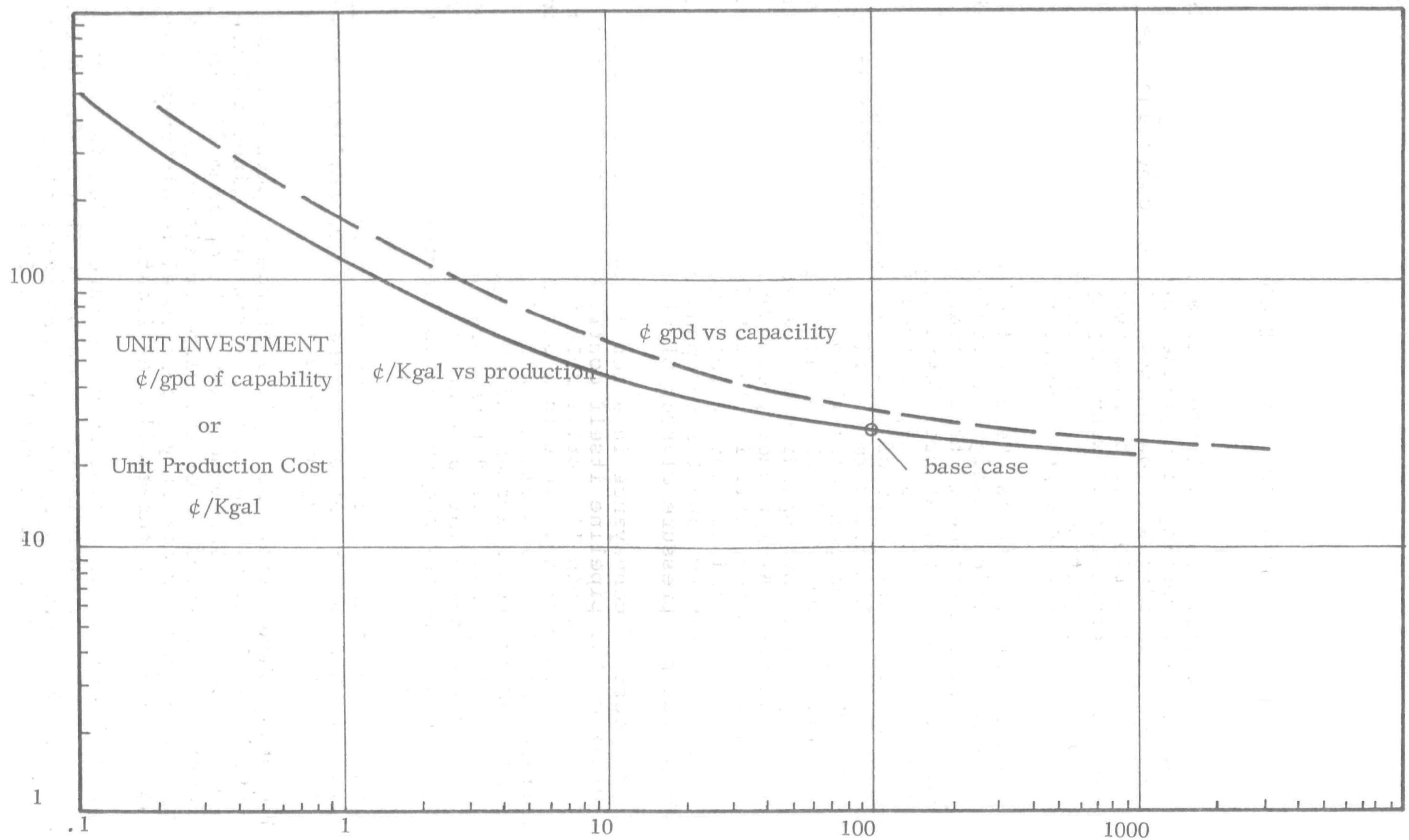


Figure 7

COMPUTER PROGRAM FOR PIPELINE CONVEYANCE COST

Chapter 4 covers the development of a computer program for the design and costing of pipelines and the conveyance of water or other fluids through them. Water conveyance is one of the important elements bearing upon the economic competition between conventional water supply and waste treatment typically by importing water from remote sites, and renovation for reuse by advanced waste treatment.

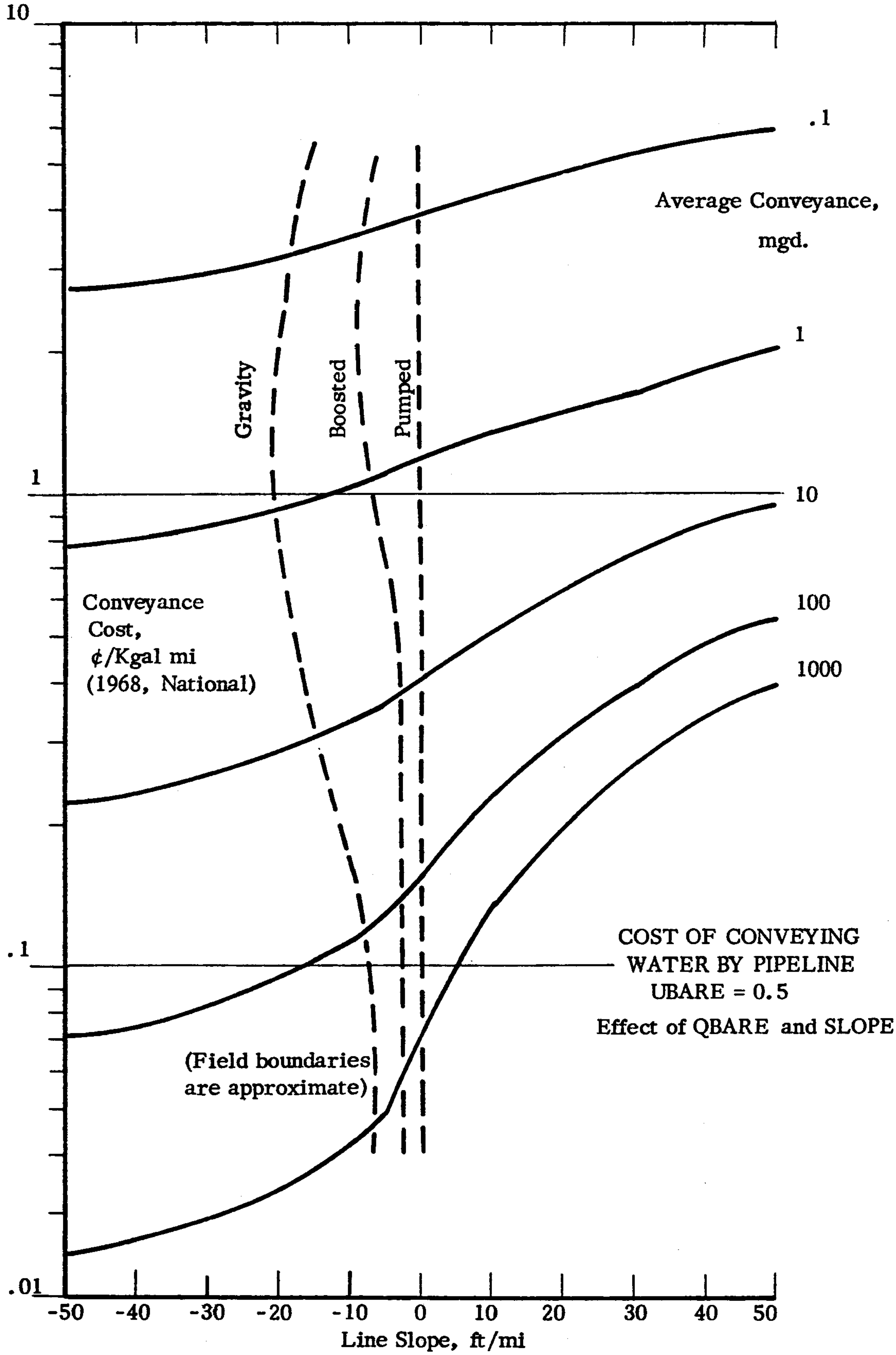
A computer program takes the specified characteristics of the conveyance situation, designs a pipeline which will minimize the cost of conveyance in that situation, and returns the design data and the cost breakdown. The line is designed in segments (up to three) as may be specified, each section being optimized for conveyance of an average amount of QBARE in a facility which has the firm capability of conveying an amount QMAX. The program generates the necessary cost indexes for the state, region (21 in the nation) and future year, as well as energy price corresponding to the state, the future year and the expected Kwh/yr energy consumption. A subroutine generates the proper friction factor from the Moody diagram. The program determines whether the line shall be pumped, boosted, or gravity, and for the pumped and boosted selects the proper psi pressure classes of pipe.

To the cost of conveyance in a horizontal line the fixed charges on the pipeline itself contributes some 70-80% of the total. The pipeline price relation therefore is very important in costing. In this study the basis is a historical correlation of the installed costs of 825 pipelines which were correlated against diameter and by region of the country. There are large regional differences in the prices of pipeline which must be taken into account in estimating the cost of conveyance. Special regionalization factors are provided for doing this.

Figure 8 shows the cost of conveyance by pipeline at a utilization factor, UBARE, of 0.5. (The firm capability is two times the average conveyance rate.)

The study showed that the capital charge on pump stations contributes 5-10% of the cost in horizontal lines and the energy about 10%. For pumped lines the optimum diameter is practically independent of the slope or static head. The conveyance cost is directly proportional to distance down to distances of one to three miles at least.

Using the future year cost index feature which is incorporated in these computer programs, it was shown that both the investment and the conveyance cost will approximately double, in current year dollars, between 1970 and 2000.



10
1
.1
.01
.1
Average Conveyance,
mgd.
1
10
100
1000
Gravity
Boosted
Pumped
Conveyance
Cost,
¢/Kgal mi
(1968, National)
COST OF CONVEYING
WATER BY PIPELINE
UBARE = 0.5
Effect of QBARE and SLOPE
(Field boundaries
are approximate)
-50
-40
-30
-20
-10
0
10
20
30
40
50
Line Slope, ft/mi

Figure 8

The cost of conveyance in the Cuero-Cibolo-San Antonio link of the Texas Water Plan had been the subject of an engineering study by a consulting engineering firm. That study laid out an actual route and designed a pipeline and pump station system under a set of ground rules laid down by the client. When the present computer program was run with the same basic data the corresponding 1969 costs of the two studies were within 7% of each other over the range of the engineering study which was 100, 200 and 300 thousand acre feet per year. This illustrates how the computer program without using any input data other than the quantities, elevations and distances can reproduce costs from rather detailed engineering studies which include field studies, map routing, topographic and geological profiles and item-by-item preliminary cost estimating. (For the exemplary quantity above most closely corresponding to the actual San Antonio case costed, the difference was only two parts in 500.)

COMPUTER PROGRAM FOR ACTIVATED SLUDGE TREATMENT COSTS

Chapter 5 takes an existing computer program for design and costing of activated sludge plants, modifies it to handle some of the actual design problems and uses it to develop capital and operating costs for the conventional sewage treatment components in the San Antonio scheme. For general application it would be necessary to have programs for other treatment types also. For example, trickling filters are more economic than activated sludge plants under some conditions, particularly at small sizes. However, activated sludge was chosen as a conventional treatment type for this project because (a) the established computer program was available, (b) activated sludge was a preferred type of treatment for larger capability plants as applicable in the San Antonio study, and (c) activated sludge is a treatment type of the existing San Antonio plants which are involved in the basin management.

The program permits any feed, any product, and any size (within limits). This means that the user may specify the raw sewage composition and the desired effluent BOD (biochemical oxygen demand). The program will then design a plant to achieve this of a size capable of handling the maximum day and will cost the treatment of the QBARE average day in the plant designed. It is not permitted to specify the total suspended solids desired in the effluent but this usually comes out of a magnitude quite close to the effluent BOD. The program will correctly handle a specified effluent BOD of ten mg/l but will not handle one as low as five, the actual limit being some undetermined value between these two.

COMPONENTS OF THE PROBLEM REMAINING UNRESOLVED

The objective of this project was to develop general procedures by which a comparison could be made and an optimization achieved between the total costs of a future water supply-pollution control system which is at or somewhere between the two extremes:

1. Conventional supply primarily by import and conventional waste treatment and discharge, and

2. Complete reuse with no discharge

At the inception the problem was admitted to be complicated and possibly massive but it was thought that those problems which could be foreseen could be solved by the application of known techniques. For example, it was thought that the "placement problem," the problem of how many AWT plants of what sizes and where as contrasted with a single AWT plant treating all the waste, could be treated as a network problem once the basic cost relations had been worked out. However, as the basic data and relationships revealed themselves it was discovered that municipal recycle contained some problems that had not been suspected and attacked before. These included the central role of the loss ratio in the compositional changes on recycle, the seasonality of the loss ratio and the day-to-day imbalance of the water-sewage relation and finally the inter-relationship of the independent parameters, quantity demineralized and quantity discharged, as they affected the composition of the blend, the "recycle problem". Because of the magnitude and the difficulty of these unsuspected problems, there still remain a number of components of the over-all problem which are unresolved. The types of these fall into several categories:

1. Problems for which techniques are known but which are massive and set aside in favor of problems heretofore unattacked. Examples: the placement problem, demineralization design and costing.

2. Problems requiring the collection of additional basic data primarily in other cities, for the present well enough known for San Antonio. Examples: seasonality of municipal increment, seasonality of loss ratios.

3. Problems representing special details for the San Antonio case or for which approximate solutions are allowable, or which probably will not be generally encountered. Examples: the alternate (Colorado-Applewhite) source for San Antonio, canal conveyance, design and cost for ground water facilities.

4. The recycle problem, the algorithm which determines the optimum quantities for demineralization and for discharge to meet the blend constraints, a problem which our studies to date show is solvable but which we have not yet completed.

Table 6 lists these components remaining unresolved and shows whether or not they are needed for a decision in the San Antonio case and in the general case. Under the general case the term "probably not" signifies that it probably is not necessary to work upon these problems for the general case because: canal conveyance will probably be rarely met with in actual practice and the costs of ground water facilities can be approximated for individual cities on the basis of historical facilities cost in that location without a large parametric design program.

Under the San Antonio case the term "probably not" means something else. It takes into account what we already know about the economics of the San Antonio situation, namely, that reuse appears to be slightly uneconomic compared with the conventional import scheme, and therefore any additional elaboration or additional costs taken into consideration for the reuse scheme would not change the decision since in all such cases they could only increase the reuse cost. Only one unresolved problem stands a chance of reducing the reuse cost for San Antonio, this being the placement problem. The major portion of this problem is being worked out on another project using the STORET sewer design scheme. Taken one by one: the Colorado-Applewhite source including the canal conveyance from the Colorado source will probably result in a lower cost for the conventional supply than here computed and this will not change the decision. The recycle algorithm and the storage problem could only increase the cost of the reuse scheme and thus would not alter the decision. The demineralization costs have been briefly reviewed by Ionics Inc., the vendor, with the comment "your figures on ED costs seem remarkably up-to-date." The costs for the actual San Antonio water would probably differ little from those shown.

TABLE 6

COMPONENTS REMAINING UNRESOLVED

Component of the problem remaining unresolved	Needed for Decision in: San Antonio Case	General Case
Colorado-Applewhite source, replacing Cuero-Cibolo	probably not	no
The "Placement Problem"; area AWT instead of single AWT at Rilling site	yes	yes
The "Recycle Problem"; completion of recycle algorithm for Q demineralized and Q discharged	probably not	yes
The "Storage Problem"; day-by-day differences water-sewage	probably not	yes
Demineralization design and cost program	probably not	yes
Canal conveyance design and cost program	probably not	probably not
Seasonality of municipal increment and completion of basic data San Antonio and other cities	probably not	yes
Loss ratio relations other cities-seasonality	no	yes
Design and cost for ground water facilities	no	probably not

To assess as "probably not" the need for studies of the seasonality of the municipal increment and the magnitude of the increment for those contaminants not specifically known for San Antonio is indeed a presumption. Even if demineralization would not be required because of some of the contaminants whose increment quantities are not known for San Antonio, still this would not change the fact that demineralization is required for some of those that are known. But as for seasonality it might indeed be so that the municipal increment does have a seasonal variation and this might be in the direction of being low in the winter-time and high in the summer and providentially might allow the scheme to sneak by without demineralization. But this just would be more good luck than one could hope for.

REMAINING COMPONENTS OF THE GENERAL PROBLEM

The project took as many components of the San Antonio problem as could be handled within the time and funds available and worked upon them. It attempted to provide general solutions for as many of these as time and funds allowed. Those remaining unresolved from such an attempt have been described in the previous section.

There remain a number of facets of the problem outlined in the original concept and the various proposals which were not worked upon at all.

One of the use alternatives specifically possible in San Antonio and presumably usable generally where the situation allows, was the exchange of conventional effluent for source water used for irrigation. The San Antonio situation is that some 20 mgd average are withdrawn from the underground aquifer and used for irrigation about 15-20 miles west from the present sewage treatment plant, some of the area actually being in another river basin. If the irrigators would use the treatment plant effluent and cease the withdrawal from the aquifer then this additional quantity would be available for withdrawal from the aquifer for higher order uses, i.e. for potable water for the city. This would have the effect in the present scheme of increasing the limits on ground water withdrawal thus allowing the withdrawal of more ground water and the importation of less surface water, for a net economic benefit. On the cost side of the balance would be the cost of conveying the effluent to the irrigators. There would, of course, be the administrative and political problems involved in such a transfer but these are outside the scope of this project.

The present study provides the means for exploring the economics of such a transfer. The pipeline conveyance program would show the costs of the conveyance and the ground water and surface water costs could be adjusted for the new quantities. However, this was not done on the present project. In addition, some of the local agencies had funded an engineering study of the same scheme and although the final report thereon was not available the conclusion had been that such a transfer was uneconomic. It would be interesting to check this conclusion with the mechanism provided by the present study.

The situation does not fit either of the two extremes costed herein since under the reuse scheme it would involve operating one of the conventional treatment plants to produce the irrigation water. Under the conventional plan some of the plant effluent would merely be conveyed to the irrigators thus reducing the amount of discharge.

EPA was particularly interested in the economics of segregating different qualities of water for different uses. Three broad categories of uses are municipal, irrigation, and industrial. A specific use for conventional sewage treatment plant effluent as irrigation water has just been mentioned. The commodity cost of the water in this case would be zero since it is merely to be discharged anyway. However, if one considered an irrigation use in the reuse scheme the commodity cost would be greater since every gallon of water diverted from reuse to irrigation would require the generation of a gallon of water from the source. In the San Antonio case which is impinging on the peak ground water constraint this would mean additional surface water at a cost of the order of 30¢/Kgal. Balanced against that would be the possibility of by-passing some of the AWT steps, specifically the clinoptilolite-ammonia removal and the activated carbon treatment at a saving of something of the order of 18¢/Kgal. The water would have about 20 mg/l of NH3-N (ammonia nitrogen) and a COD of 82 which presumably would be acceptable for irrigation. This would also mean that the amount of makeup water would be increased thus the requirement for demineralization would be decreased for an additional saving. All this assumes, of course, that the use points for the irrigation water are relatively few and concentrated, else the cost of conveyance to the use sites would be excessive.

The reuse of lower grade water for industrial purposes was not explored in the project because San Antonio, with one exception, does not have any large industrial water users such as a paper plant, a petroleum refinery, etc. If such water users occur in a community there are a number of possibilities for reuse, or, indeed, for successive use of waste water. Probably the ammonia removal and carbon treatment in advanced waste treatment could be dispensed with for industrial cooling water with some process adjustments. Although clinoptilolite-ammonia exchange is used for ammonia removal another method of ammonia removal is simple air stripping of the entire liquor in equipment identical with cooling towers. Thus, passage through an industrial cooling tower in several recycles therein might indeed accomplish the ammonia removal which now costs something of the order of 7¢/Kgal in the AWT process. The blowdown liquor could then be returned to the AWT process to the lime stage or to the activated carbon stage as the economics dictated. Involved, of course, would be the replacement of the water lost by evaporation in the cooling process. For a study of the economics of this the project provides the conveyance costs but the AWT program would have to be modified to include the extraneous cooling use. Also, the project, of course, does not provide any information on the additional cost of using such water in the industry's cooling tower itself.

There are also possibilities for using various grades of water for industrial process use, but such uses and the requirements for them are highly specific to the particular industry. San Antonio has no such industries and it was outside the philosophy of the project to generate schemes for hypothetical situations which did not have a real embodiment on which they could be hung.

The one industrial use embodied in San Antonio is the cooling water requirement for the power plants of the City Public Service Board. The project was not able to determine to what extent these requirements were included in the use projections of the Texas Water Plan and, indeed, this was one of the developments that led to the independent exploration of the San Antonio demand situation. In any event the major interest lies in the Braunig and Calaveras power plants which will supply the bulk of the future demand and which operate on their own cooling lakes with water drawn from the San Antonio River downstream of the City's discharge point. The 1985 usage of these two plants will be approximately 45 mgd average, this being water consumption. This figure will never be exceeded because any plants for supplying San Antonio beyond the 1985 date will not be constructed within the basin. The 1985 water usage in San Antonio will be about 200 mgd average so that typically the cooling lake requirements are about one-fourth of the water use of the municipality served. In the year 2000 San Antonio design the sewage collected averaged about one-half the water use so that the water use power plant cooling consumptive use would be about one-half the sewage collected. If in general it were necessary to supply the power plant cooling use solely from the sewage collected, this would seriously cut down the extent to which other reuse could be practiced. Indeed, reuse in such a case could only supply one-quarter of the total water needs. The problem was not faced in the present project because the expected 45 mgd are withdrawn from the flow of the San Antonio River downstream from the City discharge point. The average flow in the river is about 180 mgd of which about 90 mgd are return flow from the collected and treated sewage. Thus, the average flow of the river in excess of the sewage discharged is about 90 mgd. The power plant cooling requirement is only 45 mgd and the cooling lake comprises damping storage for the peaking. Because of this it was judged that the power plant cooling requirement in San Antonio is not part of the reuse picture. This dictated the development of the project's own demand figures which made it of no consequence whether or not the Texas Water Plan figures included or did not include the power plant cooling water.

San Antonio discharges excess sludge and also bypasses some sewage flows into an 800 acre lake, Mitchell Lake, which serves as a holding basin and oxidation pond. The original concept included the study of the use of Mitchell Lake as an oxidation pond, or the separation of Mitchell Lake from the sewage system so that it might be rehabilitated for recreation, storage or other uses. The Mitchell Lake problem also received a low priority and was not worked upon. The lake and the plant already for many years have supplied irrigation water and this irrigation water would have to be replaced if the status quo were to be maintained with a reuse scheme. The project as it stands then condemns these irrigation uses to oblivion. The alternative would be, in the reuse scheme, to operate the sewage treatment plants to produce the approximately 12 mgd of effluent now used for irrigation south of San Antonio, at an additional (increment) cost of about 6¢/Kgal.

The original suggestion for this project contained the phrase "collect every drop of water available to the basin in wastes and storm drainage." This project does not do that. It specifically takes nothing from the natural flow of the San Antonio River in the local area except to withhold the contribution of the present sewage treatment plant effluent. To have done so would have involved the placement and construction of a storage reservoir somewhere immediately south of San Antonio. This would have been a major alteration of the Texas Water Plan for this area although obviously this would not have been any consideration for studies in other areas. If the scheme had used the entire flow of the San Antonio River, say at Elmendorf, it would have dried up the river for the downstream users including the power plants. Also, the total flow of the river is actually not sufficient to supply the water needs so that reliance on some other reservoir and conveyance from that point would be required. The present embodiment leaves enough water in the San Antonio River to supply the downstream users including the power plant lakes and the irrigators.

CHAPTER 2

COMPUTER PROGRAM FOR DESIGN AND COSTING OF THE LIME-CLINOPTILOLITE-CARBON PROCESS FOR WASTE WATER RENOVATION

This chapter covers the development of a computer program for the key element in the project, namely, for the design and costing of the lime-clinoptilolite-carbon process for renovating municipal waste waters for reuse. The over-all process points toward an advanced waste treatment system whereby water meeting potable standards is produced from waste waters.

The major steps are:

1. Lime clarification with recalcination of the lime...reducing the suspended solids, the organic content both suspended and dissolved, and the phosphate content of the waste.

2. Clinoptilolite ion exchange regeneration and stripping...removing the ammonia nitrogen from the waste and concentrating it in a small volume of ion exchange regenerant from which it is air stripped.

3. Activated carbon adsorption...removing the organics residual from lime clarification.

These steps are followed by a final chlorination to assure disinfection of the water.

In this process all the wash liquors generated in the later stages are returned to the lime clarification step so that no liquids leave the system other than in the product water and the only solid for disposal is the inert residue from the lime slaker. The organics are burned off in the lime recalcination kiln and the ammonia leaves as a gas from the stripping tower.

Selecting this process for the basis of the present study was a calculated risk. The process had been piloted on a moderate scale but as applied to secondary sewage treatment plant effluent, not to raw sewage. Applied to raw sewage the process was under study during the design period, at the Blue Plains, District of Columbia, Experimental Plant operated by EPA. It appeared, and still appears so, that this process, the so-called independent physical-chemical process, was a likely contender for water renovation as against the conventional biological processes with supplementary (tertiary) treatment, in part because it was more readily controllable for varying production rates and not subject to the erratic fluctuations that plague the biological processes. Furthermore, renovation by conventional biological treatment followed by tertiary treatment would involve exactly the same process steps--lime, clinoptilolite or other forms of ammonia removal, and carbon, and the cost of these tertiary steps would be only very slightly less than the cost of the same steps applied directly to raw sewage. In other words, the cost of renovating secondary effluent would have been only slightly less than the cost of renovating raw sewage and, in addition, there would have to be borne the basic cost of the conventional biological process itself. It was decided, therefore, to use the independent physical-chemical process even though (1) it had not been fully proven, and (2) the basic performance data were not yet complete.

Under these circumstances it is readily conceded and should be emphasized that the present design and computer program is highly preliminary and is to be considered not an end in itself but only one of the steps toward answering the question: "With what we know about it now, how does reuse compare economically with a conventional system?"

Not enough is known about the equilibrium, stoichiometric, and rate processes involved to construct a true mathematical model, i.e., a model in which any parameter change will be reflected in a corresponding performance change. For example, in the activated carbon stage the COD of the effluent is set by the value assigned to the parameter COD89, in the exemplary work, set at 8. The COD actually reached in the effluent for a fixed feed composition will in a real plant vary with the equipment configuration, the contact time, and the carbon loading factor. Lacking knowledge of the relationship among these the program merely provides for setting the contact time and carbon loading factor...or in other words, it allows the user to make his own selection of carbon loading factor and contact time which he thinks will produce the desired COD in the effluent.

In using the program the user may select any combination of feed water quality parameters (the ions should be in stoichiometric balance) and any reasonable combinations of the other decision parameters. Using these, the program will design and cost the equipment so that the plant capability is QDOT, the design capability mgd, and will cost the operation when it is operated in that equipment at QBARE, the expected average production rate, mgd. Obviously, at reasonable utilization factors (UBAR = QBARE/QDOT) of 0.4 to 0.7, the product quality will be different at QBARE than it is at QDOT. For example, the longer contact time in the carbon adsorbers should improve the COD quality of the product. The program does not take this into account. It does, however, reduce the operating costs approximately correctly, for example, by reducing the cost of pumping energy corresponding to the flow.

GENERAL PROCEDURE IN DEVELOPING THE COMPUTER PROGRAMS

For the LIME subroutine as well as the CLINOPTILOLITE and ACTIVATED CARBON subroutine , the general procedure was to develop and debug these subroutines individually and run some sensitivity analyses on a program version containing extensive printouts. In these operating labor, engineering, and buildings were set to zero since they were to be applied on the entire plant as described beyond.

The sensitivity runs are not explored thoroughly and in some cases use computations which were later superceded or corrected. However, the sensitivity runs are not of particular interest to the parent project.

Buildings

The kiln, the accelators, the carbon regeneration furnace, the preliminary treatment and the chlorination tanks would not be housed. All other facilities would be housed. In the present program the cost of buildings was taken as 10% of the subtotal investment, which makes allowance for the outside locations of some portions of the equipment.

Engineering

Engineering as an investment item was applied on the value of the subtotal plant according to the relation shown in the ENGR FUNCTION subprogram. This had previously been developed from a number of engineering fee schedules.

Operating Labor

Operating labor was estimated by visualizing the operating activities of a 10 mgd plant as in Table 7. Nonoperating labor was applied according to the schedule in Table 8. Operating labor at other mgd levels was obtained from the 10 mgd estimate by using the log-log slope typically found in chemical process plants (1). The estimate for total labor is shown in Table 9, the exponential relationship in Line 405 of the Program.

TABLE 7

OPERATING LABOR ESTIMATE

10 mgd Plant

	Man hours per day
Preliminary	3
Lime	20
Clinoptilolite	18
Carbon	6
Chlorination	2
Disposal	8
	57

TABLE 8

NONOPERATING LABOR ESTIMATE

Man hrs/day

mgd	Chemist	Clerical	Asst.Supt.	Supt.	Custodial	Total Non-Operation
.1	1	0	0	0	0	8
1	1	1	0	1	0	24
10	1	1	0	1	1	32
30	2	2	1	1	2	68
100	4	2	3	1	3	104

TABLE 9

TOTAL LABOR ESTIMATE

Man hrs/day

mgd	Nonoperating	Operating	Total
.1	8	16	24
1	24	30	54
10	32	57	89
30	68	77	145
100	104	103	207

When the nonoperating labor at applicable estimated pay levels for each category was added to the operating labor at each mgd level the average total labor rate was 1.12 times the $3.00 per hour operating labor rate. The factor 1.12 in Line 405 makes this adjustment.

Preliminary Treatment

Investment and operating costs for preliminary treatment were taken from Reference 2.

Residue Disposal

The cost of hauling and sanitary landfill disposal of the slaker residue is taken as 1.5$/ton of (moist) residue. Moisture content was taken as 30%.

The UNITS Subroutine

The UNITS subroutine and associated PARAB3, BAJO and statements in the Program determines the optimum number of major units to be used. The concept is as follows:

The plant design for fail-safe operation requires that the plant fulfill its function even though one unit is out of service. By "fulfill its function" is meant to be capable of the design capability or some specified fraction thereof. When an equipment unit is capable of being pushed beyond its nominal capability as for example an Accelator, then this fraction can be less than 1.0. In the case of the accelators in this program the fail-safe principle is that they must be capable of 65% of the design capability with one unit out of service. The principle in general requires at least two units. And if there are only two units each must have the design capability and thus the total capability two times that without the fail-safe principle. If three units are used then each can have a capability of one-half the design capability such that the total is only 1.5 times the design capability. Carrying this to the extreme one would seek the largest possible number of units limited only by the smallest practicable unit available, so as to have the least excess capability. However, as the number of units is increased and the size of individual units decreased the unit cost (e.g., cost per gallon per day of capability) of each increases. Accordingly as the number of units is increased on the one hand the cost is lowered because of lowering the excess capability but on the other hand the cost is increased because of increasing the unit cost of each unit. Therefore, there is an optimum number of units. The UNITS and associated subroutines determine the number of units which will give a minimum production cost.

In the LIME subroutine UNITS determines the minimum investments for Accelators and filters (separately), since the minimum in production costs occurs when these are minimized individually.

In a complete optimization scheme the number of units would be simply another one of the parameters to be optimized. In the present version, only the one dimensional optimization is used.

LIME CLARIFICATION STAGE DESIGN

A flow sheet of the lime clarification stage with stream numbers is shown on the next page. The preliminary treatment includes a screen chamber including a comminutor, an aero-degritter, overflow and by-pass chamber and Parshall flume.

<u>Basic Performance Data</u>

Table 10 shows the performance of the system at Blue Plains as operated up to April 1970 (3).

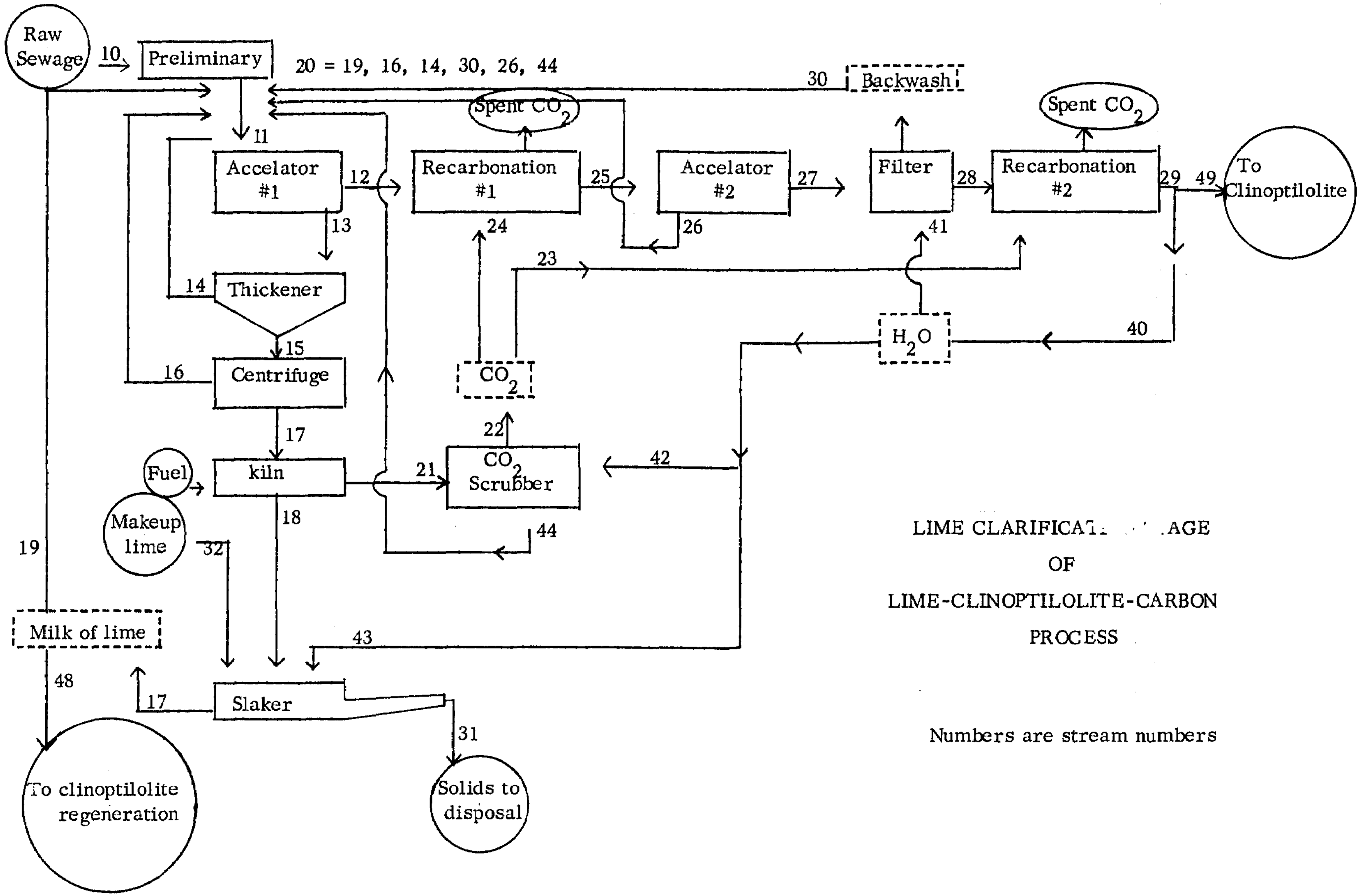
TABLE 10

BLUE PLAINS PERFORMANCE DATA ON RAW SEWAGE

Concentrations in mg/l (3)
Removals as Fractions

	BOD	COD	TOC*	PO_4	NH_3-N
Raw sewage	142	347	118	27	13.6
After lime	31	66	26	1.4	12.8
Removal, lime	.78	.81	.78	.95	.06
After filter	24	54	20	.95	-
Removal, filter	.23	.18	.23	.32	-
After clinoptilolite	-	-	-	-	2.3
Removal, clinoptilolite	-	-	-	-	.82
After carbon	3.7	8.0	3.7	.64	-
Removal, carbon	.85	.85	.81	.32	-
Removal, over-all	.97	.97	.97	.98	.83

* Total organic carbon



LIME CLARIFICAT[illegible]AGE

OF

LIME-CLINOPTILOLITE-CARBON

PROCESS

Numbers are stream numbers

At the time this Program was developed there was available a mathematical model of lime treatment (4). This work on this difficult subject was not used in the present program because the design was for Densators, because the performance data was for secondary effluent rather than raw waste, and because the present authors have come to distrust solubility and solubility product relations as applied to calcium carbonate and phosphates in waste treatment. It was preferred to use empirical performance data such as in Table 10 and 11.

In this program the COD is used as the parameter for the organics. The removal in the Accelator stages is about 80%, and about 18% of what remains is removed in the filter. The phosphate is reduced to 1.4 mg/l. In laboratory experiments at Cincinnati (5) the PO_4 was reduced to 1-3 mg/l. The program uses 2.0, a concentration parameter rather than a fraction removal parameter.

Table 11 shows the values taken for the controlling parameters in the lime clarification stage (6,7).

CaO Dosage

To avoid the confusion which exists in the literature over lime terminology the following definitions are used in this work:

CaO or calcium oxide - the chemical substance CaO

$Ca(OH)_2$ or calcium hydroxide - the chemical substance $Ca(OH)_2$

Quick lime - the technical grade solid comprising CaO as the major component and used for its CaO content

Hydrated lime - the technical grade solid containing largely $Ca(OH)_2$ and used for its $Ca(OH)_2$ or equivalent CaO content

Lime - the technical grade solid, either quick lime or hydrated lime

Milk of lime - an aqueous slurry containing particulate $Ca(OH)_2$ and other solids, $Ca(OH)_2$ being a major component; made by mixing water and lime

TABLE 11

LIME CLARIFICATION STAGE ASSUMPTIONS
FOR BASE CASE PERFORMANCE

Symbol	Description	Units	Value	Source
XMGH12	Mg in Accelator #1 overflow	mg/l*	3.	6
PO412	PO_4 in Accelator #1 overflow	mg/l	2.	3,5
TSS12	Total Suspended solids Accelator #1 overflow	mg/l	10.	6
	Total suspended solids Accelator #2 overflow	mg/l	10.	6
TSOL13	Total suspended solids Accelator #1 underflow	mg/l	10^5	6
FCODAC	Fraction COD entering Accelators which is removed in the two Accelators	fraction	.8	3
FCODF	Fraction COD entering filter which is removed in filter	fraction	.18	3
FINRTD	Fraction of inerts entering slaker which leave as disposed residue	fraction	.9	6
CAC26	$CaCO_3$ in Accelator #2 underflow	mg/l	$1.5*10^5$	6
CAC27	$CaCO_3$ in Accelator #2 overflow	mg/l	35.	6
TSOL14	TSS in thickener overflow	mg/l	100.	6
TSOL15	TSS in thickener underflow	mg/l	$2.5*10^5$	7
TSOL16	TSS in centrifuge overflow	mg/l	$4.7*10^4$	7
TSOL17	TSS in centrifuge underflow	mg/l	$6.5*10^5$	7
	pH of Accelator #1 overflow	pH	11.0	6
	pH of Accelator #2 overflow	pH	9.5	6
	CO_2 required to achieve this	mg/l	30.	6
	Removal of PO_4 in Accelator #2	fraction	0.	6
	CO_2 in scrubber exit gas	%	25.	7
	Ratio backwash to filter exit	fraction	.03	

*Milligrams per liter

Reference 8 presents a relationship for determining CaO dosage, mg/l from waste water alkalinity, mg/l equivalent $CaCO_3$, derived from their own investigations as well as several others. The CaO requirement is that to bring the waste water to a pH $\geq$ 11.0. The investigations were performed with actual municipal waste waters having alkalinities between 60 and 450 mg/l and for the Reference 8 sample a PO_4 content of 7.2 mg/l. The composition of the actual waste may vary greatly from those used in the investigation. A modification may be necessary. A sixth degree polynominal, that given in Lines 1105-1107 of the Program, was fitted to the data. The equation gives negative values for dosage if the alkalinity is less than 60 mg/l. This is handled by a lower constraint of 50 mg/l on the CaO dosage. It should not be trusted for alkalinities greater than 450 mg/l.

Lime Slaker

The particular lime slaker used in this version of the lime clarification step is the Infilco "Viscomatic" (9) which allows separation of the impurities, MgO, hydroxyapatite ($Ca5OH(PO_4)3$), and inerts, in a grit chamber and their removal by a flight conveyor (6). The use of this slaker eliminates the necessity for discarding lime in order to dispose of the impurities. In the Program the slaker is operated to produce a milk of lime with a water/CaO ratio of 7.72 corresponding to 1.05 pounds CaO/gallon. (9)

Reference 9 provides some data points for the relation between percent CaO in the feed to the slaker and percent $Ca(OH)_2$ in the residue from the slaker, respectively 0.8747, 0.282, .959, .664, .959, .628. The relation must also pass through the points 0, 0, 1.0 and 1.0. A relation which approximately reproduces these pairs is:

FCAOHD = FCAOS**10

The recycle around the slaker is brought to balance by iteration between Lines 1665 and 1615, the convergence being considered complete when two successive values for makeup lime differ by not more than 1% from each other.

The slaker reactions are:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

MgO ——————> Unchanged

Ca5OH(PO4)3 ——> Unchanged

Recycle Around Accelators

The process uses Accelators because they are superior to Densators for the intended service. The recycle of streams around the Accelators is accomplished by iteration between Line 1865 and Line 1201 in the Program and using material balances which involve some approximations and the neglect of some small streams in the water balance. The recycle is considered converged when two successive recycle streams (Q20) are within 0.1% of each other.

The reactions in the first Accelator are:

$$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2CaCO_3\downarrow + 2H_2O$$

$$Ca(OH)_2 + Mg^{++} \longrightarrow Ca^{++} + Mg(OH)_2\downarrow$$

$$3(PO4)^{---} + 5Ca(OH)_2 \longrightarrow Ca5OH(PO4)3\downarrow + 9(OH)^-$$

leaving excess $Ca(OH)_2$ in the liquor at pH 11. Some of the organics are hydrolyzed, others are brought down with the solids.

In the first recarbonation and second Accelator the reaction is:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3\downarrow + H_2O$$

to pH 9.5 with 35 mg/l $CaCO_3$ equivalent in solution.

The second recarbonation merely lowers the pH to 7.5 for the clinoptilolite stage without further precipitation.

In the thickener and centrifuge it is assumed that there is no segregation effect on the various solid components so that the relative composition of the suspended solids is the same in all streams. Actually the centrifuge overflow would be found somewhat enriched in Mg(OH)2. The Mg content of the liquor would in actuality affect the centrifuge performance. At Miami and also at Austin where the Mg is low the 65% solids is achieved in the centrifuge cake, but at Dayton with higher Mg only 45% is reached. Of course, this also depends on the rpm speed and the loading. Reference 8 uses recarbonation of the sludge to redissolve about 20% of the precipitated Mg(OH)2 to improve dewatering characteristics. These things are not taken into account in the present Program.

Kiln

The reactions in the kiln are taken to be the calcination of $CaCO_3$ and Mg(OH)2 to CaO and MgO and the conversion of the original suspended solids to ash by combustion. The fraction of non-volatile suspended solids in the original suspended solids is taken as 0.25 (8). The hydroxyapatite passes through the kiln unchanged.

LIME CLARIFICATION PROCESS COSTS

Accelator Investment

From Infilco price lists (6) installed costs of Accelators were obtained as a function of mgd capability at 1.5 gpm/sf rise rate. The size range covered was from .07 to 20.16 mgd, taken as the minimum and maximum size units, respectively. The relation between 1970 dollars investment and mgd capability was expressed as a fifth degree polynominal in LNS (natural logarithms) found in Line 2050 of the Program. The NTRAIN refers to the number of trains of two Accelators each. This is obtained from a subroutine UNITS which approximates the number and capability of units such that the production cost will be a minumum and the system can handle a specified fraction of plant capability with one unit out of service.

Costs Related to Recalcination

Some basic data on actual costs of installed recalcination facilities for lime softening plants including thickener, centrifuge and kiln were available in References 7 and 10. Other workers (10) had computed some of these on the basis of 1.2 tons CaO per mg of production which obtains at Tahoe. The available data were further explored with the result that the 1.2 ratio was considered typical of softening plants as well as the Tahoe waste treatment plant. Since the calcination in the softening plants produced a 93% available CaO lime, the ratio of pounds of kiln product to pounds of CaO in the lime is 1.07. The resulting data ranging from 6.4 to 161 tons per day of product were fitted with the following equation:

VRCALC (K$, 1970) = 178.959*(TLBS18/2000)**.535022

where:

(TLBS18/2000) = tons per day of kiln product
K$ = thousand dollars

σ ratio has this meaning: Probability is 68% that an actual value will lie between σ ratio times, and $1/\sigma$ ratio time the equation value.

Other workers (10) studied the fuel cost for several plants and used this to generate fuel costs in one of their tables. The table was reconstituted by taking 1.28(=1.2 x 1.07) tons per day kiln product per mgd. The correlation is:

fuel costs ($/day) = 11.249 x (TLBS18/2000)**.767663*UBAR

That reference gives an electrical energy cost for recalcination of 0.1¢/Kgal which under the assumptions above computes to 0.791 $/ton kiln product. Note that the energy price is buried in this cost.

<u>Costs of Recarbonation</u>

Investment in recarbonation equipment comprises the recarbonation unit (including the scrubber), the grids and the concrete basin. Infilco prices (11) and general design data (6) were used in the costing. The design bases included the following. The gas to the recarbonators will be 25% CO_2, the price list specification for lb CO_2/24 hours being for a 12% gas. Thirty mg/l of CO_2 is supplied to each unit. The grid area required is 25 sf/mgd. The basin is 10 feet deep with bottom and walls one foot thick. Concrete costs are 100 $/cu. yd. installed and grids cost 6 $/sf.

Costs of recarbonation units were available from 104 to 10,400 lb 25% CO_2/24 hours corresponding to mgd's of .51 to 51. The 13 data points were fitted to a third degree polynominal in LNS (Natural logarithms) which is found in Line 2076 of the Program with a 35% increase for installation. For large units the 50 mgd value was extrapolated at a ln-ln slope of 0.7 according to the relation in Line 2073.

The same references supplied data over the same range on the horsepower of the blower as a function of mgd to which the following relation was fitted:

COMPHP = 1.30789*Q12**.668189 -0.45166

σ ratio = 1.10

The conversion of this to energy costs for the two recarbonators is contained in the expression in Line 2248 of the Program along with the energy cost arising from pumping to the filter and to one Accelator.

<u>Cost of Filtration</u>

References 11 and 6 supply data on costs of dual media filter plants installed, over the range from .7 to 28.8 mgd, operated at 2 gpm/sf. In the Program the filters are operated at GPMSFF set to 4. and multiple units are used beyond 70 mgd at this rate, (10410 sf). The relation between installed costs K$ and square feet was expressed as a fourth degree polynominal in LNS, and is found as the exponential in Line 2150 of the Program, having been trended to 1970, N = 11, σ ratio = 1.038. The pumping energy requirement is figured assuming a Δ P of 40 psi and an efficiency of .75.

RESULTS OF INDIVIDUAL LIME CLARIFICATION RUNS

On the above basis individual runs on the design and costs of the lime clarification stage alone were made using parameter values shown in Table 11. Figure 9 shows the cost versus QBARE relation, and Figure 10 shows the sensitivity around the base case to certain of the parameters. The waste used was typical of San Antonio waste.

Figure 9 shows a cost of 6.87 ¢/Kgal for the base case at 100 mgd, utilization factor UBARE = 0.5. (UBARE = QBARE/QDOT)

The computations for the present project are being carried out on the basis of present technology and the parameter values chosen are representative of that level. However, Figure 10 shows that if the filters could be eliminated by placing the filtering burden on the clinoptilolite and the activated carbon beds the costs could be reduced by about 1.3 ¢/Kgal at 100 mgd. The filters comprise 21% of the investment. At 2 gpm/sf (gallon per minute per square foot) instead of 4, the filters would comprise about half of the total investment, greater than the cost of the Accelators and twice as great as the recalcination facility.

The sensitivity relations in Figure 10 show that the costs are quite insensitive to the water quality parameters and also to the fraction of inerts disposed of from the slaker. The process is highly capital intensive and therefore very sensitive to UBARE which therefore appears as the only controllable decision parameter by which costs might be reduced.

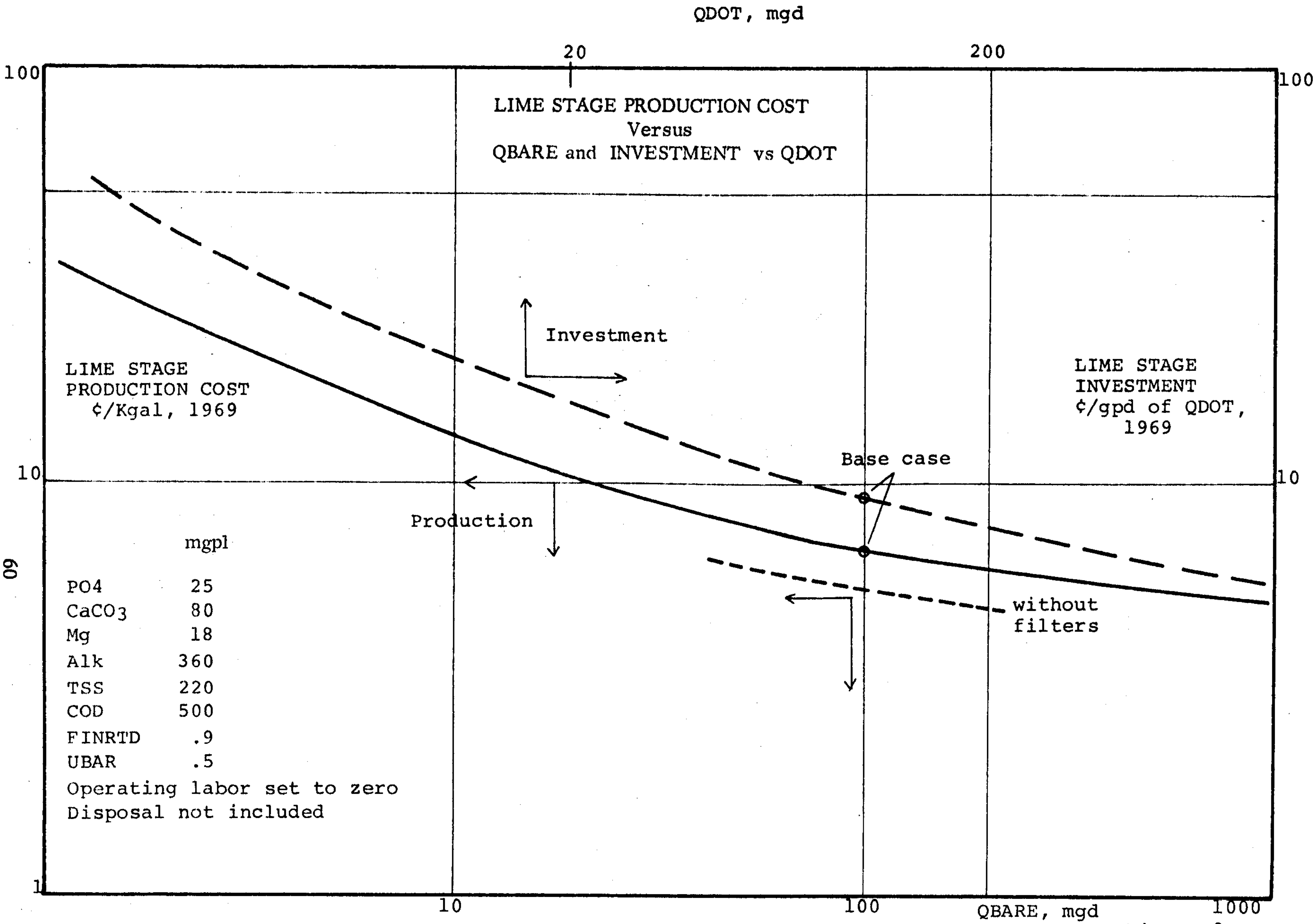

QDOT, mgd
20
200
100
10
1
LIME STAGE PRODUCTION COST
Versus
QBARE and INVESTMENT vs QDOT
Investment
LIME STAGE
PRODUCTION COST
¢/Kgal, 1969
LIME STAGE
INVESTMENT
¢/gpd of QDOT,
1969
Base case
Production
without
filters
mgpl
PO4 25
$CaCO_3$ 80
Mg 18
Alk 360
TSS 220
COD 500
FINRTD .9
UBAR .5
Operating labor set to zero
Disposal not included
10
100
QBARE, mgd
1000

Figure 9

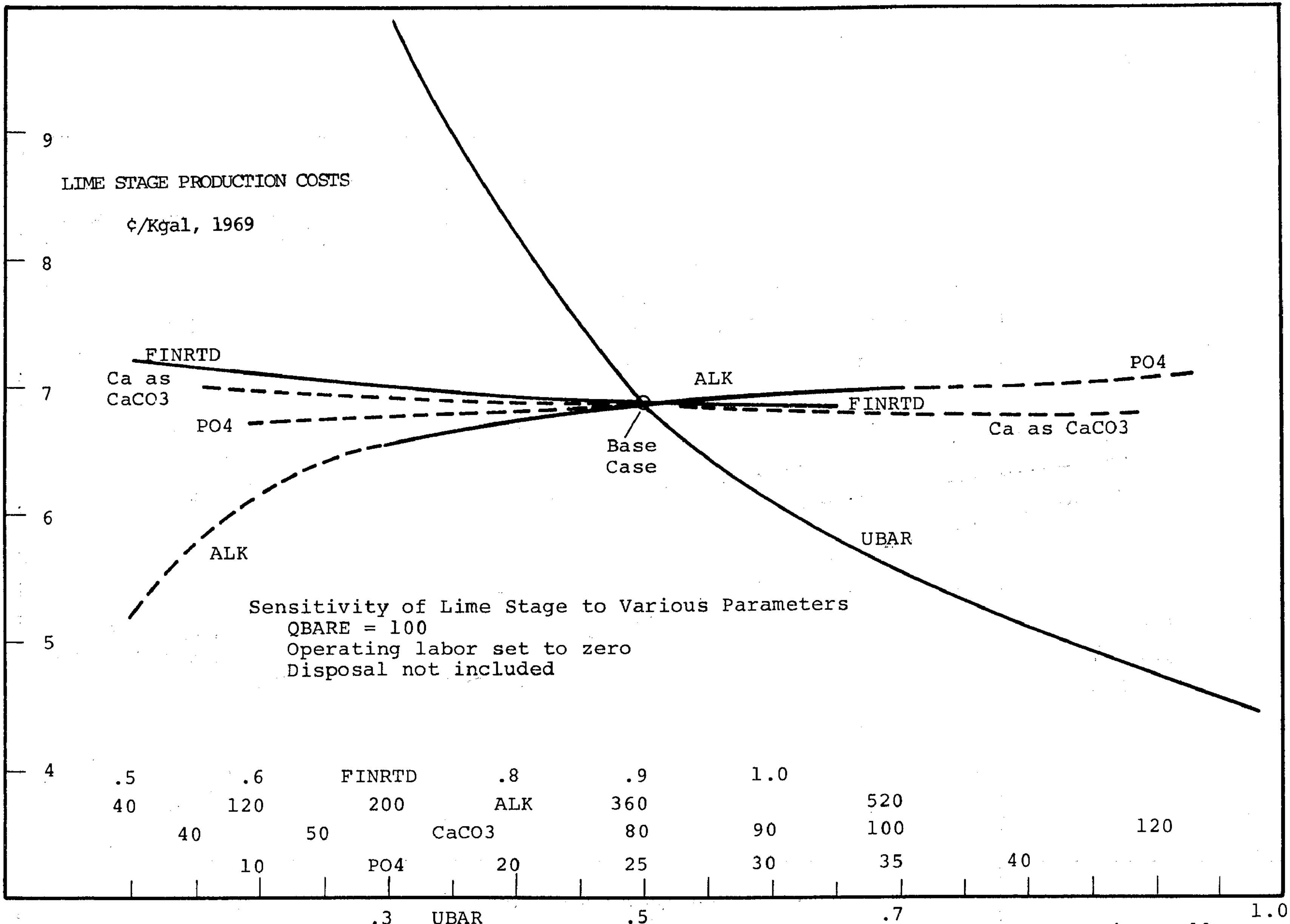

LIME STAGE PRODUCTION COSTS
¢/Kgal, 1969
9
8
7
6
5
4
FINRTD
Ca as
CaCO3
PO4
ALK
Base
Case
ALK
FINRTD
PO4
Ca as CaCO3
UBAR
Sensitivity of Lime Stage to Various Parameters
QBARE = 100
Operating labor set to zero
Disposal not included
.5
.6
FINRTD
.8
.9
1.0
40
120
200
ALK
360
520
40
50
CaCO3
80
90
100
120
10
PO4
20
25
30
35
40
.3
UBAR
.5
.7
1.0

Figure 10

CLINOPTILOLITE ION EXCHANGE STAGE DESIGN

A schematic diagram of the clinoptilolite ammonia exchange process is shown on the next page. The feed liquor exit from the lime clarification stage is fed to several clinoptilolite ion exchange beds in parallel. When a bed has reached exhaustion it is piped into the regeneration system. In the first regeneration step a regenerant liquor containing about 100 mg/l NH_3-N is circulated through the bed via Tank A until it reaches a concentration of 600 mg/l. The bed is then piped into Tank B containing 10 mg/l liquor and recirculated until the liquor has built up to 100 mg/l. Finally the exchanger is flushed with product water to free it from residual brine and lower the pH to 8.5. Then it is returned to the exhaustion line.

In the exhaustion stage the NH_3 in the liquor exchanges for Ca on the clinoptilolite. In the regeneration stage $Ca(OH)_2$ is the regenerant exchanging for NH_3 on the clinoptilolite.

When Tank A has reached 600 mg/l it is piped to the stripping columns where it is stripped in two columns in series with air which when necessary is heated to keep the liquor temperature above 25°C. The stripped liquor contained in Tank C is transferred to Tank B of the regeneration line for use in subsequent regeneration. A clarifier may be needed ahead of the stripping towers, but it is not included here.

This process has been piloted (12, 13). Other work had been done on ammonia stripping some of which was used in the present design (14). However, most of the practical design conditions represent the technology as of about April 1970 (15).

Basic Design Assumptions

Table 12 shows the design parameter assumptions for the clinoptilolite stage. In addition to the NH_4^+ the clinoptilolite also must exchange other ions particularly K^+ for which it is selective. This K^+ and the other ions must build up in the regenerant liquor since only NH_3 and any other gas-forming ions are removed by the stripper.

CLINOPTILOLITE AMMONIA EXCHANGE, SCHEMATIC

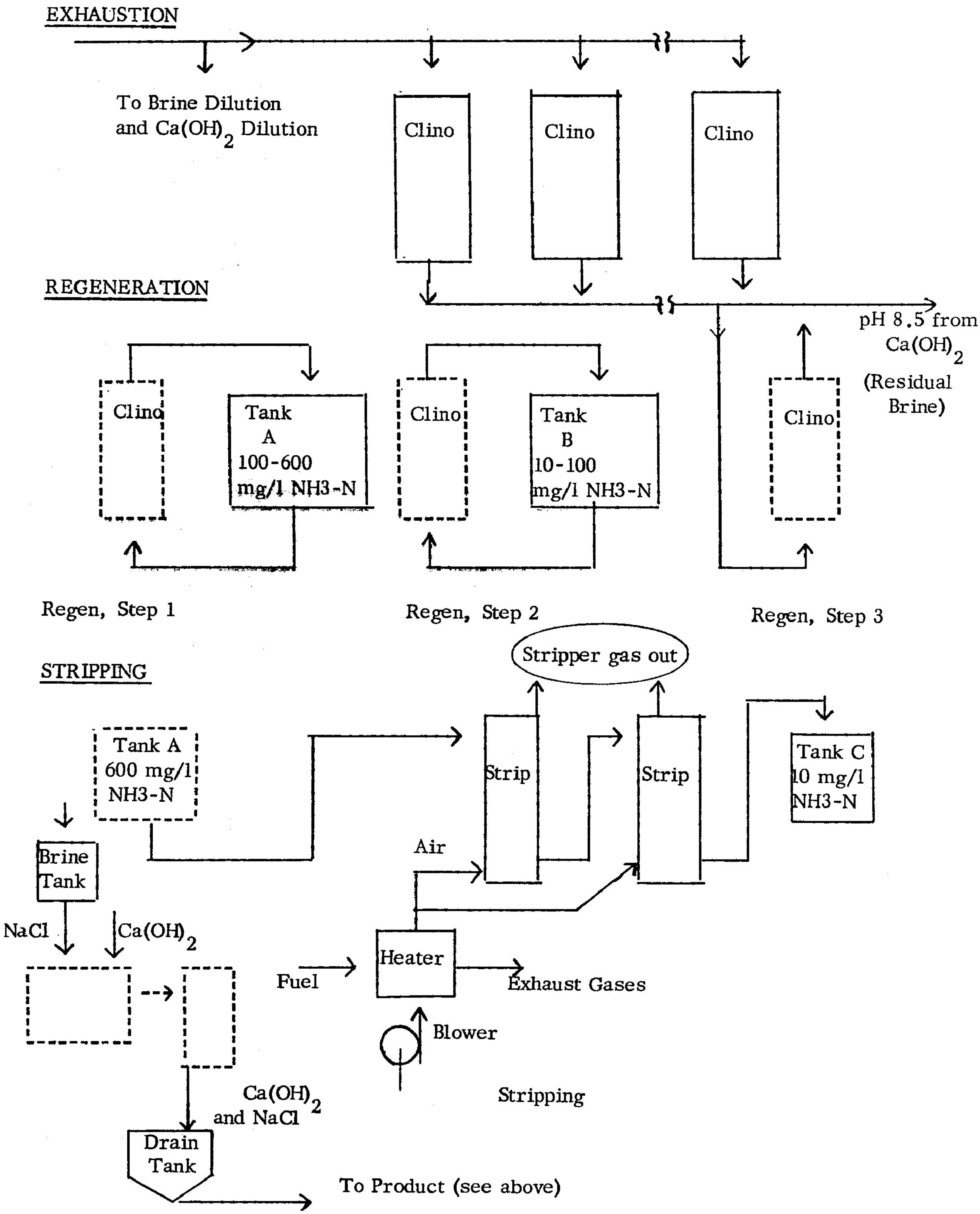


TABLE 12

CLINOPTILOLITE STAGE ASSUMPTIONS
FOR BASE CASE PARAMETER

Symbol	Description	Units	Value
AN79	NH_3-N in effluent	mg/l N	0.5
CLLF	Clinoptilolite exchange capacity	Lbs N/cf clino	.17
FCLPR	Clinoptilolite attrition loss per regeneration	fraction of bed volume	.0026
GPMSFX	Maximum allowable flow in exchanger	gpm/sf cross section	6.
GPMSFS	Liquid loading in stripper	gpm/sf cross section	5.
CFAPG	Air/liquor flow ratio in stripper	cf/gal	300.
DIAMAX	Maximum allowable diameter of exchanger	ft.	25.
DEPMAX	Maximum allowable depth of clinoptilolite bed	ft.	10.
EPUMP	Efficiency of pump, wire to water	fraction	.75
EBLOW	Efficiency of blower, wire to air	fraction	.60
	Fraction of NH_3-N removed in each stripper	fraction	.85
PRCLIN	Price of clinoptilolite	$/cf	10.
NDTL77	Days per year less than 77°F	No. days	100.
AVTL77	Average temperature when less than 77°F	°F	67.
PRNACL	Price of salt	$/lb	.01
PRMBTU	Price for heat	$/million BTU	.5
PRLIME	Price of lime	$/ton	18.5
FACAOL	Fraction of active CaO in purchased lime	fraction	.9

Consequently it should be necessary either to discard some regenerant liquor or to return it to the process in order to prevent the buildup of these other ions. The present Program does not take this into account but assumes that nothing but $NH4+$ is exchanged on the clinoptilolite.

Exchanger Number and Size

The size of the exchanger is controlled by a maximum bed depth, a maximum gpm/sf and a maximum diameter. The number of exchangers on line and the capability of each is obtained via the UNITS subroutine. The diameter and height are then adjusted to the next half-foot dimension. The time to exhaustion is computed from the bed volume per stage and the clinoptilolite capacity. The number of exchangers in regeneration at any time is computed on the basis that regeneration requires nine hours, four hours circulation in each tank and one hour for the rinse.

Regeneration System

Each regeneration system consists of three holding tanks for regenerant solution, a pump for each tank, one drain tank, and a brine tank and saturator for all the regeneration systems. It is assumed that each regeneration system will simultaneously handle two exchangers. The capacity of each holding tank is four bed volumes. The pumps are sized to circulate 10 bed volumes per hour at 35 feet head.

The initial charge of NaCl necessary to bring the regenerant liquors up to 0.1 normal is neglected and the NaCl consumption is computed on the basis that at each regeneration the regenerant liquor residual in the bed (50% voids) enters the product.

Stripper System

Each exchanger regenerated requires four bed volumes of eluent. The capability of stripper is generated from that, and the area of each stripper is determined from a loading GPMSFS, taken at 5 gpm/sf. Two pumps are required, each capable of the stripper capability. The regeneration system pumps are used for returning the stripped eluent to storage tanks. The capability of the blower to handle the two strippers is taken at 300 cf air/gal. On days when the liquor is below 25°C (77°F), heating will be required to raise the temperature to 77°F. Parameters are inserted for an arbitrary number of days per year below 77°F and the average temperature on those days.

Instead of the Marley 20 foot cross-flow tower type of stripper used at Tahoe, this design utilizes a stripping tower similar to a square-type forced-draft aerator because of the greater ease of access for cleaning. The Tahoe stripper operates on secondary effluent with NH_3-N 25-30 mg/l and achieves an 85% removal at 3.2 gpm/sf and 240 cf air per gallon. In the present design it will be assumed that a square-type aerator tower 10 feet in height will give the same 85% removal per stage operating on NH_3-N concentrations of 600 mg/l in the first tower and 90 mg/l in the second.

CLINOPTILOLITE ION EXCHANGE STAGE PROCESS COSTS

Ion ExchangerSystem Investment

Another Program (IONEX) (Reference 16) had developed costs of an ion exchange system including vessels, the regenerant tanks, and the associated valving, piping and controls. The relation appears in Line 6005 of the Program. This equation had been developed for commercially available ion exchange units with bed volume less than about 200 cf and is used in the Program for which it was developed to the largest size commercially available exchangers of about 800 cf. For the Clinoptilolite Program it will be assumed that the equation can be extrapolated to exchangers 25.5 feet in diameter and of 10 foot bed depth.

Tanks Investment

The cost of tanks is taken from data in Reference 17 and the relation is for example in Line 6020 of the Program. The factor 1.23 is a factor after Reference 18 to account for concrete foundations not included in Reference 17.

Pumps Investment

The relation for pump cost is developed from Reference 18 which gives uninstalled costs of carbon steel pumps with driver and a factor (2.4) to obtain installed costs including indirect labor. The cost of the piping is assumed to be adequately covered by the costs for the exchanger system. The relation appears in Line 6015.

Blowers Investment

Blower horsepower may be computed by Reference 19

$$HPBLOW = CFMAIR * P(in.H_2O)/(6356 * efficiency)$$

in. = inches

The efficiency of blowers is about 60%. Reference 14 computes a ΔP of 0.9 inches H_2O for a tower 10 feet wide and 27.5 feet high. A ΔP of 1.5 inches is assumed for the tower to be used. The CFMAIR is actually to be measured at the suction pressure and temperature. These data result in the horse-power equation given in Line 5330 of the Program. The maximum blower size is taken at 5000 HP.

The relation between blower cost and horsepower is taken from Reference 20 and the graph there gives results in a relation shown in Line 6045 of the Program where the factor of 2 enters because there are two stripping towers.

Stripping Tower Investment

The stripping tower to be used is similar to a square-type forced-draft aerator for which manufacturers prices were obtained (21). These prices include blowers. The estimated blower cost was subtracted from the quoted prices and the installed price adjusted for three additional trays to get the 10 foot height to be used. A resulting relation between tower cross-sectional area and cost is that shown in Line 6035 of the Program.

Pipe Investment

It is assumed that piping for the tower is similar to that for horizontal pressure vessels at an estimated cost of 42% of the tower cost (18). Assume that "piping" for the blower is for the duct work associated and is similar to that for air coolers, factor 18% (18).

Energy Cost

Electrical energy is needed for regeneration pumps, stripper pumps, stripper blowers, and exchanger pumps. It is assumed that the flow through the exchanger is laminar and consequently pumping power is proportional to square of flow rate. For the blower the flow is assumed turbulent so that the energy is proportional to the flow rate cubed. This computation is in Line 6535 of the Program.

Lime Cost

The lime consumption is taken as that equivalent to NH_3 released, in Line 5175 and the cost to purchase this is computed in Line 6520. If there is excess $Ca(OH)_2$ from the lime clarification stage the cost is proportionately reduced in Line 6522.

RESULTS OF INDIVIDUAL CLINOPTILOLITE ION EXCHANGE RUNS

On the above basis, individual runs on the design and costs of the clinoptilolite ion exchange stage alone were made using the parameter values in Table 12. Figure 11 shows the cost versus QBARE relation and Figure 12 shows the sensitivity around the base case to certain of the parameters. The base case at 100 mgd shows a cost of 7.42¢/Kgal. The cost is not decreasing very much beyond 100 mgd because the maximum sizes of equipment have been reached.

The clinoptilolite ion exchange stage is highly sensitive to the parameters. It is thought by some that the clinoptilolite loss fraction might eventually be reduced to 1/10th of its current value, in which case the cost would be reduced by 1.7¢/Kgal. Also, the current price of clinoptilolite at 10$/cf, about 30¢/lb seems quite high for a mined and processed mineral. The initial clinoptilolite comprises about one-quarter of the investment and the makeup clinoptilolite about one-quarter of the production costs. The cost is particularly sensitive to the ammonia nitrogen in the feed, approximately proportional to it, thus if the NH_3-N in the feed were 20 instead of 15 the cost would be increased by 1.4¢/Kgal. The cost is extremely sensitive to the maximum diameter allowed for the exchanger vessel, reaching a minimum at about 2¢/Kgal below the base case somewhere in the region of 75 feet.

However, the present application of this Program in this project is restricted to present technology.

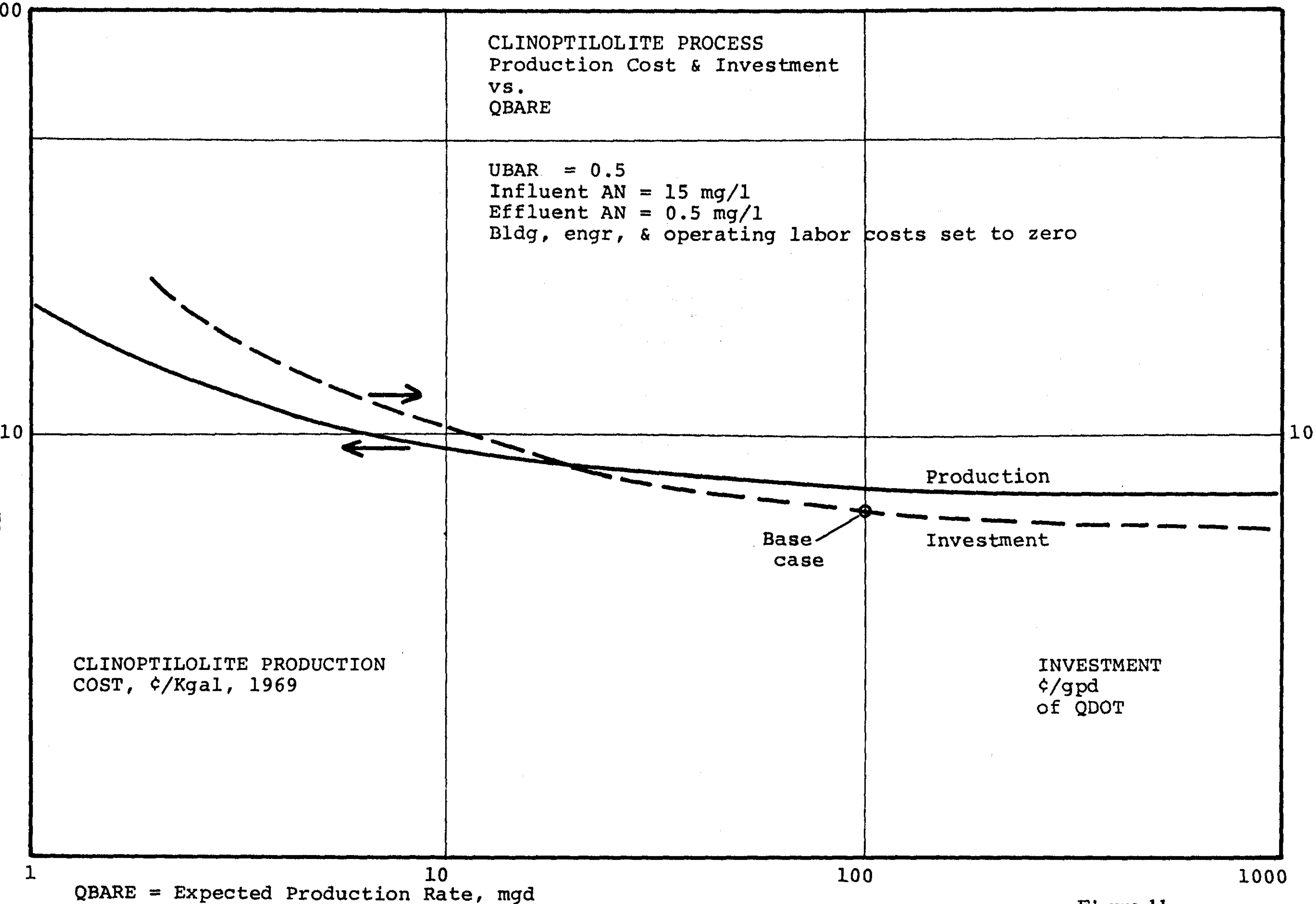

CLINOPTILOLITE PROCESS
Production Cost & Investment
vs.
QBARE
UBAR = 0.5
Influent AN = 15 mg/l
Effluent AN = 0.5 mg/l
Bldg, engr, & operating labor costs set to zero
Production
Investment
Base case
CLINOPTILOLITE PRODUCTION COST, ¢/Kgal, 1969
INVESTMENT ¢/gpd of QDOT
100
10
10
1
10
100
1000
QBARE = Expected Production Rate, mgd

Figure 11

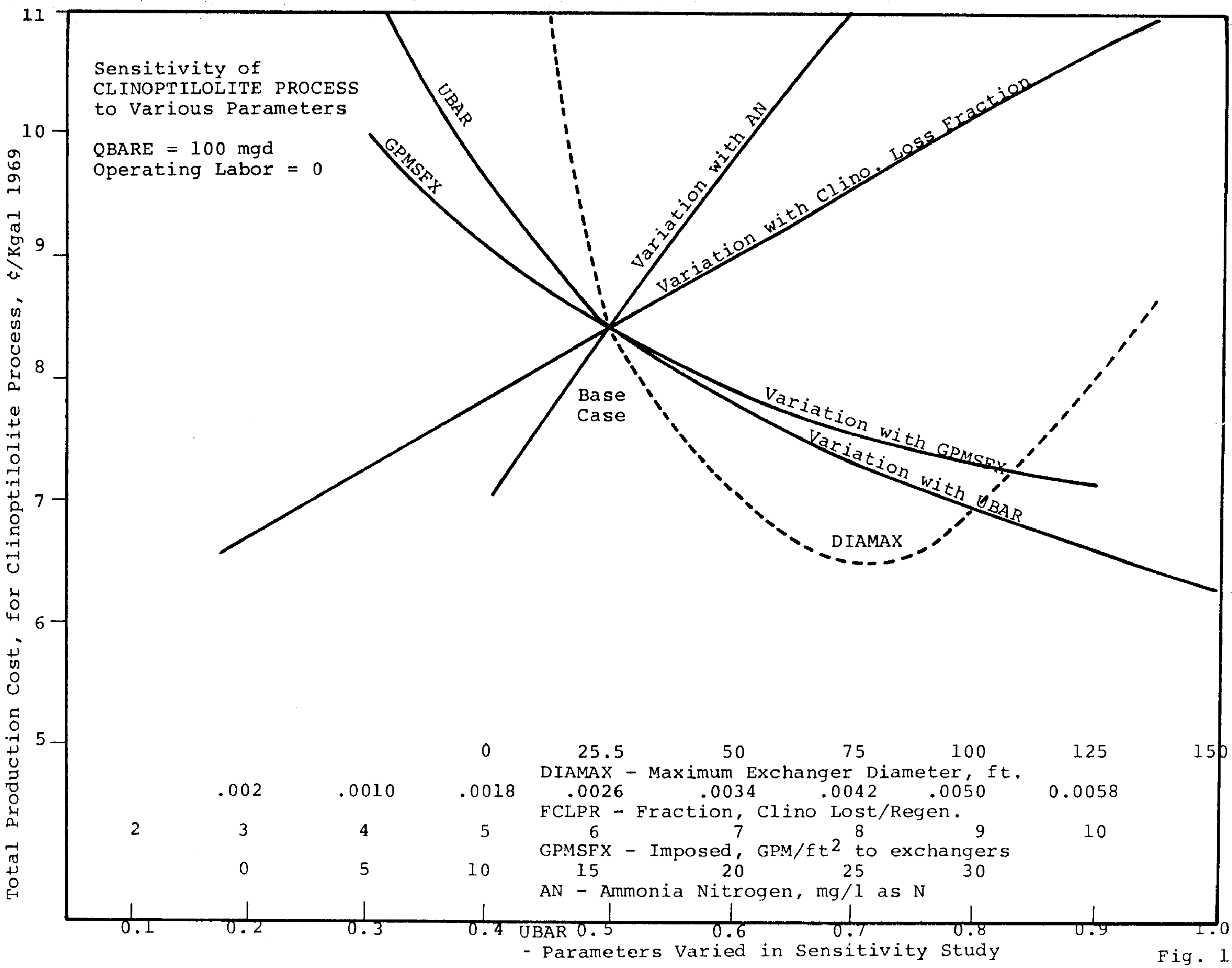

Sensitivity of
CLINOPTILOLITE PROCESS
to Various Parameters
QBARE = 100 mgd
Operating Labor = 0
Total Production Cost, for Clinoptilolite Process, ¢/Kgal 1969
11
10
9
8
7
6
5
UBAR
GPMSFX
Variation with AN
Variation with Clino. Loss Fraction
Base Case
Variation with GPMSFX
Variation with UBAR
DIAMAX
0 25.5 50 75 100 125 150
DIAMAX - Maximum Exchanger Diameter, ft.
.002 .0010 .0018 .0026 .0034 .0042 .0050 0.0058
FCLPR - Fraction, Clino Lost/Regen.
2 3 4 5 6 7 8 9 10
GPMSFX - Imposed, GPM/ft2 to exchangers
0 5 10 15 20 25 30
AN - Ammonia Nitrogen, mg/l as N
0.1 0.2 0.3 0.4 UBAR 0.5 0.6 0.7 0.8 0.9 1.0
- Parameters Varied in Sensitivity Study

Fig. 12

ACTIVATED CARBON ADSORPTION STAGE DESIGN

On another project the authors, like a number of investigators, have attempted to find a basis for the rational design of activated carbon adsorption for waste waters only to conclude that the behavior of waste water with activated carbon does not follow the laws and relations which have been developed for other adsorption processes and upon which scientific designs can be based. Without actual experimentation the presently available data do not allow the prediction of required contact times and carbon loading factor (capacity for organics) necessary to achieve a given effluent. In view of that, the present design uses a carbon loading factor and a contact time as input variables. Until better information is developed the designer must first determine experimentally with the liquor to be processed just what carbon loading factor and contact time is required to achieve his specifications. The contact time of 50 minutes and the carbon loading factor of 0.5 lbCOD/lbC (pounds COD per pound carbon) for an effluent of 8 COD, used in the base case, are thought to be conservative for most liquors and typical carbons.

The term "contact time" is reluctantly retained in this report because it has crept into common usage. However, it should be recognized that this term is a misnomer and does not reveal the average time of contact of the liquor with the carbon. "Contact time" is the time required to pass one bed volume of feed liquor. Since carbon has a void space of about 36-38%, the actual average time of contact of the liquor with the carbon is about one-third the "contact time." A rational unit, preferable because it avoids the indefiniteness of "contact time" is gpm/cf (gallon per minute per cubic foot) which is now coming into use in ion exchange technology. The relation is:

$$7.48/(\text{gpm/cf}) = \text{contact time, minutes}$$

Fifty minute contact time is about .15 gpm/cf.

The two major design and cost studies on activated carbon (as applied to secondary effluent) are those of References 22, 23, and 24. Condensed cost data from 22 appear in Reference 25.

Most of the performance relationships and cost data used herein were taken from these two studies.

A schematic of a two-stage, two-train adsorption process is shown on the next page. The term "train" refers to the two series of adsorbers, ABE and CDF, run in parallel. The term "stage" refers to the two contactors on line at any one time in each train, in the sketch, A and B and C and D. The feed liquor flows through the two stages in series and the two trains in parallel and issues as product. When lead adsorber, A, reaches exhaustion it is taken off stream and the second adsorber B is made the lead adsorber, the spare E becoming the second adsorber. The sketch is shown at the condition in which adsorber E containing carbon has just been taken off the line. Adsorber F is empty. The spent carbon is conveyed as a slurry to a screen from where it is passed through a rotary hearth regeneration furnace where it is reactivated in a steam atmosphere. As it leaves the furnace it is quenched and transported again in slurry form to adsorber F which had been empty. The regeneration operation and this transfer require many days and is timed so that adsorber F will be full of carbon and adsorber E empty, by the time it is necessary to place F in service through the exhaustion of C. Makeup carbon is added to replenish the carbon loss in the regeneration process. In the complete recycle scheme all backwash waters, scrubber waters and carbon fines are returned to the Accelator, but this return is not taken into account in the present design.

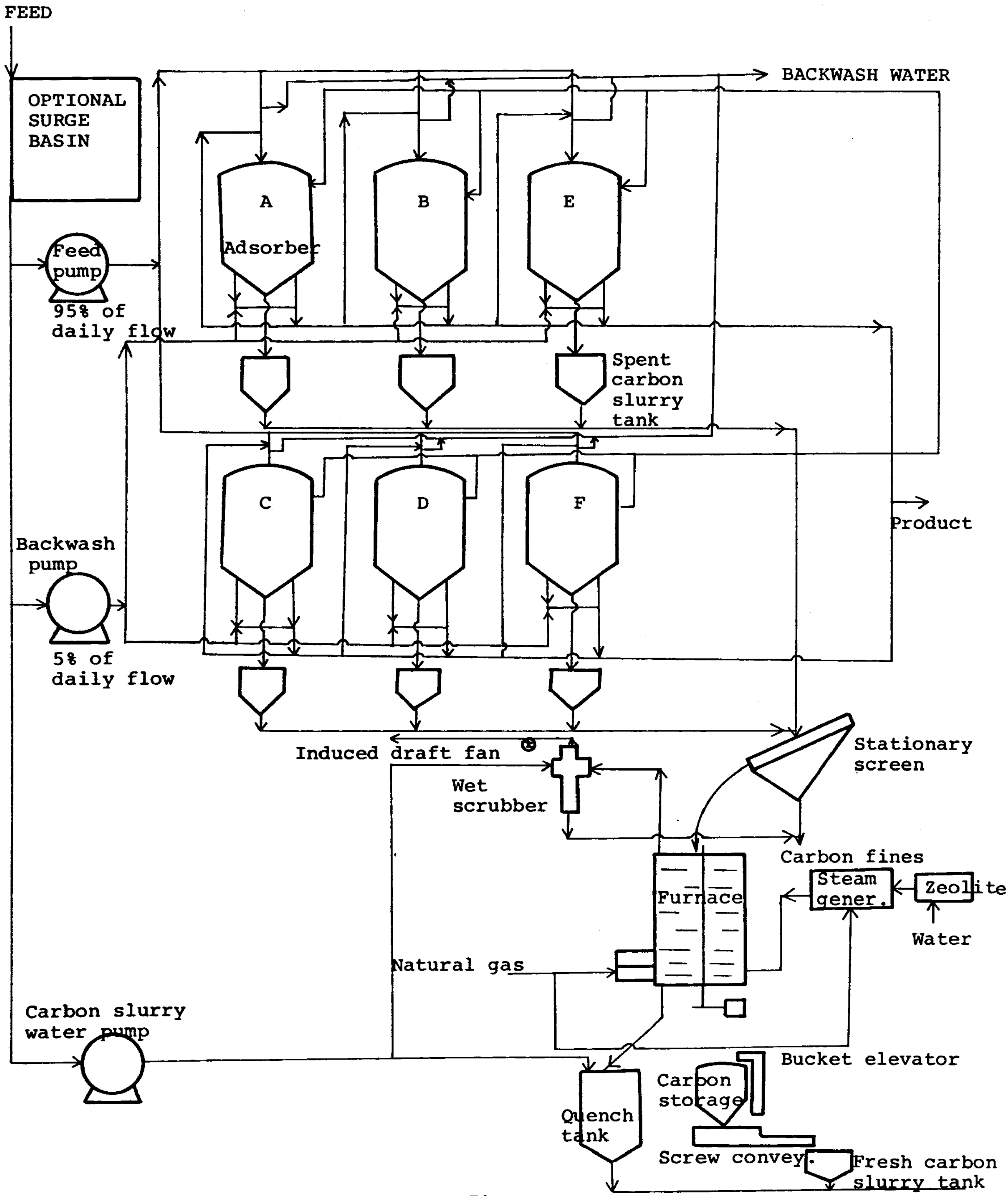
Design of Adsorber Beds

Central to the design after the contact time and carbon loading factor is the constraint comprising a maximum gpm/sf (gallon per minute per square foot), GPMSF, through the adsorber.

The total required volume of adsorber beds on line (BEDVOL) is computed from QDOT and contact time. If the gpm/sf through the adsorber is greater than about 13, the pressure drop through the adsorber may be greater than 15 psi which is considered a limiting level. Bed depth is then computed from gpm/sf, contact time, and number of stages, and is brought back to the constraints of 2.5 and 25 feet if outside these. The UNITS subroutine determines the optimum number of trains and the capacity of each. The bed volume per stage and the diameter is then computed.

The number of spare adsorbers, E and F of the sketch, is taken as two for every 10 trains or fraction thereof.

EXAMPLE OF TWO-STAGE CARBON ADSORPTION PROCESS



Furnace Area

The required hearth area of the furnace, sf, was correlated with lbs (pounds) C/day regenerated from the data of Reference 22. The relation is found in Line 8400 of the Program, obtained from 17 points, σ ratio 1.13.

Energy Consumption

The two basic cost references are not in good agreement on the energy consumption. Shown in Table 13 is the estimated consumption for a two-stage plant of three sizes.

TABLE 13

ENERGY CONSUMPTION, KWH/Kgal
(kilowatt hours per kilogallon)

mgd	23, 24	22
1	1.21	.496
10	1.00	.773
	1.36	
100	.79	.372

All five points were used in developing the relation:

KWH/Kgal = .939669*QBARE**(-.0775243)

7 points, σ ratio = 1.51

Backwash Systems

The number of backwash systems was taken as one-half the number of spare adsorbers, i.e. one for each 10 trains or fraction thereof, but this is not used in the final version of the Program.

ACTIVATED CARBON ADSORPTION STAGE PROCESS COSTS

Cost of Adsorber Vessels

The two main cost references present the cost of adsorber vessels as well as of other equipment in different ways. Reference 22 provides a "capital cost" to which is added 40% for contingencies, engineering and profit. In the present study Reference 22 capital cost figures are increased by 30% to obtain investment ex engineering and buildings, 10% of this 40% being considered as engineering. Reference 23 presents "major materials" which is multiplied by a factor of the order of 1.7 to obtain plant investment. In the present study the Reference 23 "major materials" are multiplied by 1.7 to obtain investment ex engineering and building. When plotted against total volume in the adsorber vessel including freeboard the two sets of raw data adjusted to 1968 define two trend lines having the same log-log slope but with Reference 23 (12 points, σ ratio 1.10) being more than two times the Reference 22 points (24 points, σ ratio 1.29). Both sets of points began at about 2000 cubic feet but the Reference 22 points extended to 140,000 whereas the Reference 23 points extended only to 30,000. For that reason the final chosen equation was obtained by taking the arithmetic average of the exponents and the coefficients of the two sets yielding the equation in Line 8505 of the Program:

VADS, K$ = .187254*VOL**.593364

where

VADS = K$ per adsorber vessel

VOL = cubic feet of volume in vessel including freeboard

Cost of Regeneration System

The cost of the regeneration system in Reference 22 is related to the square feet of furnace hearth by the exponential relation in Line 8510 of the Program; number of points 10, range 28 to 1600 sf, σ 1.10. Derived from the Reference 22 40% for contingencies engineering and contractors profit, a factor of 1.3 is used to generate investment, 10% being considered as engineering.

Pumps and Sumps Cost

The two main cost references differ in their estimated costs for pumps (23) and the corresponding pumps and sumps (22). For a two stage system Reference 22 costs which are independent of contact time, increase as the 0.3 power of mgd over 10-100 mgd. The cost at 100 mgd is less than two times that at 10 mgd. Reference 23 costs are higher than the Reference 22 and have about a 0.6 factor. Because of the more reasonable slope the Reference 23 costs are chosen, the relation being:

K$(1968), two stages = 29.3693*QDOT**.710743,

found in Line 8514 in the Program.

With respect to the number of stages the Reference 22 costs at 10 mgd are independent of contact time and increase as number of stages increase. Reference 23 costs at 50 minute contact time and 10 mgd decrease as number of stages increases. Unable to resolve this difference without detailed design work, the present Program takes pumps and sumps cost as independent of number of stages. The cost of pumps and sumps is less than 5% of the total capital cost at any mgd size.

Reference 22 gives separately the cost of the backwash system, largely independent of the number of stages, and which is related to the gallons per minute backwash rate by:

K$(1968, investment ex engineering) = 0.444*GPMBW**.493

This is about the same as the Reference 23 investment for "pumps" at 1 mgd. If it is assumed that the Reference 22 pumps and sumps plus backwash systems correspond with the Reference 23 pumps then it is found that the Reference 22 costs for the two are about the same as the Reference 23 costs at 1 mgd but are still well below the Reference 23 costs and with an 0.3 factor at the larger sizes. Accordingly, the Program uses the Reference 23 costs as representatives of pumps and sumps and backwash systems.

Piping Costs

Both references give piping costs. When adjusted to investment ex engineering and plotted against gpm flow per train, (adsorber flow rate) the two sets follow a single trend line (Line 8525 in the Program):

K$ per adsorber, 1968, ex engineering = 2.41222*ADSFR**
.386757

24 points, σ ratio 1.29

where

ADSFR = flow rate, gpm per adsorber train

Cost of Electrical System and Instrumentation

Reference 22 gives separately the costs for electrical system and for instruments. The ratio of the cost for both together at NSTAGE (number of stages) to the cost at two stages follows closely:

ratio = .70455 + NSTAGE*.147708

At two stages the costs bear the following relation to mgd:

K$(1968) electrical plus instruments ex engineering = 46.4174*QDOT**.386189

It is assumed that the stage ratio at 10 mgd is also applicable at other mgd levels. The combined equation is found in Line 8530 of the Program.

Concrete Costs

References 23, 24 give separate costs for concrete, some of which in some cases are used for a one-day surge basin not included in the present design. A correlation could not be established. Concrete costs for foundations, etc., instead were taken from Reference 18 who gives material costs for concrete as a percentage of bare module cost (corresponding to investment installed ex engineering) of 1.2% for centrifugal pumps and drives, 2.3% for process vessels, and 4.4% for furnaces. It is assumed that the installed cost of concrete will be about four times the material cost leading to the relation shown in Line 8545 of the Program.

Makeup Carbon Cost

Carbon loss in regeneration is taken at five percent per regeneration. The price used in the exemplary runs is 26¢ per pound. Fuel consumption is taken as 4250 BTU/lb (British thermal units per pound) carbon regenerated (24). In the exemplary runs the price of fuel was taken as 25¢/mBTU (million BTU).

RESULTS OF INDIVIDUAL ACTIVATED CARBON ADSORPTION RUNS

On the above basis individual runs on the design and costs of the activated carbon stage alone were made with parameter values as in Table 14. Figure 13 shows the cost versus QBARE relation.

TABLE 14

PARAMETER VALUES USED IN BASE CASE ACTIVATED CARBON RUNS

Variable Names	Description	Values Used
NSTAGE	Number of adsorber vessels in a train	2
GPMSF	Flow rate through beds	6 gpm/sf
RHO	Bulk density of carbon	30. lbs/cf
PRCAR	Price of carbon	26. ¢/lb
PRFUEL	Price of fuel	25.¢/mBTU
GPMBW (not used)	Backwash rate	gpm/sf
COD89	COD in process effluent	8. mgpl
CT	Contact time	50 min.(minutes)
CLF	Carbon loading factor	.5 lb COD/lb carbon
F	Fraction of QDOT under fail-safe condition	1.

Figure 14 shows the sensitivity around a base case to certain of the parameters. These sensitivity runs were made before final corrections and adjustments had been made in the Program from which Figure 13 is drawn. However, the sensitivity relations will not be greatly different from the final Program. The cost levels themselves are not directly comparable with the costs of Figure 13...for instance the sensitivity runs base case used a COD in the influent of 50 mgpl, whereas in the complete lime-clinoptilolite-activated carbon scheme the feed to the activated carbon is 82 mgpl.

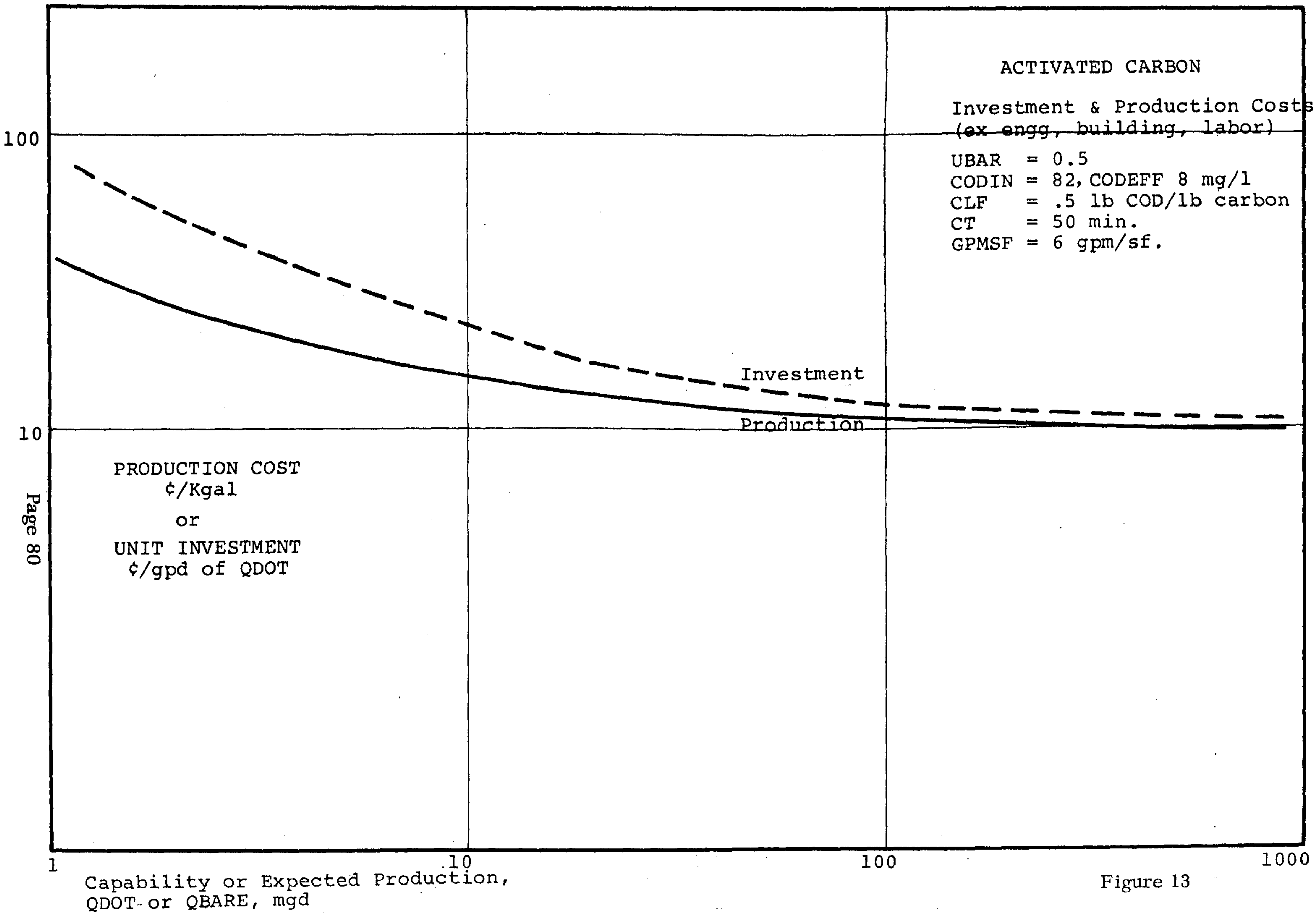

ACTIVATED CARBON
Investment & Production Costs
(ex engg, building, labor)
UBAR = 0.5
CODIN = 82, CODEFF 8 mg/l
CLF = .5 lb COD/lb carbon
CT = 50 min.
GPMSF = 6 gpm/sf.
Investment
Production
PRODUCTION COST
¢/Kgal
or
UNIT INVESTMENT
¢/gpd of QDOT
100
10
1
10
100
1000
Capability or Expected Production,
QDOT or QBARE, mgd

Figure 13

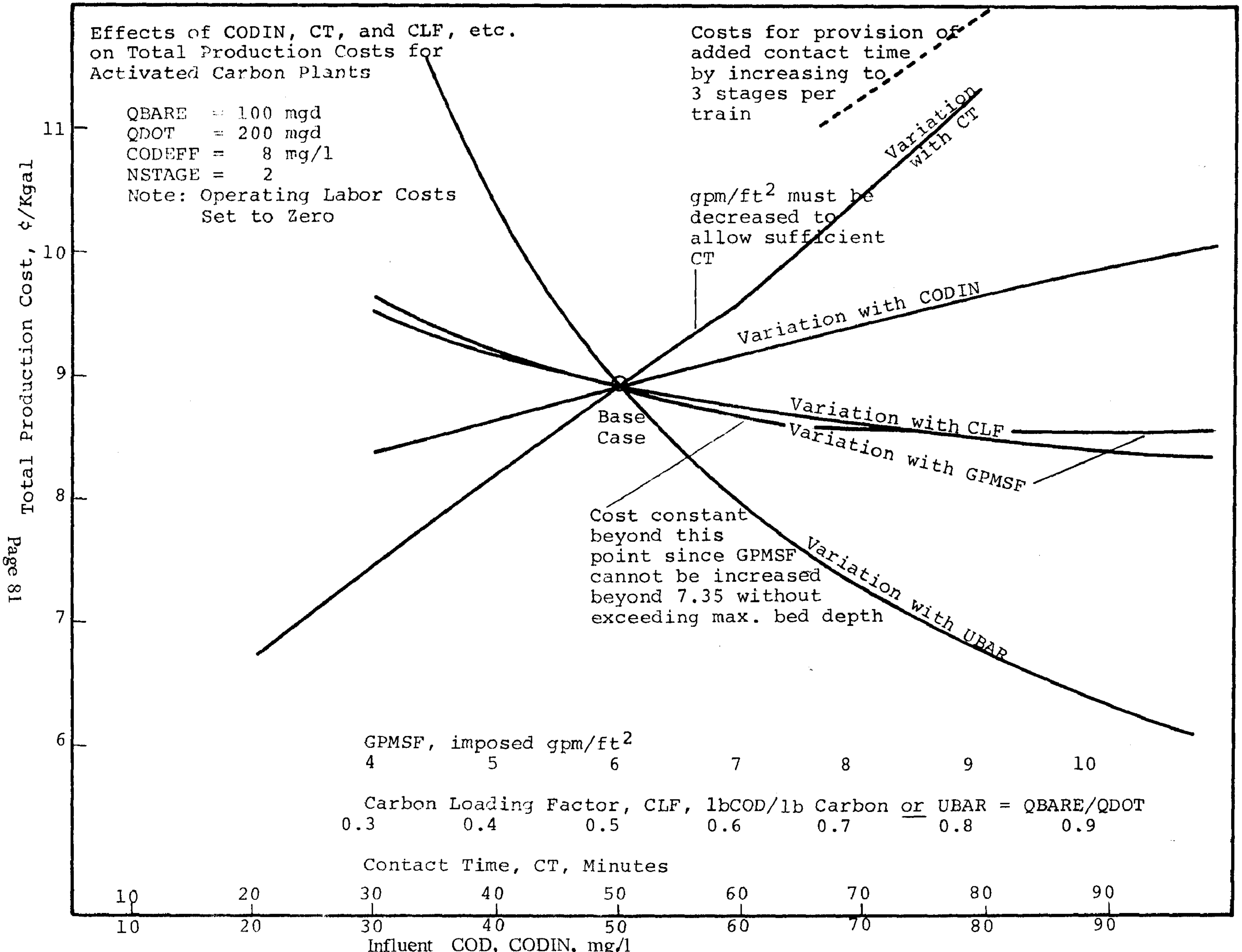

Effects of CODIN, CT, and CLF, etc. on Total Production Costs for Activated Carbon Plants
QBARE = 100 mgd
QDOT = 200 mgd
CODEFF = 8 mg/l
NSTAGE = 2
Note: Operating Labor Costs Set to Zero
Costs for provision of added contact time by increasing to 3 stages per train
Variation with CT
gpm/ft2 must be decreased to allow sufficient CT
Variation with CODIN
Variation with CLF
Variation with GPMSF
Base Case
Cost constant beyond this point since GPMSF cannot be increased beyond 7.35 without exceeding max. bed depth
Variation with UBAR
Total Production Cost, ¢/Kgal
11
10
9
8
7
6
GPMSF, imposed gpm/ft2
4 5 6 7 8 9 10
Carbon Loading Factor, CLF, lbCOD/lb Carbon or UBAR = QBARE/QDOT
0.3 0.4 0.5 0.6 0.7 0.8 0.9
Contact Time, CT, Minutes
10 20 30 40 50 60 70 80 90
10 20 30 40 50 60 70 80 90
Influent COD, CODIN, mg/l

Figure 14

It is seen that the cost is highly sensitive to the contact time. A drop in the contact time from 50 minutes to 30 minutes would lower costs by about 1.5¢/Kgal. A special study was made to determine the effect of providing additional contact time by increasing from two stages to three stages per train. The results, shown, confirm other more detailed studies in which two stages have proved to be the optimum.

The cost is reasonably sensitive to the COD in the feed to the activated carbon stage indicating the desirability of high removals of COD in the lime clarification stage, if possible. The sensitivity to the carbon loading factor is not very great, nor is the sensitivity to the gallons per minute per square foot flow rate.

The cost is highly sensitive to utilization factor since the process is highly capital intensive. In the final Program at 100 mgd more than half the production cost comes from the capital charge and about a quarter from the maintenance and repair which is proportional to investment.

COMPLETE AWT PROCESS RUNS

The Computer Program for the complete AWT process comprising preliminary treatment, lime clarification, clinoptilolite ion exchange, activated carbon adsorption chlorination, and ultimate disposal is given in a following section. Thereafter follows the definitions of the variables and a description of the Program. The exemplary runs were made on a composition typical of San Antonio sewage shown in Table 15.

TABLE 15

TYPICAL SAN ANTONIO SEWAGE COMPOSITION USED IN EXEMPLARY RUNS

SMATX Subscripts	Contaminant	Value Used in Exemplary, mgpl
(1, 3)	Na^+	174. (adjusted to achieve ionic balance)
(1, 4)	K^+	12.
(1, 5)	Ammonia N	15.
(1, 6)	Ca^{++}	80.
(1, 7)	Mg^{++}	18.
(1, 8)	Cl^-	82.
(1, 9)	F^-	.3
(1, 10)	NO_2^-	2.
(1, 11)	NO_3^-	12.
(1, 12)	HCO_3^-	360.
(1, 13)	$CO_3^=$	0.
(1, 14)	$SO_4^=$	52.
(1, 15)	$SiO_3^=$	15.
(1, 16)	$PO_4^{\equiv}$	25.
(1, 17)	COD	500.
(1, 18)	VSS	163.
(1, 19)	NVSS	57.
(1, 20)	TDI	not used

Other data common to all subroutines used in the exemplary runs are:

Parameter Name	Description	Value Used In Exemplary
PLF	Plant life	20 Years
TX	Tax rate	.01 Annual fraction of investment
XINS	Insurance rate	.01 Annual fraction of investment
RET	Insurance rate	.045 Annual fraction of investment
CKWH	Energy price	1.¢/Kwh
CYMSI	Current year Marshall & Stevens Chemical Process Industries Equipment Cost Index	285. for 1969
RTLAB	Base labor price	3.00$/man hour for operating labor
PYEX	Payroll extras factor	.45 Fraction of payroll

A printout of the base case at 100 mgd, utilization factor 0.5, is given on the next two pages with 1969, National costs. The individual process summaries show separately the amortization and operating costs for each of the three major processes. These costs do not include buildings, disposal, engineering or operating labor, which are treated as separate "processes." Under the heading "OVERALL AWT PROCESS" the term DISP, TPD, in this case 80.821 tons per day, refers to the quantity of moist residue for ultimate disposal under conditions of average production. The table "CONTAM. IN OUT" refers to the mgpl composition of the overall feed and the product. The investment costs are shown for each process in terms of K$, percent of the total by process, and unit investment in ¢/gpd of capability (QDOT) and of average production (QBARE). Production costs, operating plus capital charge, are shown by process in K$/yr, ¢/Kgal, and percent of the total.

At 100 mgd average production and 200 mgd capability the total AWT cost is 26.748¢/Kgal of which about 37% arises from the carbon stage and about 24% from each of the lime and clinoptilolite stages. Overall capital charges amount to 14.728¢/Kgal and operating costs 12.020.

```
 10/27/70. 17.22.06.
PROGRAM    AWT27



----------LIME PROCESS----------

 QBARE     100.000  QDOT      200.000  UBAR       .50000
CACO3  80.0, MG 18.0, PO4 25.0, ALK 360.0, TSS10 220.0, COD 500.0


 COST SUMMARY, CENTS/KGAL

 AMORT. =  3.766, OPER. =  2.722, TOTAL =  6.488



-----CLINOPTILOLITE PROCESS-----

 VARIABLE PARAMETERS FOR THIS CASE

 QBARE  100.00   QDOT   200.00   UBAR   .50000   AN50   15.00

 COST SUMMARY, CENTS/KGAL

 AMORT. =  3.025, OPER. =  3.439, TOTAL =  6.464



 ---ACTIVATED CARBON PROCESS---



 QDOT =     200.000 MGD, QBARE =     100.000 MGD, UBAR = .5000
 CLF = .500, CT = 50.0, CODIN = 62.0, CODEF =  8.0


 COST SUMMARY, CENTS/KGAL

 AMORT. =  5.827, OPER. =  3.963, TOTAL =  9.790
```

---- OVERALL AWT PROCESS ----

QBARE 100.00 QDOT 200.00 UBAR .50000 DISP.,TPD 80.021

CONTAM.	IN	OUT
NA	174.00	160.12
K	12.00	12.00
NH4	15.00	.50
CA	80.00	64.02
MG	18.00	1.25
CL	82.00	99.44
F	.30	.30
NO2	2.00	2.00
NO3	12.00	12.00
HCO3	360.00	69.09
CO3	0.	0.
SO4	52.00	52.00
SIO3	15.00	15.00
PO4	25.00	.90
COD	500.00	8.00
VSS	163.00	.70
NVSS	57.00	.30

INVESTMENT COSTS, K$

		PCT. OF	CENTS/GPD OF	
PROCESS	K$	TOTAL	QDOT	QBARE
PRELIM.	483.163	.87	.242	.483
LIME	14189.357	25.57	7.095	14.189
CLINOP.	11395.506	20.54	5.698	11.396
CARBON	21954.947	39.57	10.977	21.955
CHLOR.	478.042	.86	.239	.478
BUILDINGS	4850.102	8.74	2.425	4.850
DISPOSAL	0.	0.	0.	0.
ENGR.	2138.145	3.85	1.069	2.138
TOTAL	55489.261	100.00	27.745	55.489

PRODUCTION COSTS

PROCESS	K$/YEAR	CENTS/KGAL	PCT.
PRELIM.	74.131	.203	.76
LIME	2367.977	6.488	24.25
CLINOP.	2359.267	6.464	24.17
CARBON	3573.404	9.790	36.60
CHLOR.	204.292	.560	2.09
BUILDINGS	469.859	1.287	4.81
DISPOSAL	44.278	.121	.45
ENGR.	207.135	.567	2.12
OPR. LABOR	462.707	1.268	4.74
TOTAL	9763.052	26.748	100.00

COST SUMMARY, CENTS/KGAL

AMORT. = 14.728, OPER. = 12.020, TOTAL = 26.748

With the 100 mgd as a base case the Program was used to generate costs at other average production levels. The results are shown in Figure 15 and Table 16. The unit costs decrease in a normal manner with increasing average production. The change is very small beyond 100 mgd primarily because the maximum sizes of most of the equipment units have been reached and capability increases are achieved by replication. At 100 mgd the optimum design calls for 11 Accelator trains, 5 filters, 47 clinoptilolite exchanger trains, and 47 carbon adsorber trains, all of these close to the maximum sizes available. Obviously future cost production studies should explore the possibilities of relaxing these upper constraints on equipment sizes. The present project has not thoroughly explored these constraint relaxations.

TABLE 16

EFFECT OF QBARE ON AWT COST

QBARE	.1	1	10	100	177	1000
QDOT	.2	2	20	200	350	2000
Unit investment ¢/gpd of capability	497.0	106.4	43.79	27.75	26.38	23.82
Unit production cost, ¢/Kgal	508.9	112.7	43.62	26.75	25.05	22.57
Percent Contribution of Major Processes to Production Cost						
Lime	35.4	29.3	29.7	24.2	23.2	21.2
Clinoptilolite	8.3	13.3	18.1	24.1	25.3	27.6
Carbon	19.6	22.3	28.5	36.6	37.8	39.8

Figure 16 shows the sensitivity of the overall AWT process to utilization factor and to the fraction of the COD removed in the Accelators. The process is highly sensitive to utilization factor. In the 100 mgd size the cost could be as low as 18¢/Kgal if a utilization factor of about 1.0 could be achieved. To achieve such a utilization factor in a municipal waste treatment plant, with the flow fluctuations characteristic of such plants, would require storage of the raw waste for at least days and possibly weeks or months.

COST OF AWT BY THE LIME-CLINOPTILOLITE - CARBON PROCESS

San Antonio Sewage 1968 Utilization Factor,
UBAR = 0.5
FCODAC = .8

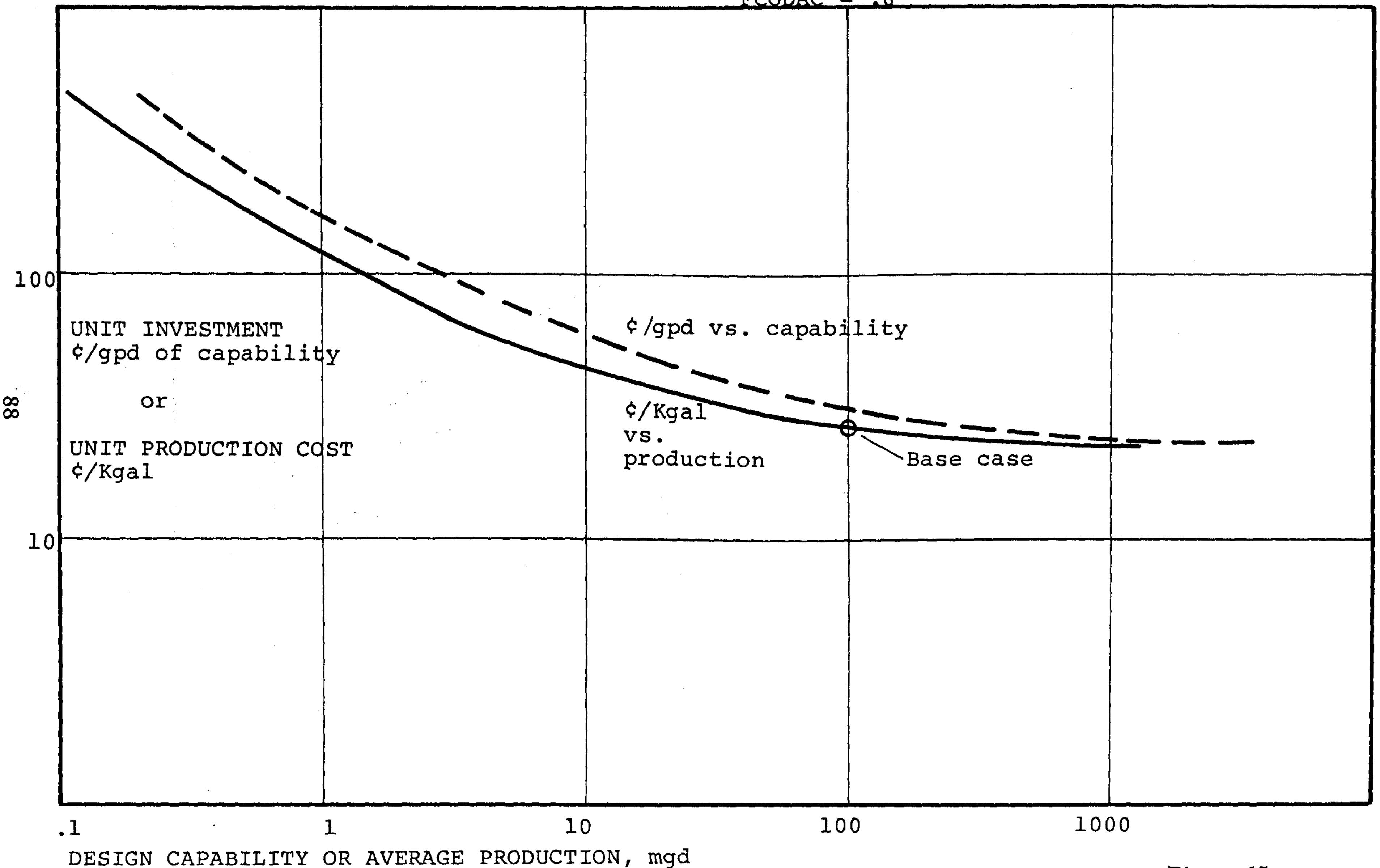


Figure 15

SENSITIVITY OF AWT Costs to Utilization Factor and to
Fraction of COD removed by Accelators

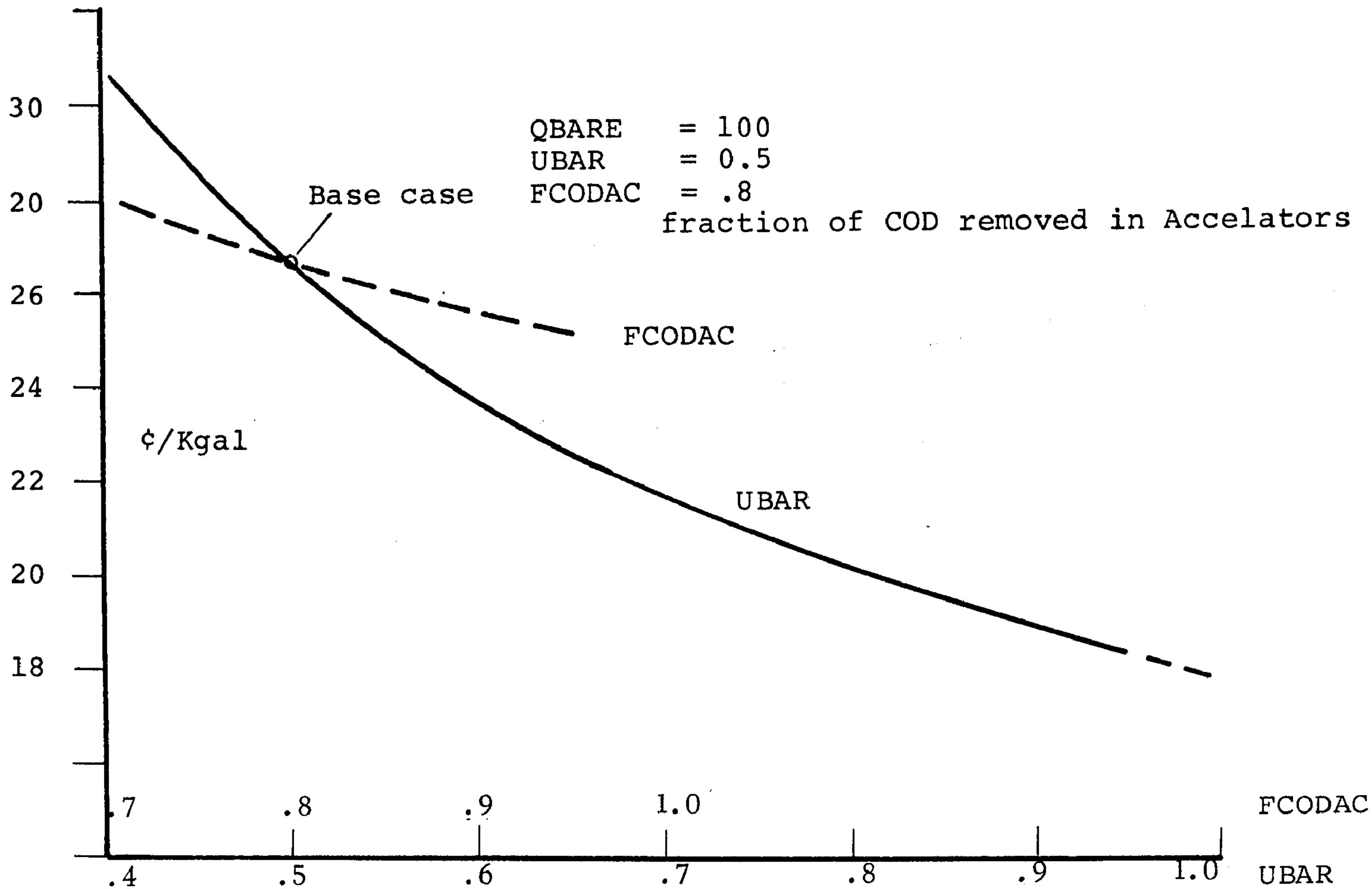


Figure 16

One case explores the sensitivity of the AWT cost to the fraction of COD removed in the Accelators. This is not the overall percentage removal of COD but measures the fraction of the total COD influent to the Accelators which does not appear in the exit liquor from the Accelator. As this fraction is increased the load on the activated carbon is decreased. Increasing the FCODAC from .8 to .9 would bring about a reduction of about 1.0¢/Kgal from the 26.75¢/Kgal cost of the base case at 100 mgd.

Costs for San Antonio 2000

The next page comprises the printout results of the AWT process for San Antonio in the year 2000 considered as a single central plant. The costs are 1969, San Antonio. The QDOT capability is 350 mgd and the average production 177 mgd. The total investment, excluding land is estimated at 86.0m$. The total production costs are estimated at 15.3m$ annually, a unit cost of 23.8¢/Kgal in the year 2000. The average amount of moist solids for ultimate disposal is 143.05 tons per day.

```
11/05/70. 16.24.34.
PROGRAM   AWTFIN

----------
```

---- OVERALL AWT PROCESS ----

QBARE 177.00   QDOT 350.00   UBAR .50571   DISP.,TPD 143.053

INVESTMENT COSTS, K$

PROCESS	K$	PCT. OF TOTAL	CENTS/GPD OF QDOT	CENTS/GPD OF QBARE
PRIMARY	625.647	.73	.179	.353
LIME	20454.389	23.77	5.844	11.556
CLINOP.	18260.176	21.22	5.217	10.316
CARBON	35338.354	41.06	10.097	19.965
CHLOR.	630.553	.73	.180	.356
BUILDINGS	7530.912	8.75	2.152	4.255
DISPOSAL	0.	0.	0.	0.
ENGR.	3217.865	3.74	.919	1.818
TOTAL	86057.895	100.00	24.588	48.620

PRODUCTION COSTS

PROCESS	K$/YEAR	CENTS/KGAL	PCT.
PRIMARY	112.834	.175	.73
LIME	3479.671	5.386	22.67
CLINOP.	3916.268	6.062	25.51
CARBON	5829.357	9.023	37.97
CHLOR.	348.967	.540	2.27
BUILDINGS	729.566	1.129	4.75
DISPOSAL	71.532	.111	.47
ENGR.	311.734	.483	2.03
OPR. LABOR	551.903	.854	3.60
TOTAL	15351.832	23.763	100.00

COST SUMMARY, CENTS/KGAL

AMORT. = 12.905, OPER. = 10.858, TOTAL = 23.763

STOP.

CPU SECONDS 11.763

DESCRIPTION OF COMPUTER PROGRAM AWTLCC

Program AWTLCC is a subroutine to be used in a larger RECYCLE Program for exploring reuse systems. Since AWTLCC itself is a subroutine the listed Program provides a main Program TAWT which calls AWTLCC itself. AWTLCC operates by calling the following six process subroutines:

1. PRLM - preliminary treatment
2. LIME - lime clarification
3. CLINOP - clinoptilolite ammonia exchange
4. ACTCAR - activated carbon adsorption
5. CHLOR - post chlorination
6. DISP - a rudimentary computation of ultimate disposal cost

It also used the following non-process subroutines:

COSTC - for computing ¢/Kgal costs, percent contribution to costs, etc.
UNITS - for computing optimum number of units, used for Accelators, filters, and clinoptilolite and carbon trains
PARAB3 - used in the UNITS scheme
BAJO - used in the UNITS scheme
ENGR - a function subprogram for computing engineering costs

The Program is constructed to operate on a CDC 6400 computer via a time sharing terminal. The core space required is 8000 words (60 bit words). Program length is 35,840 characters and requires about 12 seconds CPU to compile and execute.

There are two types of input data, one contained in data initialization statements in the Program, the other contained in a data file named SEW.

The data initialization at Line 25 and 26 sets the printout regime as follows:

IPRINT (1) = 0 suppresses effluent and influent concentration
IPRINT (2) = 0 suppresses diagnostic printout of UNITS searches
IPRINT (4) = 0 suppresses capital cost
IPRINT (5) = 0 suppresses production cost
IPRINT (6) = 0 suppresses summary printouts for individual processes
IPRINT (3) is not used

Data common to all cost computations is initialized in lines 117, 118, and 119, these being plant life, tax rate, insurance rate, interest rate, energy price, current year Marshall & Stevens Chemical Process Industry Cost Index (MSI), factor for maintenance, repair and minor replacement, labor price, payroll extras factor, current year Building Cost Index for the Region and National BCI for the year of the MSI.

Data initialization for the LIME subroutine are contained in lines 1025-1027, in the exemplary runs in accordance with the list given in Table 11. Data initialization for the clinoptilolite subroutine is contained in lines 5025-5031 according to the listing in Table 12. Data initialization for the activated carbon subroutine is found in lines 822-823 according to the listing in Table 14.

The data file SEW is called from Line 1025. It contains the stream matrix parameters SMATX(1,I), each value on a separate line. The first two I elements are QDOT and QBARE, the remaining 18 elements, the concentration parameters for the raw sewage as listed in Table 15.

Incidentally although the UNITS optimization was developed to handle the possible characteristics of an unknown cost function, out of 40 cases run for this report, 10 for each application, there were 30 cases in which the optimum was the minimum number of units, 9 cases in which it was one greater than the minimum, one case two greater than the minimum, and no cases where the optimum occurred further away than this. Accordingly the strategy of the optimization was altered to explore first these positions near the minumum number of units. As a result the subroutines PARAB3 and BAJO will be very infrequently called upon.

The Programs trend the cost to 1969 National by means of the Marshall and Stevens Chemical Process Industries Equipment Cost Index (Value: 285). It regionalizes by the ENR Building Cost Index. The denominator in the conversion, the National BCI must be set for the year of the MSI base. As it stands the denominator is set at 1969 (802) and the current year BCI is set at Dallas (San Antonio), 732. Cost elements not adjusted by these indexes are those involving PRFUEL, PRCAR, PRMBTU, PRLIME, PRLAB, CKWH, PRCLIN, PRNACL which should be set corresponding to the region and year desired.

```
PROGRAM AWTLCC  LKR PROJECT-162 F [illegible] AACOG AND FWQA 11/6/70

 11/07/70. 08.50.39.


10 PROGRAM TAWT(INPUT,OUTPUT,TAPE1)
13 COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
14 COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
15 COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
16 COMMON/BLK1/CYBCI
20 DIMENSION VTOT(20),WTOT(20),IPRINT(6),SMATX(20,8)
21 DIMENSION IX(4),YY(4)
25 DATA ((IPRINT(I),I=1,6)=
26+ 0,0,0,1,1,0)
30 CALL AWTLCC(SMATX)
35 STOP
40 END
100 SUBROUTINE AWTLCC(SMATX)
103 COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
104 COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
105 COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
106 COMMON/BLK1/CYBCI
107 DIMENSION SMATX(20,8),IX(4),YY(4)
108 DIMENSION VTOT(20),WTOT(20),IPRINT(6),PNAME(10),CNAME(20),ARRAY(7)
109 DATA PNAME/10HPRELIM.    ,10HLIME       ,10HCLINOP    ,
110+10HCARBON     ,10HCHLOR.     ,10HBUILDINGS ,10HDISPOSAL  ,
111+10HENGR.      ,10HOPR. LABOR,10HTOTAL     /
113 DATA((CNAME(I),I=3,19)=4HNA   ,4HK    ,4HNH4 ,4HCA   ,4HMG  ,
114+ 4HCL  ,4HF   ,4HNO2 ,4HNO3 ,4HHCO3,4HCO3 ,4HSO4 ,4HSIO3,
115+ 4HPO4 ,4HCOD ,4HVSS ,4HNVSS)
116 DATA IFILT/1/
117 DATA PLF,TX,XINS,RET,CKWH,CYMSI,FACMR,PYEX,PRLAB/
118+20.,.01,.01,.045,1.,285.0,.04,.45,3./
119 DATA CYBCI,BCINMS/732.,802./
120 DITIF=TX+XINS+RET/(1.0-(1.0+RET)**(-PLF))
121 RTLAB=PRLAB*(1.+PYEX)
122 CIR=CYMSI/273.1*CYBCI/BCINMS
125 CALL RETR(1,3HSEW)
130 DO 135 I=1,19
135 135 READ(1,)LINE,SMATX(I,1)
140 QDOT=SMATX(1,1)
145 QBARE=SMATX(2,1)
150 UBAR=QBARE/QDOT
200 CALL PRLM(SMATX)

215 CALL LIME(SMATX,IFILT,XSCAOH,DSPTPD)
220 220 CALL CLINOP(SMATX,XSCAOH)
230 230 CALL ACTCAR(SMATX)
240 CALL CHLOR(SMATX)
241PRINT,CIR
260 260 CALL DISP(VTOT,WTOT,DITIF,DSPTPD,UBAR,CIR,CYMSI)
300 VTEMP=0
305 DO 310 I=1,5
310 310 VTEMP=VTEMP+VTOT(I)
312 VTOT(6)=VTEMP*.1
313 VTEMP=VTEMP+VTOT(6)+VTOT(7)-VCLIN-VCAR
315 VTOT(8)=VTEMP*ENGR(VTEMP)
```

241 PRINT, CIR

```
320 VTOT(10)=VTEMP+VTOT(8)+VCLIN+VCAR
400 WTOT(8)=DITIF*VTOT(8)*1000
401 WTOT(6)=VTOT(6)*DITIF*1000
405 WTOT(9)=1.12*RTLAB*(49.*QDOT**.315)*365.24
410 WTOT(10)=0
415 DO 420 I=1,9
420 420 WTOT(10)=WTOT(10)+WTOT(I)
425 AVDSP=DSPTPD*UBAR
500 PRINT 800
505 PRINT 801,QBARE,QDOT,UBAR,AVDSP
506C ----PRINT(1) CONTAM IN AND OUT-----
510 IF(IPRINT(1))600,600,515
515 515 PRINT 802
520 DO 525 I=3,19
525 525 PRINT 803,CNAME(I),SMATX(I,1),SMATX(I,6)
599C ----PRINT(4) INVESTMENT COSTS------
600 600 IF(IPRINT(4))700,700,605
605 605 PRINT 804
610 PRINT 805
615 PRINT 806
620 ARRAY(5)=VTOT(10)/100.
625 ARRAY(6)=QDOT*10.
630 ARRAY(7)=QBARE*10.
635 DO 645 I=1,8
640 CALL COSTC(ARRAY,VTOT(I))
645 645 PRINT 807,PNAME(I),(ARRAY(J),J=1,4)
650 CALL COSTC(ARRAY,VTOT(10))
655 PRINT 808,PNAME(10),(ARRAY(J),J=1,4)
699C ----PRINT(5) PRODUCTION COSTS------
700 700 IF(IPRINT(5))755,755,705
705 705 PRINT 810
710 PRINT 811
715 ARRAY(5)=1000.
720 ARRAY(6)=3650.*QBARE
725 ARRAY(7)=WTOT(10)/100.
730 DO 740 I=1,9
735 CALL COSTC(ARRAY,WTOT(I))
740 740 PRINT 812,PNAME(I),(ARRAY(J),J=2,4)
745 CALL COSTC(ARRAY,WTOT(10))
750 PRINT 813,PNAME(10),(ARRAY(J),J=2,4)
755 755 AMORT=VTOT(10)*DITIF/3.65/QBARE
760 WTOTAL=WTOT(10)/3650./QBARE
765 WOP=WTOTAL-AMORT
770 PRINT 820
775 PRINT 825,AMORT,WOP,WTOTAL
798 798 CONTINUE
799 799 RETURN
800 800 FORMAT(///* ---- OVERALL AWT PROCESS ----*)
801C *SEE LINE 830 FOR FORMAT 801*
802 802 FORMAT(//* CONTAM. IN      OUT*)
803 803 FORMAT(1X,A4,F9.2,F8.2)
804 804 FORMAT(//* INVESTMENT COSTS, K$*)
```

```
PROGRAM AWTLCC  LKR PROJECT-162 FOR AACOG AND FWQA 11/6/70

 11/07/70. 08.50.39.


805 FORMAT(/24X*PCT. OF     CENTS/GPD OF*)
806 FORMAT(* PROCESS*10X*K$*5X*TOTAL*4X*QDOT*5X*QBARE*)
807 FORMAT(1X,A10,F10.3,F7.2,2F10.3)
808 FORMAT(/1X,A10,F10.3,F7.2,2F10.3)
810 FORMAT(//* PRODUCTION COSTS*)
811 FORMAT(/* PROCESS*8X*K$/YEAR  CENTS/KGAL  PCT.*)
812 FORMAT(1X,A10,2F10.3,F7.2)
813 FORMAT(/1X,A10,2F10.3,F7.2)
820 FORMAT(//,* COST SUMMARY, CENTS/KGAL*)
825 FORMAT(/, *AMORT. =*,F7.3,*, OPER. =*,F7.3,
+*, TOTAL =*,F7.3,/)
801 FORMAT(/* QBARE*F8.2,3X,*QDOT*F9.2,3X,*UBAR*F7.5,3X,
+*DISP.,TPD*,F10.3)
END
SUBROUTINE PRLM(SMATX)
COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
DIMENSION SMATX(20,8)
DIMENSION VTOT(20),WTOT(20),IPRINT(6)
DO 920 I=1,20
920 SMATX(I,2)=SMATX(I,1)
QDOT=SMATX(1,1)
QBARE=SMATX(2,1)
VTOT(1)=14.7*QDOT**0.625*CIR*273.1/237.8
WCCHG=DITIF*VTOT(1)
WOM=(500*QBARE+2150*QBARE**0.37)*CIR*273.1/237.8
C ***WOM INCLUDES LABOR, BUT LET IT GO.***
WTOT(1)=WCCHG+WOM
RETURN
END
SUBROUTINE LIME(SMATX,IFILT,XSCAOH,DSFTPD)
COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
COMMON/BLK1/CYBCI
DIMENSION SMATX(20,8),IX(4),YY(4)
DIMENSION VTOT(20),WTOT(20),IPRINT(6),ARRAY(7)
REAL NVSS12,NVSS13,NVSS14,NVSS15,NVSS16,NVSS17,NVSS18,NVSS19,
+NVSS20,NVSS27,NVSS28,NVSS10
DATA XMGH12,PO412,TSS12,CAC26,CAC27,TSOL13,TSOL14,TSOL15,TSOL16,
+TSOL17,FACAOL,FINRTD,PRLIME,FCODAC,FCODF,GPMSFF/
+3.,2.,10.,1.5E5,35.,1E5,100.,2.5E5,4.7E4,
+6.5E5,0.9,0.9,18.50,0.8,0.18,4./
QDOT=SMATX(1,2)
QBARE=SMATX(2,2)
UBAR=QBARE/QDOT
CAC10=SMATX(6,2)
XMG10=SMATX(7,2)
ALK10=SMATX(12,2)
PO410=SMATX(16,2)
COD10=SMATX(17,2)
VSS10=SMATX(18,2)
NVSS10=SMATX(19,2)
```

```
1082 TSS10=NVSS10+VSS10
1085 FVSS=0.2*VSS10/(VSS10+NVSS10)
1090 FNVSS=0.2-FVSS
1100 Q10=Q11=Q12=Q25=Q27=Q29=Q49=QDOT
1102 XMUL=XSCAOH=Q48=0
1103 PCAC14=PCAC16=PINR19=PCAC20=PVSS20=PNVSS20=PMGH20=PAPA20=0.
1105 DOSCAO=-701.706+18.9183*ALK10-0.151669*ALK10**2+6.73099E-4*
1106+ALK10**3-1.67022E-6*ALK10**4+2.17110E-9*ALK10**5-1.14985E-12*
1107+ALK10**6
1109 ICAOFLG=1
1110 IF(DOSCAO-50)1115,1115,1120
1115 1115 DOSCAO=50
1116 ICAOFLG=2
1120 1120 ITER1=1
1125 PCAOHR=DOSCAO*QDOT*8.33*1.321
1130 Q19=DOSCAO*Q10*7.72E-6
1199C **REENTRY FROM 1865 FOR OVERALL LIME STAGE ITERATIONS**
1200C ***PERFORMANCE OF ACCELATORS***
1201 1201 CONTINUE
1210 PCAC26=8.33*QDOT*(CAC10+DOSCAO*100.09/56.08-2.*ALK10)
1211+-8.33*(QDOT*PO410-Q12*PO412)*5*100.09/(3*95.00)-8.33*Q27*CAC27
1212 IF(PCAC26)1213,1214,1214
1213 1213 Q26=0 $ ICAOFLG=3
1214 1214 CONTINUE
1215 Q26=PCAC26/CAC26/8.33
1220 PCAC13=PCAC14+PCAC16+PCAC26+8.33*QDOT*ALK10*2-8.33*Q27*CAC27
1225 PMGH13=QDOT*XMG10*8.33*2.399-Q12*XMGH12*8.33+PMGH20
1230 PAPA13=(QDOT*PO410-Q12*PO412)*8.33*1.763+PAPA20
1232 VSS12=TSS12*FVSS/(FVSS+FNVSS)
1233 NVSS12=TSS12-VSS12
1235 PVSS13=(QDOT*VSS10-Q12*VSS12)*8.33+PVSS20
1237 PNVSS13=(QDOT*NVSS10-Q12*NVSS12)*8.33+PINR19+PVSS20*FNVSS/FVSS
1240 TLBS13=PCAC13+PMGH13+PAPA13+PVSS13+PNVSS13
1245 FCACO3=PCAC13/TLBS13
1250 FMGOH=PMGH13/TLBS13
1255 FAPAT=PAPA13/TLBS13
1260 FVSS=PVSS13/TLBS13
1265 FNVSS=PNVSS13/TLBS13
1270 Q13=TLBS13/TSOL13/8.33
1275 COD27=(1-FCODAC)*COD10
1280C **** PERFORMANCE OF SECOND RECARBONATOR ****
1285 ALK30=CAC27+30.*50./44.
1300C ***THICKENER PERFORMANCE***
1310 Q14=Q13*(TSOL15-TSOL13)/(TSOL15-TSOL14)
1312 PCAC14=FCACO3*TSOL14*8.33*Q14
1315 Q15=Q13-Q14
1400C ***CENTRIFUGE PERFORMANCE***
1410 Q16=Q15*(TSOL17-TSOL15)/(TSOL17-TSOL16)
1412 PCAC16=FCACO3*TSOL16*8.33*Q16
1415 Q17=Q15-Q16
1500C ***KILN PERFORMANCE***
1501 PCAC17=PCAC13-PCAC14-PCAC16
```

```
1503 TLBS17=TLBS13*PCAC17/PCAC13
1505 PMGH17=TLBS17*FMGOH
1510 PAPA17=TLBS17*FAPAT
1515 PVSS17=TLBS17*FVSS
1517 PNVSS17=TLBS17*FNVSS
1520 PCAO18=PCAC17*0.5603
1525 PMGO18=PMGH17*0.6906
1530 PAPA18=PAPA17
1535 PASH=PNVSS17
1540 TLBS18=PCAO18+PMGO18+PAPA18+PASH
1600C ***SLAKER PERFORMANCE***
1610 ITER2=1
1612 LFLAG=1
1614C **REENTRY FROM 1655 FOR SLAKER ITERATIONS**
1615 1615 FCAOS=(FACAOL*XMUL+PCAO18)/(FACAOL*XMUL+TLBS18)
1620 FCAOHD=FCAOS**10
1622 PINRTS=TLBS18-PCAO18+XMUL*(1-FACAOL)
1625 TLBS31=FINRTD*PINRTS/(1-FCAOHD)
1630 PCAOHD=FCAOHD*TLBS31
1632 GO TO(1635,1656),LFLAG
1635 1635 XMULN=(DOSCAO*QDOT*8.33-(PCAO18-PCAOHD*0.7568))/FACAOL
1636 IF(XMULN)1637,1640,1640
1637 1637 LFLAG=2
1638 XMUL=XMULN=0
1639 GO TO 1615
1640 1640 IF(ABS((XMULN-XMUL)/XMULN)-0.01)1660,1660,1645
1645 1645 XMUL=XMULN
1650 ITER2=ITER2+1
1655 GO TO 1615
1656 1656 XSCAOH=PCAO18*1.321-PCAOHD-PCAOHR
1660 1660 CONTINUE
1665 PINR47=(1-FINRTD)*PINRTS
1670 PCAOH47=PCAO18*1.321+(1-FACAOL)*XMUL*1.321-PCAOHD
1675 TLBS47=PCAOH47+PINR47
1680 Q47=TLBS47*9/8.33E6
1685 Q19=Q47*(1-XSCAOH/PCAOH47)
1690 PNVSS19=PINR47*(1-XSCAOH/PCAOH47)
1691 PINR19=PNVSS19
1695 XMUL=XMULN
1700C ***FILTER PERFORMANCE AND SCRUBBER PERFORMANCE***
1705 Q12=Q11-Q13
1708 Q27=Q12-Q26
1709 Q41=Q30=0
1710 COD28=COD27
1711 PO428=PO412
1712 VSS27=VSS28=TSS12*FVSS/(FVSS+FNVSS)
1713 NVSS27=NVSS28=TSS12*FNVSS/(FVSS+FNVSS)
1714 IF(IFILT)1720,1720,1715
1715 1715 PO428=.67*PO412
1716 1716 Q41=Q30=0.03*Q27
1717 COD28=COD27*(1-FCODF)
1718 VSS28=.1*VSS27
```

PROGRAM AWTLCC LKR PROJECT-162 FOR AACOG AND FWQA 11/6/70

11/07/70. 08.50.39.

```
1719 NVSS28=.1*NVSS27
1720 1720 PVSS30=(VSS27-VSS28)*8.33*Q27
1725 PNVSS30=(NVSS27-NVSS28)*8.33*Q27
1730 Q28=Q29=Q27
1740 Q42=0.01225*QDOT
1800C ***RECYCLE STREAMS***
1810 Q43=Q19*8./9.
1815 QN20=Q14+Q16+Q19+Q41+Q42+Q43
1825 1825 IF(ABS((QN20-Q20)/QN20)-0.001)1900,1900,1830
1830 1830 Q20=QN20
1835 PCAC20=PCAC14+PCAC16
1840 PMGH20=(Q14*TSOL14+Q16*TSOL16)*FMGOH*8.33
1845 PAPA20=(Q14*TSOL14+Q16*TSOL16)*FAPAT*8.33
1850 PVSS20=(Q14*TSOL14+Q16*TSOL16)*FVSS*8.33+PVSS30
1855 PNVSS20=(Q14*TSOL14+Q16*TSOL16)*FNVSS*8.33*PNVSS30
1860 Q11=Q10+Q20
1862 ITER1=ITER1+1
1865 GO TO 1201
1900 1900 CONTINUE
1901C **** EFFLUENT STREAM ****
1905 Q20=QN20
1910 Q11=Q10+Q20
1915 DSPTPD=TLBS31/2000/0.70
1920 DO 1925 I=1,20
1925 1925 SMATX(I,3)=SMATX(I,2)
1930 SMATX(6,3)=CAC27
1935 SMATX(7,3)=XMGH12/2.399
1940 SMATX(12,3)=ALK30
1945 SMATX(16,3)=PO428
1950 SMATX(17,3)=COD28
1955 SMATX(18,3)=VSS28
1960 SMATX(19,3)=NVSS28
2000C -----ACCELATOR SIZING-----
2005 2005 CONTINUE
2006 QMAX=20.16 $QMIN=0.7 $QDOTU=Q11 $ F=.65
2008 NCALLU=N5=NCALLC=VACCEL=0
2010 2010 CALL UNITS(NTRAIN,QTRAIN,VACCEL,N5)
2011 IF(NOWGO.EQ.1) GO TO 2050
2013C------COMPUTATION RE-ENTRY,ACCEL-----
2014 2014 X=ALOG(QTRAIN) $NCALLC=NCALLC+1
2016 VACCEL=NTRAIN*2*EXP(10.5803+0.356282*X+0.114333*X**2+0.0374586*
2017+X**3-0.00403479*X**4-0.00366915*X**5)/1000.*CIR*273.1/294.2
2018 VPUMP=NTRAIN*2.4*(7.5771E-4*(20*QTRAIN)**0.740863+0.433922)*
2019+CIR
2020 VACCEL=VACCEL+VPUMP$IF(IPRINT(2))2025,2025,2021
2021 2021 PRINT 2022,NCALLC,NTRAIN,QTRAIN,VACCEL
2022 2022 FORMAT(2X,I2,2X*NTRAIN: *I4,2X*QTRAIN: *
2023+F10.3,2X*VACCEL: *F13.3)
2024C------ACCELATOR OTFIMIZATION------
2025 2025 IF(N5)2032,2032,2026
2026 2026 N5=0 $ YY(2)=VACCEL
2028 2028 CALL PARAB3(NTRAIN,QTRAIN)
```

PROGRAM AWTLCC LRR PROJECT-162 FOR AACOG AND FWQA 11/6/70

11/07/70. 08.50.39.

```
2030 GO TO 2014
2032 2032 IF(NOWGO)2034,2050,2050
2034 2034 IF(NCALLU-7)2010,2036,2040
2036 2036 YY(2)=VACCEL $ GO TO 2014
2040 2040 IX(4)=NTRAIN $YY(4)=VACCEL
2042 CALL BAJO(NTRAIN,QTRAIN,J)
2044 IF(NOWGO)2046,2014,2050
2046 2046 GO TO (2014,2028,2028,2014,2028)J
2050 2050 CONTINUE
2055 RLTPD=PCAO18/2000.
2060 RLPMGD=RLTPD/QDOT
2062 TSPMGD=TLBS18/2000/QDOT
2063 RECOV=PCAO18/(QDOT*DOSCAO*8.33)
2065 VRCALC=178.959*(TLBS18/2000)**0.535022*CIR
2070 RCAREA=Q12*25
2071 VCONC=100./27.*(40*(1+SQRT(RCAREA))+(2+SQRT(RCAREA))**2)
2072 VGRIDS=RCAREA*6.
2073 VCARBU=40500*(Q12/50)**0.7
2074 IF(Q12-50.)2075,2077,2077
2075 2075 X=ALOG(Q12)
2076 VCARBU=1.35*EXP(8.35461+.178289*X+.0350484*X**2+.0122392*X**3)
2077 2077 VRCARB=2*(VCARBU+VGRIDS+VCONC)/1000.*CIR*273.1/294.2
2100C---FILTER SIZING-----
2105 VFILT=NFILT=0
2110 IF(IFILT)2199,2199,2115
2115 2115 NCALLU=NCALLC=N5=VFILT=0
212  FTOT=Q27/0.00144/GPMSFF
2121 QDOTU=AFTOT $F=.8
2122C----OPTIMIZE FILTER AREA,NOT FLOW RATE---
2125 QMAX=AFMAX=10000.
2130 QMIN=AFMIN=250.
2135 2135 CALL UNITS(NFILT,AFILT,VFILT,N5)
2136 IF(NOWGO.EQ.1) GO TO 2196
2144C-----COMPUTATION RE-ENTRY,FILT-------
2145 2145 X=ALOG(0.00288*AFILT)
2147 NCALLC=NCALLC+1
2150 VFILT=NFILT*EXP(4.81926+0.535745*X-0.115997*X**2+0.0633145*
2151+X**3-0.00718024*X**4)*CIR*273.1/294.2
2152 IF(IPRINT(2))2159,2159,2157
2153 2153 FORMAT(2X,I2,2X*NFILT: *I4,2X*AFILT: *
2154+F10.3,2X*VFILT: *F10.3)
2155C-----FILTER OPTIMIZATION
2156 IF(N5) 2170,2170,2160
2157 2157 PRINT 2153,NCALLC,NFILT,AFILT,VFILT
2158C------FILTER OPTIMIZATION----------
2159 2159 IF(N5)2170,2170,2160
2160 2160 N5=0 $ YY(2)=VFILT
2165 2165 CALL PARAB3(NFILT,AFILT) $ GO TO 2145
2170 2170 IF(NOWGO) 2175,2196,2196
2175 2175 IF(NCALLU-7)2135,2180,2185
2180 2180 YY(2)=VFILT $ GO TO 2145
2185 2185 IX(4)=NFILT $ YY(4)=VFILT $ CALL BAJO(NFILT,AFILT,J)
```

```
IF(NOWGO) 2194,2145,2196
2194 GO TO (2145,2165,2165,2145,2165) J
2196 CONTINUE
2199 VTOT(2)=VACCEL+VRCALC+VRCARB+VFILT
C ****OPERATING COSTS***
C -----NOTE: LABOR COSTS ARE SET TO ZERO------
WCCHG=DITIF*VTOT(2)*1000
WMUL=PRLIME=XMUL/2000*365.24*UBAR
WFUEL=365.24*11.2492*(TLBS18/2000*UBAR)**0.767663*CYBCI/754.
COMPHP=1.30789*Q12**0.668189-0.45166
POWACC=1.0*Q11*0.7452/0.75
POWPMP=Q11*20./3957./0.75*0.7452
POWCOMP=.47757*COMPHP
POWFILT=1.4E5*Q41*IFILT
POWKILN=0.792*TLBS18/2000
WPOW=((POWACC+(POWCOMP+POWPMP)*UBAR)*24*365.24
++POWFILT*UBAR)*CKWH/100+365.24*POWKILN
WMRR=1000*FACMR*VTOT(2)
WTOT(2)=WCCHG+WMUL+WFUEL+WPOW+WOL+WMRR
C ***PRINT STATEMENTS***
IF(IPRINT(6))3500,3500,3005
3005 PRINT 4904
GO TO (3009,3007,3008),ICAOFLG
3007 PRINT 4900 $ GO TO 3009
3008 PRINT 4990
3009 CONTINUE
PRINT 4906,QBARE,QDOT,UBAR
PRINT 4907,CAC10,XMG10,PO410,ALK10,TSS10,COD10
3400 PRINT 4950
AMORT=WCCHG/3650/QBARE
WOP=(WTOT(2)-WCCHG)/3650/QBARE
WTOTAL=AMORT+WOP
PRINT 4951,AMORT,WOP,WTOTAL
3500 RETURN
4900 FORMAT(/ *CAO DOSE ARBITRARILY SET AT 50 MG/L*/)
4902 FORMAT(I5)
4904 FORMAT(////,*----------LIME PROCESS----------*)
4905 FORMAT(//, * IMPOSED CONSTANT DESIGN PARAMETERS*)
4906 FORMAT(/* QBARE*F11.3,2X*QDOT*F12.3,2X,*UBAR*F12.5)
4907 FORMAT(*CACO3*F6.1*, MG*F5.1*, PO4*F5.1*, ALK*,
+F6.1*, TSS10*F6.1*, COD*F6.1)
4950 FORMAT(//,* COST SUMMARY, CENTS/KGAL*)
4951 FORMAT(/,* AMORT. =*,F7.3,*, OPER. =*,F7.3,*, TOTAL =*,
+F7.3,//)
4990 FORMAT(/* Q26 NEGATIVE.   ARBITRARILY SET TO ZERO.*/)
END
SUBROUTINE CLINOP(SMATX,XSCAOH)
COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
COMMON/UNITS/IX,YY,QMAX,QMIN,QDOT,F,NOWGO,MMMAX,MMMIN
COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
DIMENSION SMATX(20,8)
DIMENSION VTOT(20),WTOT(20),IPRINT(6),ARRAY(7)
```

```
PROGRAM AWTLCC  LKR PROJECT-162 FOR AACOG AND FWQA 11/6/70
 11/07/70. 08.50.39.


 DIMENSION IX(4),YY(4)
 DATA AN79,CLLF,FCLPR,GPMSFX,GPMSFS,CFAPG,DIAMAX,DEPMAX,
+FRCLIN,PRNACL,PRLIME,FACAOL,EPUMP,EBLOW,NDTL77,AVTL77,PRMBTU
+/0.5,0.17,0.0026,6.,5.,300.,25.5,10.,
+10.,0.01,18.50,0.9,0.75,0.60,100,67.,0.5/
 NCALLU=NCALLC=N5=WTOT(3)=0
 Q50=Q79=QDOT=QDOTU=SMATX(1,3)$F=1.
 QBARE=SMATX(2,3)
 UBAR=QBARE/QDOT
 AN50=SMATX(5,3)
C ----------EXCHANGER NUMBER AND SIZE----------
 BEDDEP=DEPMAX
 QMAX=GPMSFX*0.00144*0.785398*DIAMAX**2
 QMIN=GPMSFX*.00144*.785398
 5115 CALL UNITS(NEXCHL,QEXCH,WTOT(3),N5)
 IF(NOWGO.EQ.1)GO TO 6775
C ----- COMPUTATION ENTRY POINT ----
 5120 AREA=QEXCH/.00144/GPMSFX
 NCALLC=NCALLC+1
 DIAM=SQRT(AREA/0.785398)
 NHFT=2*DIAM+0.99999
 DIAM=0.5*NHFT
 AREA=0.785398*DIAM**2
 BVSTG=BEDDEP*AREA
 GPMSFC=QDOT/(NEXCHL*0.00144*AREA)
 TLOAD=BEDDEP*CLLF/(GPMSFC*(AN50-AN79)*499.8)*1E6
 NEXCHR=NEXCHL*9./TLOAD+0.99999
 NEXCHT=NEXCHL+NEXCHR
 HPXPMP=QDOT/2/0.00144*35/3957/EPUMP
 PCAOH=QDOT*8.33*(AN50-AN79)/14.01*74.10/2
 PLIME=PCAOH*56.08/74.10/FACAOL
C ----------REGENERATION----------
 NRGS=0.5*NEXCHR+0.9
 CHTANK=4*BVSTG*7.4806
 CDTANK=1.5*BVSTG*7.4806
 GPMREG=1.25*BVSTG
 ANXRGD=NEXCHL*24/TLOAD
 PSALT=ANXRGD*BVSTG*.18244
 HPRPMP=GPMREG*35/3957/EPUMP
C ----------STRIPPER----------
 GPMSTR=ANXRGD*BVSTG/48
 TAREA=GPMSTR/GPMSFS
 CFMAIR=CFAPG*GPMSTR
 BTUAIR=CFMAIR*29./392.*1440*NDTL77*0.238*(77-AVTL77)
 BTULIQ=GPMSTR*8.33*1440*NDTL77*(77-AVTL77)
 HPSPMP=GPMSTR*35/3957/EPUMP
 NBLOW=1
 HPBLOW=0.000236*CFMAIR/EBLOW
 IF(HPBLOW-5000.)5350,5350,5340
 5340 NBLOW=HPBLOW/5000+0.99999
 HPBLOW=HPBLOW/NBLOW
 5350 CONTINUE
```

PROGRAM AWTLCC LKR PROJECT-162 FOR AACOG AND FWQA 11/6/70

11/07/70. 08.50.39.

```
6000C ----------CAPITAL COSTS
6005 VEXCH=NEXCHT*1.56611*BVSTG**0.504425*CIR
6010 VCLIN=PRCLIN*NEXCHT*BVSTG/1000
6015 VXPUMP=2*2.4*(7.57718E-4*(35*QDOT/2/0.00144)**0.740863+0.433922)
6016+*CIR
6020 VHTANK=3*NRGS*1.23*(0.00506131*CHTANK**0.688148+0.139225)
6021+*CIR*273.1/241.8
6025 VDTANK=NRGS*1.23*(0.00506131*CDTANK**0.688148+0.139225)
6026+*CIR*273.1/241.8
6030 VRPUMP=3*NRGS*2.4*(7.57718E-4*(35*GPMREG)**0.740863+0.433922)
6031+*CIR
6035 VTOWER=2*(0.0890*TAREA+0.719873)*CIR*273.1/294.2
6040 VSPUMP=2*2.4*(7.57718E-4*(35*GPMSTR)**0.740863+0.433922)
6041+*CIR
6045 VBLOW=NBLOW*2*(0.303308*HPBLOW**0.698176+0.379419)*CIR*273.1
6046+/108.7
6050 VSPIPE=0.42*VTOWER+0.18*VBLOW
6055 VTOT(3)=VEXCH+VCLIN+VXPUMP+VHTANK+VDTANK+VRPUMP+VTOWER+
6056+VSPUMP+VBLOW+VSPIPE
6500C --------OPERATING COSTS-------
6501C *****NOTE:LABOR COSTS SET TO ZERO********
6510 WCCHG=DITIF*VTOT(3)*1000
6515 WMUC=FCLPR*ANXRGD*365.25*BVSTG*PRCLIN*UBAR
6520 WLIME=PLIME/2000*365.24*PRLIME*UBAR
6521 IF(XSCAOH)6525,6525,6522
6522 6522 WLIME=WLIME*(PCAOH-XSCAOH)/PCAOH
6523 IF(WLIME)6524,6524,6525
6524 6524 WLIME=0
6525 6525 WSALT=PSALT*365.25*PRNACL*UBAR
6530 WFUEL=(BTUAIR+BTULIQ)*1.E-6*PRMBTU
6535 HPQBAR=(2*HPXPMP+NRGS*3*HPRPMP/UBAR+2*HPSPMP/UBAR+UBAR*HPBLOW)
6536+*UBAR**2
6540 WPOW=0.7452*HPQBAR*24*365.25*CKWH/100
6550 WMRR=1000*FACMR*(VTOT(3)-VCLIN)
6551 WTOT(3)= WCCHG+WMUC+WLIME+WSALT+WFUEL+WPOW+WMRR
6555 IF (IPRINT(2)) 6705,6705,6556
6556 6556 PRINT 6557,NCALLC,NEXCHL,QEXCH,WTOT(3)
6557 6557 FORMAT(2X,I2,2X*NEXCHL: *I4,2X*QEXCH: *F10.3,2X*WTOT(3): *
6558+F13.3)
6700C -----OPTIMIZATION-------
6705 6705 IF(N5)6730,6730,6710
6710 6710 N5=0
6715 YY(2)=WTOT(3)
6720 6720 CALL PARAB3(NEXCHL,QEXCH)
6725 GO TO 5120
6730 6730 IF(NOWGO)6735,6775,6775
6735 6735 IF(NCALLU-7)5115,6740,6750
6740 6740 YY(2)=WTOT(3)
6745 GO TO 5120
6750 6750 IX(4)=NEXCHL
6755 YY(4)=WTOT(3)
6760 CALL BAUO(NEXCHL,QEXCH,J)
```

```
6765 IF(NOWGO)6770,5120,6775
6770 6770 GO TO(5120,6720,6720,5120,6720)J
6775 6775 CONTINUE
6777 PRINT 6778
6778 6778 FORMAT(*----------*,//)
6800C **EFFLUENT STREAM***
6805 6805 DO 5410 I=1,20
6810 5410 SMATX(I,4)=SMATX(I,3)
6815 SMATX(3,4)=SMATX(3,3)+PSALT*23.00/58.45/(QDOT*8.33)
6820C **NOTE+ ONLY NH3 ASSUMED EXCHANGED**
6825 SMATX(5,4)=AN79
6830 SMATX(6,4)=SMATX(6,3)+PCAOH*56.08/74.10/(QDOT*8.33)
6835 SMATX(8,4)=SMATX(8,3)+PSALT*35.45/58.45/(QDOT*8.33)
7000C----PRINT STATEMENT
7005 IF(IPRINT(6)) 7799,7799,7010
7010 7010 PRINT 7901
7020 PRINT 7903,QBARE,QDOT,UBAR,AN50
7600 7600 PRINT 7970
7605 AMORT=WCCHG/3650/QBARE
7610 WOP=(WTOT(3)-WCCHG)/3650/QBARE
7615 WTOTAL=WOP+AMORT
7620 PRINT 7971,AMORT,WOP,WTOTAL
7799 7799 RETURN
7800C ----FORMAT STATEMENTS
7801 7901 FORMAT(////,*-----CLINOPTILOLITE PROCESS-----*)
7805 7903 FORMAT(/,* QBARE*F8.2,3X,*QDOT*,F9.2,3X,*UBAR*,
7806+F9.5,3X,*AN50*,F9.2)
                                  7896 7970 FORMAT(//,* COST SUMMARY, CENTS
KGAL*)                                        /
7897 7971 FORMAT(/,* AMORT. =*,F7.3,*, OPER. =*,F7.3,*, TOTAL =*,
7898+F7.3)
7999 END
8000 SUBROUTINE ACTCAR(SMATX)
8003 COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
8004 COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
8005 COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
8019 DIMENSION SMATX(20,8),IX(4),YY(4)
8020 DIMENSION VTOT(20),WTOT(20),IPRINT(6),ARRAY(7)
8022 DATA NSTAGE,GPMSF,RHO,PRCAR,PRFUEL,GPMBW,COD89,CT,CLF/
8023+ 2,6.,30.,26.,25.,8.,8.,50.,.5/
8025 QDOT=QDOTU=SMATX(1,4) $ F=1.
8027 QBARE=SMATX(2,4)
8030 UBAR=QBARE/QDOT
8032 COD80=SMATX(17,4)
8035 IF(GPMSF-13)8045,8045,8040
8040 8040 PRINT 50
8045 8045 DOSAGE=8.33*(COD80-COD89)/CLF
8050 CREGDY=DOSAGE*QDOT
8054 BEDVOL=QDOT*CT*92.833
8060 YRKWH = 365.24*939.669*QBARE**.9224757
8061 WPOW= YRKWH*CKWH/100
8065C---SEED DOSAGES AND NUMBER OF TRAINS---
8100 8100 GPMSFC=GPMSF
```

PROGRAM AWTLCC LKP PROJECT-162 FOR AACOG AND FWQA 11/6/70

11/07/70. 10.34.19.

```
8105 8105 BEDDEP=GPMSFC*CT/7.4806/NSTAGE
8110 IF(BEDDEP-25.)8125,8135,8115
8115 8115 GPMSFC=25.*7.4806*NSTAGE/CT
8120 BEDDEP=25.
8125 8125 IF(BEDDEP-2.5)8130,8135,8135
8130 8130 BEDDEP=2.5
8135 8135 QMAX=0.785398*25.5**2*0.00144*GPMSFC
8136 QMIN=.785398*.00144*GPMSFC
8138 NCALLU=NCALLC=N5=WTOT(4)=0
8140 8140 CALL UNITS(NTRAIN,QTRAIN,WTOT(4),N5)
8141 IF(NOWGO.EQ.1) GO TO 8595
8144C----COMPUTATION RE-ENTRY,ACTCAR----
8145 8145 BVSTG=BEDVOL/(NSTAGE*NTRAIN)
8146 NCALLC=NCALLC+1
8150 DIAM=(BVSTG/BEDDEP/0.785398)**0.5
8300 8300 CONTINUE
8315 8315 NHFT=2*DIAM+0.99999
8320 DIAM=0.5*NHFT
8325 AREA=0.785398*DIAM**2
8327 BEDDEP=BVSTG/AREA
8330 NHFT=2.6*BEDDEP+0.99999
8335 HGT=0.5*NHFT
8337 GPMSFC=QTRAIN/0.00144/AREA
8340 NSPARE=2+2*(NTRAIN/10)
8345 NADSO=NTRAIN*NSTAGE
8350 NADST=NADSO+NSPARE
8360 VOL=AREA*HGT
8400 FAREA=.000640472*CREGDY**1.29912
8405 IF(FAREA-28.26)8410,8415,8415
8410 8410 FAREA=28.26
8415 8415 CARB=(NADSO+NSPARE/2)*BVSTG*RHO
8427 ADSFR=QDOT/NTRAIN/.00144
8430 CRGDYE=UBAR*CREGDY
8500C          ***********INVESTMENT COSTS***********
8505 VADS=NADST*0.187254*VOL**0.593364*CIR
8510 VFUR=1.3*19.0042*FAREA**0.39326*CIR
8514 VPASBW=29.3693*QDOT**.710743*CIR
8525 VPIP=(NADSO+NSPARE/2)*2.41222*ADSFR**.386757*CIR
8530 VELIN=(46.4174*QDOT**.386189)*(.70455+NSTAGE*.147708)*
8531+CIR
8540 VCAR=PRCAR*CARB/1E5
8545 VCON=.048*VPASBW+.092*VADS+.176*VFUR
8560 VTOT(4)=VADS+VFUR+VPASBW+VPIP+VELIN+VCAR+VCON
8565C           **********OPERATING COSTS**************
8567 WCCHG=DITIF*VTOT(4)*1000
8570 WCAR=CRGDYE*PRCAR*3.6524*.05
8571 WFUEL=0.0155125*CRGDYE*PRFUEL
8572 WOL=0
8573 WMRR=1000.*FACMR*(VTOT(4)-VCAR)
8574 WTOT(4)=WCCHG+WCAR+WPOW+WFUEL+WOL+WMRR
8580 IF(IPRINT(2))8585,8585,8581
8581 8581 PRINT 8582,NCALLC,NTRAIN,QTRAIN,WTOT(4)
```

```
PROGRAM AWTLCC  LRR PROJECT-162 FOR AACOG AND FWQA 11/6/70

 11/07/70. 10.34.19.

8582 FORMAT(2X,I2,2X*NTRAIN: *I4,2X*QTRAIN: *F10.3,2X
+*WTOT(4): *F12.3)
C----ACTCAR OPTIMIZATION
8585 IF(N5)8589,8589,8586
8586 N5=0 $ YY(2)=WTOT(4)
8587 CALL PARAB3(NTRAIN,QTRAIN)
GO TO 8145
8589 IF(NOWGO) 8590,8595,8595
8590 IF(NCALLU-7) 8140,8591,8592
8591 YY(2)=WTOT(3) $ GO TO 8145
8592 IX(4)=NTRAIN $YY(4)=WTOT(4) $CALL BAJO(NTRAIN,QTRAIN,J)
IF(NOWGO) 8594,8145,8595
8594 GO TO(8145,8587,8587,8145,8587)J
8595 CONTINUE
8600 IF(IPRINT(6))8899,8899,8601
8601 PRINT 1
PRINT 3, QDOT,QBARE,UBAR
PRINT 4,CLF,CT,COD89,COD80
8860 PRINT 70
AMORT=WCCHG/3650/QBARE
WOP=(WTOT(4)-WCCHG)/3650/QBARE
WTOTAL=WOP+AMORT
PRINT 71,AMORT,WOP,WTOTAL
8899 CONTINUE
1 FORMAT(///,1X,*---ACTIVATED CARBON PROCESS---*)
3 FORMAT(/,1X,*QDOT =*,F11.3,* MGD, QBARE =*,F11.3,
+* MGD, UBAR =*,F6.4)
4 FORMAT(1X*CLF =*F5.3,*, CT =*F5.1*, CODEF =*F6.4,1+,
+4X*CODIN =*F5.1)
50 FORMAT(* FLOW RATE OVER 13 GPM/SQ.FT. CHECK PRESS. DROP.*)
70 FORMAT(//,* COST SUMMARY, CENTS/KGAL*)
71 FORMAT(/,* AMORT. =*,F7.3,*, OPER. =*,F7.3,*, TOTAL =*,F7.3)
C*******EFFLUENT STREAM******
DO 8460 J=1,20
8460 SMATX(J,5)=SMATX(J,4)
SMATX(16,5)=SMATX(16,4)*0.67
SMATX(17,5)=COD89
RETURN
END
SUBROUTINE CHLOR(SMATX)
COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
COMMON/BLK1/CYBCI
DIMENSION SMATX(20,8)
DIMENSION VTOT(20),WTOT(20),IPRINT(6)
DO 9020 I=1,20
9020 SMATX(I,6)=SMATX(I,5)
QDOT=SMATX(1,5)
QBARE=SMATX(2,5)
VTOT(5)=13.5*QDOT**.658*CIR*273.1/262.9
WCCHG=VTOT(5)*DITIF
WOM=3178.*QBARE**.904*CYBCI/718.
WTOT(5)=WCCHG+WOM
```

```
9055 SMATX(8,6)=SMATX(8,5)+8.
9056C ---- ABOVE ASSUMES ALL CL2 CONVERTED TO CL-. ----
9060 RETURN
9065 END
9200 SUBROUTINE DISP(VTOT,WTOT,DITIF,DSPTPD,UBAR,CIR,CYMSI)
9205 DIMENSION VTOT(20),WTOT(20)
9210 VTOT(7)=0
9215 WTOT(7)=1.5*365.24*UBAR*DSPTPD*CIR*273.1/CYMSI+VTOT(7)*DITIF*1000
9220 RETURN
9225 END
10000 SUBROUTINE COSTC(ARRAY,VALUE)
10005 DIMENSION ARRAY(7)
10010 ARRAY(1)=VALUE
10015 DO 10020 I=2,4
10020 10020 ARRAY(I)=ARRAY(1)/ARRAY(I+3)
10025 RETURN
10030 END
12000 FUNCTION ENGR(VALUE)
12005 ENGR=0.154874*VALUE**(-0.122012)
12010 IF(ENGR.LT.0.05)ENGR=0.05
12100 RETURN
12105 END
13000 SUBROUTINE UNITS(MBACK,QBACK,W,N5)
13001C  OPTIMUM NUMBER OF UNITS AND SIZES THEREOF TO PRODUCE QDOTU
13002C  OR F*QDOTU WITH ONE UNIT OUT.  FIRST CALL GIVES BOUNDARIES
13003C  OF THE DOMAIN OF M AND Q, AND RETURNS FIRST M AND Q TO USE.
13004C  SUCCESSIVE CALLS EXPLORE DOMAIN TO LOCATE OPTIMUM.
13005 COMMON/BO/CKWH,CYMSI,VTOT,WTOT,FACMR,IPRINT,DITIF,VCLIN,VCAR,CIR
13006 DIMENSION IPRINT(6)
13014 DIMENSION IX(4),YY(4)
13015 COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
13016 COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
13020 M(X)=MAX0((INT(F*QDOTU/X+2.-1.E-7)),INT(QDOTU/X+1.-1.E-7))
13030 Q(K)= AMAX1(F*QDOTU/(K-1),QDOTU/K)
13040 NCALLU=NCALLU+1
13050 GO TO (60,200,220,220,250,300,400)NCALLU
13060 60 MM=M(QMAX)
13065 NOWGO=-1 $WLAST=1.E17
13070 IF (MM-2) 80,90,90
13080 80 MM=2
13090 90 QQ=Q(MM)
13100 IF (QQ-QMIN) 110,120,120
13110 110 QQ=QMIN
13120 120 MBACK=MMMIN=MM
13130 QBACK=QQMAX=QQ
13140 140 QQMIN = QMIN
13150 MMMAX = M(QMIN)
13151 IF (IPRINT(2)) 170,170,160
13152 IF(MMMIN-MMMAX)160,154,160
13154 154 NOWGO=0
13158 158 FORMAT(//,*----------*)
13159 160 PRINT 158
13151

13155 160 IF IPRINT (2) 170, 170, 159

13159 159 PRINT 158
```

```
PRINT 161
161 FORMAT(*  UNITS DOMAIN:*,4X,*MMIN  MMAX    QMAX     QMIN*)
PRINT 163, MMMIN,MMMAX,QQMAX,QQMIN
163 FORMAT(20X,I3,I6,F10.3,F9.3)
170 RETURN
200 WLAST=W$MBACK=MBACK+1$GO TO 900
220 IF(W-WLAST)200,255,255
250 IF(W-WLAST)260,255,255
255 MBACK=MBACK-1$NOWGO=0$GO TO 900
260 IF(MBACK-MMMAX)270,265,265
265 NOWGO=1 $ GO TO 998
270 YY(1)=W$IX(1)=MBACK$MBACK=MMMAX$GO TO 900
300 WLAST=W$MBACK=MBACK-1$GO TO 900
400 IF(W-WLAST)450,406,406
406 IF(YY(1)-W) 450,450,410
410 MBACK=MMMAX$NOWGO=0$GO TO 900
450 IX(3)=MBACK$YY(3)=W$NWAY=MMMAX/10+1
IX(2)=MBACK=(NWAY*IX(1)+IX(3))/(NWAY+1)
N5=1$NCALLU=8$GO TO 900
900 QBACK=Q(MBACK)
998 RETURN
END
SUBROUTINE PARAB3(MBACK,QBACK)
C GIVES PARAB THROUGH 3 POINTS AND X AT MINIMUM,OR A CANDIDATE
C X CONSTRAINED
DIMENSION IX(4),YY(4)
COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
Q(K) = AMAX1(F*QDOTU/(K-1),QDOTU/K)
J=0 $ NCALLP=NCALLP+1
C1=IX(1)-IX(2) $ C2=IX(2)-IX(3)
C=((YY(1)-YY(2))/C1-(YY(2)-YY(3))/C2)/(IX(1)-IX(3))
IF (C) 46,46,50
46 PRINT,*APPROXIMATING PARAB HAS A MAXIMUM. NCALLP=*,NCALLP
IF(YY(3)-YY(1)) 49,48,48
48 IXLOW=IX(1) $ MUSE=MMMIN-1 $ GO TO 150
49 IXLOW=IX(3) $ MUSE=MMMAX+1
150 IX(4)=(IXLOW+IX(2))/2 $ IF (IX(4)-IX(2)) 151,152,151
151 IF(IX(4)-IXLOW) 75,152,75
152 IX(4)=(IXLOW+MUSE)/2 $GO TO 75
50 B=(YY(1)-YY(2))/C1-(IX(1)+IX(2))*C
A = YY(1) -B*IX(1) - C*(IX(1)**2)
XP= -B/(2*C)  $ YP = A+B*XP+C*XP**2
PRINT 64, XP,YP
64 FORMAT(*PARAB OPT X =*,F10.3,*  MIN Y =*,F10.3)
IX(4)= XP
75 IF(IX(4)-MMMAX)73,79,72
72 IX(4)=MMMAX$OBFLAG=-1 $GO TO 78
73 IF(IX(4)-MMMIN)74,79,79
74 IX(4)=MMMIN $ OBFLAG=1 $ GO TO 78
78 PRINT,*IX(4) RETURNED FROM OUT OF BOUNDS*
J=0 $ GO TO 4140
```

```
14130 79 J=0 $ OBFLAG=0
14140 4140 DO 88 I=1,3
14150 IF(IX(4)-IX(I)) 88,85,88
14160 85 J=I $ PRINT 86,NCALLP,I,IX(4)
14170 86 FORMAT(*IX(4) RETURNED FROM PARAB3 AT NCALL *,I3,
14180+ * SAME AS IX(*,I2,*); = *,I3)
14190 88 CONTINUE
14200C  ----NEW X(4) FOR DUPLICATES  ----
14210 IF(J) 194,194,191
14220 191 GO TO (4221,200,4221)J
14221 4221 IF(OBFLAG) 4222,4223,4222
14222 4222 IX(4)=IX(2)+OBFLAG $ GO TO 90
14223 4223 GO TO (192,200,193)J
14230 192 IX4DUP=0 $ GO TO 48
14240 193 IX4DUP=0 $ GO TO 49
14250 194 IX4DUP=0 $ GO TO 90
14260 200 IF(YY(3)-YY(1)) 220,210,210
14270 210 IXLOW=IX(1) $ IXHI=IX(3) $ GO TO 240
14280 220 IXLOW=IX(3) $ IXHI=IX(1)
14290 240 IF(IX(4)-IX4DUP)250,280,250
14300 250 IF(IX(2)-IXLOW-1)260,270,260
14310 260 IX4DUP=IX(4)$IX(4)=(IXLOW+IX(2))/2$GO TO 90
14320 270 IX4DUP=IX(4)$IX(4)=(IXHI+IX(2))/2$GO TO 90
14330 280 IF(IX(2)-IXHI+1)300,290,300
14340 290 IX(4)=IX(2)-1$GO TO 90
14350 300 IX(4)=IX(2)+1
14360 90 MBACK=IX(4) $ QBACK=Q(MBACK) $ YY(4)=0
14370 RETURN
14380 END
15000 SUBROUTINE BAJO(MBACK,QBACK,J)
15010C OUT OF 4 POINTS RETURNS 3 LOWEST BRACKETING
15011C A MIMIMUM; OR IF NONE, 3 LOWEST
15012C AND CANDIDATE FOR A MIMIMUM BRACKETER
15014 DIMENSION IX(4),YY(4)
15015 COMMON/UNITS/IX,YY,QMAX,QMIN,QDOTU,F,NOWGO,MMMAX,MMMIN
15016 COMMON/NCALL/NCALLC,NCALLU,NCALLP,NCALLB
15019 Q(K) = AMAX1(F*QDOTU/(K-1),QDOTU/K)
15020 YMIN=1E17 $ J=0 $ N=4
15030 NCALLB=NCALLB+1
15035 IXWAS4=IX(4)
15071 DO 95 K=1,3
15072 N=N-1
15075 DO 95 I=1,N
15080 IF(IX(I)-IX(I+1)) 95,95,85
15085 85 XTEMP=IX(I) $ YTEMP=YY(I) $ YY(I)=YY(I+1)
15090 IX(I)=IX(I+1) $ IX(I+1)=XTEMP $ YY(I+1)=YTEMP
15095 95 CONTINUE
15100 DO 130 I=1,4
15110 IF(YY(I)-YMIN) 120,130,130
15120 120 YMIN=YY(I) $IMIN=I
15130 130 CONTINUE
15135 J=IMIN
```

PROGRAM AWTLCC LKB PROJECT-162 FOR AACOG AND FWQA 11/6/70

11/07/70. 10.34.19.

```
IF (J-2) 140,137,140
137 MMMIN=IX(1) $ MMMAX=IX(3)
PRINT 139,MMMIN,MMMAX
139 FORMAT(*MMMIN=*,I4,2X,*MMMAX=*,I4)
140 GO TO (190,320,160,160) J
C ----160 ARRANGE ---
160 XTEMP=IX(1) $ YTEMP=YY(1)
DO 175 I=1,3
IX(I)=IX(I+1)
175 YY(I)=YY(I+1)
IX(4)=XTEMP$ YY(4)=YTEMP
190 GO TO (195,320,320,200)IMIN
C ----190 NEW X(4) ---
195 MUSE=MMMIN $ GO TO 205
200 MUSE=MMMAX
205 IX(4) =(MUSE+IX(IMIN))/2
MBACK=IX(4) $ QBACK=Q(MBACK)
PRINT,*THREE LOWEST NOT MINIMUM*
C ---TEXT FOR X CONVERGENCE---
320 GO TO (399,330,330,399) J
330 IF(1-(IX(3)-IX(2))*(IX(2)-IX(1)))360,340,360
340 IF(IX(2)-IXWAS4)350,345,350
345 NOWGO=1$GO TO 400
350 NOWGO=0 $ MBACK=IX(4)=IX(2) $ GO TO 399
360 J=5
399 QBACK=Q(MBACK)
400 RETURN
END
```

- - - T H E   E N D - - -

VARIABLE NAMES

Variable Names For The General Program

AMORT	Amortization cost, ¢/Kgal
ARRAY	Array used for cost calculations
BCINMS	National BCI for Year of CYMSI
CKWH	Cents per kilowatt hour, ¢/kwh
CODnn	COD in stream nn, mg/l
CYBCI	Current year Building Cost Index for Region
CYMSI	Current Year Marshall & Stevens Chemical Process Industries Equipment Cost Index
DITIF	Amortization rate, depreciation, interest, taxes, insurance annual fraction of investment
ENGR	Engineering, fraction of subtotal investment
EPUMP	Efficiency of pumps
FACMR	Maintenance and repair factor, fraction of VTOT/year
IPRINT(n)	Print decision variables, n = 1-6
J	Dummy variable for UNITS subroutine
NSTAGE	No. of stages in series
NTRAIN	No. of trains of units operating in parallel
PLF	Plant life (years)
PYREX	Payroll extras factor
QBARE	Expected flow rate into plant, mgd
QDOT	Design flow rate into plant, mgd
Qnn	Flow rate of stream nn, mgd
RET	Interest rate, fractinn of VTOT/year
RTLAB	$/man hour labor rate including payroll extras
TX	Tax rate, fraction of VTOT/year
UBAR	Utilization factor, QBARE/QDOT

VTOT(n)	Investment, total of process n, K$
WCCHG	Capital investment charge, $/year
WMRR	Cost of maintenance & repair, $/year
WOP	Cost of operation, ¢/Kgal
WTOT(n)	Total production cost, $ /year, for process n
WTOTAL	Total production cost, ¢/Kgal
XINS	Insurance rate, fraction of VTOT per year

Variable Names for Lime Process

AFILT	Filter area, sq. ft.
ALKnn	Alkalinity in stream nn, mg/l $CaCO_3$
CACnn	$CaCO_3$ in stream nn, mg/l
COMPHP	Horsepower of compressors, HP
DLIME	Required CaO dose, mg CaO/liter
FACAOL	Fraction of new lime which is active CaO
FAPAT	Fraction of $Ca_5OH(PO4)_3$ in solids exit. Accelator #1
FCACO3	Fraction of $CaCO_3$ in solids exit. Accelator #1
FCAOHD	Fraction of $Ca(OH)_2$ in solids disposed of from slaker.
FCAOS	Fraction of CaO in solids feed to slaker
FCODAC	Fraction of COD entering Accelators removed by Accelators
FCODF	Fraction of filter influent COD removed by filter
FINERT	Fraction of inerts in solids exit. Accelator #1
FINRTD	Fraction of inerts entering slaker which leave in disposed residue
FMGOH	Fraction of $Mg(OH)_2$ in solids exit. Accelator #1
FNVSS	Fraction non-volatile SS in suspended solids
FTSS	Fraction of TSS in solids exit. Accelator #1
FVSS	Fraction volatile SS in suspended solids
IFILT	"Is there a filter?" 0 = no, 1 = yes
NFILT	No. of filter trains required in parallel

NVSS	Non-volatile suspended solids, mgpl
PAPAnn	Pound/day appatite $Ca_5OH(PO4)_3$ in stream nn
PASH	Pound/day ash exit the kiln
PCACnn	Pound/day $CaCO_3$ in stream nn
PCAOnn	Pound/day CaO in stream nn
PCAOH48	Pound/day $Ca(OH)_2$ in stream 48
PCAOHD	Pound/day $Ca(OH)_2$ disposed of from slaker (Stream 31)
PCAOHR	Pound/day $Ca(OH)_2$ recycled to supply DLIME
PINRnn	Pound/day inerts in stream nn
PINRTS	Pound/day inerts entering slaker from kiln and makeup lime
PMGHnn	Pound/day $Mg(OH)_2$ in stream nn
PMGOnn	Pound/day MgO in stream nn
PO4nn	Concentration of $PO4^{--}$ in solids in stream nn, mg/l
PRLIME	Price of new lime, $/ton
PTSSnn	Pound/day total suspended solids in stream nn
QN20	Newly computed recycle stream 20
RCAREA	Area of recarbonation grids in one unit, $ft.^2$
RECOF	Recovery fraction of lime (lb/day CaO exit kiln/(lb/day CaO in makeup lime)
RLPMGD	Recovered lime per mgd, tons CaO recycled/Q10
RLTPD	Recovered lime, tons/day, exit the kiln
TLBSnn	Total lb/day solids (dissolved & suspended) in stream nn
TSOLnn	mg/l total solids in stream nn
TSPMGD	Tons of solids exit kiln per mgd of Q10
TSSnn	mg/l suspended solids in stream nn
VCARBU	K$ for each recarbonation unit
VCONC	K$ for recarbonation basin concrete
VFILT	K$ for filters
VGRIDS	K$ for recarbonation grids
VRCALC	K$ for recalcination facility
VRCARB	K$ for recarbonation, VCARBU + VCONC + VGRIDS
VSS	Volatile suspended solids , mgpl

WFUEL	\$/year for kiln fuel
WMUL	\$/year for makeup lime
WPOW	\$/year for electrical power
X	Dummy variable for approximation formulas
XMGnn	mg/l Mg in stream nn
XMGHnn	mg/l $Mg(OH)_2$ in stream nn
XMUL	Makeup lime, lb/day, as delivered (including inerts)
XMULN	Newly-calculated value of XMUL
XSCAOH	Excess $Ca(OH)_2$ produced beyond requirement for DLIME, lb/day

Variable Names For Clinoptilolite Process

ANnn	Ammonia nitrogen, stream nn, mg/l as nitrogen
ANXRGD	Average no. of exchangers regenerated per day at QDOT
AREA	Ion exchanger cross-section area, $ft.^2$
AVTL77	Average eluant temperature when less than 77^o, ^oF
BEDDEP	Depth of resin in ion exchange beds, ft.
BTUAIR	BTU/year required to heat stripping air to 77^o F (25^oC)
BTULIQ	BTU/year required to heat eluant to 77^o F
BVSTG	Bed volume per stage, $ft.^3$
CDTANK	Capacity of one drain tank, gal.
CFAPG	Cu. ft. air per gallon of eluant, $ft.^3$/gal.
CFMAIR	Cu. ft. per minute of air to stripper, $ft.^3$/min.
CHTANK	Capacity of one holding tank, gal.
CLLF	Clinoptilolite loading factor, lb. NH_3-N/$ft.^3$ resin
DEPMAX	Maximum depth allowable for clino. bed, ft.
DIAM	Diameter of clino. exchanger, ft.
DIAMAX	Maximum allowable diameter of ion exchange vessel, ft.

EBLOW	Efficiency of blower
FACAOL	Fraction of active CaO in lime used for regeneration
FCLPR	Fraction of clino. lost per regeneration
GPMREG	Regeneration flow rate, gpm
GPMSFC	Calculated gpm/ft.^{2} in exchangers
GPMSFS	gpm/ft.^{2} liquid loading to stripping tower
GPMSFX	Imposed maximum gpm/ft.^{2} in exchangers
GPMSTR	Flow rate of eluant to stripper, gpm
HPBLOW	Horsepower of one blower, HP
HPQBAR	Total horsepower required for pumps and blowers at production of QBARE, HP
HPRPMP	Horsepower of one regeneration pump, HP
HPSPMP	Horsepower of one stripper pump, HP
HPXPMP	Horsepower of one exchanger pump (2 required for plant), HP
I	Subscript dummy variable
NBLOW	No. of blowers in stripper system
NDTL77	No. of days per year eluant temperature is less than 77°F (25°C)
NEXCHL	No. of exchangers on line (at QDOT)
NEXCHR	No. of exchangers being regenerated (at QDOT)
NEXCHT	Total no. of exchangers installed
NHFT	No. of half-feet in exchanger diameter
NRGS	No. of regeneration systems
PCAOH	Pounds/day of $Ca(OH)_2$ used for regeneration (excluding inerts)
PRCLIN	Price of clinoptilolite, \$/ft.^{3}
PLIME	Pounds/day of lime used for regeneration (including inerts)
PRMBTU	Price of one million BTU, \$/mBTU
PRNACL	Price of NaCl, \$/lb.
QEXCH	Design production of one exchanger, mgd
QMAX	Maximum production allowable for one exchanger, mgd
QSMALL	Design production for plants small enough to use only one exchanger (not used)

TAREA	Stripping tower cross-section area, $ft.^2$
TLOAD	Time to exhaust one exchanger at QEXCH, and QDOT, hours
VBLOW	Investment of blowers, K$
VCLIN	Investment of initial clinoptilolite, K$
VDTANK	Investment of drain tanks, K$
VEXCH	Investment of exchangers and associated pipes, valves and brine tanks, K$
VHTANK	Investment of holding tanks, K$
VRPUMP	Investment of regeneration pumps, K$
VSPIPE	Investment of stripper system piping, K$
VSPUMP	Investment of stripper system pumps, K$
VTOWER	Investment of 2 stripping towers, K$
VXPUMP	Investment of 2 exchanger pumps, K$
WLIME	Cost of regenerant lime, $/year
WMUC	Cost of makeup clinoptilolite, $/year
WPOW	Cost of electrical power, $/year
WSALT	Cost of salt for regeneration, $/year

Variable Names For Activated Carbon Process

ADSFR	Adsorber flow rate (gpm) at QDOT
AREA	Surface area of one adsorber, $ft.^2$
BEDDEP	Depth of carbon in one adsorber, ft.
BEDVOL	Cu. ft. carbon required at QDOT
BVSTG	Bed volume/stage, cu.ft.
BWFR	Backwash flow rate, gpm
CARB	Total pounds carbon in equipment
CLF	Carbon loading factor, lb. COD/lb. carbon
CODEF	ppm, COD in effluent
CODIN	ppm, COD in influent

CREGDY	Pound carbon/day regenerated at QDOT
CRGDYE	Pound/day carbon regenerated at QBARE
CT	Contact time (minutes)
DIAM	Diameter of one adsorber, ft.
DOSAGE	Pound carbon/million gal. water
FAREA	Furnace area for regeneration of carbon, $ft.^2$
GPMBW	$gpm/ft.^2$ flow rate for backwash water
GPMSF	$gpm/ft.^2$
GPMSFC	Calculated $gpm/ft.^2$ flow (as opposed to GPMSF which is imposed) at flow rate of QDOT
NADSO	No. of adsorbers operating (total, all trains)
NADST	Total no. of adsorbers, including spares
NSPARE	No. of spare adsorbers
PRCAR	Price of carbon, ¢/lb.
PRFUEL	Price of fuel ¢/mBTU
RHO	Density of carbon, $lb/ft.^3$
VOL	Total volume of one adsorber, $ft.^3$

CHAPTER 3

THE LOGISTICS OF MUNICIPAL RECYCLE ILLUSTRATED BY THE SAN ANTONIO SUPPLY IN THE YEAR 2000

THE FLOW PATTERN IN MUNICIPAL RECYCLE

Outline of the Recycle Pattern

Figure 17 is a schematic flow diagram showing the flow pattern in municipal water use and recycle. The portions boxed in heavy solid lines are the inputs and outputs from the municipal system. The portion boxed in heavy dashed lines is the advanced waste treatment appendage to the conventional system which permits recycle. The unblocked portions of the chart are the conventional system.

The inputs to the system are the source water and the contaminant increment which occurs on one pass through the municipality, the latter including both the organic, the inorganic and the organism additions to the water through use. The water passes through the distribution and use system picking up the contaminant increment and is collected in the waste collection system. From the distribution and use block there occurs a loss of water used in irrigation, lawn watering, street washing, etc., here termed "lawn loss." From the waste collection system there occurs a loss from seepage out of the pipes, termed "pipe loss." Actually there may and does occur infiltration into the waste collection system from ground water but this is not taken into account in the present study so that the pipe loss is actually the net of infiltration and pipe loss.

That portion of the waste which enters the collection system and does not appear in pipe loss is delivered to the conventional waste treatment plant where most of the organics and the organisms are removed or rendered harmless and only a negligible loss of the water itself occurs. The effluent from the waste treatment plant is discharged to a receiving water body or water course. Thus, the output from the municipal system is the lawn loss, pipe loss, and the disposal quantity. All of the input must appear as output with the exception of the organics which are oxidized into harmless gases in the conventional waste treatment. Thus the water content of the input must equal the water content of the output, and the contaminants both in the water source and in the municipal increment must equal the contaminants in lawn loss plus pipe loss plus discharge. These contaminants are primarily the minerals, which pass through the treatment system unchanged.

PROCESS ELEMENT SEQUENCE IN MUNICIPAL RECYCLE

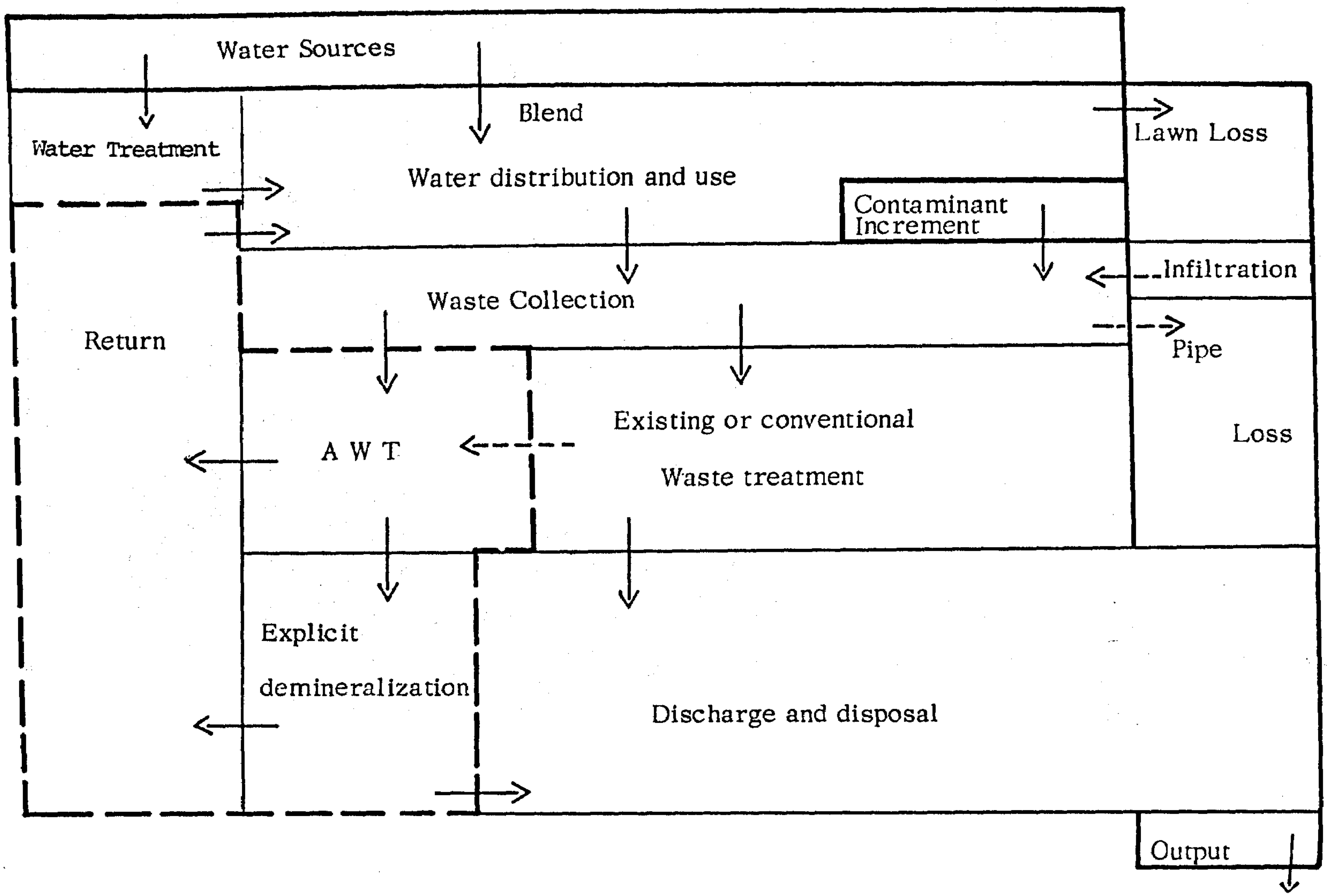


Figure 17

In municipal recycle three elements are appended which recycle some or all of the water to the distribution system. (1) One of these elements obviously is the return or "conveyance back," namely, the conveyance system used to return the water from the collection point to the use point. (2) The advanced waste treatment process has the purpose of further reducing the organic and organism content beyond that achieved in conventional waste treatment. (3) The AWT process may also achieve a demineralization incidental to the other processes going on in AWT. If this incidental demineralization is not adequate then there must be further appended an explicit demineralization process to remove the inorganic ions which have been added by use. Waste streams may be developed from the AWT process or the explicit demineralization process which would require disposal.

In a simple municipal process in which the water is taken from a stream upstream and the treated effluent is discharged downstream, the ultimate in pollution control is to so treat the waste that its level of contamination is no greater than that at the intake, thus leaving the stream to which the effluent is discharged no more contaminated than it was before use. It is obvious that if this ideal situation were reached the use would equally well be served by returning the purified discharge to the intake such that there would be no discharge to the stream. This recycle, completely closed with respect to water, is the ultimate goal of advanced waste treatment for reuse. In this scheme the output modes for the contamination which occurs in use are through the lawn loss, through the pipe loss, and by ultimate disposal of the wastes from the treatment processes as dry solids or gases.

The present study accepts the lawn loss and the pipe loss and attempts to develop process schemes by which the quantity of discharge may be appreciably reduced.

If it were reduced to zero, the quantity of water to be taken from the source, that is the quantity of makeup water, would be an amount to equal the lawn loss and the pipe loss. Actually it may be found that to carry the recycle to this extreme, that is to cut the discharge to zero, would be more expensive than to stop at some intermediate point. For example, the reduction of the discharge to solids and the disposal of the solids may prove much more expensive than the reduction of the discharge to a concentrated solution and the disposal of that, containing some water. The objective of the project is to provide means for determining in any specific case just where this optimum quantity of discharge lies, that is which quantity of discharge would produce the cheapest overall system and still meet the water and discharge quality constraints. And this does not exclude the possibility that that optimum point may be in some particular cases exactly where it is now, namely, to discharge all and recycle none.

Qualitatively the factors which move this optimum point towards zero discharge may be identified, a priori. They are:

1. A high cost of the water source.
2. A low cost of the recycle processes (the heavy dashed box on the chart).
3. A low cost for disposal (as distinct from discharge).
4. Extreme quality restrictions on discharge.

<u>The Central Role of Loss Ratio</u>

The input-output water balance for the system described is:

$$M = L + P + D$$

where

M = makeup water quantity, in ratio to water used

L = lawn loss quantity, in ratio to water used

P = pipe loss quantity, in ratio to water used

D = discharge or disposal quantity, in ratio to water used

A characteristic quantity termed "loss ratio" determines these input-output relations:

$$\text{Loss ratio} = (L + P)$$

The total loss, lawn plus pipe, is the difference between the water distributed and the sewage collected at the treatment plant. The contaminants enter with the makeup water and with the municipal increment. They leave in the lawn loss, the pipe loss and the discharge or disposal. In a conventional once-through municipal system all the water used in each pass appears as losses or discharge and disposal and thus all the contaminants entering in each pass leave the system in these three streams.

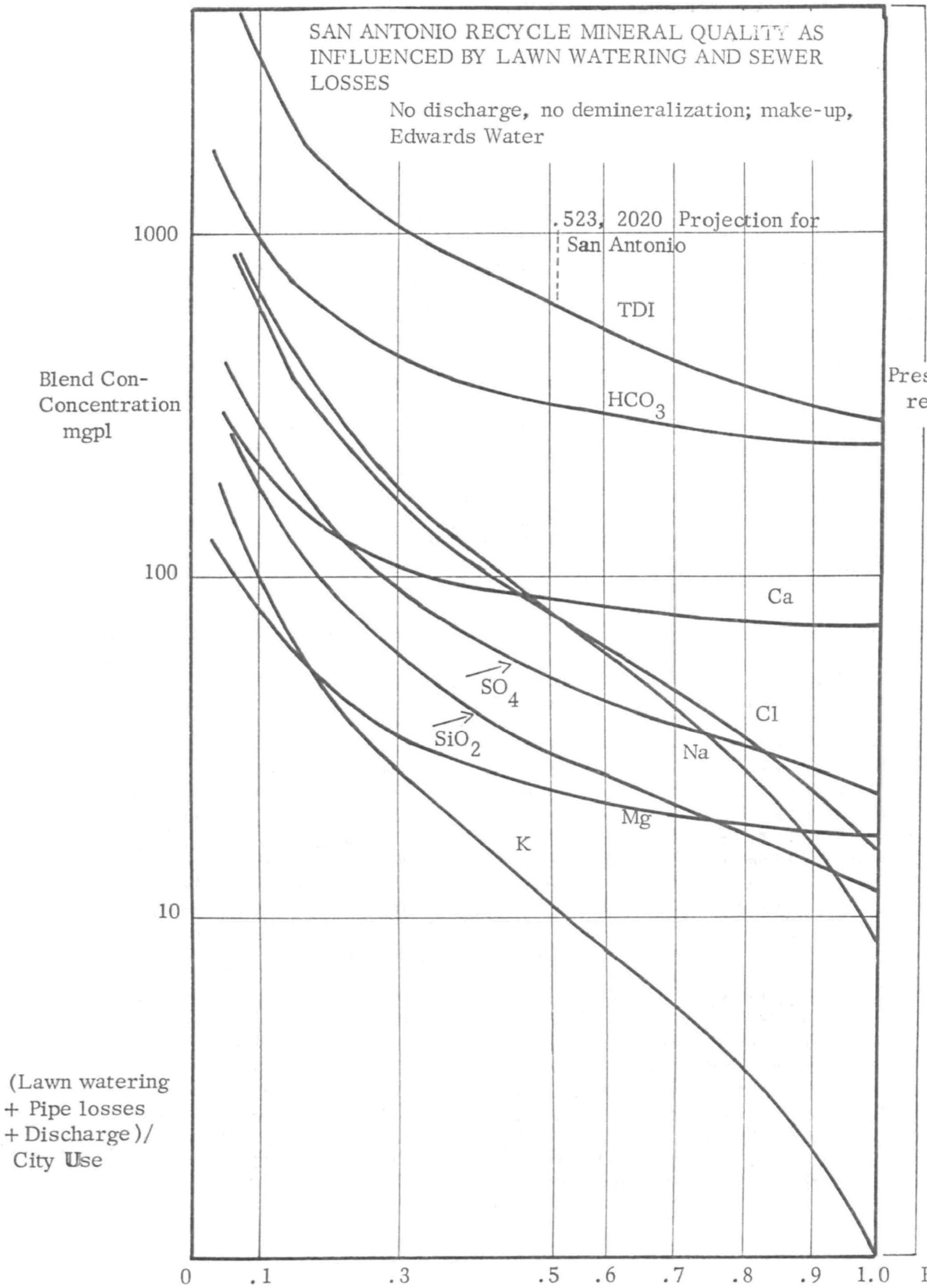
If now some of the discharge is returned for use, without demineralization, then the inorganic contaminants will build up in the recycling water until their concentration in the waste collected is high enough so that the water lost and discharged can now carry out the input contaminant. Thereafter the system will operate at this steady state concentration. If some of these concentrations of the inorganic ions are acceptable for use it is necessary either to increase the discharge quantity and thus the makeup quantity, or to take inorganic ions out of the water by demineralization and dispose of them presumably separately from discharging the water.

However, the same function, output of inorganic contaminants, is accomplished by the lawn loss and pipe loss. Therefore, to maintain the same steady state condition with the same input, a municipality with a high loss ratio will require less discharge than one with a low loss ratio. Stated in another way, this means that if the discharge is reduced to zero by recycling all of it without demineralization then the steady state contaminant level to which the system will build depends upon the loss ratio, the higher the loss ratio the lower the steady state concentrations.

Figure 18 shows a practical example of this being based on the actual input concentration and municipal increment assignable to some of the ions for San Antonio. The graph shows the concentration of these ions in the blend, that is in the water being used, when there is no discharge and no demineralization (and when the sewage treatment process does not alter the inorganic ion concentrations). Since the discharge is zero the abscissa represents the loss ratio.

It is seen that as the loss ratio is cut back the steady state concentrations in the blend increase but they do not increase very much until the loss ratios get below about 0.4. (The Texas Water Plan calls for a loss ratio of 0.523 for San Antonio for the year 2020.) If there were no demineralization and no discharge the total dissolved ions in the blend being used would rise to about 600 mgpl, the HCO_3 to about 310, the Ca to about 84, the SiO_2 to about 31. This would be the condition if the treatment consisted of conventional biological treatment. If the treatment comprised advanced waste treatment with lime the inorganic ions would be affected. The HCO_3, Ca, Mg and probably SiO_2 would be reduced. Depending upon the extent, this reduction could lower the total dissolved ions to a level even below the level in the makeup Edwards water, even without explicit demineralization.

It is possible that with a loss ratio of 0.523 the blend would be suitable for use, in the inorganic ions, without any demineralization other than that occurring in the lime treatment. On the other hand, for a loss ratio of 0.2 it is likely that demineralization would be required since the ions not removable by the lime treatment are built up to a high concentration. For example, Na and Cl are at the 300 mgpl level. Even removing the Ca and HCO_3 completely would still leave a TDI of about 800 mgpl which is not acceptable.



SAN ANTONIO RECYCLE MINERAL QUALITY AS INFLUENCED BY LAWN WATERING AND SEWER LOSSES
No discharge, no demineralization; make-up, Edwards Water
.523, 2020 Projection for San Antonio
TDI
HCO_3
Ca
SO_4
SiO_2
Cl
Na
Mg
K
1000
100
10
Blend Con-Concentration mgpl
Present, no recycle
(Lawn watering + Pipe losses + Discharge)/ City Use
0
.1
.3
.5
.6
.7
.8
.9
1.0

Figure 18

Actual Seasonal Loss Ratios at San Antonio

The 0.523 is a projected loss ratio for the year 2020. Actually the loss ratio can be expected to vary from month to month. A study was made using actual San Antonio data on total water withdrawn by all users in the sewageshed and total sewage collected by all known treatment plants, as described in the next chapter. The data for the years 1961 to 1965 are shown in Figure 19. It is seen that there is regular variation throughout the year with a high loss ratio maximum around 0.6 in the summer and a low loss ratio around 0.25 in the winter. The year-to-year pattern is rather consistent. The five year average loss ratio is about 0.38 meaning that on the average about 38% of the water withdrawn does not appear as sewage collected and therefore is not available for recycle.

Comparison of Figure 18 and Figure 19 leads to the rather unusual situation that on recycle the San Antonio water blend will be better in the summertime than it is in the winter, quite the reverse of typical conventional supply which with respect to mineral quality is usually better in the winter than in the summer. Demineralization would be required in the winter months and might not be required in the summer months.

The Seasonal Variation of the Municipal Increment

The municipal (concentration) increment as available from surveys and as used herein is the concentration difference between the sewage treatment plant effluent and the water being used, the difference being taken as the concentration increment attendant upon a single municipal pass. The data have been obtained by analyzing the waters in spot samples or as averages. The question to be explored is: 'does this municipal concentration increment have a seasonal variation corresponding with the seasonal variation of loss ratio?

To explore this let the symbols be:

B = mgd of water distributed, called BLEND
b = concentration of BLEND in some ion, ppm (parts per million)
L = mgd lawn loss, mgd
l = concentration, ppm

Similarly:

P and p = pipe loss
S and s = sewage delivered
I and i = municipal increment

WATER-SEWAGE LOSS RATIOS, SAN ANTONIO
Total water withdrawn, all users in sewage shed
Total sewage collected

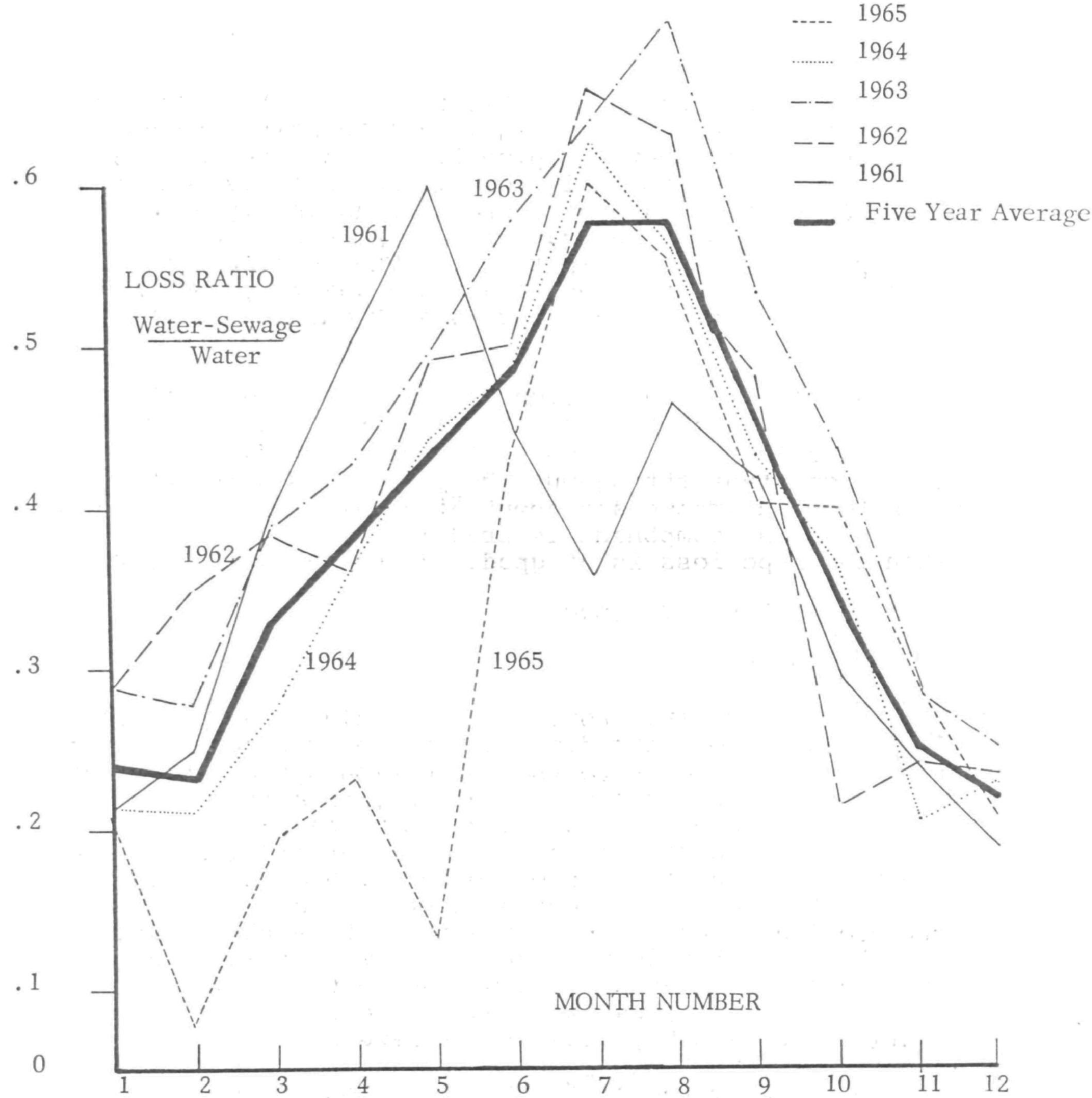


Figure 19

The symbol i represents the municipal concentration increment, ppm, determined as described. I, the liquid volume associated, is zero. The daily quantity of ion entering with the BLEND is Bb, of which the units are ppmmg (parts per million times million gallons) a weight of ion equal to 8.34 lbs.

A material balance will show that on the day the i was measured:

$$B - L = S + P$$

Total input of ion = Bb + (B - L)i, QI = (B - L)i = (S + P)i, where QI is the symbol for the municipal Quantity Increment, ppmmg. This assumes that the pipe loss is of the same concentration as the sewage delivered at the analysis point. (In conventional sewage treatment there is practically zero change in the inorganic ion concentrations other than sometimes phosphate and possibly ammonium-nitrate.) The question is: how do the concentration increment i and the quantity increment (B - L)i change with season, that is as B changes and L changes?

Figure 20 shows, as gpcd (gallon per capita per day) the quantities B and S for San Antonio developed from the data used in Figure 19. It is seen that the sewage flow is practically constant throughout the year. The lawn and pipe losses in the wintertime are about 35 gpcd. If it is assumed that the lawn loss component is practically zero in the wintertime then the pipe loss is 35 gpcd. (See Figure 28 beyond.)

$$(P + L) \text{ winter} = 35 \text{ gpcd}$$
$$L \text{ winter} = 0$$
$$P \text{ winter} = 35$$

Formally this water here provisionally assigned as pipe loss actually includes some irreducible minimum of water use which does not return the water to the collection system and which is not seasonal, such as street flushing, fire fighting, etc. However, this pipe loss cannot be greater than about 35 gpcd. In the peak months something of the order of 160 gpcd is used for lawn watering and similar purposes which do not return the water to the sewage collection system. San Antonio has very few combined sewers, and while it is true that a heavy rain will be reflected in an increased sewage flow, the monthly sewage flow does not follow the monthly rainfall pattern, thus let it be assumed that there is little actual infiltration...presumably because the sewers are well above the water table. That being the case, if the sewage flow is constant there is no reason for the pipe loss to vary with the season. Accordingly,

MONTHLY AVERAGE PER CAPITA WATER WITHDRAWAL AND SEWAGE DELIVERED - SAN ANTONIO 1961-65

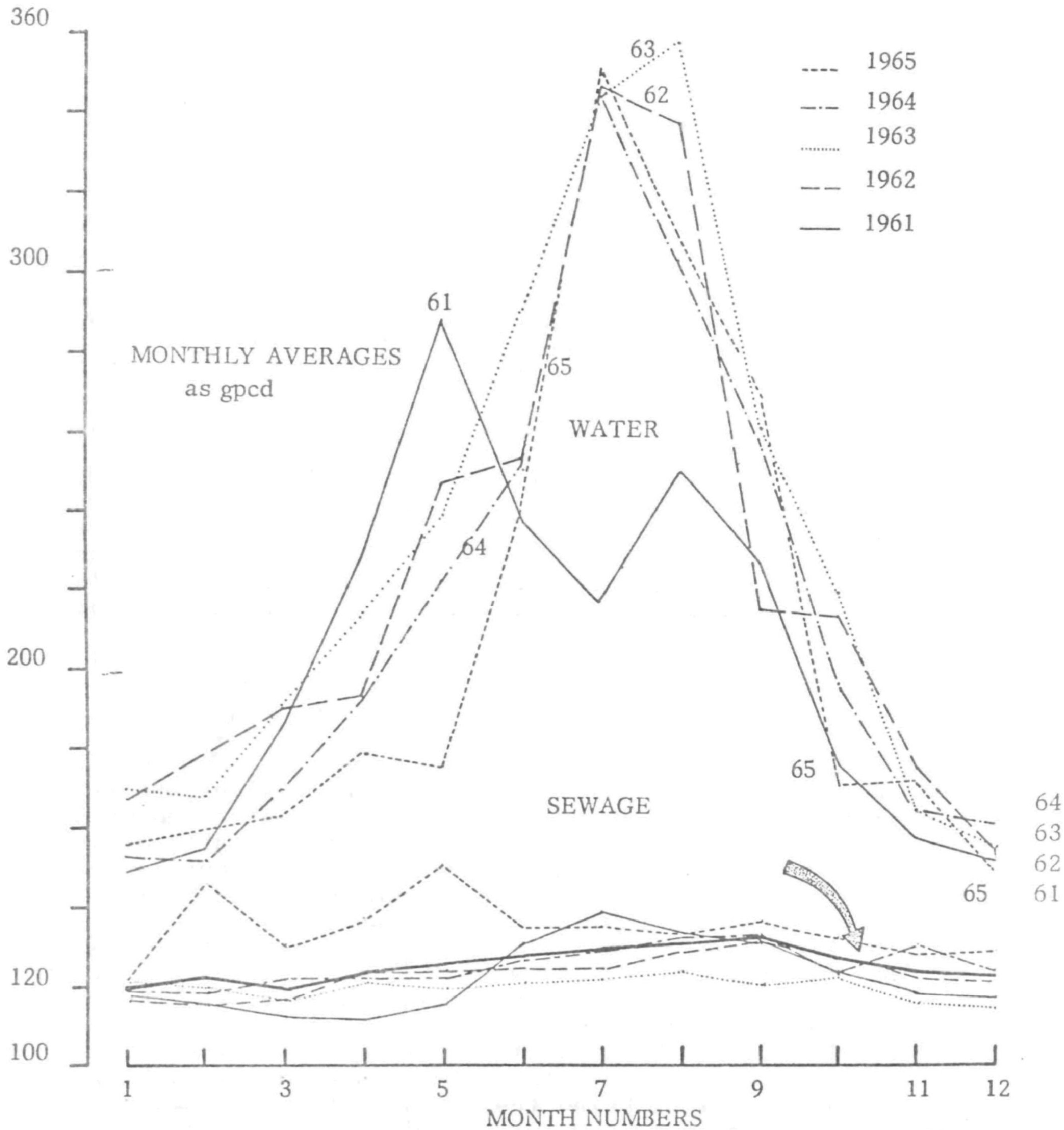


Figure 20

$P = \text{constant at 35 gpcd}$

Now since P is constant and S is constant

$$S + P = \text{constant} = B - L = \text{approximately 155 gpcd}$$

and incidentally P = approximately .295P = approximately .23 (S + P).

If (S + P) is constant then the quantity increment QI = (S + P)i must vary directly as i the concentration increment.

We do not know either how the quantity increment varies or how the concentration increment varies. However, it does seem logical that quantity increment, namely, the amount of ions put into the sanitary sewer system by the day-to-day activities of a municipality, should be constant and little affected by season, rainfall, etc. The well known and often used figure of .17 lbs BOD per capita per day, for example, implicitly bows to this concept. And if the quantity increment is constant then the concentration increment must be constant because (S + P) as just deduced is constant. However, this is only a deduction containing many assumptions and the seasonality of the municipal concentration and quantity increments must be checked in a number of communities before the general recycle problem can be attacked with confidence. For the present study it will be assumed that both the concentration increment and the quantity increment per capita are invariant.

Under recycle and reuse at steady state conditions all of this quantity increment must in some way be removed from the system. However, some of this removal is accomplished by the pipe loss and the lawn loss. In the conventional system the remainder is removed by discharge. In the recycle and reuse system this amount must be removed by the AWT process including, if necessary, explicit demineralization. The quantity involved termed net quantity increment is:

$$NQI = S(b + i) - Bb, \text{ ppmmgd}$$

In the recycle and reuse scheme the blend is no longer the source water as it is with the conventional scheme but comprises the blend of the source water with the return recycled water. The NQI equation shows that if the blend is to be maintained at the same concentration throughout the year, then S(b + i) being constant the net quantity increment decreases as the blend quantity increases. This means that the load on the explicit demineralization unit will be less in the summertime when B is high and greater in the wintertime when B is low. An illustration of this is given in the demineralization section of Chapter 6.

The Geographical Variation of Loss Ratio

The seasonal variation of loss ratio has been presented for San Antonio. However, it is highly likely that this seasonal pattern will vary with geography and climate as well as socio-economic factors which vary from city to city. We have already demonstrated that the seasonal pattern of loss ratio is a highly important factor in the engineering and the economics of recycle. Before general recycle computations nationwide can be made it will be necessary to develop such data for numerous cities.

The Detailed Recycle Scheme

Figure 21 is a more detailed flow diagram for municipal recycle with special regard to mineral quality. The capital letter designations are quantities in mgd per mgd of water supplied to the distribution system, i.e. of blend. (Note the difference from the symbols as used on the immediately preceding pages.) The lower case letters are the concentrations of an individual ion in each stream.

The SOURCE includes the present source and its conveyance line and the existing conventional water treatment, if any. In addition, a supplemental source is provided. These are combined as makeup water which is the input water.

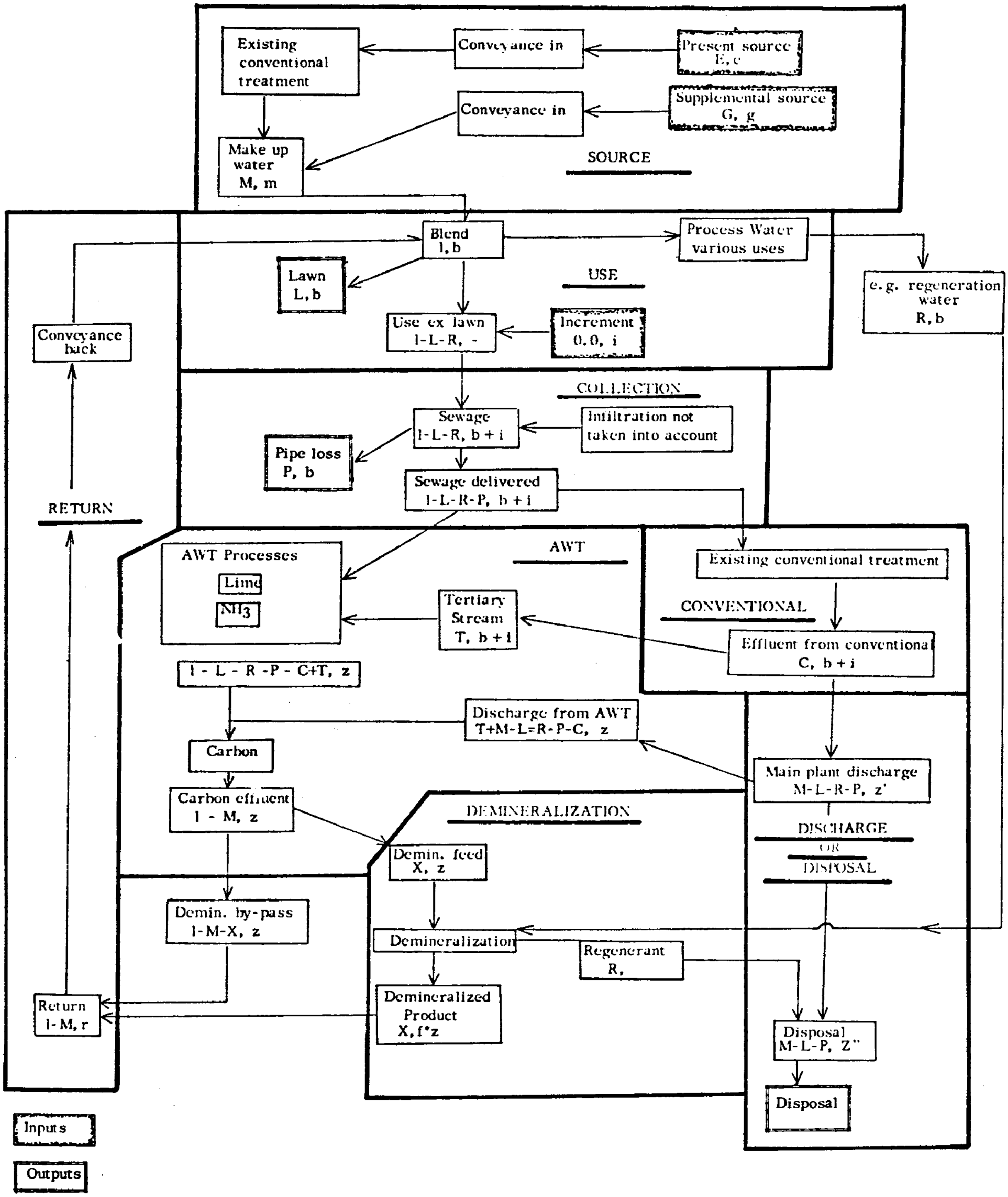
In the USE step the makeup water is blended with the return water to make the blend, the water supplied to the distribution system. A small amount of blend is used in the various subsequent processes. Shown on the chart is a use for regeneration water for ion exchange demineralization. The lawn loss output comes out of the blend. The remainder is the water to which the municipal increment is applied to produce sewage.

In COLLECTION the sewage is transported through the collection system with an attendant pipe loss, the net of infiltration and true pipe loss.

For CONVENTIONAL systems the sewage is delivered to an existing conventional treatment plant which produces "secondary effluent" which is discharged.

In the AWT recycle scheme the sewage is delivered to the AWT process where under the scheme of this study it is treated with lime to reduce the organics, Ca, HCO_3, Mg, and PO_4; then treated to remove the NH_3 and finally passed through activated carbon treatment to remove the last traces of organics. It is also provided that the effluent from conventional secondary treatment may be treated in a tertiary stream, the same processes for tertiary treatment being required as are here shown for direct AWT. The discharge from AWT is discussed later.

FLOW DIAGRAM MUNICIPAL RECYCLE
(with special regard to mineral quality)



M, L, etc = quantities, e.g. mgd, of each stream.

m, b, etc. = concentrations, e.g. mcl, of jth ion in each stream.

f = leakage in demineralization

Figure 21

If DEMINERALIZATION is required the carbon effluent is treated by some demineralization process here shown as an ion exchange process, producing a demineralized product. The product from several of the possible demineralization processes would be more pure than required for recycle and therefore, it is possible to by-pass some of the carbon effluent around the demineralization process.

The by-pass and the demineralized product are mixed as the RETURN liquor which is conveyed back to the distribution system.

The ultimate goal of recycle is to achieve zero discharge. If in the flow chart shown the AWT and demineralization processes could accomplish the necessary purification then the conventional treatment line could be eliminated and the only disposal would be of the demineralization waste water. However, some demineralization processes are not capable of removing all ionic contaminants. Those that are removed are output from the system in the regeneration water but those that are not removed must be output by a purge of the recycling liquor before the concentration of the particular ion reaches unacceptable levels. In an AWT system not incorporating a conventional waste treatment plant it would be inefficient to discharge the carbon effluent since probably for discharge or disposal it is not necessary to remove the last traces of organics. Accordingly, it is likely that the discharge from the AWT process would be made prior to the carbon treatment. If, however, the system contains a conventional treatment plant, for which the capital costs are already sunk, it would probably be more economic to operate the existing conventional plant in order to achieve an effluent suitable for discharge which could serve as the purge for the ions suffering excessive build up.

There are numerous possibilities not shown on the chart. For example, it might occur that the effluent from the conventional treatment plant was discharged to a stream while the regeneration water from demineralization and other process waters from the AWT processes, if any, are handled by ultimate disposal in some manner.

Also, of course, ultimately this project should seek to provide for situations in which the split of the delivered sewage between the existing and the AWT processes is not a matter of choice but is forced by some physical configuration. For example, it might be uneconomic to convey into an AWT sewage shed the flow now going to an existing conventional treatment plant.

PRELIMINARY LOGISTICS OF THE SAN ANTONIO SUPPLY IN THE YEAR 2000

This section develops data for San Antonio and uses these to determine the flow pattern in the year 2000 for two extreme situations: (1) conventional supply, treatment and discharge with no demineralization, and (2) complete recycle and reuse via advanced waste treatment with no discharge (and no demineralization). The costs of these two extremes are developed in Chapter 6.

Area Population Projection

The preliminary 1970 Census places the population of the San Antonio District as 684,322 on April 1, 1970. The district includes the City of San Antonio and its surrounding communities and military bases, thus approximating the population served by the water and sewage system corresponding to the 1961 to 1965 water and sewage data described in the previous chapter.

The actual 1960 to 1970 growth for the San Antonio District falls considerably short of the growth projected by the Texas Water Plan for the major cities of the county. However, it is assumed in this study that in the year 2000 the system under consideration will be serving the entire population of Bexar County. The Texas Water Plan projections for the 1960 to 1970 growth of the County were closer to the actual experienced growth. The experienced growth to the 1970 Census population of 830,661 was about 20% from the 1960 population and a projection at 20% per decade yields 1.44 million population for the County in the year 2000 which is satisfactorily close to the Texas Water Plan projection for that year of 1.42 million. The 2000 projection of the Texas Water Plan for the major cities of the County is 1.33.

Historical Water Withdrawal and Sewage Delivered

To obtain the seasonal gpcd figures mentioned in the previous chapter and used in this chapter the following procedure was used. The U.S. Geological Survey San Antonio office collects annual data on the pumpage from the aquifer for Bexar County and other surrounding counties broken down in detail by the actual withdrawal agency of which the major one, of course, is the San Antonio City Water Board. The breakdown includes the some 25 other independent public supplies, the military bases, the City parks and zoo, industry broken down by individual establishments, private commercial use, air conditioning, etc., private schools, country clubs, etc., flowing wells, springs, domestic stock and country estates, and irrigation. For the years 1956 to 1965 this tabulation is available by months. From this total pumpage from the aquifer, which represents the sole water supply, there are subtracted the flowing wells, the springs, the irrigation, and the domestic and stock; the remainder taken to represent the water withdrawn which is potentially contributory to the sewer system.

Annual and monthly figures for sewage delivered are available for the Rilling Road and Leon Creek sewage treatment plants. For the seasonal studies of the previous chapter the annual sewage delivered at the smaller sewage treatment plants in the area was estimated by the procedure described beyond under long term sewage trend. The total sewage delivered each month was estimated by applying to the sum of the Rilling Road and Leon Creek plant flows the annual factors, ranging from 1.041 to 1.050, determined in the long term study.

The flow of the San Antonio River at the Elmendorf Street gauge is available from October 1962. The flow for previous months was estimated by a correlation between the Elmendorf flow and the Falls City station flow for the period October 1962 to September 1966. The relation is:

Elmendorf = .934997*Falls City**(1.0146)

The correlation coefficient is .98220; the σ ratio 1.103. This relation is not used in the present project because the project does not go so far as to consider the possibility of using the future Elmendorf net flow for water supply.

The population at each month in the 1961 to 1965 period was computed by assuming a uniform logarithmic increase between the San Antonio District populations of 618,944 in 1960 and 684,322 in 1970, a monthly increase of 0.083713%.

The monthly data so developed have been used in the previous section (Figures 19 and 20) illustrating the pattern and are used beyond in setting the logistics of the 2000 supply (Figure 28).

In an effort to obtain some correlation which might allow predictions, some manipulations of the five year data were made. "Reducing" the loss ratios by dividing each by the average of the monthly loss ratios for the year does not effect much of a compression of the band such as observed in Figure 19.

While there is a downward trend as expected, the monthly loss ratios are not correlated simply with the monthly rainfall... in other words, very little of the variance in the 60 monthly loss ratios is removed by plotting against monthly rainfall.

The 60 loss ratios do show a correlation in the expected direction with average monthly temperature, increasing as the average monthly temperature increases from about 45 to 87^{o} F (degrees Fahrenheit). An appropriate form for the relation is a second degree polynominal. However, it is noted, as would be expected, that with approximately equal monthly temperatures the months having high rainfalls tend to have lower loss ratios. Accordingly, a better predictive equation is obtained from a multivariate regression yielding a relation:

$$Z = .703396 - .0192044T + .00214679T^2 - .0267191R$$

where

Z = calculated monthly loss ratio
T = average monthly temperature, ^{o}F
R = monthly rainfall, inches (airport)
N = 60, standard deviation = .0573, correlation coefficient = .852

About 72% of the original variance is removed by this multivariate correlation. Analysis of the residuals shows that compared to the true loss ratio the quantity Z tends to be low in the spring and high in the fall, varying sinusoidally with month throughout the year. Observationally, this means that for months having equal temperatures and equal rainfalls a calculated loss ratio tends to be lower than the observed if it is a spring month and higher if it is a fall month, and to be about equal if in the winter or at midsummer. This residual variance would be reduced if a sine term is included in the multiple regression.

Of course, it is a misnomer to call this a predictive equation since in order to use it it is necessary to know a future average monthly temperature and a future monthly rainfall. However, the analysis was made in order to be prepared for comparisons with similar data in other cities. When such a study is made it will draw on the more sophisticated studies of municipal use relations which are being made by other investigators (26,27,28,29). For example, Reference 26 provides a correlation for lawn irrigation which includes such variables as average irrigable area per dwelling unit, mean monthly temperature, monthly percent of daylight hours, effective rainfall, and an empirical monthly crop coefficient for grass.

The USGS San Antonio office has been recording, estimating, and summarizing the water withdrawal by category in Bexar and surrounding counties, published information going back to 1934. The summary sheets for these publications were located and they were brought up to 1968 from recent annual reports. The uses categorized are:

- Municipal (subtotal of 4)
- Industry (subtotal of 2)
- Country clubs, private schools, etc.
- Domestic and stock, estates, misc.
- Irrigation
- Salado Creek and other flowing wells
- San Antonio and San Pedro Springs

The four categories in the left column are those considered to measure the future water use of Bexar County. The City of Schertz is included in the municipal supply but its population is not in Bexar County. Over the years 1956 to 1968, the withdrawal for Schertz was about .25% of the total withdrawal. The County withdrawals were corrected for Schertz by subtracting Schertz in the years available and applying the ratio .9975 in other years.

To obtain the corresponding population of Bexar County leading toward a gpcd figure the Census population at each decade was interpolated between at a constant annual percentage increase. These annual increases incidentally are: 1930-1940 1.46%; 1940-1950 4.00%; 1950-1960 3.22%; 1960-1970 1.91%.

The resulting gpcd figures are shown in Figure 22. It is seen that there is no strong long term trend toward either an increase or decrease in the gpcd use. It might be considered that the trend was rising during 1935 to 1956, but with the breaking of the drought in 1957 the gpcd usage fell to the level it bore 20 years prior, and in the subsequent 10 years has hovered around 200 mgd. The 35 year average is 214.1 gpcd. Exploration for the significance of the trend taken as a Cartesian regression line indicated a slope of about 0.42 gpcd/year, and not significantly different from a slope of zero, at about a 50% level of significance.

Even if the trend should be significant the regression shows a gpcd of 207 in 1934, 220 in 1964, and 235 in 2000. Table 19 beyond, indicates that the annual average gpcd corresponding to the seasonal pattern base taken for design in 2000 is 236 gpcd.

This 35 year trend, incidentally, while small, is even larger than the long term trend for large U.S. cities in general. The hundred-year average trend for some three-score large U.S. cities is about .30 gpcd/year. That per capita municipal use is rapidly increasing is a popular misconception - if applied to even moderate sized cities.

BEXAR COUNTY ANNUAL WATER USE
ex IRRIGATION

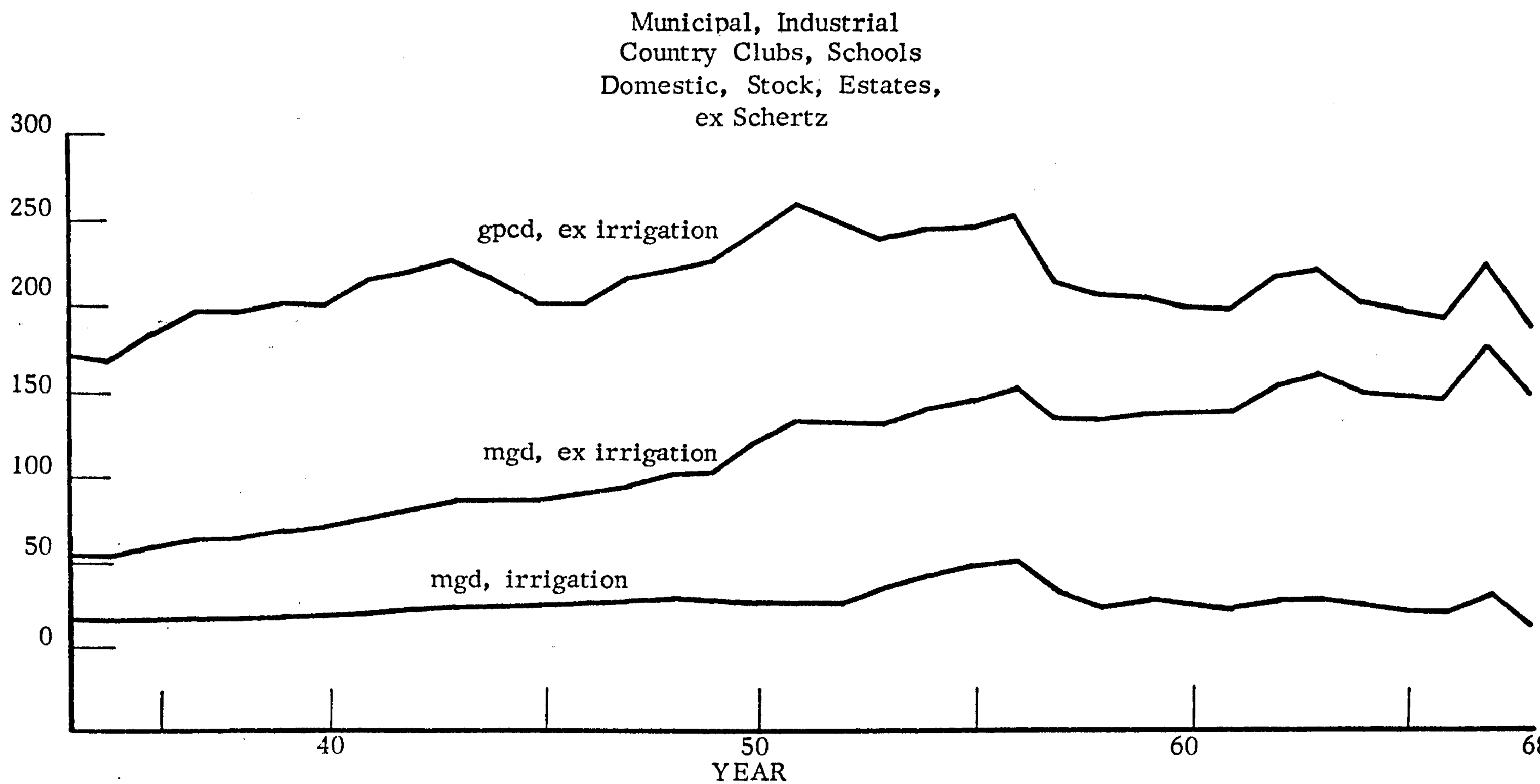


Figure 22

Not so easily resolved is the long term gpcd trend for sewage. In 1969, there were about 14 sewer collection systems and small treatment plants in addition to the two City plants, Rilling and Leon Creek. Also, there are eight incorporated communities for which Census data are available and one overall "District" which includes these, the City of San Antonio, and some contiguous urbanized territory, all within the sewageshed. The Kelly Air Force Base collection system and treatment plant has been operating since before 1940. The other small treatment plants and collection systems came into being starting about 1956 and most of them were installed by 1963. Some of the separate Census entities have been served by the City sewer system since 1940, others have varying inception dates of sewer service, up to as late as 1966.

Data on starting dates for service to the various communities were obtained from San Antonio City Hall (Finance Department) together with some data on connections. Data on current production rates of the various treatment plants were obtained from TWQB (Texas Water Quality Board), except the historical record for Rilling, Leon Creek and Kelly AFB (Air Force Base). Data on the starting date of these treatment plants were obtained from the operating agencies, Water Control and Improvement Districts, etc. together with information on the generalized growth pattern of each. Sewage flows between the starting date and 1969 were then estimated in accordance with the growth pattern. For Rilling and Leon Creek the complete records were available. For Kelly AFB records were available back to 1955. Data on the Kelly performance 1940 to 1955 were obtained from the retired foreman of the plant. Populations in the intercensal years were interpolated from the Census data for the various civil divisions on a constant logarithmic increase characteristic of each decade. For other than census divisions population figures were estimated from connections. When all known surrounding communities are added to the San Antonio census population, a figure is obtained which is less than that given for the "San Antonio District." The difference was assigned to a population entity termed "missing from District" and the population for intercensal years interpolated as for an actual census division. The "missing from District" includes unincorporated areas not in the City limits but closely associated with it. The "San Antonio District" is a term generated by the local census operation, has a population somewhat less than the San Antonio urbanized area, and the population "missing from District" is about 1% of the total population served.

The total flow generated by the 17 treatment plants was divided by the total population served in the 13 population entities to generate the gpcd sewage flow. The resulting data are shown in Figure 23, the gpcd water use, the gpcd sewage collected and the difference, that is the loss between water and sewage. While the water use shows no trend except for the peak in the drought period ending 1956, the sewage data reveal an upward trend.

It is believed that part of the long term upward trend in sewage arises from a deficiency in the data, namely, that in the period before 1956 not all of the City population was served by sewers and, therefore, the denominator being too large the gpcd becomes too small. This hypothesis is confirmed by an analysis of the loss ratio (water minus sewage in ratio to water) as a function of annual rainfall shown on Figure 24. There is not much discernible trend with rainfall. If there is a trend it would appear to be in the proper direction that is toward lower loss ratios at higher rainfall. However, the important point is that the data fall in two groups, 1957 to 1968, and prior to 1957. The latter loss ratios fall in a group significantly higher than the former. This is the condition that would result if the sewage gpcd's were too low in the period prior to 1957. To resolve this question would require a detailed study of the population in the various tracts served by sewers in each year as the City expanded its sewer system.

Figure 25 shows the time trend of the loss ratio from which it is apparent even ignoring the pre-1957 data that the loss ratio is in a downward trend, resulting from an increasing sewage flow in the face of a constant water use. The increasing sewage flow might have been attributed to an erroneous inclusion of the numerous small systems which have sprung up since about 1957. However, even if this had been the case the effect of these on total sewage flow has been indeed quite minor. The ratio of total sewage flow to the flow from the City's two treatment plants was about 1.04 around 1957 and has gradually risen to about 1.07 and this 3% difference is not nearly enough to bring the loss ratio from around .4 to around .2.

Without further study this project cannot arrive at a prediction for the future sewage flow and loss ratio. The design arrived at in the subsequent section "Logistics of the 2000 Supply" takes the upper envelopes of the 1961 to 1965 period as the total use and makeup quantities and assumes no change from 1961-65.

LONG TERM WATER AND SEWAGE RELATIONS
SAN ANTONIO

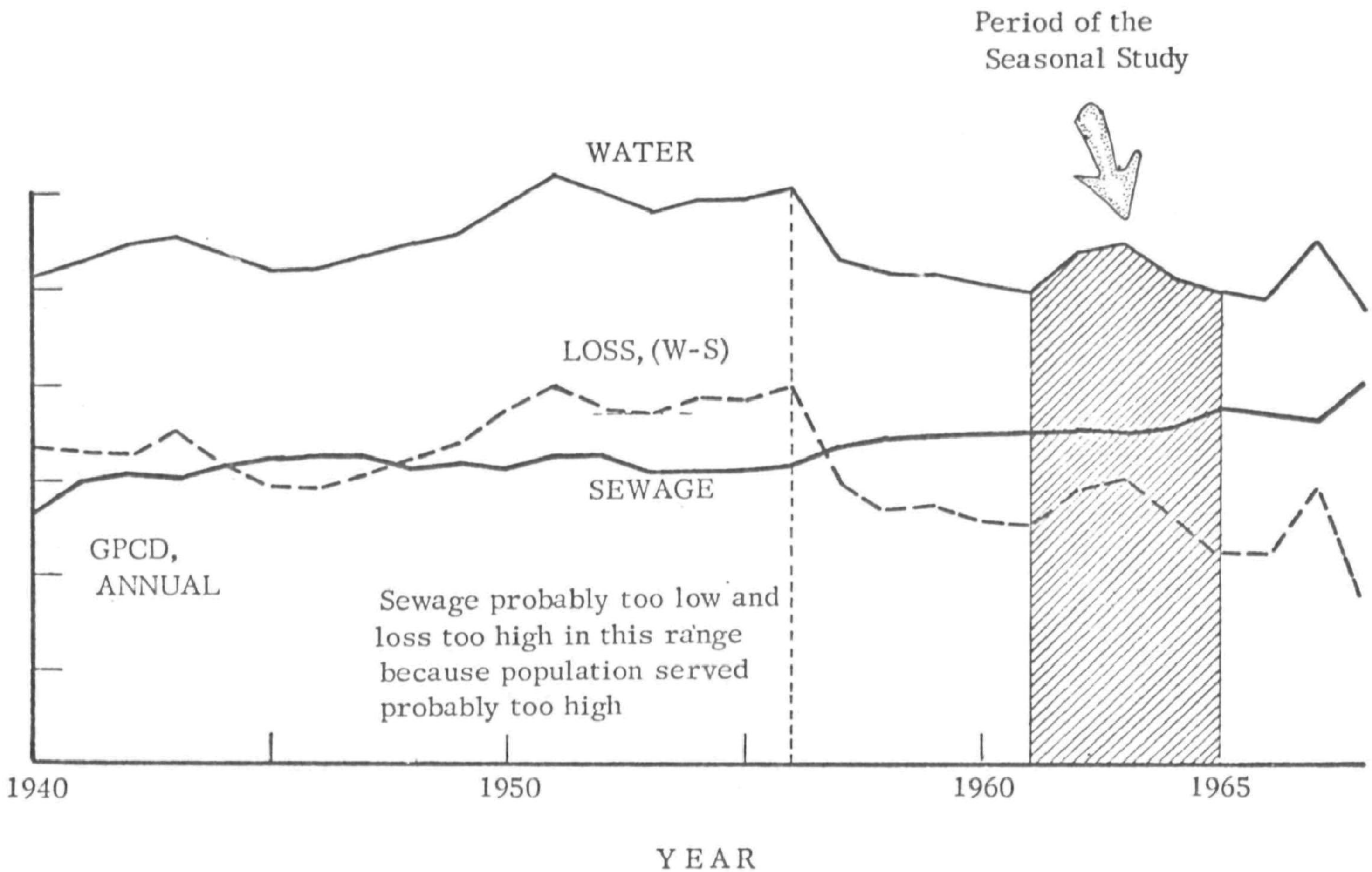


Figure 23

ANNUAL RAINFALL vs. LOSS RATIO

RELATIONS, SAN ANTONIO

(Showing two distinct time groupings)

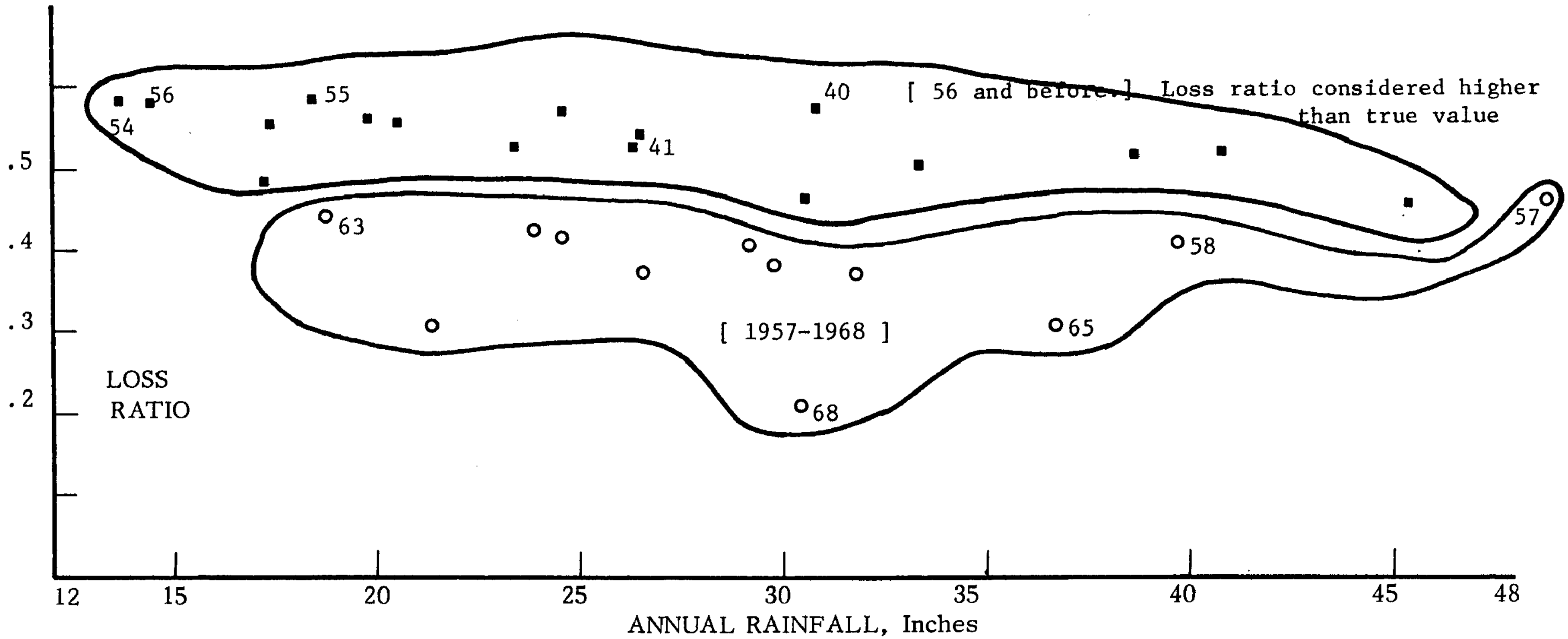


Figure 24

LONG TERM ANNUAL LOSS RATIO

SAN ANTONIO

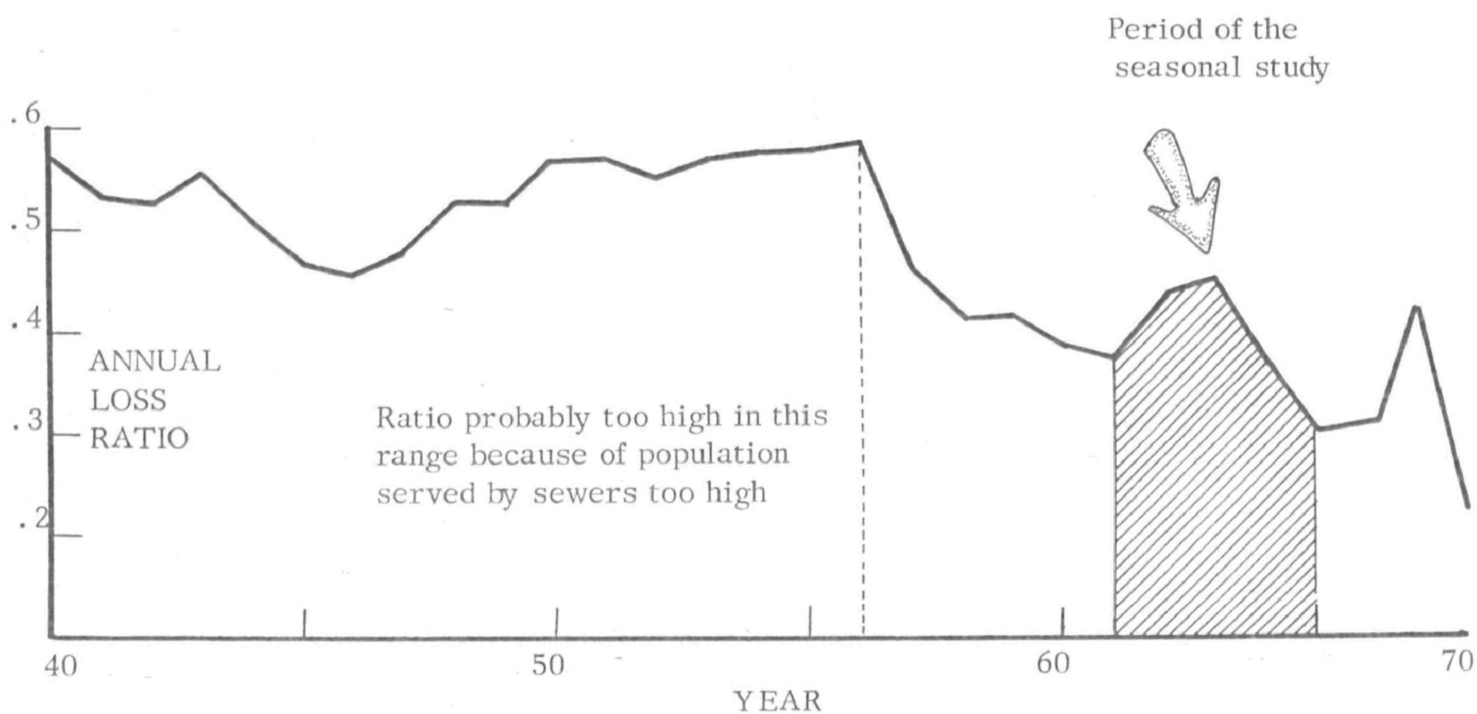


Figure 25

In San Antonio the maximum day in each year occurs in the maximum month or in an adjacent month. Data are conveniently available 1953 to 1969. To eliminate the variability of population served and total annual water use there was computed the ratio of the maximum day to the maximum month, both expressed in mgd terms. Plotted, these ratios showed a cyclic pattern with no time trend. The 17 ratios are log-normally distributed with a mean of 1.21 and a σ ratio of 1.06 (68% of the points lie within about 6% of the mean). The population 90 percentile is 1.30. This means that there is only a 10% chance that the ratio in any single year might be greater than 1.30. The population 10% is 1.12.

It is concluded that once the maximum month has been established in the planning, the maximum day can be established as 30% higher.

Similarly the annual reports and other data from the City of San Antonio sewage treatment plants, available 1950 to 1968 can be used to assess the maximum day/maximum month ratio for sewage collected. Plotted, the data show no time trend. The 20 points are log-normally distributed with a mean of 1.46 and a σ ratio of 1.20, signifying that about 68% of the points lie within about 20% of the mean. The population 90% for the ratio is 1.85. It is concluded that there is only a 10% chance that this ratio in any year may be above 1.85. Accordingly, this factor can be used to compute the maximum design day from the maximum month. The sewage maximum day is higher and has a greater variance than the water maximum day, presumably because of the great influence of rainfall on sewage flow.

In a more thorough study than is possible here it would be desired to study not only the maximum day for water and for sewage, but also the maximum day for the difference between them and, indeed, the whole statistics of this net difference. For in a reuse scheme, unless storage is resorted to, only that much waste water can be recovered on each day as the community uses water on that day. Any daily excess of sewage collected over water used must be discharged, and any daily excess of water used over sewage collected must be made up by makeup water. This aspect must be left for further detailed investigation.

Existing Facilities

The peak day capability of the three existing or planned San Antonio conventional sewage treatment plants, the Rilling, the Leon Creek and the Salado are Rilling 80, Leon Creek 12, and Salado (under construction) 24, for a combined peak day capability of 116 mgd. These figures are based on detention times in the aeration basins sufficient to provide an effluent meeting the present specifications (30). The average production from these plants as operated at present is greater than they will be able to supply under the seasonal use pattern later to be developed for this study.

The City Water Board's production facilities (31) comprise eight primary stations having 34 wells and 26 smaller secondary stations having 26 wells, the installed capability of the well pumps being respectively 285.3 and 94.3 mgd. Dropping out the largest well at each primary station would reduce the capability by 81.8 mgd. Thus the ratio of installed capability to firm capability at the eight primary stations is 1.4, firm capability being defined as the highest daily production that could be obtained with the largest unit out of service. In the computations it will be assumed that this ratio of installed capability to firm capability will apply to the entire ground water facility system in 2000.

In addition to the City Water Board production the other municipal supplies produce an additional 20% or more. The average of the ratios of the total water production from all municipal supplies to that from the City Water Board over the four years 1965 to 1968 was 1.229. Assuming that the installed capability follows the same ratio as the production, the estimated installed capability of all existing municipal wells would be 466 mgd, and by application of the 1.4 factor the estimated firm capability of all existing municipal wells 333 mgd.

The Municipal Increment for San Antonio

Table 17 shows the assignment of the San Antonio municipal increment either from the San Antonio data or where this was not available taken from the average for western cities. In the former case, the western cities average is shown also for comparision with the apparent San Antonio increment. The average increment for the western cities comes from one to 22 cities from Reference 32.

TABLE 17

MUNICIPAL INCREMENT, SAN ANTONIO AND WESTERN CITIES AVERAGE

	Apparent Increment S.A.	Western Cities Average
MAJOR IONS		
Na		74
K		11
NH_4		18
Ca	15	13
Mg	0	7
Fe(2)	.4	.2
Cl	67	92
HCO_3		81
NO_3		7
NO_2		2
F	-	-
SO_4		29
CO_3		-1
SiO_3		17
PO_4, total	(raw)20	28
PO_4, ortho		25
MISCELLANEOUS		
Total alkalinity		66
Conductance	-	-
Residue		352
Temperature	0	
pH	.0	-.4
Hardness	43	58
MINOR ELEMENTS		
Al	.8	
Ba	< .4	
B	.3	
Mn	< .1	
Sr	-	
Cr	< .2	
Pb	< .8	
Mo	< .2	
Co	< .2	
Ni	< .2	
Cu	.3	
Sn	< .2	
Zn	< .5	
Ag	< .2	
Li	-	
ORGANIC		
BOD		23
COD		(96)

The study took the analytical data for the water supply and the sewage treatment effluent for a number of cities, up to as many as 33 for some contaminants, and developed the range and averages for the concentration increment for eastern cities, western cities, and for both together. The San Antonio data came from analytical data on the composite water 1/1/64 (31), and from the average of six well stations 2/8/62 (33). The minor elements analysis came from spectrographic analysis from one of the stations. The waste water analyses which were for sewage treatment plant effluent except as noted came from analysis of the effluent of the West plant in the Rilling Road complex made on composites between 5/28 and 6/9/68, the minor elements again by spectrographic analysis.

Also included were some spot analyses of raw sewage on the north side of the sewageshed 1968 (34). Also used were some data from the Rilling complex July and August 1966 showing the hardness and incidentally demonstrating that hardness does not change on passage through the treatment plant. The figure for total phosphate is one of those obtained from the raw sewage and this is somewhat important since San Antonio plants effect a reduction in phosphate. Some of the other analyses also were from raw sewage but this is not important since there is no change in those ions on passage through the sewage treatment.

This Table should not be taken as anything more than a very sketchy approximation to the real situation in San Antonio. In the first place as has previously been indicated, we are not sure that the municipal concentration increment does not fluctuate according to season, but the analyses are based on spot samples or short time composites. Secondly, as Reference 32 shows, the ranges from city to city for each contaminant are considerable. About an eightfold range is typical for the western cities.

It is also clear that these increments, coming from averages and spot analyses, will not be in ionic balance. This is not of particular importance except for explicit demineralization processes. When used for such purposes the water composition must be adjusted for ionic balance.

If these data are used for the design of a recycle system, it should be recognized that the result would be only illustrative. How far such a design would be from reality in equipment sizes, in performance, and in dollars is completely unknown and a real design would have to await much more extensive data for the individual city.

The General Pattern of Compositional Changes on Recycle

Figure 18 has shown how the composition of the blend water for San Antonio would depend upon the loss ratio with no discharge and no demineralization if there were no compositional changes in the waste treatment process. The monthly loss ratios having been developed as in Table 19 beyond it is possible to show how the average monthly composition of the blend would change from month to month.

Since the Program AWTLCC (Chapter 2) provides the composition of the AWT effluent for any given feed composition it would be possible also to incorporate the effects of the compositional changes which occur in the AWT process. The equilibrium composition of the blend must be obtained by iteration, as in a recycling flow sheet. When the complete RECYCLE program is established this will be done. Meanwhile the compositional effects of the AWT process were approximated from AWT runs already made and this surrogate AWT process was used in a small program (WGMONSA) to compute the blend composition for San Antonio.

The values used in the composition study are shown in Table 18, the first column being the composition of the source water, i.e. of the present San Antonio supply, the second column being the municipal increment as previously established; and the third and fourth column pertaining to the AWT process itself. In the third column is given the effluent concentration for those contaminants for which that value is set by the assumptions, for example, 0.5 mgpl for NH_3-N. In the fourth column are given the changes in concentration for those contaminants not so set. These are the changes actually observed and generated by the AWT program operating on San Antonio waste as described in Chapter 2.

Figure 26 shows the concentrations of some of the contaminants as a function of the loss ratio. Comparison with Figure 18 reveals the significant differences attendant upon the compositional changes in AWT. Na and Cl are higher because NaCl is used as a reagent in AWT and contaminates the product water. Ca is unaffected by loss ratio because it happens that the increment taken is almost exactly the same as the fixed concentration taken for the concentration in the AWT effluent and accordingly, the loss of Ca is almost precisely equal to the increment of Ca at a blend level close to the source water level. The behavior of Mg and HCO_3 is quite different from that in Figure 18 because large removals of these contaminants occur in AWT. Indeed, contrary to the general trend the lower the loss ratio the lower the concentration of these two contaminants in the blend. The overall effect of the AWT compositional changes is to lower the TDI over that of Figure 18.

TABLE 18

VALUES USED IN COMPOSITION STUDY WQMONSA

	Source Water	Municipal Increment	AWT Effluent Conc.*	AWT Effluent Δ Conc.
Na	7.8	74.		-6.12
K	1.0	11.		0.
NH_4	0.	18.	0.5	
Ca	64.	15.	64.02	
Mg	17.	0.	1.25	
Cl	15.	67.		-17.44
F	0.3	0.		0.
NO_2	0.	2.		0.
NO_3	4.5	7.		0.
HCO_3	241.	81.	69.09	
CO_3	0.	0.		0.
SO_4	23.	29.		0.
SiO_3	15.2	17.		0.
PO_4	0.	20.	0.9	
COD	0.	492.	8.	
VSS	0.	162.3	0.7	
NVSS	0.	56.7	0.3	
TDI	48.2(2)	341		(1)

(1) Summed by the Program
(2) Unlisted ions to bring total ions to 437
* Concentration

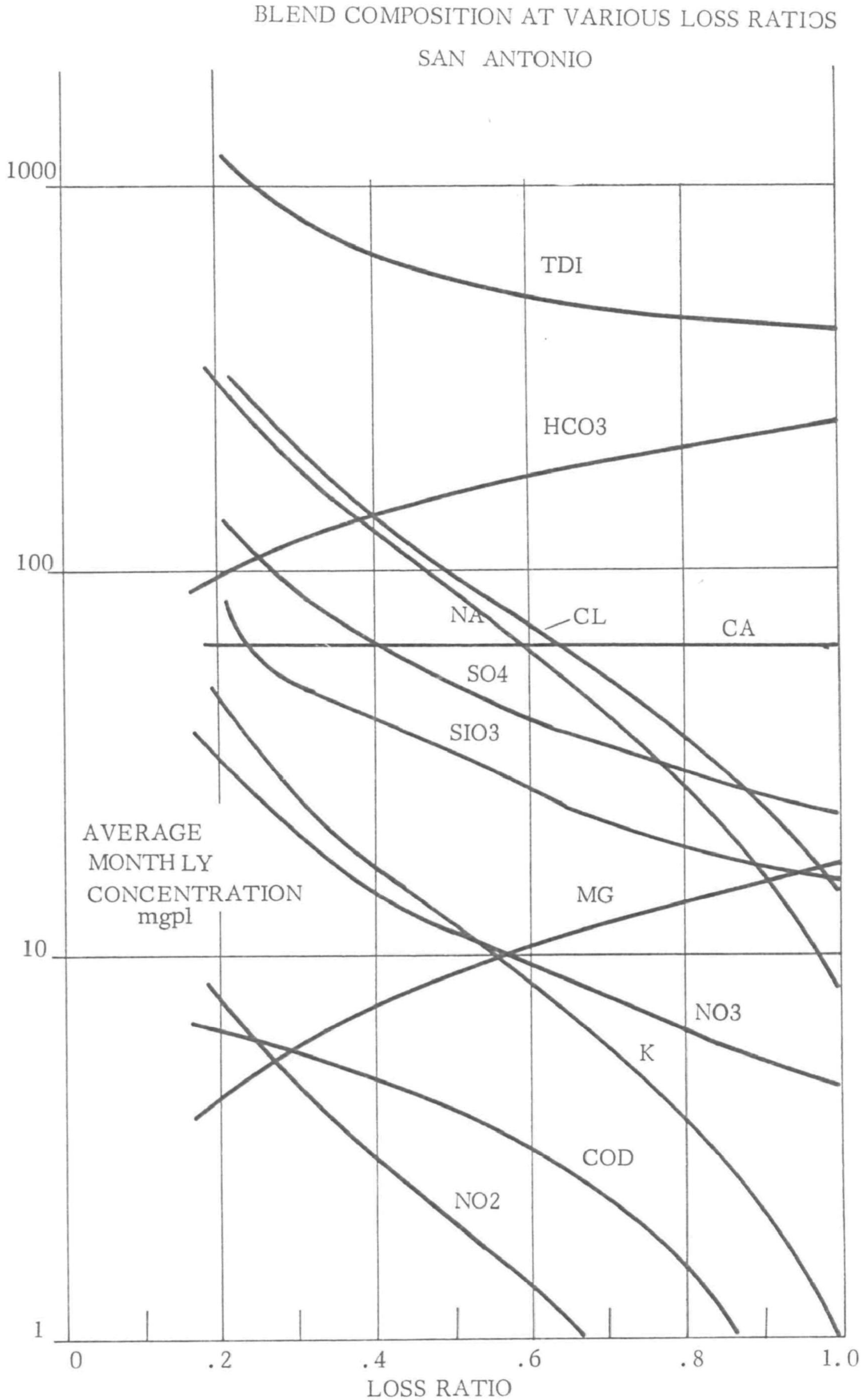
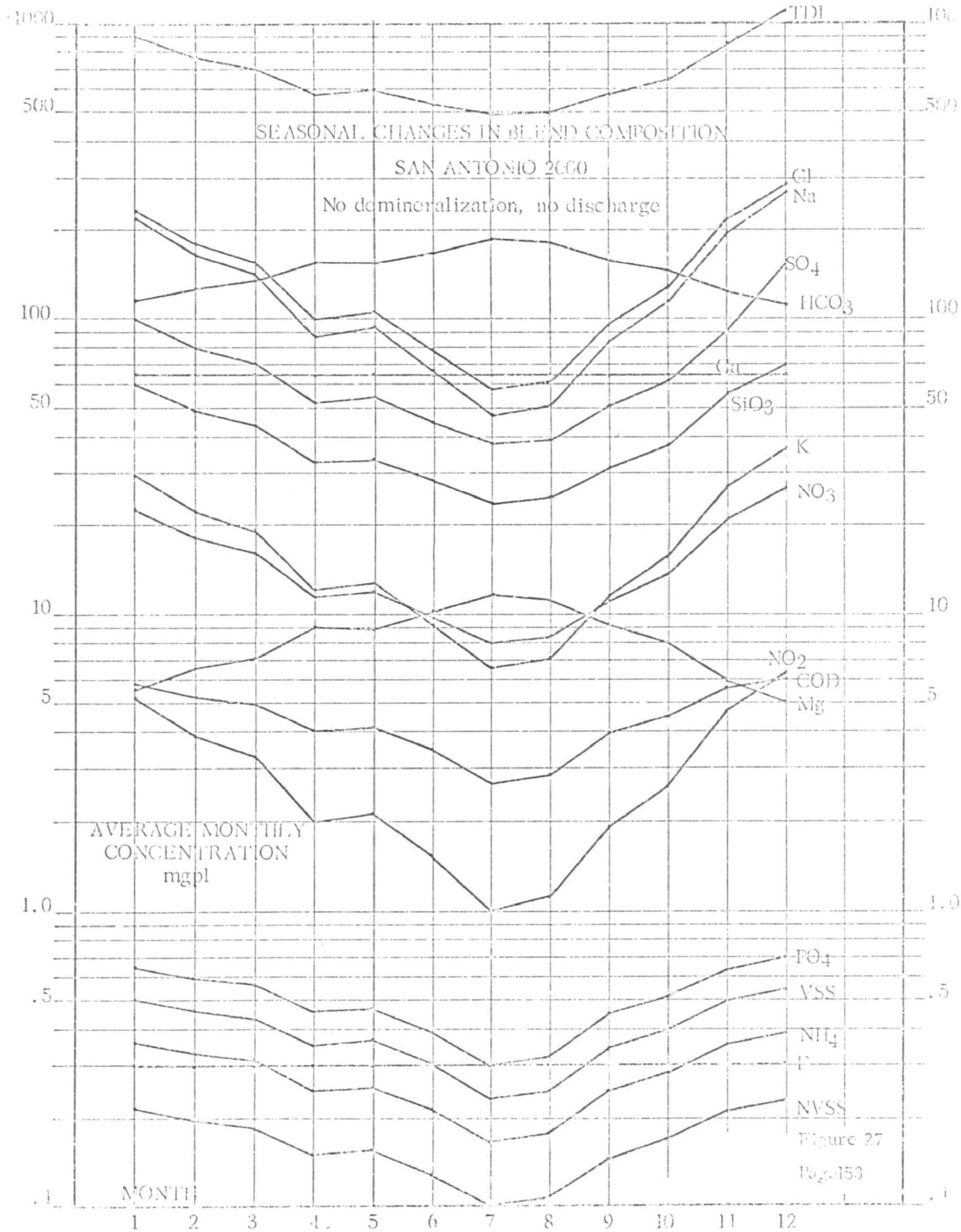

BLEND COMPOSITION AT VARIOUS LOSS RATIOS
SAN ANTONIO
1000
100
10
1
TDI
HCO3
NA
CL
CA
SO4
SIO3
AVERAGE
MONTHLY
CONCENTRATION
mgpl
MG
NO3
K
COD
NO2
0
.2
.4
.6
.8
1.0
LOSS RATIO

Figure 26

Figure 27 shows the average monthly compositions of the blend water for each month resulting from the design loss ratios of Table 19. It is seen that the TDI is lowest in July and August and highest in December and January, and that this also is true of all the other contaminants except Mg and HCO_3 for which the reverse is true.

The major revelation, however, is that under these conditions the mineral composition of the blend is too high in any month of the year. The TDI of the undemineralized blend barely falls below 500 mgpl in July and August and in December reaches more than 1,000. Since the compositional changes of AWT have only been approximated in the program which generated this figure there is a slight possibility that the blend resulting from AWT runs will be somewhat different, and possibly better. But this is not very likely.

Accordingly, it appears likely that either demineralization or discharge or both will be required in order to generate a blend of sufficiently low TDI to be generally acceptable, in San Antonio. Conditions would be better if the city had a higher loss ratio or had a lower municipal increment. San Antonio already has an extremely high loss ratio, up to more than 60% in July and August and it is doubtful if there will be found in the nation many other cities having loss ratios this high. As for the municipal increment, the increments used for San Antonio either are or were deliberately selected close to the average for western cities. Accordingly, probably about half of the western cities have lower municipal increments and, eastern municipal increments being generally lower, more than half of the eastern cities have lower increments. A separate study is being suggested of monthly loss ratios and municipal increments in other cities but it seems clear that there are cities, San Antonio being one of them, in which either demineralization or discharge will be required to maintain blend quality at an acceptable level.



SEASONAL CHANGES IN BLEND COMPOSITION
SAN ANTONIO 2000
No demineralization, no discharge
AVERAGE MONTHLY CONCENTRATION mgpl
MONTH
1000
500
100
50
10
5
1.0
.5
.1
1
2
3
4
5
6
7
8
9
10
11
12
TDI
Cl
Na
SO_4
HCO_3
Ca
SiO_2
K
NO_3
NO_2
COD
Mg
PO_4
VSS
NH_4
F
NVSS

Figure 27

Logistics of the 2000 Supply

Figure 28 shows the monthly average per capita excess of water withdrawal over sewage delivered for the 1961 to 1965 period generated from the aforementioned data. These curves represent the gpcd of makeup water that would have to be supplied if the entire sewage flow were reused. The five-year average is 89 gpcd. For the design basis for this study the upper envelope points of these curves were taken except for May where the 1961 point is very high, in which case the second highest was used. The monthly figures for the envelope are shown in Column 2, Table 19. Multiplication of these figures by 1.44 million yields the monthly average design mgd of makeup for the year 2000 shown in Column 3, of Table 19, and as the correspondingly labeled curve in Figure 29. This annual average design is 114 gpcd, higher than the 89 gpcd five-year average because the upper envelope was used in the design.

A similar procedure using the upper envelope was applied to the water withdrawal curves from Figure 20 of the last section and represented as total intake in Column 4, Table 19. These gpcd rates applied to the 1970 population give the 1970 intake shown in Column 5, and applied to the 2000 population give the 2000 intake in Column 6, represented in the corresponding labeled curve, Figure 29.

There are two constraints on the use of ground water, an annual constraint of 215 thousand acre feet per year imposed by the Texas Water Plan as a safe annual yield which will maintain the flow of the springs, and a peak monthly withdrawal constraint. The experienced peak monthly withdrawal in the 1961 to 1965 period was about 9,400 mg (million gallons) for the total pumpage, corresponding with about 7,000 mg withdrawal contributory to the sewers, that is after the deductions for irrigation, flowing wells, etc. The maximum limitation of 10,000 to 11,000 mg per month for July and August consecutively has been offered as a constraint (35). In average mgd units these constraints are 192 mgd annual, and 339 mgd for the July-August peak months.

Column 6 indicates that ground water within these constraints cannot supply the year 2000 demand since this calls for an annual average of 341 mgd and a peak month of 515, both of which exceed the constraints.

MONTHLY AVERAGE PER CAPITA EXCESS OF WATER WITHDRAWAL

OVER SEWAGE DELIVERED

SAN ANTONIO 1961-1965

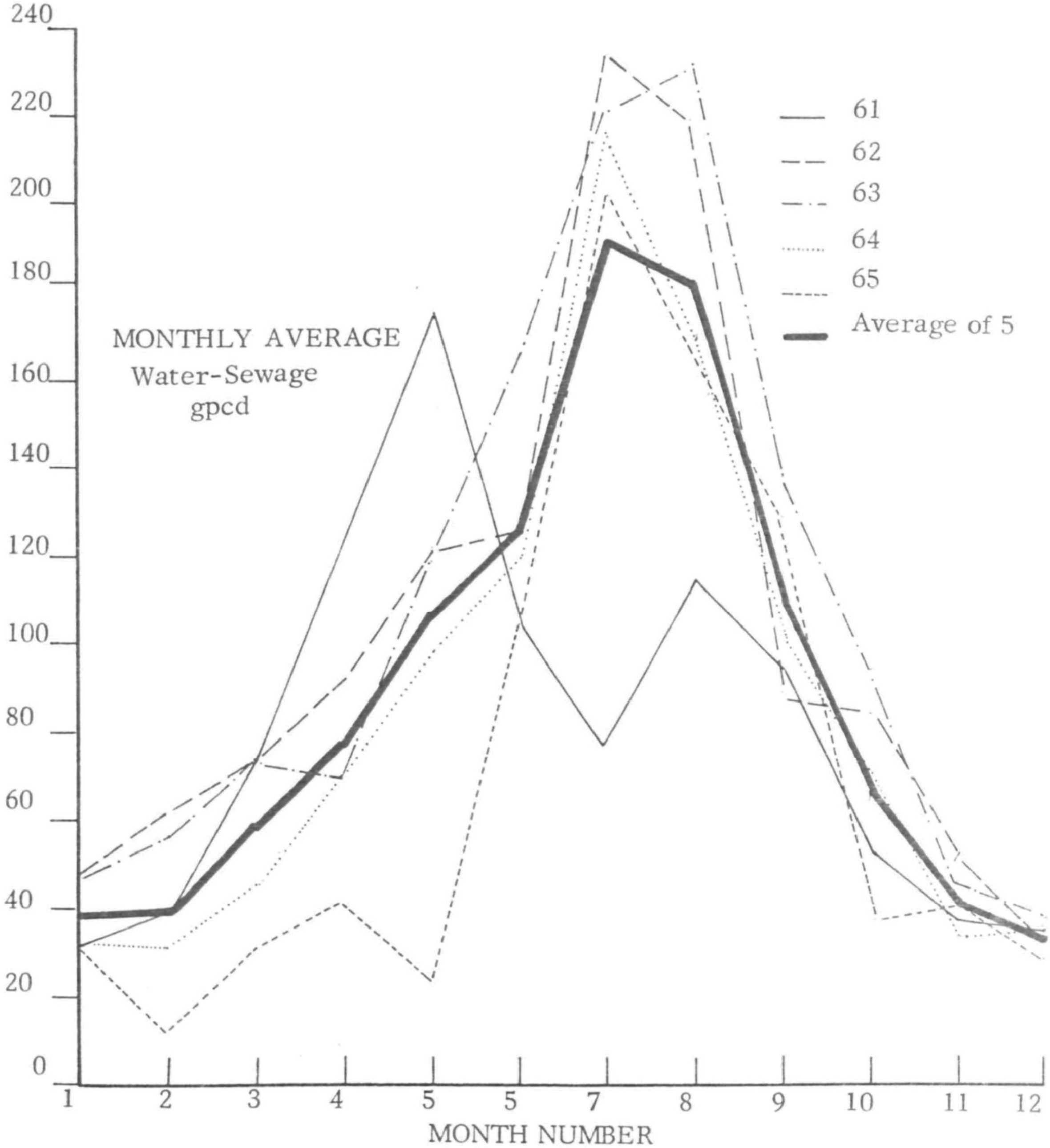
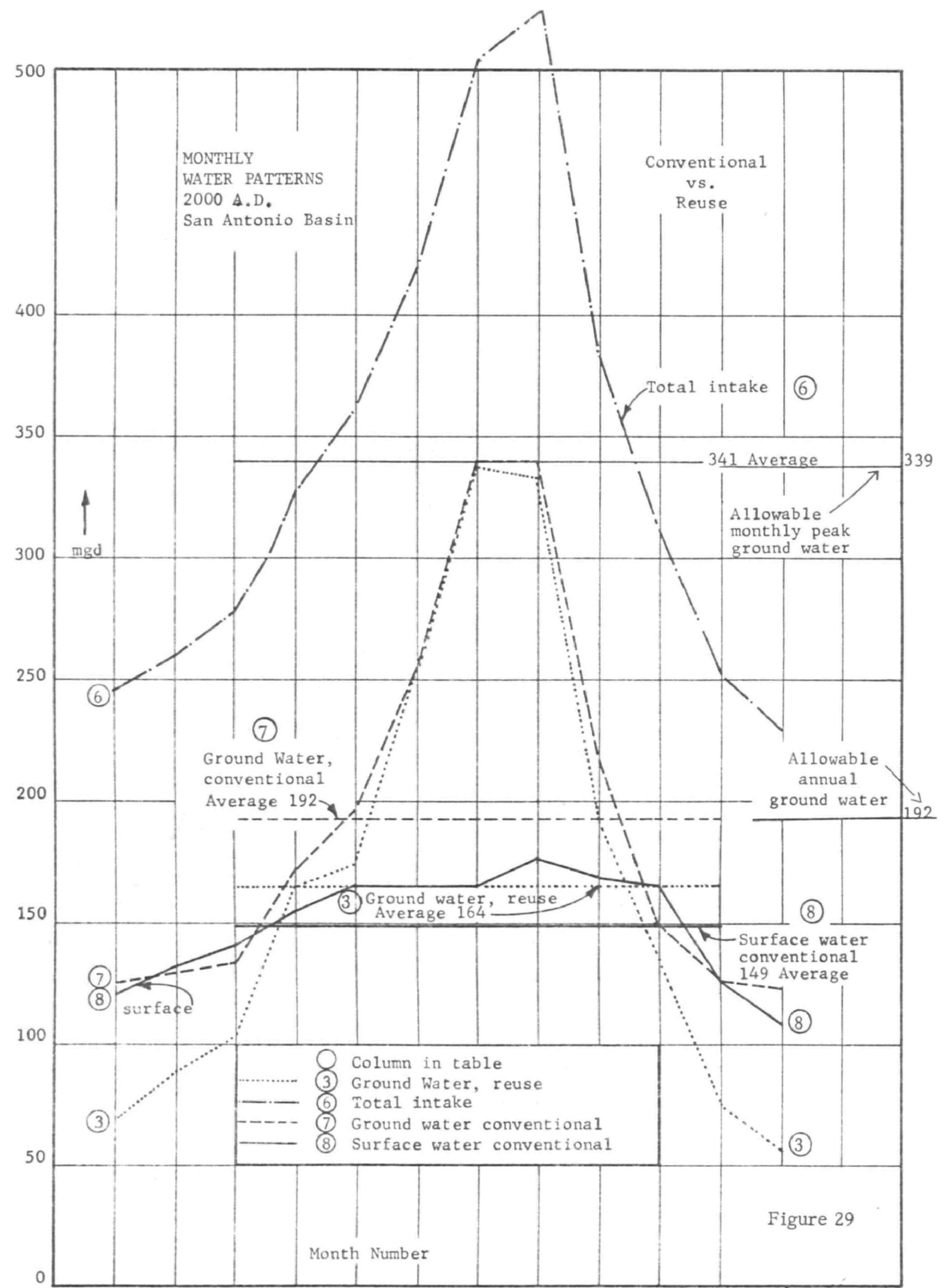


Figure 28



MONTHLY
WATER PATTERNS
2000 A.D.
San Antonio Basin
Conventional
vs.
Reuse
500
400
350
300
250
200
150
100
50
0
mgd
Total intake ⑥
341 Average
339
Allowable
monthly peak
ground water
⑦
Ground Water,
conventional
Average 192
Allowable
annual
ground water
192
③ Ground water, reuse
Average 164
⑧
Surface water
conventional
149 Average
⑥
⑦
⑧
surface
③
⑧
③
○ Column in table
③ Ground Water, reuse
⑥ Total intake
⑦ Ground water conventional
⑧ Surface water conventional
Month Number
1
2
3
4
5
6
7
8
9
10
11
12

Figure 29

TABLE 19

SEASONAL LOGISTICS OF WATER SUPPLY

BEXAR COUNTY, 2000, CONVENTIONAL vs. REUSE

1	2	3	4	5	6	7	8	9
	Makeup		Total Intake			Conventional 2000		
Month	gpcd	mgd 2000	gpcd	mgd 1970	mgd 2000	Proposed ground water pattern, mgd	Required surface water 6-7	Sewage treatment or AWT 6-3
1	47	68	170	117	245	125	120	177
2	61	88	180	124	259	129	132	171
3	72	104	192	132	276	136	140	172
4	113	164	228	157	328	172	156	164
5	121	174	250	172	360	195	165	186
6	165	238	290	200	418	253	165	180
7	233	336	350	241	504	339	165	168
8	231	332	358	247	515	339	176	183
9	137	197	268	185	386	218	168	189
10	94	136	218	150	314	149	165	178
11	52	75	174	120	251	126	125	176
12	38	55	160	110	230	122	108	175
Avg.	114	164	236	163	341	192	149	177

But Column 3 shows that ground water used alone as makeup in a recycle scheme would be adequate in the year 2000. The peak month is 336 mgd compared to the constraint of 339 and the annual is 164 compared to the constraint of 192. Therefore, if all the waste water could be recycled the entire makeup to the year 2000 could be supplied by the allowable ground water withdrawal.

Projection of the population to years beyond 2000 indicates that the peak month constraint is just barely met since it would be violated about the year 2005. The annual constraint would be exceeded about the year 2017. Starting in 2001 there would have to be provided some surface storage for ground water pumped in the winter and spring months and stored to avoid exceeding the peak allowable in July and August. The storage period and quantity would have to become larger and larger as the population grew. Beginning in 2017 no amount of storage would suffice and it would be necessary to supplement the ground water supply.

However, of course, these projections depend upon the constancy of the gpcd water use and sewage delivered. Under a reuse scheme any steps taken to reduce the gpcd water intake and increase the gpcd sewage collected would be favorable toward postponing these critical dates.

In any event if the sewage collected would be completely recovered the allowable ground water withdrawal would meet the requirement in the target year 2000. However, anything even slightly less than 100% recovery of the sewage collected would violate the peak month constraint in 2000.

As may be seen the thrust of this project is to utilize ground water to the fullest before drawing upon surface water supplies. The reason is economic. Ground water will cost less than conveyance of water from Cuero and Cibolo reservoirs or from the Colorado River. Obviously, economics demand that the cheaper source be used to its limit before resorting to the more expensive source. The cost disparity is even greater than the mere conveyance costs suggest since surface water would require treatment at a cost of additional cents per kilogallon.

But this consideration of using the cheaper source also applies to the competitive scheme of conventional supply. Even if water were to be imported this conventional system would make use of the cheaper ground water up to the allowable limit in order to reduce the overall cost of the supply. In order to fairly take this into account in comparing the economics of reuse versus conventional importation, it is necessary to determine the monthly pattern of ground water use in 2000 which will (a) produce an annual amount equal to the annual constraint, and (b) avoid exceeding the monthly constraint in any month, and (c) minimize the cost of the conveyance and treatment of the imported water. The last goal involves maximizing the utilization factor of the pipeline, and also of the water treatment plant. Utilization factor is the ratio of the average production to the design capability. The ¢/Kgal cost increases as utilization factor decreases. Therefore, maximizing the utilization factor minimizes the cost.

Column 8 shows the requirement for import water if the ground water is pumped so as to just attain the monthly and annual constraints. Since the intake in the maximum month is fixed and the ground water contribution also fixed this means that the import water requirement in that maximum intake month is also fixed, at 176 mgd. The remaining months of the ground water withdrawal in Column 7 have been adjusted so as to meet the constraints and to have no month's requirement for import water greater than the maximum 193 mgd. Column 8 is the difference between the ground water and the total intake. These two curves, (7 and 8), also are shown on Figure 29.

Table 20 summarizes the quantities involved in the conventional and reuse schemes in 2000. Under the reuse scheme the average withdrawal of ground water would be 164 mgd and the peak day 435 mgd for utilization factor of .359. The lawn and pipe losses would be 164 and the amount returned to San Antonio River zero.

Under the conventional import scheme the average withdrawal of ground water would be the limit, 192 mgd, and the peak monthly also the limit, 339 mgd. The average surface water withdrawal would be 149 mgd. The total withdrawal would be 341 mgd with the peak day 670 mgd for an overall utilization factor of the system of .51. The lawn and pipe losses would be 164 mgd and the quantity returned to the San Antonio River 177 mgd.

In the conventional import scheme the load for the peak day can be thrown toward the ground water or toward the surface water and in practice this would be done in the direction and to the extent that produced the minimum overall cost. If all of the burden of the peak day were thrown on the imported surface water the peak day for ground water would be the same as the peak monthly 339 and the remainder of the overall 670 mgd peak day load would be placed upon the surface water, 331 mgd. In that case the utilization factors for the ground water would be .567 and for the surface water .429. In the other direction the entire burden for the overall peak day

TABLE 20

LOGISTICS OF THE NEW SUPPLY - 2000

Note: Peak day is the 90% level--i.e. expected to be exceeded in only 10% of the years.

	AWT Reuse Scheme mgd	Conventional Import Scheme mgd
Ground water withdrawal, average	164	192
Peak monthly	336	339
Peak day	435	339/440/494
Utilization factor	.377	.567/.436/.389
Surface water withdrawal, average		149
Peak monthly	none	176
Peak day	withdrawn	331/230/176
Utilization factor		.429/.649/.845
Total withdrawal	164	341
Peak monthly	336	515
Peak day	435	670
Overall utilization factor	.377	.510
Water treatment, average		149
Peak monthly	not	176
Peak day	used	331/230/176
Utilization factor		.429/.649/.845
Lawn and pipe losses	164	164
	(AWT)	(Conventional STP)
Sewage treatment or AWT, average	177	177
Peak monthly	189	189
Peak day	350	350
Utilization factor	.506	.506
Demineralization, average (rough)	117	
Peak monthly	261	not
Peak day	486	used
Utilization factor	.241	
Disposal to the Gulf, average	7	
Peak monthly	- -	not
Peak day	14	used
Utilization factor	.5	
Discharge to San Antonio River	none discharged	177
Storage required	yes	no

could be placed upon the ground water which would give it a peak day of 494 and a utilization factor of .389, leaving 176 mgd as the peak day for the surface water for a utilization factor of .845. The present project does not as yet go so far as to determine the proper allocation between the two sources. Instead, the 1.3 factor which relates peak month to peak day for the demand characteristics (at the 90 percentile level) is applied to both the ground water and the surface water resulting in a peak day for ground water of 440 and for surface water of 230 mgd, with corresponding utilization factors of .436 and .649.

The category "demineralization and by-pass" refers to the explicit demineralization portion of the recycle scheme. It has been shown that some demineralization will be required even in the summer months where the blend is of the better quality if a TDI much less than 500 mgpl is to be achieved in the blend. The extent of demineralization need only be such as to produce in the blend concentrations of the various contaminants which just pass the blend requirements. Obviously, to reach say 400 mgpl of TDI in July and August from 500 mgpl will require a lesser degree of demineralization than in December and January from about 1,000 mgpl. Some demineralization processes, for example, reverse osmosis, can be operated to achieve various degrees of demineralization in the effluent. If such a process is used it would be continuously adjusted to achieve the degree of demineralization required day-by-day to meet the blend constraint. Other types of demineralization, for example, ion exchange, more or less completely demineralize the water and cannot efficiently be modified day-to-day to do otherwise. In such cases in order to avoid the economic inefficiency of over-demineralizing the quantity demineralized would be varied by by-passing some of the AWT effluent around the explicit demineralization stage. The determination of the exact amount of by-pass which with a given discharge is allowable in order to just meet the blend constraints is the purpose of the RECYCLE program, not yet completed. For a rough approximation to their quantities, see the demineralization section in Chapter 6 of this series. Table 20 merely indicates that the requirements for explicit demineralization cannot be greater than the figure given, but it may be less.

Table 21 provides some details on the treatment plant requirements. The combined peak day capability of the three existing or planned San Antonio conventional sewage treatment plants, the Rilling, the Leon Creek, and the Salado will be 116 mgd. The corresponding average flow handled by these plants under the seasonal pattern described will be 59 mgd. Therefore, the new capability required in 2000 will be 234 mgd which will handle an average flow of 118 mgd. This may be compared with the requirement for the AWT plant, from Table 20, of 350 mgd capability, and average flow of 177 mgd.

TABLE 21

LOGISTICS OF THE NEW SUPPLY - 2000
Sewage and Water Treatment Plant Alternatives

	mgd	
	AWT Reuse Scheme	Conventional Import Scheme
Existing or U.C. STP (3 plants)		
Peak day capability	not	116
Average	used	59
New capability required	(AWT)	(STP)
Peak day	350	234
Peak monthly	189	-
Average	177	118
Utilization factor	.506	.506
Discharged to San Antonio River	none	177
Demineralization and by-pass*		
Peak day	350	
Peak monthly	189	not
Average	177	needed
Utilization factor	.506	

* Demineralization required cannot be greater than this

Water treatment		
Peak day		331/230/176
Peak monthly	not	176
Average	needed	149
Utilization factor		.429/.649/.845

Table 22 provides some details on the ground water facility requirements, using the utilization factors characteristic of the AWT reuse scheme and the conventional import scheme from Table 20. With these utilization factors the average production from the existing ground water facilities would be 125 mgd for the AWT reuse scheme and 145 for the conventional import scheme, since the latter would operate at a higher utilization factor. The new facility required would be 102 mgd and 107 mgd, respectively, of firm capability an average production for the new facility of 39 and 47 mgd, respectively.

TABLE 22

LOGISTICS OF THE NEW SUPPLY - 2000
Ground Water Facility Alternatives

	mgd	
	AWT Reuse Scheme	Conventional Import Scheme
Existing GW facilities		
Peak day firm capability	333	333
Average	125	145
New facility required		
Peak day, firm	102	107
Average	39	47
Utilization factor	.377	.436

Table 23 shows the conveyance alternatives. The AWT reuse scheme in the single AWT plant embodiment would require the conveyance back from the AWT plant illustratively at the Rilling site to the water distribution system illustratively taken as the Hildebrand tank in the north part of the City. This pipeline conveyance system would have a peak day of 350 mgd and an average of 177.

For the conventional import scheme, several alternative sources are available. One of these is the Cuero Reservoir supplemented by the Cibolo Reservoir. Since Cuero is in the Guadalupe Basin the Texas Water Plan calls for a "reimbursement" of the Guadalupe Basin by the San Antonio Basin by a transfer from Goliad Reservoir to the Guadalupe in the neighborhood of Victoria. This conveyance is part of the Cuero-Cibolo system and part of the cost. Another alternative is the conveyance of water from the Colorado at Austin much of which would be by canal. A preliminary engineering study has been performed on these two alternatives (36). A still more recent alternative involves an Applewhite Reservoir on the Medina River which is now being studied by the City Water Board. The Applewhite Reservoir is not in the published versions of the Texas Water Plan. Other alternatives, some of which have received engineering study, include Canyon Reservoir, and Cloptin Crossing Reservoir.

TABLE 23

LOGISTICS OF THE NEW SUPPLY - 2000
Conveyance Alternatives

	mgd AWT Reuse Scheme	mgd Conventional Import Scheme
Cuero and Cibolo to Hildebrand		
Peak day	0	230
Average	0	149
Goliad to Victoria		
Peak day	0	141.4
Average	0	113.1
Rilling to Hildebrand		
Peak day	350	0
Average	177	0

When engineers come to a final decision on one of these or other alternative conventional supplies they will take into account the engineering, economic, and political considerations which govern such choices. The politics and the emotions surrounding alternative Texas water schemes can become heated. Our selection of the Cuero-Cibolo alternative for the conventional supply in this study should be taken as purely illustrative and not a recommendation for that scheme as against any other. Our proposal for this recognized that alternative conventional water supply schemes are multifarious and this project could not hope to be instrumental in selecting the best of them for any particular city. Such a selection even for a single city would in general require more funds than allotted to our entire project, the main purpose of which was to obtain a methodology for a comparison between reuse and the best alternative conventional supply. San Antonio was selected as the practical situation on which to explore the methodology and when a final decision is reached by other parties as to the best of the conventional supply alternatives the corresponding logistical and cost data can be plugged into the model for a comparison.

Among the available alternatives the Cuero-Cibolo scheme was chosen for this illustrative comparison for the following reasons. The quantities, the reservoir yields, the distances, and the reimbursement requirements were clearly set forth in the Texas Water Plan (37). For the Lake Austin and some of the other alternative schemes the reimbursement feature under the Texas Water Plan was not clear. The Lake Austin conveyance system would be largely by canal with seepage losses and costs thereof unknown. We believe that the future water supply of cities will be conveyed mostly by pipeline, only to a small extent by canal, and our project did not yet cover canal conveyance models. The Applewhite scheme had not been sufficiently formulated to use in our illustrative model.

THE NATURE OF THE RECYCLE PROBLEM

One of the major alternatives to have been studied in this project is recycle and reuse, to as high a degree as possible, or at least to as high a degree as economic. It was therefore necessary to come to quantitative grips with the problem that is usually swept under the rug in discussions on reuse. Most discussions of reuse are content implicity or explicity to consider a single reuse, relying on some treatment process to produce a water for reuse that is acceptable, and in some components not too much worse than the original starting water. This is fine for a single reuse, but if one is considering indefinite reuse, these components in which the return is only a little worse than the original water must build up in the recycling water and ultimately become intolerable. The standard reply to this extension of the problem in turn is that the worst liquor, in our case the secondary effluent, will be purged from the system to maintain the return at an acceptable level in all components. This is where the problem is usually left. We believe no one has ever worked out a quantitative balance for a real recycle and reuse process and particularly determined whether or not the purged quantity might not be so great as to leave little for reuse.

The problem turns out to be very complicated mathematically and in the real application is further complicated by the high seasonality of the loss ratio. At one stage of the study it appeared that the problem was one to which no solution existed. The project now has demonstrated that a solution does exist but we have not had enough time to complete the solution (this was but one of 22 tasks under the project). This chapter outlines the nature of the problem, the boundaries and constraints in it, and the method by which the solution is to be achieved.

The problem is stated as follows:

> In a system of recycle for reuse having water for use as a blend of makeup water and recycled water, having a contaminant increment attendant upon use, having losses in use not returned to the treatment plant (lawn losses), having losses in transit of waste not returned to the treatment plant (pipe losses), having conventional sewage treatment, having advanced waste treatment with some attendant demineralization, having explicit demineralization and allowing some by-pass thereof and having discharge and disposal.

GIVEN: makeup water quality in N contaminants, criteria (maxima) for water quality in use in N contaminants, municipal concentration increment in N contaminants, quantity of pipe losses, quantity of lawn losses, any set of treatment and advanced treatment processes, any set of explicit demineralization processes, criteria for water quality of the discharge in N contaminants, and any set of disposal processes.

DETERMINE: for any given quantity of effluent discharged what quantity of the recycle must be demineralized (and what quantity by-passed) in order to maintain in the blend water and the discharge a steady state concentration meeting the criteria in N contaminants.

A Glimpse at the Solution

The work toward the solution of this problem has revealed the following. The answers to the problem comprise the quantities to be demineralized and the quantities to be discharged. For any given set of conditions, water use quantity, losses, municipal concentration increment, characteristics of treatment and demineralization processes, etc., there may be or there may not be a feasible solution. If there is, there are a set of discharge quantities that will allow a solution which just fails to violate the criteria. This set of values is continuous and has upper and lower limits which are non-trivial, i.e. do not merely comprise zero percent and 100 percent of the sewage quantity. For any of the allowed discharge quantities there are two demineralization quantities which will satisfy the criteria. Thus, the solution comprises a set of "pairs" of discharge and conjugate demineralization quantities which are inter-determined...that is if one is chosen the other two are fixed. The set of demineralization quantities is also continuous and bounded non-trivially. The pairing relation is reciprocal, that is if the demineralization quantity is chosen its paired discharge quantities are fixed, and likewise, if a discharge quantity is chosen its paired demineralization quantities are fixed. Finally, each pair of solution quantities has an associated cost for the entire system and in general one of these pairs shows a cost lower than all others, i.e. is an optimum.

Linear Programming Model

With this much information those familiar with the field will assign this as a linear programming problem. In the simplified form it is indeed a linear programming problem. In the real-world form it is not a linear programming problem, but we shall discuss it first in the simplified form to lay the groundwork for the real problem. Figure 30 is a flow chart of a simplified municipal recycle scheme showing quantities of water and concentrations and quantities (ppmmgd) (mgpl times mgd) of a particular ion. A subscript j is to be considered as applying to concentrations and ion quantities as well as leakage. The flow diagram has been simplified by assuming that no mineral change or mineral addition occurs in the conventional STP or AWT processes. Also, no water occurs as waste or backwash from the demineralization process; the mathematics is simplified to make the leakage independent of the feed concentration and to place no constraints on the discharge quantity or concentration.

It is seen that the overall input is the makeup water M and the municipal increment. The output is the lawn loss L, the pipe loss P and the discharge M-L-P. The amount demineralized is X.

There are two overall material balance relations on water quantity and ion quantity. One of these comes from the overall input-output balance. The other comes from the two possible computations for the ion quantity in the return, one from a backward computation and one from a forward computation. Both of these relations yield the identical equation which is the basic material balance equation of the problem:

$$Mm + Bi = M + X\ (1 - f)\ (b + i) \qquad (1)$$

To make it easier to discuss the problem we shall replace this equation with another obtained by dividing through by B, retaining now the symbol M to represent M/B and X to represent X/B. The equation then becomes:

$$Mm + i = M + X\ (1 - f)\ (b + i) \qquad (2)$$

In solving this to meet a given BLEND quality, β, and ignoring any discharge specification the constraints are:

$$0 \leq (X + M) \leq 1$$

$$0 \leq M \leq 1$$

$$0 \leq X \leq 1$$

$$0 \leq f \leq 1$$

$$0 \leq (L + P) \leq M$$

$$\therefore (L + P) \leq 1$$

$$b \leq \beta$$

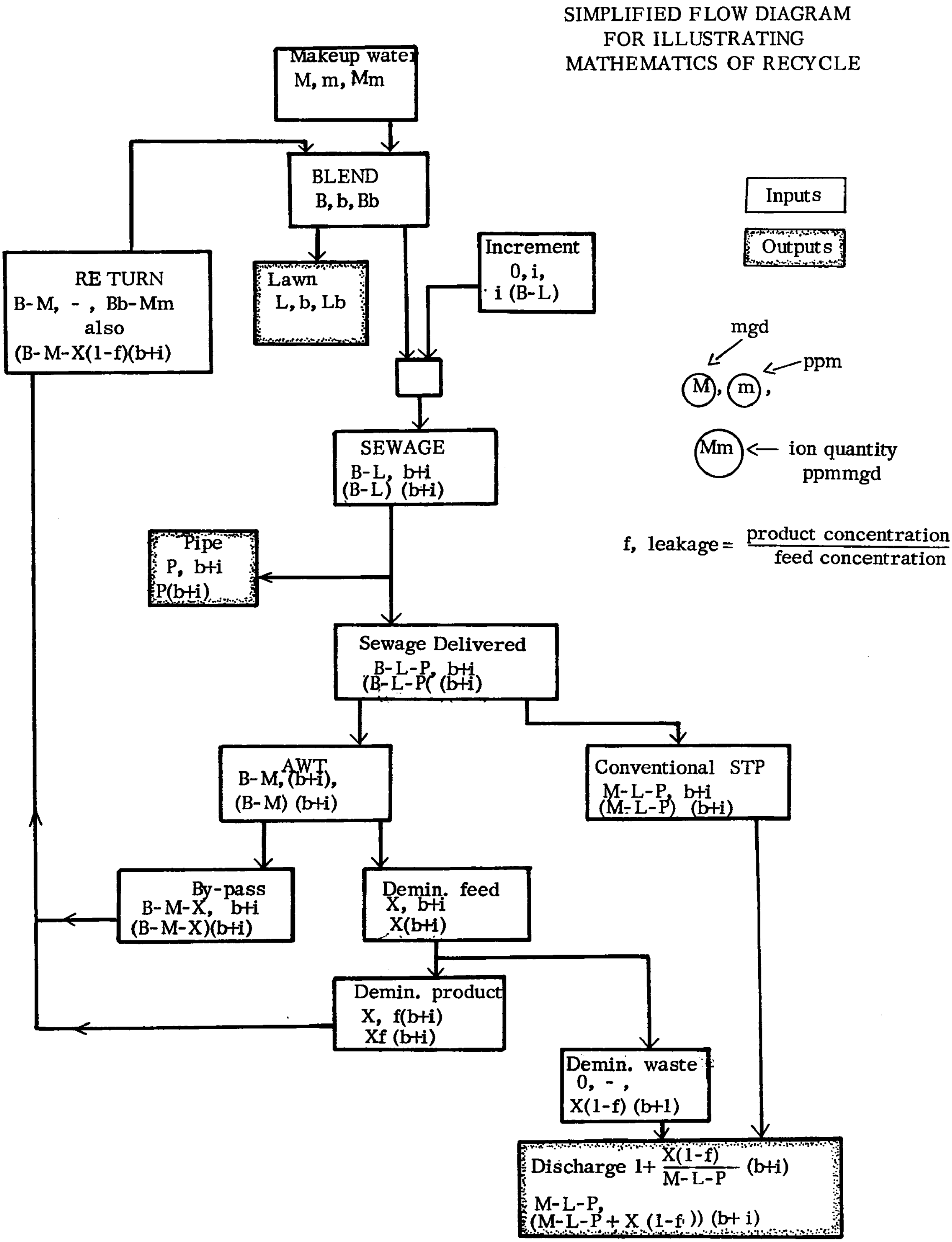

SIMPLIFIED FLOW DIAGRAM
FOR ILLUSTRATING
MATHEMATICS OF RECYCLE
Makeup water
M, m, Mm
BLEND
B, b, Bb
Inputs
Outputs
RETURN
B-M, - , Bb-Mm
also
(B-M-X(1-f)(b+i)
Lawn
L, b, Lb
Increment
0, i,
i (B-L)
mgd
ppm
M, m,
Mm ion quantity
ppmmgd
SEWAGE
B-L, b+i
(B-L) (b+i)
f, leakage = product concentration / feed concentration
Pipe
P, b+i
P(b+i)
Sewage Delivered
B-L-P, b+i
(B-L-P((b+i)
AWT
B-M, (b+i),
(B-M) (b+i)
Conventional STP
M-L-P, b+i
(M-L-P) (b+i)
By-pass
B-M-X, b+i
(B-M-X)(b+i)
Demin. feed
X, b+i
X(b+i)
Demin. product
X, f(b+i)
Xf (b+i)
Demin. waste
0, - ,
X(1-f) (b+1)
Discharge 1+ X(1-f)/(M-L-P) (b+i)
M-L-P,
(M-L-P + X (1-f)) (b+ i)

Figure 30

The Basic Linear X, M Relation

The linear relation is between X and M:

$$X = \frac{M(m-b-i) + i}{(1-f)(b+i)} \qquad (3)$$

$$M = \frac{X(1-f)(b+i) - i}{(m-b-i)} \qquad (4)$$

For each ion there is a value of X which will just meet the β constraint on that ion in the blend. Call this Σ.

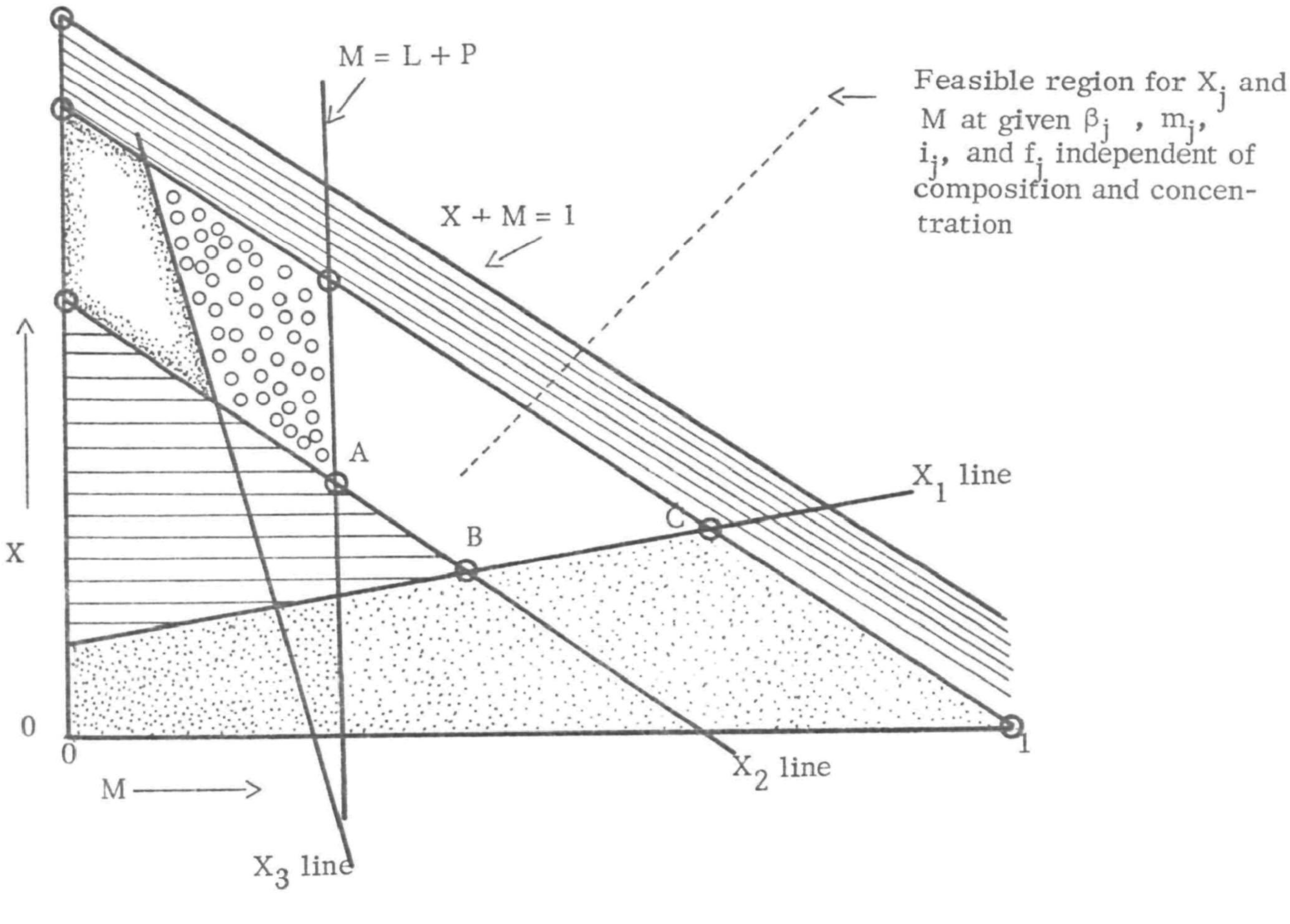
$$\Sigma_j = \frac{M(m_j - \beta_j - i_j) + i_j}{(1 - f_j)(\beta_j + i_j)} \qquad (5)$$

At any given M value the highest of the Σ_j's is of course the X that must be used. Call this Σ^*. The blend concentration of that ion will just meet the β constraint for that ion, and the concentrations of all the other ions will be less than their β constraints, according to:

$$b_k = \frac{Mm_k + i_k}{M + \Sigma^*(1 - f_k)} - i_k \qquad \beta_k \qquad (6)$$

where k is the subscript representing any of the other ions.

A schematic linear programming diagram for X and M is shown in Figure 31.



M = L + P
Feasible region for X_j and M at given β_j, m_j, i_j, and f_j independent of composition and concentration
X + M = 1
A
B
C
X_1 line
X
0
0
1
M
X_2 line
X_3 line

Figure 31

In this diagram on the simplified model with three ions it is seen that X is a linear function of M for each ion. The constraints that X and M must lie between zero and one are shown on the axes; the constraint X + M = 1 is the hypotenuse. The X1 line represents the relation for ion number 1. Having been drawn it divides the diagram into two regions; that above the line being allowed, that below the line being disallowed because X, M pairs in that region would not achieve the βj criterion. The X2 line when drawn similarly excludes an area below it, in the sense of at lower X's. Similarly the X3 line. The X3 excluded region, however, has no effect because it is over-ridden by the line representing the constraint that M = (L + P).

The Feasible Region

Thus the only region in the entire field which is feasible for meeting the β constraints on the various ions is the unshaded polygon. Any other combination of X and M would fail to meet the blend criterion for at least one of the ions.

Note that it is not necessary that there be any feasible region at all. For example, if L + P were quite high, higher for example than the intersection of the X1 line with the hypotenuse, then there would be no feasible region, which means that there is no possible combination of X and M which would meet the blend constraints. In other words, no real system could hold the blend concentration which is specified.

Non-Linearities

So far this has appeared to be a straight linear programming problem in which the next step would be to impose a linear cost surface on the diagram, and to recognize that the lowest cost feasible solution must occur at one of the apexes. However, the real situation is not amenable to simple linear programming because the system departs from linearity in at least three ways.

First, the cost surface is not planar, and therefore the contours representing that surface on the linear programming diagram are not linear. In general this means that the minimum cost solution is not necessarily an apex and could even be in the interior of the feasible region. The real situation is not as recalcitrant as this, however, and it will shortly be shown that the minimum cost solution lies on one of the feasible region boundaries.

Second, the linearity of the X, M lines depends on the assumption that the leakage, f, is independent of the composition and concentration of the demineralization feed. In most demineralization processes this is not strictly true (with some it is strongly untrue) and this non-constancy of f makes the X, M lines non-linear.

Third, in some demineralization processes the concentration of some ions in the product must depend upon the combination of concentrations of its companion product ions. For example, in ion exchange the concentration of Na in the product is determined not by a leakage unique to itself but by the leakages of the other ions since its leakage only occurs in maintaining ionic balance. This not only makes the line for Na non-linear but it also makes non-linear the line for total dissolved ions which can also be one of the β constraints.

Ions Not Amenable to Demineralization

Some demineralization processes fail to remove any of certain ions, e.g. $SiO_3^{=}$ in weak base anion exchange. For such ions (1 - f) becomes zero, and the overall material balance equation becomes:

$$Mm + i = M(b + i) \tag{7}$$

For each ion there is a value of M which will just meet the β constraint on that ion in the blend. Call this M_j:

$$M_j = -i_j / (m_j - \beta_j - i_j) \tag{8}$$

For any set of ions there is one ion which will give the highest of the M_j values. Call this value M*, which is the lower bound on M to meet the blend criteria for all ions for which (1 - f) approaches zero. This boundary is a vertical line on the linear programming diagram, which may be above or below M = L + P. The highest of the several lower bounds, M* or M = L + P is the controlling bound for M and sets a minimum M. Of course, it is understood that these vertical boundaries might be completely over-ridden by the exclusion fields of some of the other ions and so not come into consideration. (However, the existence of these vertical lines determines a strategy in the computer solution.)

The Cost Surface

While the cost surface is not planar and thus it is not possible to place the optimum at an apex, nevertheless it is possible to make some general statements about the cost surface which can give a further clue as to the solution. The following chart shows how the costs of the various cost components change as M increases at constant X and as X increases at constant M.

Increase in Cost	No Change	Decrease in Cost
As M increases at constant X:		
New water Sewage treatment Disposal (of discharge)	Demineralization Disposal (of demin. waste)	AWT Conveyance back to point of use
As X increases at constant M:		
Demineralization Disposal (of regeneration waste)	New water Sewage treatment AWT Disposal (of discharge) Conveyance back	None

This shows that as X decreases at constant M no cost component increases, some remain unchanged, but two components decrease. Therefore, at constant M as X decreases, total cost decreases. It follows that no point in the interior of the feasible region can be economic over a point vertically beneath it at a lower X value. The minimum cost will be found on one of the boundaries of the feasible polygon but not on a boundary which has any other boundary vertically beneath it. To illustrate, the minimum cost will be found somewhere along the line segments A, B, C in Figure 31. The mathematical description of the situation is:

$$(dCOST/dX)_M > 0$$

Unfortunately, the relation for the change of cost with M at constant x cannot yet be so simplified. We do not yet know the nature of the surface in the M direction since it contains both positive and negative partial derivatives.

No Demineralization

The relations in certain reduced forms of the recycle pattern are of interest. With no demineralization X = 0 and for all ions the relation is as for a single ion with f = 1. The makeup necessary to maintain a given blend constraint for a given ion is as in equation (8). The M_j's are the intersections of the X vs. M lines with the X axis. The highest of the M_j's, called M*, is the controlling M and the concentration of all the other ions is given by:

$$b_j = m_j - i_j + i_j / M^* \tag{9}$$

No Discharge

With no discharge M is fixed at M* = L + P, and the X necessary to achieve the blend constraint for each ion is given by:

$$X_j = \frac{M^* (m_j - \beta_j - i_j)}{(1 - f)(\beta_j - i_j)} \tag{10}$$

The highest of the X_j's, called Σ^*, is the controlling one, i.e. the demineralization required to maintain a given blend constraint, and the concentration of each of the other ions is given by equation (6).

No Discharge and No Demineralization

With no discharge and no demineralization X = 0 and M = L + P. This is the only value that M can have, called M*, and the blend concentration of each ion will be given by equation (9). This is the relation on which Figure 18 is computed. If any of the b_j's is greater than the corresponding β_j the blend constraint cannot be met for that ion and the constraint must be relaxed or else discharge or demineralization must be allowed.

This can be re-expressed:

$$(b - m) = i\left(\frac{1}{L+P}\right) = i\left(\frac{1}{M^*} - 1\right)$$

This states that the increase of the blend concentration over the makeup water concentration in any ion depends only on the municipal concentration increment and on the loss ratio.

The Real Recycle Pattern

The real recycle pattern is more complicated than this simplified form in at least the following ways:

There are some 50 likely contaminant ions that should be explored for buildup. Possibly any ion may prove to be the controlling one.

The leakages are functions of the concentration and composition of the demineralization feed.

Some water may be used in the backwash, regeneration and reject from the demineralization process.

Disposal of the demineralization waste separately from the discharge may be indicated.

The AWT process causes changes in the ionic concentrations, indeed some ions are actually added to the water in the AWT process comprising an additional input.

Where there is no existing conventional plant it may be desirable to discharge at an intermediate stage in the AWT process, e.g. prior to the carbon stage, or this may be so even if there is an existing conventional plant.

The presentation has been in terms of a fixed usage, B, lawn loss L, pipe loss P, and sewage delivered (B - L - P). Actually B and L are subject to seasonal variations. The physical system must be capable of handling the worst conditions and the costs to be optimized are the summations over the year under the fluctuating seasonal conditions.

Possibly the municipal increment also has a seasonal variation.

The nature of the seasonal variations does not allow the picking of a particular time instant, i.e. a particular month, as containing the extremes for design. The highest requirement for hydraulic flow occurs in July and August but the highest requirement for demineralization occurs in December-January. Thus, for example, the makeup water system must be sized on the July-August flow but the demineralization equipment must be sized on the December-January flow.

Status of the Computer Program RECYCLE

The reader who has waded through the increasing degrees of complexity in the foregoing exposition may now understand why so many discussions on recycle stop at "let's treat the sewage to make drinking water out of it and put it back into the mains."

Under this project we have developed several computer programs for solving the recycle problem in increasing degrees of complexity. None of the ones that are completed are close enough to reality to be worth reporting. The one that is close enough (and still a long way from design reality) is not complete, and cannot be completed within the time schedule of the project.

That program handles the following degree of complexity. About 20 of the major ions plus COD are considered. The quantities are fixed and are not seasonally varied. The physical system comprises a single makeup source, a single AWT plant, a single conventional sewage treatment plant, and a single explicit demineralization plant. No constraints are placed on the discharge (in dissolved ions). The program only determines the feasible boundary in the X, M field and does not as yet find the optimum pair for minimum cost. During the development the program uses surrogate AWT and activated sludge subroutines for simulating AWT performance and conventional STP performance but the full programs are available in Chapter 2 and Chapter 5. The program uses a surrogate subroutine for approximating the performance of a demineralization process. Programs are available for reverse osmosis ion exchange and electrodialysis, but none of these are in shape for immediate insertion into the recycle program.

As for the current program the mathematics have been worked out and require checking. The computer program itself has been roughly flow-charted but not written.

Despite the incompleteness of our work on the recycle problem, we believe that the most important accomplishment of the project has been the demonstration of the nature and the complexity of the recycle problem.

CHAPTER 4

COMPUTER PROGRAM FOR DESIGN AND COSTING OF CONVEYING WATER BY PIPELINE

This Chapter covers the development of a computer program for the design and costing of pipelines and the conveyance of water or other fluids through them. Water conveyance is one of the important elements bearing upon the economic competition between conventional water supply and wate treatment typically by importing water from remote sites, and renovation or reuse by advanced waste treatment.

WHAT THIS PROGRAM DOES

This program takes the specified characteristics of the conveyance situation, designs a pipeline which will minimize the cost of conveyance in that situation, and returns the design data and the cost breakdown. The special details are as follows.

The line is designed in segments (up to three) as may be specified. As the program now stands each segment may have its individual mileage, beginning elevation, ending elevation, terrain factor (a factor concerning the cost of line maintenance) and construction factor (a factor concerning a construction cost). The program optimizes each segment and returns the design characteristics of each segment and the cost of the entire line.

The input quantities conveyed, obviously the same for each segment, are: QMAX, the mgd on the maximum day in the design period; QBARE, the expected average mgd over the entire design period; and two quantities not yet used in the program, the actual average day as distinguished from the expected average day, and the minimum day. The maximum and average gph and gpm rates are taken to be 1/24 and 1/1440 times the mgd rates.

The program optimizes each segment for the conveyance of QBARE in a facility which has the firm capability of conveying QMAX.

Within each segment having multiple pump stations the program designs with equal-sized stations, a design which if it could be achieved in actual practice would minimize the cost over unequal-sized stations. The program generates a firming factor which computes installed pump station horsepower from firm pump horsepower.

Given the state and the region in which the bulk of the line lies and the future year for which the estimate is desired the program then generates the necessary cost indexes for the future year and for the region. If the ¢/Kwh energy price is not given the program generates an energy price corresponding to the state, the future year, and the expected Kwh/yr energy consumption.

The viscosity and density of water are computed from the water temperature given. Similar relations for other fluids could be inserted.

In place of the commonly used Hazen-Williams coefficient this program generates the friction factor from the Moody diagram from the known relations including solving the non-explicit Colebrook and White formula for friction factor in the transition and turbulent regions. This subroutine, MOODY, returns not only the computed friction factor but also the Reynolds number and the flow type whether laminar, critical, or transition, or turbulent.

Within the head limitation given as input the program determines the head per station (for other than gravity lines) and from this selects the highest pressure class of pipe to be used apportioning lower pressure classes along the line as the pressure decreases, and computes the cost of the total of the various pressure classes.

The program reports the optimum conveyance type whether gravity, boosted, or pumped, having selected whichever is the cheapest among these.

WHAT THE PROGRAM DOES NOT DO

Some of the items mentioned in this section are discussed more fully in the text. All of them possibly might better appear in a discussion and recommendation section following the text. However, they are placed here in order that the reader may peruse the rest of the text with the foreknowledge of what the program does and does not do.

The program uses the annual cost method rather than the present value method partly because it is simpler and partly because many of the programs with which this one will be tied are couched in the annual cost and ¢/Kgal terms rather than the present value terms.

The program does not compute the costs for each year's production as it occurs, presumably under some growth pattern. Instead, it computes a cost as if each day's flow were the average flow over the entire period, namely QBARE. Other studies of the authors have shown that this produces a cost which is lower than the true cost, but not much lower.

The program does not adjust for inflation during the project life. It computes all costs in "current year dollars"...i.e. if IYEAR is set to 1980 all costs will be in 1980 dollars.

The program does not stage the construction of facilities. It assumes that all facilities are constructed in a given year, the "current year," and of such a size as to meet the requirements in the target year, in this project 2000 A.D.

Pipe sizes and pump station horsepower are treated as continuous functions, not discrete functions as they are in actuality.

It is assumed that in any segment the hydraulic gradient created by equal size pump stations will at every point be higher than ground elevation. This might not actually be the case if the profile is not of constant slope throughout the segment. The most obvious of such violations is accounted for by the stipulation that no segment may have an intermediate high point which is higher than both the beginning and the ending elevation. This serves to break the pipeline into segments which are less likely to have the hydraulic gradient intersecting the ground elevation. Even in this case, difficulties are encountered when the segments consist of a relatively short lift segment followed by a segment with a small negative slope. This is more fully discussed at the proper point in the text.

The program does not take into account the higher pressure class of pipe which would be required at the bottom of a U-shaped profile, nor does it assign a pressure class other than 100 psi for gravity lines.

SYSTEM DESIGN

Pump Station Design Computations

The philosophy of the design model is to achieve the necessary total horsepower for pumping by using equally-sized pump stations. Previous work (38-44) has shown that for pump station costs, as well as most other investment costs, the lowest cost is achieved by using equal-sized units. Any departure from this so as to have unequal-sized units results in a higher cost. Real pipelines, of course, cannot achieve exactly equal-sized pump stations and to the extent this is not achieved real costs will be somewhat higher than those computed by the model.

Under this philosophy the pump station computations are as follows:

```
FRHDOT = 318.4346*FDOT*QDOT**2/DIAM**5
TDHDOT = FRHDOT+SLOPE
NUMSTA = (TDHDOT*PMILE/HDLIM+.99999)
PUMILE = PMILE/NUMSTA
HDSTA  = TDHDOT*PUMILE
HPSTAF = 0.175615*QDOT*DENS*HDSTA/EFF
HPSTAI = HPSTAF*FIRM
```

where:

- FRHDOT = Friction head at design capability, feet of fluid per mile
- FDOT = Moody friction factor at design capability
- QDOT = Design capability, mgd
- DIAM = Inside pipe diameter, feet
- TDHDOT = Total dynamic head, feet of fluid per mile
- SLOPE = Uniform slope of pipeline, feet/mile, (elevation difference/pipeline miles)
- NUMSTA = Number of equal-sized pump stations (truncated to "the least integer not less than")
- PMILE = Pipeline length, miles
- HDLIM = Head limitation on pump station, feet of fluid
- PUMILE = Interstation distance, miles
- HDSTA = Head per station, feet of fluid
- HPSTAF = Firm horsepower per station
- DENS = Fluid density, gm/ml
- EFF = Wire to water efficiency, fraction
- HPSTAI = Installed horsepower per station
- FIRM = Firming factor, ratio of installed horsepower to firm horsepower

The Moody friction factor, or rather the Moody correlation of the Darcy friction factor (45), is computed by a subroutine MOODY developed for this study, which generates the MOODY friction factor, over most of the range according to the Colebrook and White formula, and also generates the Reynolds number and the flow type, whether turbulent, transition, critical, or laminar. Since the Colebrook and White formula is non-explicit for the friction factor the subroutine uses an iterative procedure for solving the equation. The other parameters required in addition to the flow rate and the diameter are viscosity, VIS, and absolute roughness, EPS. The absolute roughness used in the exemplary computations is 0.0003 feet, corresponding to new or fairly new smooth concrete average workmanship or hot asphalt dipped or centrifugally applied concrete lined steel pipe, continuous interior butt welded (46).

The equations for density and viscosity given in the program listing cover the range from 4 to 36 degrees C (centigrade). The density equation exactly reproduces a five-place density tabulation with standard error of estimate being about $3x10^{-6}$. The viscosity equation has a standard error of estimate of about .0057 in millistokes, corresponding to about 0.05%. It is converted to viscosity in $feet^2$/second.

The wire-to-water efficiency used in the exemplary computation is 0.75.

The firming factor is taken as 2.0 at QDOT 1.0 or less, and 1.25 at QDOT 10.0 or more, Cartesian linearly interpolated between.

Types of Conveyance Situations

Depending upon the pipeline slope and the variations in required daily flow there exist four distinguishable types of conveyance situations. With the range of daily flows from QMIN the minimum to QMAX the maximum, whether or not pumping is required on a given day, that is at a given flow, depends upon the relative magnitudes of the friction head at that flow and the pipeline slope. The total head loss, feet/mile, is the algebraic sum of the friction head loss and the slope, both in feet/mile.

Consider the changing situations as a high positive slope is continually decreased. At any slope above zero pumping will be required on every day, that is at QMIN as well as QMAX, and the situation is termed "pumped." As the slope continues to decrease through zero and becomes slightly negative there is no change, in that pumping is still required on each day but the pumped flow is assisted by the gravity gradient and this situation is termed "pumped, gravity assisted" or "assisted pumped." Mathematically this is in no way different from the pumped situation. However, as the slope continues to become more negative it eventually reaches a condition at which the absolute value of the slope is greater than the absolute value of the friction head on the minimum day. Thus, on such days the sum of the friction head and the slope becomes negative and the energy requirement is zero. The conveyance situation under this circumstance is that gravity alone is adequate to convey the required flow on some days but not on all days and the situation is termed "gravity boosted." Finally, as static head continues to become more negative it reaches some magnitude such that absolute value of the static head is greater than the friction head even on the maximum day, i.e., on the design day. Beyond this pumping is not required on any day and indeed pump stations are not required. The energy consumption is zero and the situation is called "gravity."

Table 24 shows some of the characteristics of these types of conveyance situations as defined by the indicated relationships between slope and friction head, where:

FMIN = Friction factor for the minimum flow
FDOT = Friction factor for the design flow
QMIN = Minimum daily flow, mgd
QDOT = Design or maximum daily flow, mgd
DIAM = Inside pipe diameter, feet

For the gravity situation optimization is not required since the lowest cost is obtained at the pipe diameter which will make the friction on the maximum day just equal to the negative of the slope. Thus:

```
DIAMG = ((318.4346*FDOT*QDOT**2/(-SLOPE))**.2
```

where:

DIAMG = Diameter of the smallest line that will just suffice on the maximum day

For the other three situations optimization is required.

It will be found that for the pumped and pumped gravity assisted conveyance types the optimum diameter of the pipeline is practically independent of the slope. The very small dependency that does occur results from the somewhat erratic effect of pump station horsepower on pump station OMR as used in the program.

In the gravity, boosted conveyance type if the slope lies in the range between the QMIN and the QDOT term (i.e. if the slope is not simply the negative of the QMIN term), then there will be days in which the friction head is less than the negative of the slope, and on those days the TDH becomes negative. Since the energy term in the energy summation is proportional to TDH these days would appear in the summation as negative energy days. Of course, the correct energy consumption in such days is zero and such TDH values must be returned to zero.

TABLE 24

TYPES OF CONVEYANCE SITUATIONS

Range of Slope	Type of Conveyance	Optimization Required	Is Optimum Diam. Dependent on Slope?	Pump Stations	Cost Equation
$+\infty$ to 0	Pumped	Yes	No	Yes	As written
0 to $-318.4346\ FMIN \frac{QMIN^2}{DIAM^5}$	Pumped, Gravity assisted	Yes	No	Yes	As written
$318.4346\ FMIN \frac{QMIN^2}{DIAM^5}$ to $-318.4346\ FDOT \frac{QDOT^2}{DIAM^5}$	Gravity boosted	Yes	Yes	Yes	Modified*
$-318.4346\ FDOT \frac{QDOT^2}{DIAM^5}$ to $-\infty$	Gravity	No	Yes	No	Modified*

*Modification consists of replacing negative total dynamic heads with zero in the summation term.

$$318.4346 = \frac{5280}{.6463229 * 2g\left(\frac{\pi}{4}\right)}$$

.6463229 = conversion cfs to mgd

g = 32.17398, standard gravity

The relations shown in Table 24 are explicit and give sharp demarcations between conveyance types for a given diameter. However, the problem is to determine which coneyance type is the cheapest at the optimum diameter. For the trivial transition between pumped and pump assisted the decision is clear since it merely involves whether the slope is positive or negative. However, for the other two transitions between gravity and gravity boosted and between gravity boosted and pumped assisted, under certain conditions even high precision computer optimization breaks down in making the decision. Under these conditions the present program utilizes a small area of tolerance in making an arbitrary decision and does not arrive at a mathematically precise transition. However, the area of tolerance is so small as to be inconsequential in the practical application.

Q Variable and Q Constant

The discussion up to this point has involved the real situation in which the daily flows are varying. However, this would involve an integration over the varying flows in computing the energy cost. To avoid this degree of complexity the present program substitutes for the real situation a simplified situation in which the flow on each day is held constant at the average flow value, QBARE, where QBARE is the average flow expected over the project period. However, the pipeline is designed so that the system can achieve the design flow, QMAX. Since the energy cost is proportional to the cube of the flow, the cost for the simplified model with Q constant will always be less than the cost computed with the real model with Q variable. However, the authors (40) have tested this approximation by comparing the costs for a Q constant model against those for a Q variable model in which the variability is among the highest occurring in real water conveyance systems. It was found that the Q constant model produces costs which are for most slopes within 5% of the extreme Q variable model. The discrepancy reaches as high as 10% at slopes in the vicinity of zero. As slopes decrease in the direction of the gravity line the discrepancy decreases until it vanishes for the gravity line, since the energy term drops out. Likewise, as slopes increase to high positive values most of the energy cost becomes that for overcoming the static head and the discrepancy again approaches zero. Most water conveyance variabilities do not approach the extreme used in the comparison and the simplified model accordingly provides a satisfactory approximation for the intended purposes. (It is intended later to incorporate the Q variable model in the program.)

In terms of the simplified model then the conveyance types have the following strict meanings. For the gravity situation there are no pump stations and no energy is expended on any day. For the pumped and pumped assisted situations there are pump stations and energy is expended on each day, the energy being that required for a flow of QBARE. For the gravity boosted situation pump stations are required (in order to have the capability of meeting the maximum day) but no energy is expended on any day. The pump station capital charge and the pump station OMR costs are incurred.

A common occurrence in pipeline profiles comprises a rather short segment to an intervening high point followed by a longer segment of negative slope. If it should turn out that the negative slope section is optimum as a gravity line while the positive slope section is, of course, the pumped type then the program accepts that situation. However, if the negative slope segment should turn out to be a pumped assisted or boosted line then the program provides a small pump station for the positive slope segment and one or more pump stations for the negative slope segment. In that case it would in general prove cheaper to consider the line as a single segment in which the hydraulic gradient at the beginning is great enough so as to exceed the elevation of the intervening high point at that high point. This would make the pump stations of equal size in the program design and more nearly of equal size in the real design.

The present program does not explore that alternative since it is one of a number of problem situations relating to the proper gradients for and segmenting of pipelines for real terrain profiles which hopefully may be tackled in a more detailed future version of this program. Meanwhile for such profiles as described above the costs generated will be in error by being slightly too high.

Optimization Strategy

The strategy used in selecting the cheapest pipeline is as follows. If the slope is steeper than -50 feet/mile it is judged that there is practically no chance that a boosted line would be economic and only the gravity line is computed. If the slope is greater than zero feet/mile only a pumped line will suffice and only a pumped conveyance type is computed. If the slope is negative between 0 and -50 feet/mile the gravity line is first computed and then the line with pump stations is computed, a process involving optimization and which may result in a boosted or an assisted conveyance type. If the optimization search does not find a cost less than 110% of the gravity cost in eight iterations it is concluded that the optimization is homing in on a value which cannot be as low as the gravity line.

Accordingly, the search is terminated at eight iterations and the gravity line selected. If the optimization search produces any cost less than 110% of the gravity cost there is judged to be a possibility that the ultimate optimum will be less than the gravity cost and accordingly the optimization search is continued to the convergence. If the so-located optimum shows a cost less than the gravity line it is selected.

Pipeline Investment

A concurrent study (47) correlates the investment costs trended to 1968 for some 825 pipelines and presents equations and cost index factors by which the investment in a pipeline can be estimated for any diameter and any of the 21 regions. It is shown that there are large regional differences in costs of pipelines which must be taken into account in estimating the cost of conveyance. The equations reduce to the three relations in Statements 300-304 of the Program which also include the regional and temporal cost adjustments and the special regional pipeline cost adjustment.

The σ ratio for the correlation is approximately 1.3. A correlation is also given for the cost of offshore pipelines, but this is not included in the program since very few water conveyance systems will be submarine.

The parameter CONSFAC (construction factor) is provided to permit an engineering judgment on the deviation of estimated costs for a particular installation from the median costs given by the equations. Thus, for example, setting CONSFAC at 1.3 will produce a cost which is on the average exceeded by only 16% of the pipelines in the basic data. The user is cautioned against using the construction factor intuitively as a regionalization factor. The cost index system already takes into account the fact that pipelines in the Boston region cost 2.5-3 times as much as those in the Denver region. The CONSFAC is to be used to adjust for costs which are atypical within a given region. The user is also cautioned against over emphasizing the right-of-way costs in setting a CONSFAC. As shown in the reference, right-of-way costs in general are but a small portion of total pipeline investment. If right-of-way costs were increased tenfold over the average the cost of pipelines would only be doubled over the average.

Only a small fraction of the mileage represented by the 825 pipelines in the basic data occurs in urbanized territory, so that overall the construction factor should be greater than 1.0 for water lines in urbanized territory. But in urbanized regions as, for example, the Boston region, a greater fraction of the pipelines in the basic data occur in urbanized territory as compared with an open country area such as Denver or Atlanta. Accordingly, the construction factor for urbanized territory for the Boston region should probably be lower than would be the construction factor for urbanized territory in the Atlanta region. The authors can give no firm guidelines for construction factors in urbanized territory. However, a construction factor of 2.0 represents a cost which is exceeded by only about 8% of the pipelines in a given region.

The reference shows that down to two or three miles there is no effect of length on unit investment, a constancy that must break down, of course, at very short distances.

Pump Station Investment

Earlier studies (40) developed a correlation of pump station investment as a function of installed wire horsepower. This relation with appropriate cost index adjustments is found as Statement 452 in the Program.

It is recognized that major factors influencing pump station investment are not only horsepower but also TDH (total dynamic head) and firming factor. Since the above relation was developed other authors have developed correlations which take some of these into account. However, some of these are not supported by actual data in the publications; others have used firm capability rather than installed capability in the correlation; and it was felt that the subject really required rather an intensive review using actual investment as installed. This was judged too big a task for the present purposes, particularly since pump station investment is generally a rather small fraction of total investment in a conveyance system and makes a relatively small contribution to the cost.

Pump station price is trended by the USBR (United States Bureau of Reclamation) Pumping Plant Building and Equipment Cost Index and regionalized by the BCI (Engineering News Record Building Cost Index).

OMR on Pipeline

The correlation used for OMR (operation, maintenance, repair and minor replacement) on pipeline is from earlier work (40) admittedly based on rather poor data. However, the contribution of OMR on pipeline to total cost is quite small and a greater degree of accuracy is probably not warranted. The relations are given in Statements 314-335 in the Program. A terrain factor (TERFAC) of 1.0 represents good terrain conditions for maintenance in relatively open country and ready access. Suggested terrain factors for other conditions are:

Medium marsh	2.0
Bad swamp	3-6
Mountainous	(5)

An appropriate terrain factor for urbanized territory is difficult to assign. A provisional suggestion is 1.2 for that mileage in urbanized territory.

The OMR costs are average over the pipe lifetime. Appropriate factors, not used in the program, for other ages are suggested as:

New lines	0.2
10 years old	0.7

Pump Station Operation and Maintenance Costs

The Bureau of Reclamation (48) studied 174 pumping plants ranging in size from 5 to 15,000 horsepower and concluded from the data that annual operation and maintenance costs can best be estimated by considering operation costs and maintenance costs separately.

Multiple correlation against a number of possible parameters indicated that the factor having the most influence on operation costs are attendance (whether unattended, semi-attended, or attended), station capability, design TDH, and length of the operating season. The last of these refers to the operation of particularly irrigation pumping plants during only the irrigation season. For maintenance costs the significant parameters were station capability (mgd), station horsepower and annual water pumped.

The maintenance and operation covered are for the pumps, motors, accessory electric equipment, miscellaneous equipment, and the plant structure. The costs do not include the operation and maintenance costs for the intake channel or the G&A (general and administration) expenses. More details on definitions and coverage will be found in the reference.

The nomographs and the equations presented in the reference were translated into a portion of the computer program, Statements 453-504 in the Program. The basic computations allow for selection of any degree of attendance with any horsepower. The present program assumes an unattended plant if installed station HP (horsepower) is 450 or less, a semi-attended plant if it is 5,000 or less and an attended plant if it is greater than 5,000. If the installed station horsepower is over 15,000 a different relation is used as explained in the reference and incorporated in the program. The program, of course, takes the season as 52 weeks per year, i.e. continuous operation. The labor portion of the O&M (operation and maintenance) costs is trended with the Labor Cost Index; the non-labor costs are trended with the Maintenance Cost Index.

Energy Costs

A Function Subroutine CKWH generates (if a ¢/Kwh electric rate is not prescribed with GVCKWH), the average electric rate for the state, the year, and the Kwh/yr consumption. The base state averages for industrial service 200,000 Kwh/mo and 1,000 Kwh demand are the January 1, 1969 state averages from Reference 49.

The adjustment for future year is by the Energy Cost Index from COSTN described beyond. The adjustment for consumption level measured by Kwh/yr was obtained by averaging the relation between cumulative ¢/Kwh and Kwh/yr obtained from a variety of electric utilities (50). This study was facilitated by a program, ELECTR, which may be of interest to some readers. It gives the cumulative ¢/Kwh effective unit price for any or any series of Kwh/mo consumptions at any load factor, from input data consisting of the block limits and block rates for Kwh and for Kw demand taken from the typical electric utility rate schedules as found for example in the National Electric Rate Book.

Incidentally, this ELECTR study revealed that it is necessary to use caution in interpreting rate schedules. Just because a rate schedule contains a lowest energy charge of .3 in the highest consumption block does not mean that the cumulative energy price will become asymptotic to three mils as energy consumption becomes very large. The rate schedules in general contain fine print that cause the asymptote rate to be considerably higher than the lowest rate in the schedule. It is not at all unusual that a rate schedule containing a three mil block actually does not allow the cumulative rate to become less than seven to eight mils.

The Cost Index System

COSTN is a Function Subprogram providing regional and temporal cost indexes which are used to adjust historical data to some common year and to adjust regional data to a national average. This subprogram will ultimately incorporate all cost indexes which are useful in chemical and water and waste process costing. The regionalized indexes in COSTN which are used in the present program are the 21 region BCI, and a pipeline adjustment factor (47); and from the non-regionalized indexes there are used the composite pipeline cost index, the electric energy cost index, the pumping plant cost index, the maintenance cost index, and the average hourly earnings in manufacturing.

The Function COSTN returns an index projected for a future year. All the indexes have been subjected to a time trend analysis. In general, it was found that the cost indexes over the past 20 years can be remarkably well represented by a Cartesian linear relation from which there are found two types of anomalies. One group of indexes has a hiatus in the period about 1960 to 1965 in which the index does not increase very much, and thereafter increases at about the same slope as before the hiatus. In these cases the projection has been made by dropping the hiatus years, in effect shifting the prior years upward in time by the amount of the hiatus such that the new set of points define a line with the same slope as before and after the hiatus.

In the other type of anomaly the reverse has occurred. Beginning somewhere in the period 1965 to 1968 many indexes have taken a sudden upward turn. This is true of all the BCI, some to an extreme degree. Since there are not enough historical years to establish a new slope or level or both if such is to be, it is very risky to make a projection. The present projections use this device: the projection has the level of the actual 1969 value at the year 1969 and has the slope of the regression line 1948 to 1968.

The energy cost index returned by COSTN is the projection of the national average cost for industrial electric service 200,000 Kwh/mo and 1,000 Kw demand (49).

RESULTS OF EXEMPLARY COMPUTATIONS

Following this section are the program listing, the variable names and instructions for running the program.

Conveyance Cost in Horizontal Lines

The characteristics of conveyance in a horizontal pipeline at a utilization factor of 0.5 under average U.S. conditions are shown in Table 25. The contribution of each of the five cost elements is shown in Figure 32.

TABLE 25

CHARACTERISTICS OF OPTIMIZED CONVEYANCE IN HORIZONTAL PIPELINES (1968, National, UBARE = 0.5)

	Average conveyance rate, mgd				
	.1	1	10	100	1000
Optimum pipe diameter, inches	5	11	32	86	220
Pump-station spacing, miles	12.5	8.3	25	33	50
Investment ¢/mile/gpd capability					
Line	8.5	2.3	0.90	0.32	0.12
Total	9.4	2.7	0.96	0.36	0.14
Conveyance cost, ¢/Kgal/mile	3.9	1.2	0.41	0.16	0.070

Contribution of Cost Elements to Conveyance Costs
Horizontal Lines, 1968, National

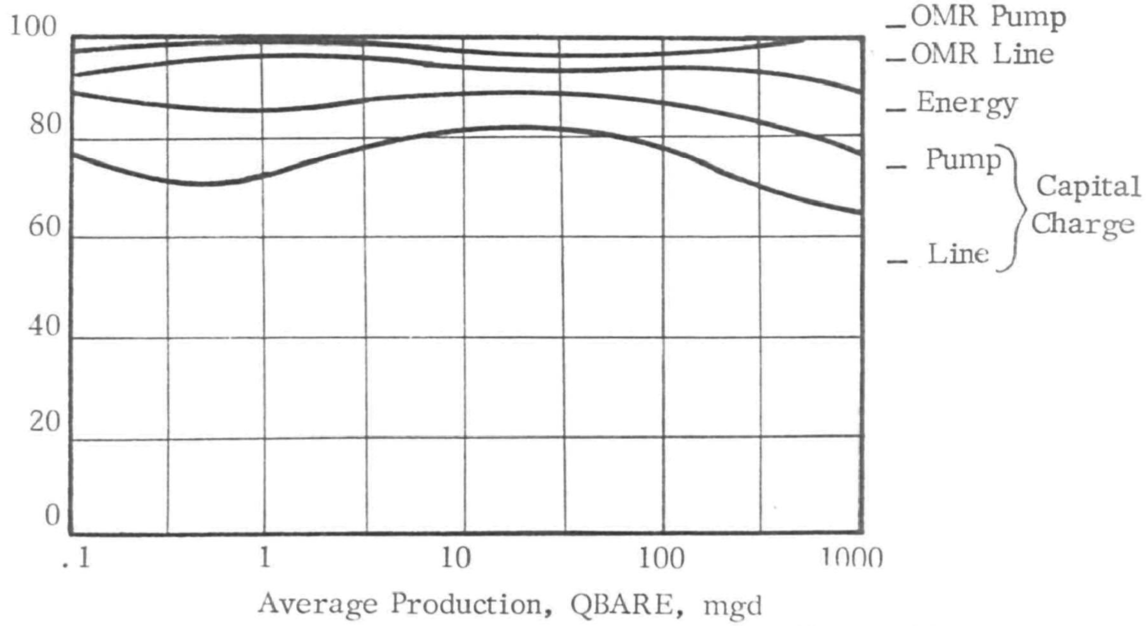


Figure 32

Parameters which enter into the conveyance cost are water temperature, pipe roughness (in computations herein taken as 0.0003 ft), pump-station efficiency (taken as constant at 0.75), firming factor (amount of emergency standby pump-station capability), over-all pipeline slope, and utilization factor (ratio of average conveyance rate to design capability). The sensitivity of conveyance cost to most of these parameters is quite small, a 100% change in parameter value bringing about only a few percent change in conveyance cost. The parameters to which conveyance cost is sensitive to a degree greater than this are pipeline investment, slope, utilization factor, and energy price.

As a determinant of conveyance cost, the price of electric energy is much less important than is generally believed, for the cost for energy is not an important factor in the total conveyance cost, except when the pipeline has a high positive slope, and then it becomes dominant only at high conveyance rates.

The effect of utilization factor on optimized costs in a horizontal line is also not very great. Over the range reasonable in municipal and industrial practice, the optimized cost change from UBARE = 0.5, with utilization factors between 0.4 and 0.7, would be less than $\pm$ 9%. These differentials should not be confused with the differential between the conveyance cost in a line optimized at one utilization factor and then operated at a different utilization factor.

Conveyance Cost in Inclined Lines

The deviation from horizontality in a pipeline is an important parameter affecting conveyance costs. Actual pipelines follow the profiles of the land, but for approximate cost computation it can be shown that every pipeline can be expressed as a two-section line, of which the one-section line is a special case. The upstream section is that from the beginning to the highest intermediate point higher than the beginning. The downstream section is from the highest intermediate point to the terminus. The model pipeline thus has two sections, the first having a positive gradient, the second a negative gradient, and either one of the two sections may be missing. Conveyance costs must be computed separately for each section, although for lines several hundred miles in length, the cost will rarely differ by more than 25% from that for a horizontal line. The program also allows segmenting of the line in other ways, so long as in any segment no intermediate high point is higher than both ends.

For a line having a positive gradient, or a negative gradient of small magnitude (such that it falls within the pumped or pumped gravity-assisted regions of Figure 34), the additional conveyance cost over that for a horizontal line is closely proportional to the slope (at constant energy price). The proportionality constant is the cost of raising a million gallons one foot, and this is termed the cost of static lift. Figure 33 shows the cost of static lift at various average conveyance rates and utilization factors, and at constant energy price of 1.5¢/Kwh. Above one mgd the cost of static lift is practically constant, and the cost in cents of raising 1,000 gallons 1,000 feet is about six times the ¢/Kwh energy price.

Note, however, that the present program lowers the energy price as annual energy consumption increases. Under these circumstances the cost of static lift reflects the changing price of energy, such that the cost of static lift decreases both as the slope increases and as the flow increases, since both of these result in higher energy consumptions and thus lower energy prices. As an example, Table 26 shows the cost of raising 1,000 gallons 1,000 feet at various QBARE. Quantitatively, the effect of slope at constant flow on the cost of static lift is small and somewhat erratic because of the optimization. The effect of flow on the cost of static lift in the ranges used is major and while the differences are reduced by optimization, they are far too large to be reversed.

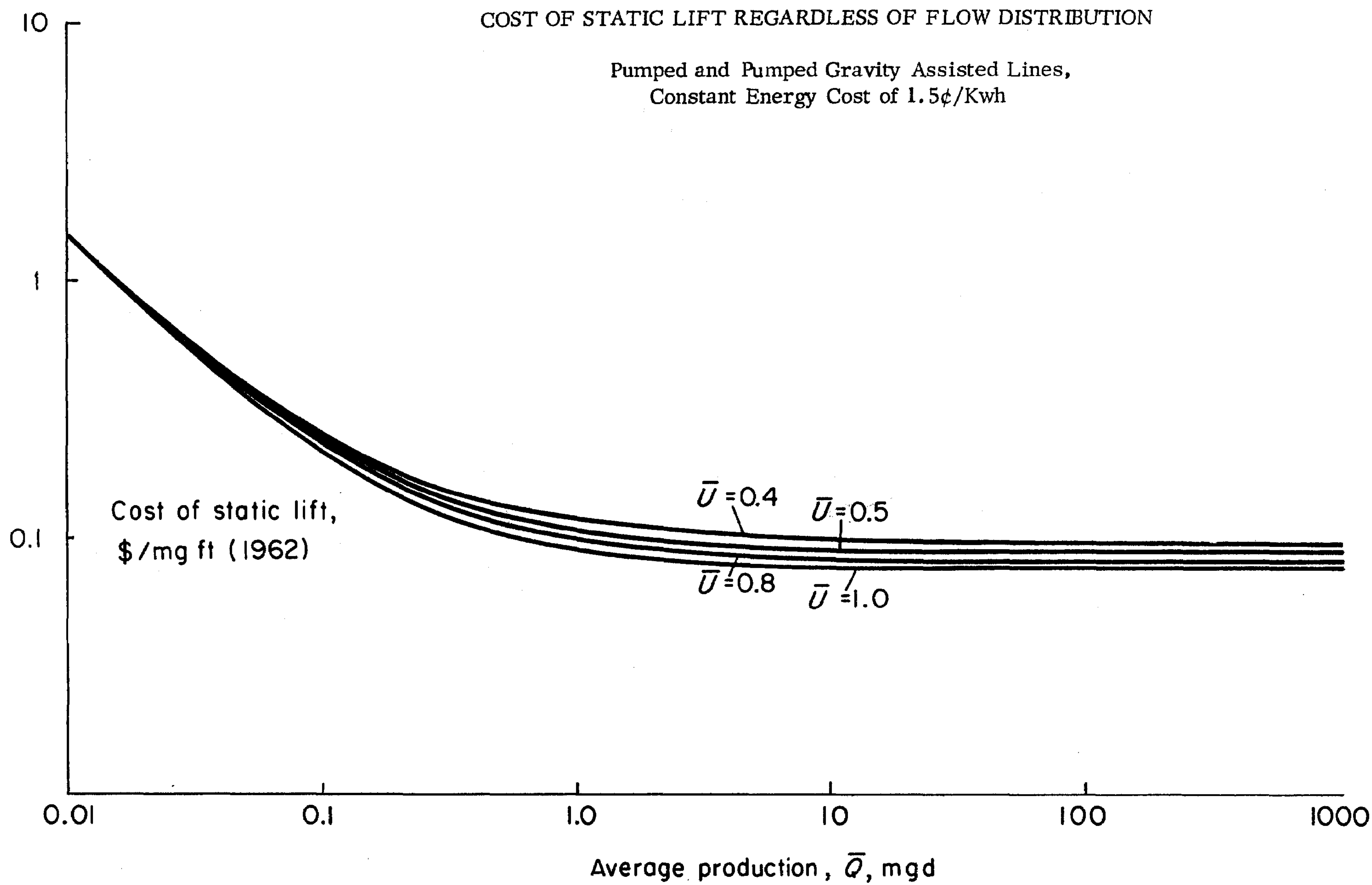

COST OF STATIC LIFT REGARDLESS OF FLOW DISTRIBUTION
Pumped and Pumped Gravity Assisted Lines,
Constant Energy Cost of 1.5¢/Kwh
10
1
0.1
Cost of static lift,
$/mg ft (1962)
$\bar{U}$ =0.4
$\bar{U}$=0.5
$\bar{U}$=0.8
$\bar{U}$ =1.0
0.01
0.1
1.0
10
100
1000
Average production, $\bar{Q}$, mgd

Figure 35

TABLE 26

EFFECT OF CONVEYANCE RATE ON COST OF STATIC LIFT
(With energy price varying)
(National, 1968, UBARE = 0.5)

QBARE mgd	Cost ¢/mg ft
.1	43.6
1	15.2
10	10.9
100	8.0
1,000	6.5

This static lift proportionality is not maintained in regions of negative slope labeled gravity and gravity boosted on Figure 34. This figure shows the effect of slope on conveyance cost at a series of average conveyance rates, computed at a utilization factor of 0.5. Figure 35 shows the contribution of the five cost elements at a high-positive and a high-negative value of slope. It is important to note that at high positive slopes energy cost displaces the fixed charges on the pipeline as average conveyance rate is increased. This means that at high slopes and at high capabilities it is the price of energy rather than the pipeline investment which is a major contributor to conveyance cost.

Effect of Pipeline Length

The cost of conveyance is directly proportional to the conveyance distance except at quite small distances, at which it is somewhat greater than the per-mile costs illustrated herein mostly because of the high unit price of the small pump stations. The distance at which this effect begins is about three miles at two mgd capability and one mile for 20 mgd and higher. The program itself correctly computes the costs even at these short distances, but it does so on the basis that the unit investment for line is unchanged at short distances. This has only been demonstrated down to two to three miles. At some unknown distance, less than this, this must no longer be true.

Conveyance Costs in the Future

The COSTN subroutine allows the projection of the cost of conveyance at future dates. Table 27 shows the costs predicted by this program for the conveyance of 100 mgd at UBARE = 0.5 in the next three decades. For a plant built in 2,000 both the unit investment and the conveyance cost will be almost double that for a 1970 plant in current year dollars.

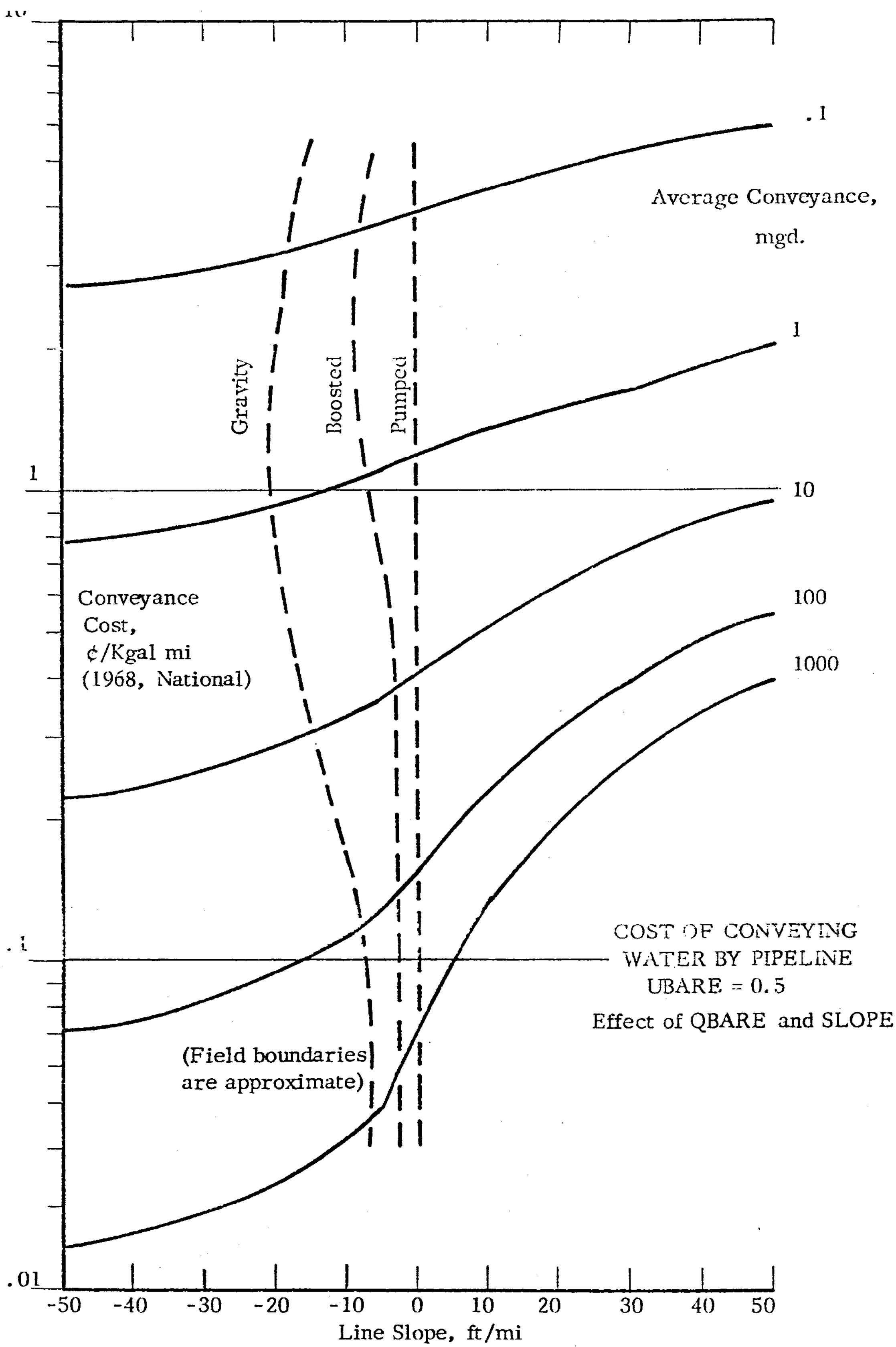
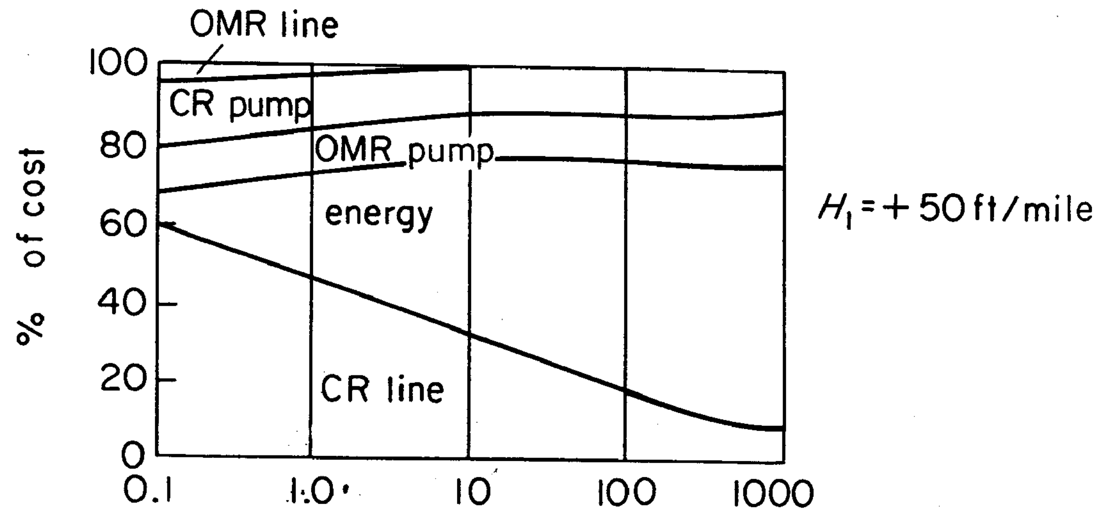
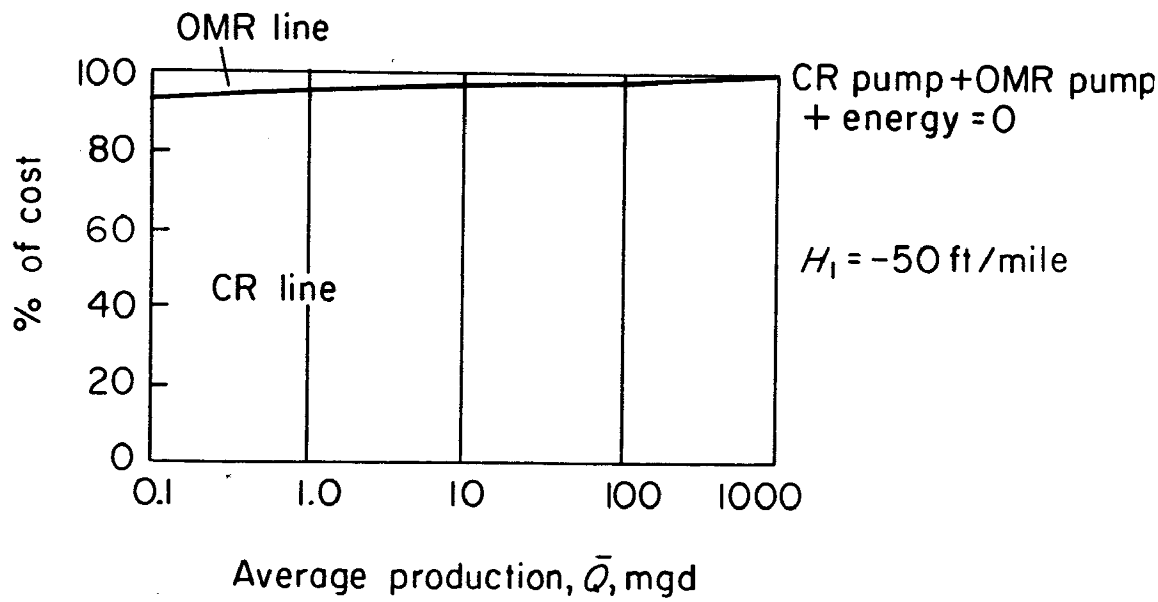

.1
Average Conveyance,
mgd.
1
10
100
1000
Gravity
Boosted
Pumped
1
.1
.01
Conveyance
Cost,
¢/Kgal mi
(1968, National)
COST OF CONVEYING
WATER BY PIPELINE
UBARE = 0.5
Effect of QBARE and SLOPE
(Field boundaries
are approximate)
-50
-40
-30
-20
-10
0
10
20
30
40
50
Line Slope, ft/mi

Figure 34


OMR line
CR pump
OMR pump
energy
CR line
% of cost
100
80
60
40
20
0
0.1
1.0
10
100
1000
H_1 = + 50 ft/mile

(a)


OMR line
CR pump + OMR pump + energy = 0
CR line
% of cost
100
80
60
40
20
0
0.1
1.0
10
100
1000
H_1 = −50 ft/mile
Average production, $\bar{Q}$, mgd

(b)

Figure 35

TABLE 27

COSTS OF CONVEYANCE IN FUTURE YEARS
Horizontal Line, 100 mgd, UBARE = 0.5, National

	1970	1980	1990	2000
Investment, ¢/gpd mile	.328	.427	.526	.625
Conveyance, ¢/Kgal mile	.147	.188	.229	.270

<u>Comparison With an Actual Engineering Estimate</u>

When the PIPELIN program was used for the San Antonio computations a comparison was made between the PIPELIN costs and the costs developed by a preliminary engineering study of a conveyance system, the Cuero-Cibolo-Hildebrand link of the Texas Water Plan, which had been made by a consulting engineering firm (51). The comparison is discussed in more detail in Chapter 6 of the report but it is briefly mentioned here since it bears on the accuracy which may be expected out of PIPELIN.

The engineering study laid out an actual route and designed a pipeline and pump station system under a set of ground rules laid down by their client. PIPELIN was run with the same basic data. The corresponding 1969 costs of the two studies were as follows:

QBARE	Conveyance Costs ¢/Kgal	
	Engineering Study	PIPELIN
100,000 afy	7.15	6.72
200,000 afy	5.72	5.70
300,000 afy	5.05	5.45

This information is presented here simply to illustrate the confidence that can be placed in PIPELIN costs as reproducing costs from rather detailed preliminary engineering studies which include field studies, map routing, topographic and geologic profiles, and item-by-item preliminary cost estimating. The firm demonstration of confidence, of course, would require many such comparisons in various regions of the country.

INSTRUCTIONS FOR RUNNING PROGRAM PIPELIN

This program is set up to run in Fortran IV on a CDC 6400 computer. There are about 900 cards. The compile time is about 11 CPU seconds and six peripheral seconds, the execute time about three and three resp. The program will compile with a core memory of 60,000 60-bit words. It will execute from a compiled program or binary deck with 22,000 core words.

The main set of data cards are those numbered 1 to 11 on Page 203. The data deck structure is shown on Page 204. The program can be manipulated to iterate successive cases with new values of one of the data cards by inserting additional data cards 12, 13, etc. and using the proper values for LOOP. The values read from the data cards are shown on the next page. Card 7 comprises actually a set of cards, one for each segment. (If the number of segments is greater than one then an instruction for a short printout will abort the run.) If it is desired to run just a single case without looping the LOOP card should be punched as one. The program also will not loop, i.e. will compute only one case, if LOOP is set at 2, 3, 4, , 6, or 10.

With LOOP at 5, 7, 8, 9, or 11 the program will return after the first case and read the next card in the deck, 12, 13, etc. With each auxillary card or card set so read it will compute one case and continue to return until the deck is exhausted, increasing the case number by one on each iteration. It is not possible in a single run to loop on more than one type of data, i.e. on more than one data card number. For example, a series of cases can be run in which the QMAX is varied (Card 8) and in a separate run a series of cases can be run in which DEGC is varied (Card 11). But it is not possible to iterate varying both QMAX and DEGC at the same time.

When looping is used the data on the new card is printed out just prior to the new case number. (This print is not suppressed with IPRINT(6).)

Data Card No.		Format No.
1	Run no.	101
2	LOOP 1, 2, 3, 4, 6, 10...will not loop 5, 7, 8, 9, 11...loops on data in corresponding data card number by reading cards 12, 13, etc.	101
3	This data card number not used	
4	IPRINT(6) zero suppresses; 1 prints: (1) parameters imposed (2) parameters of the optimized design (3) cost breakdown (4) short printout (5) search iterations out of OPTIM (6) data cards 1 to 11	85
5	STATE, NMSTAT, NREG, IYEAR	95
6	NUMSEG	101
7	One card for each segment	
7a 7b etc.	PLMILE(I), ELEVB(I), ELEVE(I), TERFAC(I), CNSFAC(I)	111
8	QMAX, QBARE, QBARA, QMIN	111
9	PLLF, PULF, BASCL, RET	111
10	TX, XINS, PRLAB, PYEX	111
11	GVCKWH, DEGC, HDLIM, EFF, EPS	111
12 13 etc.	Data for subsequent cases in loop chosen	

____ 7/8/9

____ 6/7/8/9

IBM FORTRAN Coding Form

X28-7327-6 U/M 025
Printed in U.S.A.

PROGRAM	PIPELIN
PROGRAMMER	DATA DECK STRUCTURE
DATE	7/28/70, LK
PUNCHING INSTRUCTIONS	GRAPHIC / PUNCH
PAGE	OF
CARD ELECTRO NUMBER*	

Card	Variables	Format / Notes
1	NRUN	I2
2	LOOP	I2 — 0, 5, 7, 8, 9, 10, 11 - VALID. Case Looping is possible on circled cards only. ○
4	IPRINT(I)	I6
(5)	STATE, NMSTAT, NREG, IYEAR	I2, 2A7, I2, I4
6	NUMSEG	I2
(7)	PLMILE(I), ELEVB(I), ELEVE(I), TERFAC(I), CNFAC(I)	one card for each segment
(8)+	QMAX, QBARE, QBARA, QMIN	
(9)+	PLLF, PULF, BASCL, RET	
(10)+	TX, XINS, PRLAB, PYEX	
(11)+	GVCKWH, DEGC, HDLIM, EFF, EPS	

Cards 1–11: Main Data Deck

---- Follow with cards for loops — Loop Data Deck

*A standard card form, IBM electro 888157, is available for punching statements from this form

SAMPLE PRINTOUT

```
----RUN NO.  8 ----
----DATA CARDS----
  1
111011
41TEXAS            81969
  2
     34.2000   242.5000   480.1000      1.0000   1.000000
     38.3000   480.1000   870.0000      1.0500   1.050000
    230.0000   149.0000   149.0000    149.0000
     75.0000    25.0000   100.0000      .0450
      .0100      .0100     3.0000      .4500
     0.0000    21.5000   300.0000      .7500     .000300

----CASE NO.  1 ----

            PARAMETER VALUES IMPOSED

YEAR OF ESTIMATE      1969
STATE          TEXAS

REGION NUMBER             8

                         SEGMENT 1       SEGMENT 2       SEGMENT 3

MILEAGE                    34.2000         38.3000
TERRAIN FACTOR              1.0000          1.0500
CONSTRUCTION FACTOR         1.0000          1.0500
SLOPE, FT/MILE              4.6082         11.2245

DESIGN CAPABILITY                  230.0000      MILLION GALLONS/DAY
EXPECTED AVERAGE PRODUCTION        149.0000      MILLION GALLONS/DAY
ACTUAL AVERAGE PRODUCTION          149.0000      MILLION GALLONS/DAY
MAXIMUM DAILY PRODUCTION           230.0000      MILLION GALLONS/DAY
MINIMUM DAILY PRODUCTION           149.0000      MILLION GALLONS/DAY
PIPELINE LIFE                       75           YEARS
PUMPSTATION LIFE                    25           YEARS
INTEREST RATE                        .0450       FRACTION/YEAR
INSURANCE RATE                       .0100       FRACTION/YEAR
TAX RATE                             .0100       FRACTION/YEAR
LIMITING HEAD PUMP STATIONS        300.0000      FT. OF FLUID
TEMPERATURE OF WATER                21.50        DEGREES C.
LABOR PRICE                          3.00        DOLLARS/HOUR
GIVEN ENERGY PRICE                   0.000       CENTS/KWH
PAYROLL EXTRAS FACTOR                .4500       FRACTION
```

PARAMETERS OF THE OPTIMIZED DESIGN

		SEGMENT 1	SEGMENT 2
CONVEYANCE TYPE		PUMPED	PUMPED
OPTIMUM PIPE DIAMETER I.D.	INCHES	68.4498	83.4473
MAXIMUM PRESSURE CLASS	PSI	150.0000	150.0000
NUMBER OF PUMP STATIONS	STATIONS	2	3
HEAD, PUMP STATION	FT. OF FLUID	221.3884	286.8592
INTERSTATION DISTANCE	MILES	17.1000	12.7667
DESIGN INSTALLED HP	HP/STATION	14992.4598	19426.1518
DESIGN REYNOLDS NUMBER		5.8595E+06	6.2144E+06
FLOW TYPE, DESIGN		TRANSITION	TRANSITION
FLOW TYPE, AVERAGE		TRANSITION	TRANSITION
OPTIMUM VELOCITY, DESIGN	FT./SEC.	8.3398	9.3706
VELOCITY, AVERAGE	FT./SEC.	5.4028	6.0705
DESIGN FRICTION HEAD	FT./MILE	8.3385	11.2448
AVERAGE FRICTION HEAD	FT./MILE	3.5855	4.8263
ENERGY PRICE	CENTS/KWH	.9815	.9560

COSTS BREAKDOWN

INVESTMENT

	K DOLLARS	PERCENT OF TOTAL	CENTS/GPD CAPABILITY	CENTS/GPD PRODUCTION
PIPELINE	56524.37	83.452	24.576	37.936
PUMPSTATIONS	11208.43	16.548	4.873	7.522
TOTAL	67732.80	100.	29.449	45.458
PER MILE	934.25		.496	.627

PRODUCTION

	ANNUAL K DOLLARS	UNIT COSTS CENTS/KGAL	PERCENT OF TOTAL
OMP ON PIPELINE	188.46	.346	2.593
OMP ON PUMPSTATIONS	348.42	.640	4.794
ENERGY	1979.24	3.637	27.232
TOTAL OPERATING COSTS	2516.12	4.623	34.619
CAPITAL CHARGE ON PIPELINE	3771.36	6.930	51.890
CAPITAL CHG ON PUMPSTATIONS	980.05	1.801	13.485
TOTAL PRODUCTION COSTS	7267.96	13.355	100.
PER MILE		.184	

```
      PROGRAM PIPELIN(INPUT,OUTPUT,TAPE5=INPUT)
C
C
      EXTERNAL FUNC2
      INTEGER STATE,FMT
      COMMON/MOOD1/VIS,EPS
      DIMENSION PLMILE(4),ELEVB(4),ELEVE(4),TERFAC(4),ARRAY(7),
     +GPDC(22),GPDP(16),CNSFAC(4)
      DIMENSION SEGMNT(4,25),IPRINT(6),PC(22),NMSTAT(2)
      DIMENSION CNTYPE(4),FLTYPE(4)
      DIMENSION HWCK(4)
      DATA FLTYPE/10H   LAMINAR,10H  CRITICAL,10HTRANSITION,10HTURBULENT
     + /
      DATA CNTYPE/10H   GRAVITY,10H   BOOSTED,10HASSIS PUMP,10H    PUMPE
     +D/
      ARRAY(3)=1.
   30 READ (5,101) NRUN
      PRINT 40,NRUN
   40 FORMAT(1H1,///,10X,*----RUN NO. *,I2,* ----*)
      READ (5,101) LOOP
      L=LOOP-4
      NSET=1
      READ (5,85)IPRINT
85     FORMAT(5X,6I1)
      READ (5,95) STATE,NMSTAT,NREG,IYEAR
95     FORMAT(5X,I2,2A7,I2,I4)
      CYMNI = COSTN(20,0,IYEAR)
      READ (5,101) NUMSEG
101    FORMAT(5X,I2)
      IF(IPRINT(4)*NUMSEG-1)102,102,2110
2110   PRINT 2115
2115   FORMAT(1H1,*--MORE THAN ONE SEGMENT,SET IPRINT(4)=0 FOR
     + LONG PRINTOUT---*)
      STOP
  102 DO 110 I= 1,NUMSEG
110    READ(5,111)PLMILE(I),ELEVB(I),ELEVE(I),TERFAC(I),CNSFAC(I)
  111 FORMAT (5X,4F10.4,F10.6)
      READ (5,111)QMAX,QBARE,QBARA,QMIN
      READ (5,111)PLLF,PULF,BASCL,RET
C.....CY LABOR PRICE TRENDING IS BASED ON PRLAB BEING THE 1968 PRICE....
      READ (5,111)TX,XINS,PRLAB,PYEX
      READ (5,111)GVCKWH,DEGC,HDLIM,EFF,EPS
      IF(IPRINT(6))117,117,115
  115 PRINT 118
  118 FORMAT(3X*----DATA CARDS----*)
      PRINT 101,LOOP
      PRINT 85, IPRINT
      PRINT 95,STATE,NMSTAT,NREG,IYEAR
      PRINT 101,NUMSEG
      DO 116 I=1,NUMSEG
  116 PRINT 111,PLMILE(I),ELEVB(I),ELEVE(I),TERFAC(I),CNSFAC(I)
      PRINT 111,QMAX,QBARE,QBARA,QMIN
      PRINT 111,PLLF,PULF,BASCL,RET
      PRINT 111,TX,XINS,PRLAB,PYEX
      PRINT 111,GVCKWH,DEGC,HDLIM,EFF,EPS
```

```
  117 CONTINUE
      NTIMES = 0
C.....LOOP REENTRY.....
  150 NTIMES = NTIMES+1
      IF (IPRINT(4)) 157,157,114
  157 PRINT 158, NSET
  158 FORMAT(//,10X,*----CASE NO. *,I2,* ----*)
  114 RTLAB=PPLAB*(1.+PYEX)*COSTN(11,8,IYEAR)/2.90
      IF (NTIMES-1) 120,120,75
   75 GO TO (160,160,160,120,140,140,146),L
  120 QDOT=QMAX
      QBAR=QBARE
C ..........FIRMING FACTOR..........
      IF(QDOT-1.) 133,133,135
 133   FIRM=2.
      GO TO 140
 135   IF(QDOT-10.)136,138,138
 136   FIRM=(-.75/9.)*(QDOT-1.)+2.
      GO TO 140
 138   FIRM=1.25
 140   DITPU=TX+XINS+PET/(1.-(1.+PET)**(-PULF))
      DITPL=TX+XINS+PET/(1.-(1.+PET)**(-PLLF))
  146 DENS=.999876+6.5053E-5*DEGC+8.7076E-6*DEGC**2+7.61387E-8
     +*DEGC**3-4.62174E-10*DEGC**4
      VIS=(17.8657-.586769*DEGC+.0156811*DEGC**2-2.86322E-4*DEGC
     +**3+2.45838E-6*DEGC**4)*1.076387E-6
  160 DO 65 I=1,4
      HWCK(I)=0.
      DO 65 J=1,25
      SEGMNT(I,J)=0.
 65     CONTINUE
      DO 760 NSEG=1,NUMSEG
C SETTING SEGMENT PARAMETERS
      SLOPE=(ELEVE(NSEG)-ELEVB(NSEG))/PLMILE(NSEG)
      SEGMNT(NSEG,24)=SLOPE
      TER=TERFAC(NSEG)
      CONSF=CNSFAC(NSEG)
      PMILE=PLMILE(NSEG)
      SEGMNT(NSEG,22)=100
      IF(SLOPE)182,207,207
C GRAVITY LINE
 182   KK=1$D=100.$DOLD=100.
 183   CALL MOODY(QDOT,D,REY,FMOOD,ITYPE)
      D=(318.4346*FMOOD*QDOT**2/(-SLOPE))**0.2
      IF(ABS(D-DOLD)/DOLD-.01)190,190,188
 188   DOLD=D
      GO TO 183
 190   T=D*12.
      SEGMNT(NSEG,1)=CNTYPE(1)
      SEGMNT(NSEG,2)=T
      SEGMNT(NSEG,6)=REY
      SEGMNT(NSEG,7)=FLTYPE(ITYPE)
      AVFAC=1.
      GO TO 300
  200 SEGMNT(NSEG,14)=VLINE
```

```
      SEGMNT(NSEG,17)=WCCHPL
      SEGMNT(NSEG,18)=WLOMR
      WTOT=WCCHPL+WLOMR
      SEGMNT(NSEG,22)=WTOT
      IF(SLOPE+50.)700,700,209
207    KK=4
C APPROXIMATING FIRST DIAMETER AND LIMITS, PUMPED LINE ......
209    IF(QBAR-1.)220,210,210
210    DIAM=10.*SQRT(QBAR)/12.
      DIAMLO=DIAM/2.
      DIAMHI=DIAM*2.
      GO TO 230
220    DIAM=30*SQRT(QBAR)/12.
      DIAMLO=.1
      DIAMHI=1.
      IF(DIAMLO-DIAM)224,224,222
  222 DIAMLO=DIAM/2.
      GO TO 230
  224 IF(DIAMHI-DIAM)226,230,230
  226 DIAMHI=2.*DIAM
230    IF(KK-1)234,232,234
  232 DIAMHI=D
      IF(D-DIAMLO)223,235,235
  223 DIAMLO=D/4.
  235 DIAM=DIAMLO
  234 KK=4$LLL=0$JJJ=0
      NCALL=0
      KKK=0
C-------REENTRY FOR OPTIM LOOP
CPUMP STATION BOOK 192P58
CNUMBER OF PUMP STATIONS
350    CALL MOODY(QDOT,DIAM,REY,FMOOD,ITYPE)
      FRHDOT=318.4346*FMOOD*QDOT**2/DIAM**5
      IF(FRHDOT+SLOPE)365,365,375
  365 NUMSTA=1
      HDSTA=0.
      GO TO 377
375    KK=2
      NUMSTA=((FRHDOT+SLOPE)*PMILE/HDLIM+.999999)
      HDSTA=(FRHDOT+SLOPE)*PMILE/NUMSTA
  377 PUMILE=PMILE/NUMSTA
      REYDOT=REY
      ITDOT=ITYPE
C  ..........ADJUSTING PIPE INVESTMENT FOR PRESSURE CLASS..........
      IPRES=(HDSTA/2.31+25.)/50.+.999999
      IF(IPRES.LT.2)IPRES=2
      PRCLMX=IPRES*50.
      NPCLS=IPRES-1
      AVFAC=0.
      DO 400 J=1,NPCLS
      PRCL=50.+50.*J
  400 AVFAC= AVFAC+PRSFAC(DIAM,PRCL,PASCL)
      AVFAC= AVFAC/NPCLS
290    T=DIAM*12
      KKK=KKK+1
```

```
C LINE INVESTMENT BK 102 F51
  300 CONTINUE
      CPMI = CONSF*AVFAC
      GO TO (301,301,302,301,301,301,301,303,301,302,303,301,301,302,
     1302,301,302,301,301,302,301),NREG
  301 CPMI = CPMI*1280.130478*(T+2.043655)**1.379491
      GO TO 304
  302 CPMI = CPMI*6378.011662*(T+.353008)**.931125
      GO TO 304
  303 CPMI = CPMI*117.097354*(T+5.660431)**1.979824
  304 CPMI = CPMI*COSTN(5,NREG,0)*(COSTN(1,NREG,IYEAR)/COSTN(1,21,IYEAR)
     +)*(COSTN(15,0,IYEAR)/108.1)
CLINE OMR BK 102P60
  314 IF(T-51.) 315,330,330
315     T=ALOG(T)
      PRLOMR=EXP(4.04349-.0610731*T-.0407912*T**2+.107565*T**3
     +-.0140961*T**4)*CYMNI/82.60*TER
      GO TO 335
330     PRLOMR=(23.2864+7.21732*T+.127808*T**2
     ++.00101687*T**3+1.97087E-6*T**4)*CYMNI/82.60*TER
  335 PRLOMR = PRLOMR*COSTN(1,NREG,IYEAR)/COSTN(1,21,IYEAR)
       WLOMR=PRLOMR*PMILE
      VLINE=CPMI*PMILE
      WCCHPL=VLINE*OITPL
      GO TO (200,448,448,448),KK
CHORSEPOWER
  448 HPSTAF=0.175615*ODOT*DENS*HDSTA/EFF
450     HPSTAI=HPSTAF*FIRM
C UNIT INVESTMENT AND OMR EX ENERGY
C....PUMP STATION PRICE TO BE REVISED WITH Q-TDH PARAMETER AND
C....UNITS SUBROUTINE REPLACING FIRM.....
      IF(HPSTAI-3.)451,451,452
  451 PRPUMP=20000.
      GO TO 453
  452 PRPUMP=(103.956*HPSTAI**1.00233+16274.8)*
     +(1.18-ABS(ALOG10(HPSTAI/1000.))*(.1016667))
  453 PRPUMP = PRPUMP*COSTN(19,0,IYEAR)*COSTN(1,NREG,IYEAR)/COSTN(1,21,
     +IYEAR)/146.
C V AND W PUMP
C     USBR HALESTROM, CONTINUOUS OPERATION PUMP OMR
      IF(HPSTAI-15000.)455,502,502
  455 IF(HPSTAI-450.)460,460,465
C......UNATTENDED PLANTS......
  460 PUOMR=1.8*(ODOT*1.54723)**.47*HDSTA**.26*52.**.34*(1.2*RTLAB+
     +CYMNI/82.6)
      GO TO 480
  465 IF(HPSTAI-5000.)470,470,475
C......SEMI-ATTENDED PLANTS ......
  470 PUOMR=5.2*(ODOT*1.54723)**.55*HDSTA**.25*52.*(2.8*RTLAB+CYMNI/
     +82.6)
      GO TO 480
C......ATTENDED PLANTS.......
  475 PUOMR=7.*(ODOT*1.54723)**.04*HDSTA**.13*52.*(9.5*RTLAB+
     +CYMNI/82.6)
C......PUMP MAINTENANCE......
```

```
  480 P=.49*PTLAP+CYMNI/82.60
      IF(HPSTAI-150.)485,490,490
  485 PUOMR=PUOMR+(4.*(QDOT*1.54723)**.84*HDSTA**.4*P)
      GO TO 504
  490 USBP=(QDOT*1.54723)**.11*HDSTA**.41*(QPAR*.0652425*3.06889)
     +**.43*P
      IF(HPSTAI-7000.)495,500,500
  495 PUOMR=PUOMR+2.*USBP
      GO TO 504
  500 PUOMR=PUOMR+1.7*USBP
      GO TO 504
C......MANUAL OPERATION,OVER 15000HP***
  502 HP=HPSTAI*.74566
      PUOMP=CYMNI/66.32*(43787.5+3.91876*HP**.837643)
  504 CONTINUE
      WPOMR=PUOMR*NUMSTA
      VPUMP=PPFUMF*NUMSTA
      WCCHPU=VFUMP*OTIPU
C ENERGY
      CALL MOODY(QPAR,DIAM,REY,FMOOD,ITYPE)
      FRHRAP=318.4343*FMOOD*QPAR**2/DIAM**5
      IF (FRHRAR+SLOPE)525,522,505
505    KK=4
      IF(SLOPE)515,535,535
515    KK=3
      GO TO 535
522    PRINT 523,DIAM
523    FORMAT(* BOUNDARY BOOSTED+ASSISTED AT DIAM*,
     +F10.3,*SET AS BOOSTED WITH ZERO ENERGY*)
525    WENGY=0.
      GO TO 550
  535 YRKWH=1147.9375*QBAR*DENS*(FRHRAR+SLOPE)*PMILE/(EFF*NUMSTA)
      IF(GVCKWH)544,544,543
 543   HWCK(NSEG)=GVCKWH
      GO TO 545
 544  HWCK(NSEG)=CKWH(YRKWH,GVCKWH,STATE,IYEAR)
 545  WENGY=HWCK(NSEG)*YRKWH*NUMSTA/100.
C TOTAL COST FOR OPTIM
550    WTOT=WCCHPL+WLOMF+WCCHPU+WPOMR+WENGY
      CALL OPTIM(DIAM,WTOT,DIAMLO,DIAMHI,1E-3,1E-4,NCALL,NOWGO)
C.......WTOT .GT. GRAVITY COST 8 TIMES....
      IF(JJJ)560,560,569
  560 IF(WTOT-1.1*SEGMNT(NSEG,22))562,564,564
  562 JJJ=1
      GO TO 569
  564 LLL=LLL+1
      IF(LLL-7)569,569,700
C.....PRINT(5) OPTIM SEARCHES.....
C....NOTE THAT THIS IS WTOT IN AND DIAM OUT EXCEPT ON THE OPTIMUM....
  569 IF(IPRINT(5)) 575,575,570
  570 PRINT 571, NCALL,DIAM,KK,WTOT
  571 FORMAT(1X,I3,F10.3,I3,F16.3,/)
  575 IF(NOWGO)350,580,580
580     IF(IPRINT(5)) 590,590,585
  585 PRINT 586
```

```
  586 FORMAT(1X,*OPTIMUM*)
C......GRAVITY - PUMPED DECISION......
590     IF(WTOT-SEGMNT(NSEG,22)) 600,700,700
C FILL SEGMNT WITH PUMPED DATA ..... DISPLACE GRAVITY DATA
  600 SEGMNT(NSEG,1)=CNTYPE(KK)
      SEGMNT(NSEG,2)=DIAM*12.
      SEGMNT(NSEG,3)=NUMSTA
      SEGMNT(NSEG,4)=PUMILE
      SEGMNT(NSEG,5)=HPSTAT
      SEGMNT(NSEG,6)=REYDOT
      SEGMNT(NSEG,7)=FLTYPE(ITDOT)
      T=1.969974/DIAM**2
      SEGMNT(NSEG,8)=QDOT*T
      SEGMNT(NSEG,9)=FRHDOT
      SEGMNT(NSEG,10)=REY
      SEGMNT(NSEG,11)=FLTYPE(ITYPE)
      SEGMNT(NSEG,12)=QPAR*T
      SEGMNT(NSEG,13)=FRHPAR
      SEGMNT(NSEG,14)=VLINE
      SEGMNT(NSEG,15)=VPUMP
      VTOT=VLINE+VPUMP
      SEGMNT(NSEG,16)=VTOT
      SEGMNT(NSEG,17)=WCCHPL
      SEGMNT(NSEG,18)=WLOMR
      SEGMNT(NSEG,19)=WCCHPU
      SEGMNT(NSEG,23)=HDSTA
      SEGMNT(NSEG,20)=WPOMR
      SEGMNT(NSEG,21)=WENGY
      SEGMNT(NSEG,22)=WTOT
      SEGMNT(NSEG,25)=PRCLMX
      IF(HDSTA)610,610,760
  610 PRINT 620
  620 FORMAT(*  HDSTA APPROACHING 0.*,/,*  HORSE POWER ARBITRARILY SET
     +TO 3. FOR PUMP INVESTMENT*)
      GO TO 760
CFILL SEGMENT WITH GRAVITY DATA
  700 DIAM=SEGMNT(NSEG,2)/12.
      T=1.969974/DIAM**2
      SEGMNT(NSEG,8)=QDOT*T
      SEGMNT(NSEG,12)=QPAR*T
      CALL MOODY(QPAR,DIAM,REY,FMOOD,ITYPE)
      SEGMNT(NSEG,13)=219.4346*FMOOD*QPAR**2/DIAM**5
      SEGMNT(NSEG,10)=REY
      SEGMNT(NSEG,11)=FLTYPE(ITYPE)
      SEGMNT(NSEG,15)=0.
      SEGMNT(NSEG,16)=SEGMNT(NSEG,14)
      SEGMNT(NSEG,19)=0.
      SEGMNT(NSEG,20)=0.
      SEGMNT(NSEG,21)=0.
      SEGMNT(NSEG,3)=0.
      SEGMNT(NSEG,9)=-SLOPE
      SEGMNT(NSEG,25)=0.
760     CONTINUE
      IF (IPRINT(4)) 765,765,2120
C......TOTAL SEGMENTS.    PER MILE.    PERCENT.....
```

```
  765 NTOT = NUMSEG+1
      DO 820 I=14,22
      DO 820 J=1,NUMSEG
820    SEGMNT(NTOT,I)=SEGMNT(NTOT,I)+SEGMNT(J,I)
      PLMILE(NTOT)=0
      DO 835 I=1,NUMSEG
835    PLMILE(NTOT)=PLMILE(NTOT)+PLMILE(I)
      DO 845 I=14,16
  845 PC(I)=(SEGMNT(NTOT,I)/SEGMNT(NTOT,16))*100.
      TINVPM=SEGMNT(NTOT.16)/PLMILE(NTOT)
      TOPCST=SEGMNT(NTOT,19)+SEGMNT(NTOT,20)+SEGMNT(NTOT,21)
      PCOPCT=TOPCST/SEGMNT(NTOT,22)*100.
      DO 865 I=17,21
865    PC(I)=SEGMNT(NTOT,I)/SEGMNT(NTOT,22)*100.
      ARRAY(1)=QDOT*1E6
      DO 885 I=14,16
      CALL COSTF(SEGMNT(NTOT,I),ARRAY)
885    GPDC(I)=ARRAY(6)
      CALL COSTF(TINVPM,ARRAY)
      TGPDC=ARRAY(6)
      ARRAY(1)=QBAR*1E6
      DO 905 I=14,16
      CALL COSTF(SEGMNT(NTOT,I),ARRAY)
905    GPDP(I)=ARRAY(6)
      CALL COSTF(TINVPM,ARRAY)
      TGPDP=ARRAY(6)
      ARRAY(3)=QBAR*1E3
      DO 945 I=17,22
      CALL COSTF(SEGMNT(NTOT,I),ARRAY)
945    GPDC(I)=ARRAY(5)
      CKGPM=GPDC(22)/PLMILE(NTOT)
      CALL COSTF(TOPCST,ARRAY)
      TOPCKG=ARRAY(5)
1525   FORMAT(1H1,//,25X,*COSTS BREAKDOWN*,/,15X,*INVESTMENT*,/)
1530   FORMAT(32X,*PERCENT*,7X,*CENTS/GPD*,6X,*CENTS/GPD*,
      +/,16X*K DOLLARS*,6X,*OF TOTAL*,6X,*CAPABILITY*,5X,*PRODUCTION*,/)
1535   FORMAT(1X,*PIPELINE*,6X,F10.2,6X,F8.3,7X,F8.3,7X,F8.3)
 1540 FORMAT(1X,*PUMPSTATIONS*,F12.2,6X,F8.3,7X,F8.3,7X,F8.3)
1545   FORMAT(1X,*TOTAL*,7X,F12.2,7X,*100.*,10X,F8.3,7X,F8.3,/)
 1550 FORMAT(1X,*PER MILE*,6X,F10.2,21X,F8.3,7X,F8.3)
1555   FORMAT(//,15X,*PRODUCTION*,/)
1560   FORMAT(32X,*ANNUAL*,14X,*UNIT COSTS*,/,31X,*K DOLLARS*,
      +5X,*CENTS/KGAL*,3X,*PERCENT OF TOTAL*,/)
1565   FORMAT (1X,*OMR ON PIPELINE*,14X,F10.2,6X,F8.3,8X,F8.3)
1570   FORMAT(1X,*OMR ON PUMPSTATIONS*,10X,F10.2,6X,F8.3,8X,F8.3)
1575   FORMAT(1X,*ENERGY*,23X,F10.2,6X,F8.3,8X,F8.3)
1580   FORMAT(1X,*TOTAL OPERATING COSTS*,8X,F10.2,6X,F8.3,8X,F8.3,/)
1585   FORMAT(1X,*CAPITAL CHARGE ON PIPELINE*,3X,F10.2,6X,F8.3,
      +8X,F8.3)
1590   FORMAT(1X,*CAPITAL CHG ON PUMPSTATIONS *,F11.2,6X,F8.3,
      +8X,F8.3,/)
1595   FORMAT(1X,*TOTAL PRODUCTION COSTS*,7X,F10.2,6X,F8.3,
      +9X,*100.*)
 1600 FORMAT(/,1X,*PER MILE*,37X,F8.3)
C,,.......PRINT......
```

```
C------PRINT PARAMETERS IMPOSED ----
       IF(IPRINT(1))1740,1740,1602
1602    PRINT 1800
       PRINT 1805,IYEAR
       PRINT 1810, NMSTAT
       PRINT 1815,NREG
       PRINT 1820
       PRINT 1825,((PLMILE(NSEG)),NSEG=1,NUMSEG)
       PRINT 1830,((TERFAC(NSEG)),NSEG=1,NUMSEG)
       PRINT 1833,((CNSFAC(NSEG)),NSEG=1,NUMSEG)
       PRINT 1835,((SEGMNT(NSEG,24)),NSEG=1,NUMSEG)
       PRINT 1840, QDOT
       PRINT 1845, QBARE
       PRINT 1850, QBARA
       PRINT 1855, QMAX
       PRINT 1860, QMIN
       PRINT 1865, PLLF
       PRINT 1867, PULF
       PRINT 1875, RET
       PRINT 1880,XINS
       PRINT 1885,TX
       PRINT 1890, HDLIM
       PRINT 1895, DEGC
       PRINT 1900, PRLAD
       PRINT 1905, GVCKWH
       PRINT 1910, PYEX
C------PRINT PARAMETERS OF THE OPTIMIZED DESIGN ----
1740    IF(IPRINT(2))1990,1990,1745
1745    PRINT 1920
       PRINT 1925
       PRINT 1930,((SEGMNT(NSEG,1)),NSEG=1,NUMSEG)
       PRINT 1935,((SEGMNT(NSEG,2)),NSEG=1,NUMSEG)
       PRINT 1937,((SEGMNT(NSEG,25)),NSEG=1,NUMSEG)
       PRINT 1940,((SEGMNT(NSEG,3)),NSEG=1,NUMSEG)
       PRINT 1944,((SEGMNT(NSEG,23)),NSEG=1,NUMSEG)
       PRINT 1945,((SEGMNT(NSEG,4)),NSEG=1,NUMSEG)
       PRINT 1950,((SEGMNT(NSEG,5)),NSEG=1,NUMSEG)
       PRINT 1955,((SEGMNT(NSEG,6)),NSEG=1,NUMSEG)
       PRINT 1960,((SEGMNT(NSEG,7)),NSEG=1,NUMSEG)
       PRINT 1965,((SEGMNT(NSEG,11)),NSEG=1,NUMSEG)
       PRINT 1970, ((SEGMNT(NSEG,8)),NSEG=1,NUMSEG)
       PRINT 1975,((SEGMNT(NSEG,12)),NSEG=1,NUMSEG)
       PRINT 1980, ((SEGMNT(NSEG,9)),NSEG=1,NUMSEG)
       PRINT 1985,((SEGMNT(NSEG,13)),NSEG=1,NUMSEG)
       PRINT 1988,((HWCK(NSEG)),NSEG=1,NUMSEG)
1800    FORMAT(1H0,////,20X,*PARAMETER VALUES IMPOSED*,//)
1805    FORMAT(1H0,2X,*YEAR OF ESTIMATE*,4X,I4)
1810    FORMAT(3X,*STATE*,7X,2A7)
1815    FORMAT(1H0,2X,*REGION NUMBER*,9X,I2)
 1820 FORMAT(1H0,19X,*SEGMENT 1*,6X,*SEGMENT 2*,6X,*SEGMENT 3*)
 1825 FORMAT(1H0,*MILEAGE*,12X,F10.4,2(5X,F10.4))
 1830 FORMAT(1X,*TERRAIN FACTOR*,3(5X,F10.4))
 1833 FORMAT(1X,*CONSTRUCTION FACTOR*,F10.4,2(5X,F10.4))
 1835 FORMAT(1X,*SLOPE, FT/MILE*,5X,F10.4,2(5X,F10.4),///)
1840    FORMAT(///,3X,*DESIGN CAPABILITY*,12X,F10.4,5X,
```

```
          +* MILLION GALLONS/DAY*)
 1845     FORMAT(3X,*EXPECTED AVERAGE PRODUCTION*,2X,F10.4,5X,
          +* MILLION GALLONS/DAY*)
 1850     FORMAT(3X,*ACTUAL AVERAGE PRODUCTION*,4X,F10.4,5X,
          +* MILLION GALLONS/DAY*)
 1855     FORMAT(2X,* MAXIMUM DAILY PRODUCTION*,5X,F10.4,5X,
          +* MILLION GALLONS/DAY*)
 1860     FORMAT(3X,*MINIMUM DAILY PRODUCTION*,5X,F10.4,5X,
          +* MILLION GALLONS/DAY*)
 1865     FORMAT(2X,* PIPELINE LIFE*,18X,F3.0,10X,*YEARS*)
  1867 FORMAT(3X,*PUMPSTATION LIFE*,15X,F3.0,10X,*YEARS*)
 1875     FORMAT(3X,*INTEREST RATE*,16X,F10.4,5X,*FRACTION/YEAR*)
 1880     FORMAT(3X,*INSURANCE RATE*,15X,F10.4,5X,*FRACTION/YEAR*)
 1885     FORMAT(3X,*TAX RATE*,21X,F10.4,5X,*FRACTION/YEAR*)
 1890     FORMAT(3X,*LIMITING HEAD PUMP STATIONS*,2X,F10.4,5X,
          +*FT. OF FLUID*)
 1895     FORMAT(3X,*TEMPERATURE OF WATER*,11X,F6.2,7X,*DEGREES C.*)
 1900     FORMAT(3X,*LABOR PRICE*,20X,F6.2,7X,*DOLLARS/HOUR*)
 1905     FORMAT(2X,* GIVEN ENERGY PRICE*,14X,F6.3,6X,*CENTS/KWH*)
 1910     FORMAT(3X,*PAYROLL EXTRAS FACTOR*,8X,F10.4,5X,*FRACTION*)
 1920     FORMAT(1H1,//,16X,*PARAMETERS OF THE OPTIMIZED DESIGN*,/)
  1925 FORMAT(//,35X,*SEGMENT 1*,11X,*SEGMENT 2*,11X,*SEGMENT 3*,/)
  1930 FORMAT(1H0,2X,*CONVEYANCE TYPE*,29X,A10,2(10X,A10))
  1935 FORMAT(1H0,2X,*OPTIMUM PIPE DIAMETER I.D.*,6X,*INCHES*,16X,F10.4,
          +2(10X,F10.4))
  1937 FORMAT(1H0,2X,*MAXIMUM PRESSURE CLASS*,10X,*PSI*,19X,F10.4,2(10X,
          +F10.4))
  1940 FORMAT(1H0,2X,*NUMBER OF PUMP STATIONS*,9X,*STATIONS*,16X,F3.0,
          +2(17X,F3.0))
  1944 FORMAT(1H0,2X,*HEAD, PUMP STATION*,14X,*FT. OF FLUID*,10X,F10.4,
          +2(10X,F10.4))
  1945 FORMAT(1H0,2X,*INTERSTATION DISTANCE*,11X,*MILES*,17X,F10.4,2(10X,
          +F10.4))
  1950 FORMAT(1H0,2X,*DESIGN INSTALLED HP*,13X,*HP/STATION*,12X,F10.4,
          +2(10X,F10.4))
  1955 FORMAT(1H0,2X,*DESIGN REYNOLDS NUMBER*,32X,E10.4,2(10X,E10.4))
  1960 FORMAT(1H0,2X,*FLOW TYPE, DESIGN*,37X,A10,2(10X,A10))
  1965 FORMAT(1H0,2X,*FLOW TYPE, AVERAGE*,36X,A10,2(10X,A10))
  1970 FORMAT(1H0,2X,*OPTIMUM VELOCITY, DESIGN*,8X,*FT./SEC.*,14X,F10.4,
          +2(10X,F10.4))
  1975 FORMAT(1H0,2X,*VELOCITY, AVERAGE*,15X,*FT./SEC.*,14X,F10.4,2(10X,
          +F10.4))
  1980 FORMAT(1H0,2X,*DESIGN FRICTION HEAD*,12X,*FT./MILE*,14X,F10.4,2(10
          +X,F10.4))
  1985 FORMAT(1H0,2X,*AVERAGE FRICTION HEAD*,11X,*FT./MILE*,14X,F10.4,
          +2(10X,F10.4))
  1988 FORMAT(1H0,2X,*ENERGY PRICE*,20X,*CENTS/KWH*,13X,F10.4,
          +2(10X,F10.4))
 C------PRINT COST BREAKDOWN-----
 1990     IF(IPRINT(3))2100,2100,1991
 1991    DO 1992 I=14,22
 1992     SEGMNT(NTOT,I)=SEGMNT(NTOT,I)/1000.
         TINVPM=TINVPM/1000.
         TOPCST=TOPCST/1000.
         PRINT 1625
```

```
      PRINT 1530
      PRINT 1535, SEGMNT(NTOT,14),PC(14),GPDC(14),GPDP(14)
      PRINT 1540,SEGMNT(NTOT,15),PC(15),GPDC(15),GPDP(15)
      PRINT 1545,SEGMNT(NTOT,16),GPDC(16),GPDP(16)
      PRINT 1550,TIMVPM,TGPDC,TGPDP
      PRINT 1555
      PRINT 1560
      PRINT 1565,SEGMNT(NTOT,18),GPDC(18),PC(18)
      PRINT 1570,SEGMNT(NTOT,20),GPDC(20),PC(20)
      PRINT 1575, SEGMNT(NTOT,21),GPDC(21),PC(21)
      PRINT 1580,TCPCST,TCPCKG,PCOPCT
      PRINT 1585,SEGMNT(NTOT,17),GPDC(17),PC(17)
      PRINT 1590,SEGMNT(NTOT,19),GPDC(19),PC(19)
      PRINT 1595,SEGMNT(NTOT,22),GPDC(22)
      PRINT 1600,CKGPM
C------PRINT SHORT PRINTOUT -----
 2100 IF (IPRINT(4)) 3000,3000,2120
 2120 IF(NSET-1)2130,2130,2150
 2130 PRINT 2140
 2140 FORMAT(    ///,7X,*QDOT*,12X,*QBARI*,12X,* DIAM*,12X,*SLOPE*,2X,
     +*CONVEYANCE TYPE*,4X,*CENTS/GPD MI*,4X,*DOLLARS/MG MI PRODUCTION*
     +,/)
 2150 CGPDM = SEGMNT(1,16)*100./QDOT/1E6/PMILE
      DMGMI=SEGMNT(1,22)/(QBAR*365.2425*PMILE)
      PRINT 2160,QDOT,QBARE,SEGMNT(1,2),SEGMNT(1,24),SEGMNT(1,1),CGPDM,
     +DMGMI,NSET
 2160 FORMAT(/,2X,F11.4,3(6X,F11.4),3X,A10,2(2X,F15.4),*    CASE NO.*,
     +I3)
C.....LOOP RETURNS.....
 3000 CONTINUE
      NSET=NSET+1
 3020 IF(L) 2260,2260,3025
 3025 GO TO (3030,2260,3035,3040,3045,2260,3050) L
 3030 READ (5,95) STATE,NMSTAT,NREG,IYEAR
      CYMNI = CCSTN(20,0,IYEAR)
      PRINT 96,STATE,NMSTAT,NREG,IYEAR
      GO TO 3150
 3035 DO 3036 I=1,NUMSEG
      READ(5,111) PLMILE(I),ELEVB(I),ELEVE(I),TERFAC(I),CNSFAC(I)
      PRINT 111,PLMILE(I),ELEVB(I),ELEVE(I),TERFAC(I),CNSFAC(I)
 3036 CONTINUE
      GO TO 3150
 3040 READ(5,111) QMAX,QBARE,QBARA,QMIN
      PRINT 111, QMAX,QBARE,QBARA,QMIN
      GO TO 3150
 3045 READ(5,111) PLLF,PULF,BASCL,RET
      PRINT 111,PLLF,PULF,BASCL,RET
      GO TO 3150
 3050 READ (5,111) GVCKWH,DEGC,HDLIM,EFF,EPS
      PRINT 111, GVCKWH,DEGC,HDLIM,EFF,EPS
 3150 IF (EOF,5) 2260,15
 2260 STOP
      END
      SUBROUTINE OPTIM(THISX,VALUE,XLO,XHI,CONVX,CONVV,NCALL,NOWGO)
      IF(THISX-XHI)93,93,500
```

```
   93 IF(THISX-XLO)500,99,99
   99 IF (NCALL) 10,10,11
10      BUMP=(XHI-XLO)/3
        M=N=0
        K=ILO=IHI=0
        PX=PV=0.0
        NOWGO=-1
12      ANSMN=VALUE
26      XMIN=THISX
28      THISX=XMIN+BUMP
27      IF (THISX-XLO)190,15,15
16      BUMP=BUMP*(-0.25)
        GO TO 28
15      IF(THISX-XHI) 17,17,200
11      IF (ABS(VALUE-ANSMN)-ANSMN*CONVV) 50,51,51
50      IF (ABS(THISX-XMIN)-XMIN*CONVX) 52,51,51
   52 IF(ABS(BUMP)-CONVX*THISX)53,51,51
51      IF (VALUE-ANSMN) 60,90,70
90      THISX = (THISX+XMIN)/2
        IF(THISX-XMIN)140,55,140
70      IF (M) 71,71,180
71      N=N+1
        K=0
        IF(N-1) 100,100,110
18      BUMP=(-1.0)*BUMP
        N=0
        GO TO 28
100     PX=THISX
        PV=VALUE
        GO TO 16
110     IF(PV-VALUE) 18,120,18
120     THISX=(THISX+PX)/2
        GO TO 130
130     N=0
150     K=PV=PX=0
        GO TO 27
53      IF (VALUE-ANSMN) 56,55,56
60      K=K+1
        PX=PV=0.0
        IF(K-3)12,12,80
80      BUMP=2.0*BUMP
        K=0
        GO TO 12
140     BUMP=BUMP*0.25
        N=M=1
        GO TO 150
55      NOWGO=1
210     IF(ILO)220,220,230
220     IF(IHI)17,17,250
230     PRINT 240,ILO
240     FORMAT(1X,*THERE WERE,*I3,* ATTEMPTS TO GO BEYOND
       +LOWER CONSTRAINT.*)
        GO TO 17
250     PRINT 260,IHI
   260 FORMAT(1X,*THERE WERE,*,I3,* ATTEMPTS TO GO BEYONU HIGHER CONSTRAI
```

```
     +HT.*)
 17      NCALL=NCALL+1
        RETURN
 55      NOWGO=0
        VALUE=ANSMN
        THISX=XMIN
        GO TO 210
 180     PX=THISX
        PV=VALUE
        BUMP=(-1.0)*BUMP
        J=K=0
        GO TO 28
 190     ILO=ILO+1
        IF(BUMP) 16,365,365
 365     BUMP=(-1.0)*BUMP
        GO TO 16
 200     IHI=IHI+1
        IF(BUMP) 365,365,16
   500 PRINT 501, THISX,XLO,XHI,NCALL
   501 FORMAT(* THISX =*,G12.6,*  XLO =*,G12.6,*  XHI =*,G12.6,*  NCALL =
     +*,I5)
        PRINT 502
   502 FORMAT(* THISX OUTSIDE XHI-XLO LIMITS*,/,* RUN ABORTED IN OPTIM*)
        STOP
        END
        FUNCTION CKWH(YRKWH,GVCKWH,STATE,IYEAR)
 C      COMPUTES COST OF ELEC. ENERGY VIA STATE, YEAR, AND ANNUAL KWH USE
        INTEGER STATE
        DIMENSION ENST(49)
 C NOTE *CODE FOR STATES IS -
 C (1) ALABAMA (2) ARIZONA (3) ARKANSAS (4) CALIFORNIA (5) COLORADO
 C (6) CONNECTICUT (7) DELAWARE (8) FLORIDA (9) GEORGIA (10) IDAHO
 C (11) ILLINOIS (12) INDIANA (13) IOWA (14) KANSAS (15) KENTUCKY
 C (16) LOUISIANA (17) MAINE (18) MARYLAND (19) MASSACHUSETTS
 C (20) MICHIGAN      (21) MINNESOTA (22) MISSISSIPPI (23) MISSOURI
 C (24) MONTANA (25) NEBRASKA (26) NEVADA (27) NEW HAMPSHIRE
 C (28) NEW JERSEY (29) NEW MEXICO (30) NEW YORK (31) NORTH CAROLINA
 C 32) NORTH DAKOTA (33) OHIO (34) OKLAHOMA (35) OREGON (36)PENNSYLVANIA
 C (37) RHODE ISLAND (38) SOUTH CAROLINA (39) SOUTH DAKOTA (40)TENNESSEE
 C (41) TEXAS (42) UTAH (43) VERMONT (44) VIRGINIA (45) WASHINGTON
 C (46) WEST VIRGINIA (47) WISCONSIN (48) WYOMING (49) NATIONAL.
        DATA ENST/1.488,       1.690,1.562,1.230,1.574.1.846,1.769,1.531,
      +1.491,1.360,1.745,1.594,1.8,1.877,1.432,1.469,1.788,1.357,1.947,
      +1.987,
      +1.777,1.501,1.797,1.295,1.330,1.628,1.397,1.562,1.842,2.614,1.203,
      +1.738,1.774,1.484,.943,1.562,1.78,1.324,1.794,.96,1.381,1.467,
      +1.698,1.479,.671,1.766,1.651,1.4,1.718/
        IF(GVCKWH)70,80,70
     70 CKWH=GVCKWH
        RETURN
     80 CYENI=155.5+.735884*(IYEAR-1973)
        IF(YRKWH-1910)86,85,85
     85 CKWH=ENST(STATE)*.596798*CYENI/134.8
        RETURN
     86 IF(YRKWH-1 7)87,90,90
```

```
   57 CKWH=CUST(STAT-)*2.81667*CYCNT/104.9
      RETURN
   90 Y=ALOG10(YRKWH)
      CKWH=CUST(STATE)*(-45.5929+43.4977*X-13.3442*X**2+2.34611*X**3
     +-.147561*X**4+.00391567*X**5)/1.EF 7*CYCNT/104.9
      RETURN
      END
      FUNCTION PRSFAC(DIAM,PRCL,BASCL)
C     ...........COMPUTES RATIO OF PIPELINE COST TO COST AT BASE PRESSURE
C                     CLASS.
      IF(PRCL-BASCL)8,5,8
    5 PRSFAC=1.
      GO TO 99
    8 D=12.*DIAM
      X=ALOG(D)
      IF(T-56.648)11,9,9
    9 FRACPR=-22.7552+8.3162*X-.654747*X**2
      GO TO 12
   11 FRACPR=-2.7306+2.27897*X-.455929*Y**2
   12 F1=(100.+.7*(PRCL-100.)+FRACPR*(PRCL-100.)/10.)/100.
      IF(BASCL-100.)20,10,20
   10 PRSFAC=F1
      GO TO 99
   20 F2=(100.+.7*(BASCL-100.)+FRACPR*(BASCL-100.)/10.)/100.
      PRSFAC=F1/F2
   99 RETURN
      END
```

(Continued on next page)

```
      SUBROUTINE MOODY (Q,DIAM,REY,F,ITYPE)
C  DARCY FRICTION FACTOR BY MOODY CHART AND COLEBROOK AND
C  AND WHITE FORMULA.  ALSO REYNOLDS NUMBER AND FLOW TYPE.
      COMMON/MOOD1/VIS,EPS
      REY=Q/(.50762082*DIAM*VIS)
      R=REY
      IF(R-2000.) 9,9,351
9      F=64./R
      ITYPE=1
      RETURN
351    ROUGH=EPS/DIAM
      RUFF=ROUGH/3.7
      GO=-2.*ALOG10(RUFF)
      IF(R-4000.) 9,10,10
9      RN=.0006275
      GO TO 100
10     RN=2.51/R
100    GN=-2.*ALOG10(RUFF+RN*GO)
      IF(ABS((GO-GN)/(GN)-.0001) 170,170,150
150    GO=GN
      GO TO 100
170    GN=(GN+GO)/2.
      F=(1./GN)**2
      IF(R-4000.) 11,20,20
11     R=ALOG(4000.)
      REYLG=ALOG(REY)
      F=ALOG(F)
      R2=ALOG(2000.)
      F2=ALOG(.0317)
      FL=(REYLG-R2)*(F2-F)/(R2-R)+F2
      F=EXP(FL)
      ITYPE=2
      RETURN
20     TURBF=(200./(R*ROUGH))**2.
      IF(F-TURBF) 29,30,30
29     ITYPE=3
      RETURN
30     ITYPE=4
      RETURN
      END
```

```
      SUBROUTINE COSTP(VALUE,ARRAY)
      DIMENSION ARRAY(7)
      ARRAY(4)=VALUE/1000.
      ARRAY(5)=((VALUE*1[illegible].)/(ARRAY(3)*365.2425))
      ARRAY(6)=(VALUE*100.)/ARRAY(1)
      RETURN
      END
```

```
      FUNCTION COSTN(ITYP,NREG,IYEAR)
C  THESE COST INDICES ARE LKP PROJECTIONS FOR YEAR GT 1968.
C....FOR ITYP GT. 10, NOT REGIONALIZED.  NREG = 0....
C     NREG CODES:             1=ATLANTA, 2=BALTIMORE,3=BIRMINGHAM, 4=BOSTON
C  5=CHICAGO, 6=CINCINNATI, 7=CLEVELAND, 8=DALLAS, 9=DENVER, 10=DETROIT,
C  11=KANSAS CITY, 12=LOS ANGELES, 13=MINNEAPOLIS, 14=NEW ORLEANS,
C  15=NEW YORK, 16=PHILADELPHIA, 17=PITTSBURGH, 18=ST. LOUIS,19=SAN
C  FRANCISCO, 20=SEATTLE, AND 21=NATIONAL.
C ITYP CODES:1=BCI, 2=CCI, 3=STP, 4=S, 5=PIPELINE ADJUSTMENT
C....STP AND S NOT IN YET.  ITYP 6 TO 10 LEFT FOR LATER ADDITIONS
C....OF REGIONALIZED INDICES....
C  11=AVG. HOURLY EARNINGS MFG $/HR., 12=CHEM. ENG. PLANT C.I.,
C  13=MS CHEMICAL PROCESS EQUIPMENT INDEX, 14=WPI FOR
C  INORGANIC CHEMICALS, 15=COMPOSITE PIPELINE COST INDEX, 16=ELECTRICAL
C  ENERGY CI, 17=CONCRETE DAM, 18=EARTH DAM, 19=PUMPING PLANT,
C  20=MODERN MFG MAINTENANCE INDEX.
C  EXAMPLES  (1,2,1969) = BCI,BALTIMORE,1969.  (11,  ,1970)=AVG. HRLY.
C  EARNINGS, NOT REGIONALIZED,1970.
      DIMENSION SLOPE(115),CEPT(115)
      DATA SLOPE/16.765,15.490,16.689,16.709,21.342,17.054,20.199,17.265
     +,14.092,21.282,14.993,17.072,14.947,15.096,21.773,14.297,19.226,
     +29.687,22.798,16.530,17.630,26.190,25.868,25.862,30.549,36.502,
     +30.962,39.716,21.920,25.090,39.106,27.688,37.756,32.627,24.706,
     +47.112,27.647,33.395,37.548,39.206,33.430,32.187,63*0.0,0.0773,
     +2.898,6.565,1.207,2.960,.705884,1.8,.9,5.307,2.47/
      DATA CEPT/369.,434.,336.,426.,420.,482.,476.,370.,450.,489.,478.,
     +418.,496.,416.,470.,530.,438.,446.,357.,404.,485.,418.,455.,425.,
     +567.,651.,800.,775.,544.,584.,690.,591.,536.,619.,510.,612.,662.,
     +771.,674.,554.,711.,605.,42*0.0,1.039,0.981,1.025,1.778,0.849,1.02
     +2,0.888,1.100,0.775,0.781,0.900,0.860,0.987,1.175,1.136,1.0,1.038,
     +1.0,0.820,0.843,1.0,1.3233,55.284,137.28,86.389,32.44,89.974,91.7,
     +101.52,69.8955,53.3/
      NO = 5
      IF (NREG) 998,150,170
  150 IF (ITYP.LT.11.OR.ITYP.GT.20) GO TO 900
      IND = NO*21+(ITYP-10)
      GO TO 180
  170 IF (NREG.GT.21) GO TO 910
      IF (ITYP.LE.0.OR.ITYP.GT.5) GO TO 900
      IND = 21*(ITYP-1)+NREG
  180 COSTN = CEPT(IND)+SLOPE(IND)*(IYEAR-1948)
      RETURN
  998 PRINT 210,NREG
      RETURN
  900 PRINT 901,ITYP,NREG
      RETURN
  910 PRINT 210,NREG
      RETURN
  901 FORMAT (14H0INVALID TYPE ,I3,12H FOR REGION ,I3)
  210 FORMAT (1H0,20HINVALID REGION CODE ,I3)
      END
```

NAMES OF VARIABLES

ARRAY(7)	Array used in cost computations
AVFAC	Average of pressure factor (PRESFAC) over length of line
BASCL	Base pressure class to which the pipeline costs are assigned, psi
CGPDM	Unit investment per mile, ¢/gpd mile
CKGPM	Unit production cost, ¢/Kgal per mile
COSTN	LK-R library function subprogram for cost indexes (variables unique to this program are not contained in this list)
CNSFAC(I)	Construction factor for segment I (applicable to pipeline investment cost)
CNTYPE(I)	Name for conveyance type. 1 = gravity, 2 = boosted, 3 = assisted pump, 4 = pumped
CONSF	Construction factor for pipeline in segment being computed
CPMI	Current year unit investment in pipeline, $/mile
CYENI	Current year electric energy cost index
CYMNI	Current year Marshal and Stevens Cost Index for Chemical Process Industries Equipment
D, DOLD	Initializing values of diameter for iterative search
DEGC	Expected average water temperature, degree C
DENS	Density of water at expected temperature, gm/ml
DIAM	Current inside diameter pipeline, feet
DIAMHI	Upper constraint on diameter for OPTIM optimization, feet
DIAMLO	Lower constraint on diameter for OPTIM optimization, feet
DITPL	Amortization factor for pipeline, taxes, insurance, plus capital recovery, fraction/year
DITPU	Amortization factor for pump stations, taxes, insurance, plus capital recovery, fraction/year
DMGMI	Unit conveyance cost, $/mg mile
EFF	Wire-to-water efficiency for pump stations, fraction
ELEVB(I)	Elevation of beginning point, segment I, feet, msl (mean sea level)

ELEVE(I)	Elevation ending point, segment I, feet, msl
EPS	Pipe roughness, feet
FIRM	Firming factor, ratio of installed capability to firm capability for pump stations, fraction
FLTYPE(I)	Name of flow type. 1 = laminar, 2 = critical, 3 = transition, 4 = turbulent
FMOOD	MOODY friction factor
FMT	Format number
FRACPR	Fraction for second order adjustment of pipeline cost at other than base pressure class
FRHBAR	Friction head at QBARE conditions, feet/mile
FRHDOT	Friction head under design conditions, feet/mile
GPDC(I)	Unit investment, ¢/gpd, for investment component I
GPDP(I)	¢/Kgal cost for component I
GVCKWH	Current year energy price imposed as an input parameter for state and consumption quantity, ¢/Kwh
HDLIM	Limiting head on pump stations, feet of fluid
HDSTA	Total dynamic head on pump stations, feet of fluid
HPSTAF	Firm station horsepower, HP/station
HPSTAI	Installed station horsepower, HP/station
HWCK(I)	Energy price, ¢/Kwh, for segment I
IPRES	Index for pipe pressure class, 1 = 100 psi, 2 = 100 psi, 3 = 150 psi, 4 = 200 psi, etc.
IPRINT(6)	Printout instructions as in program description
ITDOT	Holding variable for ITYPE
ITYPE	Index for flow type
IYEAR	Year of estimate, called current year, four digits
JJJ	Indicator for whether gravity versus pumped comparison is to be made
KK	Index for conveyance type
LLL	Index for number of comparisons, pumped line costs against gravity line costs
LOOP	Data card on which loop is to be made

MOODY	LK-R library subroutine for MOODY friction factor (variables unique to this subroutine are not contained in this list)
NCALL	Number of calls to OPTIM
NMSTAT(2)	State name (two seven-character words allowable)
NOWGO	Indicator in OPTIM, - 1 = optimum not yet reached, 0 or +1 = optimum reached
NPCLS	Number of pressure classes of pipe used in line
NREG	Region number according to code in Function Subroutine COSTN
NRUN	Number of runs to be made
NSEG	Segment number
NSET	Case number
NTOT	Column of SEGMNT array for summing values of segments
NUMSEG	Number of segments in the line
NUMSTA	Number of pump stations
OPTIM	LK-R library subroutine for one-dimensional optimization (variables within this subroutine are not contained in this list)
PC (I)	Percent contribution of cost component I
PCOPCT	Operating cost as percent of total cost
PLLF	Pipeline life, years
PLMILE(I)	Pipeline length, horizontal projection in segment I, miles
PMILE	Length of segment being computed, miles
PRCL	Pressure class pipe, psi
PRCLMX	Highest pressure class used, psi
PRLAB	Labor price in 1968, $/hr
PRLOMR	Current year price of OMR on pipeline, $/year per mile
PRPUMP	Current year price of pump stations, $/station
PULF	Pump station life, years
PUMILE	Interstation distance, pipeline miles per station
PUOMR	Current year price of OMR on pump stations, $/year per station
PYEX	Payroll extras factor, fraction of payroll
QBAR	Value of QBARE or QBARA currently being used in computations, mgd
QBARA	Average amount actually conveyed, mgd (not used in present version)

QBARE	Expected average conveyance over the project life, mgd (total mgd conveyed in project life, divided by total number of days in project life)
QDOT	Design capability of pipeline system, mgd
QMAX	Maximum day conveyance, mgd
QMIN	Minimum day of conveyance in project period (not used in present version)
RET	Interest rate, fraction/year
REY	Reynolds number
REYDOT	Value of Reynolds number under design conditions
RTLAB	Current year labor rate including payroll extras, $/hour
SEGMNT(I, J)	Array to hold data concerning segment I. J is the type of data
SLOPE	Average slope of pipeline in segment being computed, feet/mile
STATE	Numerical code for state, as found in Function Subroutine CKWH
T	Internal diameter in inches
TER	Terrain factor for pipeline in segment being computed, fraction
TERFAC(I)	Terrain factor for segment I (applicable to pipeline maintenance), fraction
TGPDC	Unit investment, ¢/gpd of capability per mile
TGPDP	Unit investment, ¢/gpd of average production per mile
TINVPM	Total investment per mile, $/mile
TOPCKG	Operating costs, ¢/Kgal
TOPCST	Total operating cost, $/year
TX	Tax rate, fraction/year
VIS	Viscosity of fluid at expected temperature, feet^2/second
VLINE	Line investment, $
VPUMP	Investment in pump stations, $
VTOT	Total investment, K$

WCCHPL	Annual capital charge for pipeline, $/year
WCCHPU	Annual capital charge on pump stations, $/year
WENGY	Annual cost of energy, $/year
WLOMR	Annual cost of OMR on pipeline, $/year
WPOMR	Annual cost of OMR on pump stations, $/year
WTOT	Total annual production cost, $/year
XINS	Insurance rate, fraction/year
YRKWH	Annual electric energy consumption, Kwh/year

CHAPTER 5

COMPUTER PROGRAM FOR PRELIMINARY DESIGN AND COSTING FOR ACTIVATED SLUDGE TREATMENT

MODIFICATIONS MADE TO THE GOLD PROGRAM

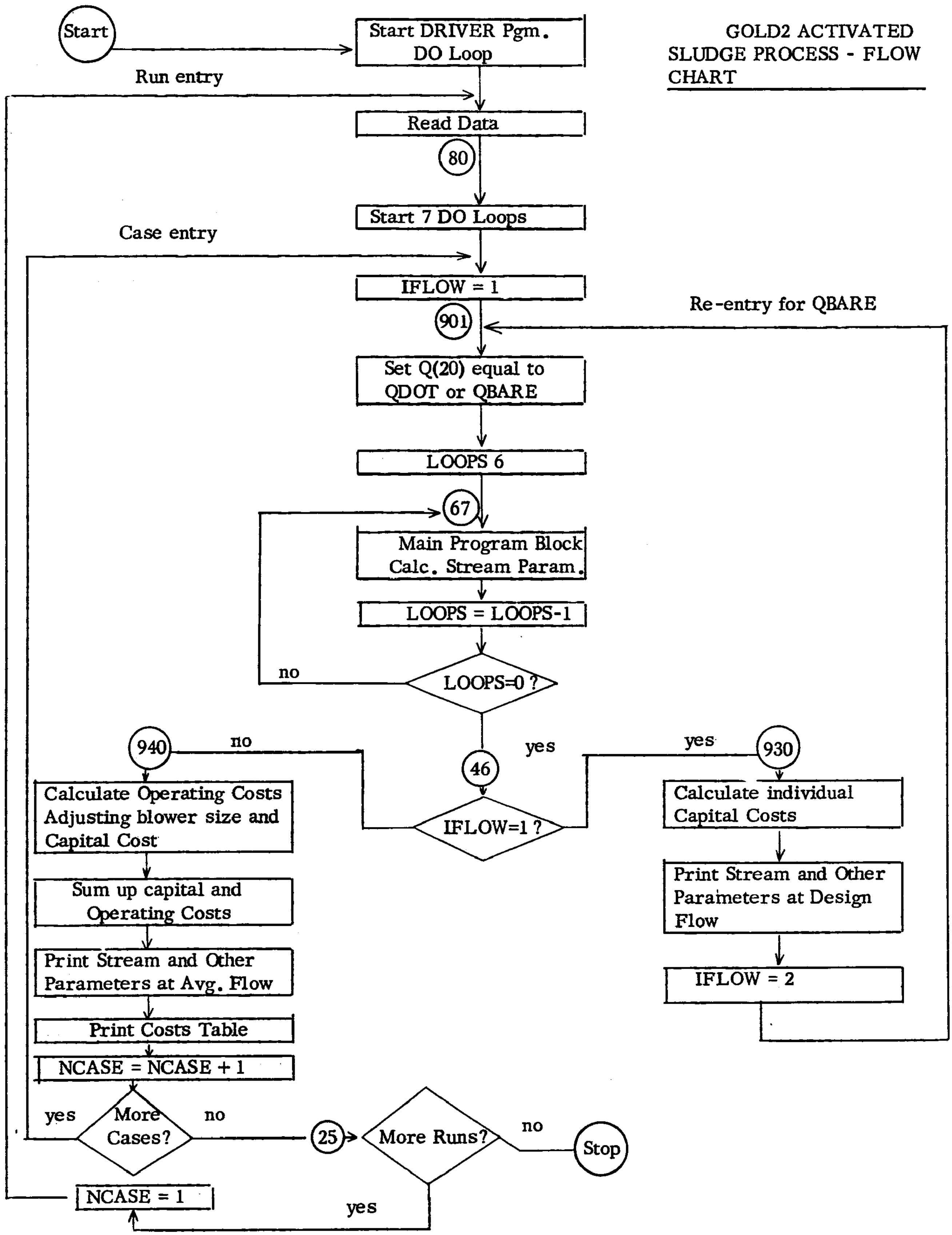
There exists a computer program for design and costing of activated sludge plants, termed the GOLD Program (52). The original GOLD Program was modified, the ultimate modification being named GOLD2. GOLD1 was an intermediate stage (53). The flow chart of GOLD2 is shown on the next page.

A driver program was added at the beginning consisting of a DO loop to repeat the program with several different data decks.

The modified program is executed twice for each case, once at Q(20)=QDOT, the design capability, and again at Q(20)=QBARE, the expected average production. The first execution with QDOT sets the equipment sizes required to achieve the specifications at a maximum production rate QDOT. Then the stream characteristics are determined for a flow rate of QBARE through a plant whose equipment sizes have been fixed by QDOT. The excess capacity factors of the original GOLD Program which are intended for a similar purpose are eliminated. The MLSS at QBARE is set back to the level corresponding to the increased detention time, approximately UBAR times the MLSS at QDOT. (UBAR=QBARE/QDOT). No attempt was made to analyze transients while flow rate is changing. Both QBARE and QDOT are steady state flow rates.

The GOLD Program sizes the blowers large enough to supply the oxygen needed if nitrification occurs, and nitrification does occur if the calculated time required to achieve nitrification (TAN) is less than the detention time in the aerator. In GOLD2 it is possible for the aerator detention time to be short enough to avoid nitrification at production rate QDOT yet be long enough to have nitrification at the lower flow rate, QBARE. In this case the program determines the production rate QNIT, the largest production rate at which nitrification still occurs, determines the size of blowers required at that production rate and compares this blower size with that previously calculated at a production rate QDOT. The blower size is set at the larger of these two, and a message is printed below the cost information stating that the blowers were sized by nitrification at QNIT.

GOLD2 uses the Engineering News Record Building Cost Index for temporal adjustments of costs. The base period is January 1960 (BCI National = 554.4), which is the GOLD report basis. GOLD2 provides for any other BCI value and runs were made with BCI=732, for San Antonio 1969.


GOLD2 ACTIVATED SLUDGE PROCESS - FLOW CHART
Start
Start DRIVER Pgm. DO Loop
Run entry
Read Data
80
Start 7 DO Loops
Case entry
IFLOW = 1
Re-entry for QBARE
901
Set Q(20) equal to QDOT or QBARE
LOOPS 6
67
Main Program Block Calc. Stream Param.
LOOPS = LOOPS-1
no
LOOPS=0 ?
940
no
yes
46
yes
930
IFLOW=1 ?
Calculate Operating Costs Adjusting blower size and Capital Cost
Calculate individual Capital Costs
Sum up capital and Operating Costs
Print Stream and Other Parameters at Design Flow
Print Stream and Other Parameters at Avg. Flow
IFLOW = 2
Print Costs Table
NCASE = NCASE + 1
yes
More Cases?
no
25
More Runs?
no
Stop
NCASE = 1
yes

The GOLD report basis for operating costs is a study dated 1966, costs presumably as of 1965. GOLD2 assumes that this is the base (BCI National=634.4), and adjusts operating costs with the current year BCI mentioned in the previous paragraph.

The GOLD Program places no constraints on the size of equipment. GOLD2 provides for replication when a maximum limiting size of equipment is reached, and also for at least two units if the sizes are above a certain minimum. The constraint values are as follows:

Equipment	Maximum Size	Use at Least Two Above This Size
Settlers	30,000 sf (square feet)	2,000 sf
Aeration Tanks	1 mg up to QDOT=200 Then linear to 6 mg over QDOT=1,200	5,000 cf
Thickeners	50,000 sf	200 sf
Vacuum Filter	800 sf	20 sf
Digesters	200,000 cf (cubic feet)	10,000 cf
Incinerator	600,000 lbs/day (pounds per day)	

In addition, for incinerators, there is a constraint of a minimum sized unit of 8,000 lbs/day, via Subroutine UNITEX. It is intended that this minimum concept and this subroutine will later be applied to all equipment.

GOLD incinerator operating costs go through a maximum at high lbs/day. GOLD2 uses the unit cost at this maximum for costs above this lbs/day at the maximum.

The GOLD Program provides a fixed input for the fraction of the time during which vacuum filters are operated. According to Sewage Treatment Plant Design Manual of Practice #8 (54) small plants operate with as little as 30 hours/week, large plants require up to 20 hours/day. The fraction of time for the vacuum filters (TVF) is made a computed parameter, 0.2 below QDOT = 1,0.8 above QDOT = 100,and TVF = 0.2*QDOT**0.30103, in between.

One of the input parameters NFORK(5) = 1 is used to eliminate the primary settler and its attendant costs. NFORK(6) is used to suppress a printout of certain selected parameters.

If the GOLD Program is run with typical sewage to produce an effluent BOD which is rather high, say 30 mgpl or more, the resultant BOD loadings, lbs BOD/day per 100 lb MLSS (mixed liquor suspended solids), become very high. This is generally considered undesirable as a reasonable sludge volume index cannot be maintained at such high loadings. The sludge volume index (SVI) passes through a minimum at some intermediate value of BOD loading (see for example 55). The GOLD Program and GOLD2 provide a fixed SVI value and thus the model is not sensitive to the real relation between BOD loading and SVI. To at least eliminate excessive BOD loadings GOLD2 contains a message and a constraint which aborts the run if the BOD loading is greater than 70.

The vacuum filter loading (VFL), the solids concentration ratio in the final settler (URSS) and the temperature (DEGC) are added to the variables which can be changed from case-to-case within the DO loops.

GOLD does not provide for ultimate disposal of the sludge residue. GOLD2 uses a cost for disposal of incinerator ash of 1.5 $/ton of ash. (This is not in the program listing herein.)

Instructions for running GOLD2 and a sample printout are found beyond.

GOLD2 RESULTS FOR SAN ANTONIO EXEMPLARY CASES

The GOLD2 Program was used to develop design and costs for activated sludge treatment for the plants involved in the San Antonio study which were:

Name of Plant	QDOT, mgd	QBARE, mgd	Capital Cost m$	Annual Cost, K$	
				Op. + Amort.*	Op. Only
A new plant	234	118	38.48	4721	-
Existing Rilling Plant	80	40.7	-	-	704.
U.C. Salado Plant	24	12.2	-	-	244.
Existing Leon Creek	12	6.1	-	-	138.

* Operation plus amortization

The information used in the present project, so far as it has gone, is the investment and annual cost (operation plus amortication), in the new plant, and the costs of operation only in the Rilling, Salado, and Leon Creek plants (all San Antonio, 1969). The concept is that the investment in the existing and under construction plants is already sunk and does not enter into the comparison with advanced waste treatment and reuse. The continuing costs in the three plants are only the operation costs. It would have been possible to obtain actual operation costs for the two existing plants from the actual records and for the under construction plant from the engineers' design. However, to handle the general case it is necessary to have a program which will generate such costs, and it was so used here. It is gratifying to note, however, how closely these computed operating costs compare with the experienced costs. The operating costs indicated for the Rilling and Leon Creek plants sum to 842 K$/year. The program is such that the operating costs are entirely a function of equipment size, i.e. of capability, and not dependent upon actual throughput. The City Finance Department's projection of the 1968-1969 fiscal year costs for "direct cost plus administration" (equivalent to operating cost here) was 795 K$. Thus, the computer program figure is within 6% of the actual experienced figure.

Those familiar with the San Antonio situation will recognize that the capability given for the Rilling Plant is not that normally associated with that plant. The QDOT used is 80 which is actually close to the average production of the Rilling Plant as now operated. The capability of 80 mgd is an estimate from the treatment plant management of the capability when operated to reliably produce an effluent of 18 BOD, 18 TSS. The values of QBARE for the plants are those which would be achieved in plants of the capability given operating under the seasonal fluctuation for San Antonio as described in Chapter 3.

The raw sewage was taken as average San Antonio sewage, composition shown in Table 28. The amortization factor used was 0.07783 comprising 30 years at 4% plus 1% taxes plus 1% insurance, (and is very close to 20 years at 4.5% without insurance and taxes or 25 years at 4.5% with 1% for both).

TABLE 28

AVERAGE COMPOSITION SAN ANTONIO SEWAGE USED IN GOLD2 RUNS

Name	Description	Value
SOC	Solid organic carbon	124
SNBC	Solid non-biodegradable carbon	30
SON	Solid organic nitrogen	12.4
SOP	Solid organic phosphorus	2.7
SFM	Solid fixed matter	35
DOC	Dissolved organic carbon	51
DNBC	Dissolved non-biodegradable carbon	11
DN	Dissolved nitrogen (organic + NH3)	20.3
DP	Dissolved phosphorus	5.4
DFM	Dissolved fixed matter	628
DEGC	Temperature degree C	25
ALK	Alkalinity as CaCO3	282
TSS	Total suspended solids	220
	Total BOD	250
	NH3 nitrogen	15.2
	PO4	24.9

INSTRUCTIONS FOR RUNNING GOLD2

This program is set up to run in Fortran IV on a CDC 6400 computer. There are about 1050 cards. The compile time is about 25 CPU seconds and six peripheral seconds, the execute time about two and four resp. About 15 of the 25 compile seconds accrue from the extensive PRINT and FORMAT statements. The program will compile with a core memory of 100,000 60-bit words. It will execute from a compiled program or binary deck with 23,600 core words.

The following data cards are needed.

		Format No.
First Card:	Number of runs to be made	809
Next Cards:	Numbers to be assigned to the various runs being made, one card for each number	809

The RUN Loops re-enter at this point.

Next Card:	NFORK instructions NFORK(1) = 1, provides sludge drying beds instead of vacuum filters; zero provides vacuum filters. (Note: Neither Ref. 52 nor GOLD2 actually provide the sludge drying bed option, so zero must be specified.) NKORK(2) = 1, bypasses printout of stream parameters; = zero prints these parameters. NFORK(3) = 1, bypasses printout of other plant parameters; = zero prints these parameters. NFORK(4) = 1, bypasses printout of individual component costs and prints only total costs; = zero allows all costs to be printed. NFORK(5) = 1, eliminates primary settler; = zero incorporates primary settler. NFORK(6) = 1, suppresses printout of certain selected parameters; = zero prints these.	114
Two Cards, Sewage Parameters (11):	SOC, SNBC, SON, SOP, SFM, DOC, DNBC, DN, DP, DFM, ALK	101

Six CArds, Plant
Parameters (24)

	URPS, XRSS, CAER 20, AEFF 20, DO CKWH, AF, GSS, TRR, TSS(12), GTH, GSTH, ERR, TSS(15), WRE, GE, GES, TDIG, TD, TSS(16), SBL	102
	BCI, SVI	801

The NCASE entry is at this point, the various cases within each RUN being made up from combinations of the succeeding data cards. But each RUN has the NFORK instructions and sewage and plant parameters from the preceding nine cards.

2-11 Cards:	URSS data; the first of these cards gives the number of URSS values to be explored, the remaining cards the individual values, one per card.	107
2-11 Cards:	DEGC data; the first of these cards gives the number of DEGC values to be explored, the remaining cards the individual values, one per card.	107
2-11 Cards:	MLSS data; the first of these cards gives the number of MLSS values to be explored, the remaining cards the individual values, one per card.	107
2-11 Cards:	DEMBOD data; the first card giving the number of data items, the remaining cards the individual DEMBOD data.	107
2-11 Cards:	QDOT and QBARE data; the first card gives the number of pairs of values the remaining cards the actual pairs of values, one pair per card.	802
2-11 Cards:	FRPS data, same general style as the preceding.	107
2-11 Cards:	VFL data, same as preceding.	107

When the data deck is set up in this way the program will produce the number of runs specified on the first card, each run according to its own set of NFORK instructions and sewage and plant parameters. Within each run the program will produce one case for each combination of the data on URSS, DEGC, MLSS, DEMBOD, QDOT and QBARE, FRPS, VFL, a total number of cases in each run equal to the product of the number of data items in the seven classes.

Any of the sewage or plant parameters or any other suitable parameters could be brought out into the NCASE loops by so modifying the program or the parameters brought out could be returned to the sewage parameters set or plant parameters set by a reversing modification.

A sample printout follows.

..... INPUT DATA, RUN 36

```
0000000000
124.0000 30.0000 12.4000  2.7000 35.0000 51.0000 11.0000 20.3000  5.4000
282.0000
400.0000   .0200  1.0000
     .05000      1.00000      .01000      .07783  2000.00000
      .9500  60000.0000     750.0000      9.0000       .7600
  60000.0000       3.0000     800.0000      9.0000     33.3000
     15.0000     200.0000       4.4000
  732.00  100.00
  1
    3.00
  1
   25.00
  1
 6000.00
  1
   18.00
  1
  234.00  118.00
  1
     .50
  1
    4.90
```

QDOT = 234.000 MILLION GALLONS/DAY
QBARE = 118.000 MILLION GALLONS/DAY
UBAR = .504

PARAMETER	CONDITIONS AT QDOT	CONDITIONS AT QBARE	UNITS
EFFLUENT BOD	18.00	17.99	MG/L OXYGEN
BOD REMOVAL	92.82	92.82	PERCENT
BOD LOADING	61.10	61.18	LB/DAY BOD PER 100 LB MLSS
AER. DETEN. TIME	1.07	2.09	HOURS
NITRIFICATION	0	0	(1=YES, 0=NO)
EFFLUENT NITRATE	0.00	0.00	MG/L NITROGEN
EFFLUENT NH3-N	20.84	20.44	MG/L NITROGEN
EFFLUENT TSS	15.71	20.43	MG/L MASS
MIXED LIQUOR SS	6000	3018	MG/L MASS
SLUDGE RETURN	.97	.94	FRACTION
DISCHARGE	233.95	117.97	MILLION GAL/DAY
VAC. FILT. LOADING	4.90	4.90	GAL/HR-SF
INCINERATOR ASH	31.68	15.57	TON/DAY

BUILDING COST INDEX = 732.0
AMORTIZATION FACTOR = .07783

NUMBER OF		SIZE OF EACH	UNITS
PRIMARY SETTLERS	6	29.176	KSF
AERATORS	10	1.070	MILLION GAL
FINAL SETTLERS	8	29.617	KSF
THICKENERS	2	32.777	KSF
DIGESTERS	12	187.405	KCF
ELUTRIATION TANKS	1	26.766	KSF
VACUUM FILTERS	5	666.863	SF
INCINERATORS	2	91.278	TON/DAY

COMPONENT OR ITEM	CAPITAL COSTS K-DOLLARS	CAPITAL COSTS PERCENT	AMORT. PLUS OPERATING COSTS K-$/YEAR	AMORT. PLUS OPERATING COSTS CENTS/KGAL	AMORT. PLUS OPERATING COSTS PERCENT
PRELIM. TREATMENT	774.413	2.01	142.843	.3317	3.03
PRIMARY SETTLER	4160.943	10.81	563.997	1.3095	11.95
AERATOR	3903.222	10.14	481.932	1.1190	10.21
AIR BLOWERS	1263.938	3.28	328.586	.7629	6.96
FINAL SETTLER	5247.319	13.64	408.399	.9482	8.65
SLUDGE RET. PUMPS	920.949	2.39	71.677	.1664	1.52
CONTROL HOUSE	3172.535	8.24	246.918	.5733	5.23
SLUDGE THICKENER	2234.482	5.81	173.910	.4038	3.68
DIGESTER	4675.017	12.15	507.004	1.1772	10.74
SLUDGE ELUTRIATION	904.263	2.35	70.379	.1634	1.49
VACUUM FILTRATION	2271.404	5.90	600.290	1.3938	12.71
SLUDGE INCIN.	7846.277	20.39	764.369	1.7747	16.19
ASH DISPOSAL	0.000	0.00	9.843	.0229	.21
CHLORINATION	202.420	.53	280.634	.6516	5.94
SITE DEVELOPMENT	906.592	2.36	70.560	.1638	1.49

TOT. CAPITAL COST		38483.772		
AS CENTS/GPD OF				
	QDOT	16.446		
	QBARE	32.613		
TOTAL AMORTIZATION AND OPERATION COST		4721.342	10.9620	100.00
OPERATING COST ONLY		1726.150	4.0078	36.56

CENTS PER POUND OF BOD REMOVED = 5.6578
CENTS PER POUND OF TSS REMOVED = 4.7219

```
      PROGRAM GOLD(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION NRUN(10)
      DIMENSION ODCT(10),OBARE(10),CCPCT(15),AOCPCT(15)
      DIMENSION EBOD(2),TBODRE(2),BCOLD(2),DTEN(2),NIT(2),
     1TOTSS(2),XNO3(2),XNH3(2),TASH(2)
      DIMENSION Q(20),SOC(20),SNBC(20),SON(20),SOP(20),SFM(20),DOC(20),
     1 DNBC(20),DN(20),DP(20),DFM(20),SBOD(20),DBOD(20),CCOST(15),
     2 COSTO(15),ACOST(15),AOCOS(15),NFORK(10),ASS(12),EMBOD(10),
     3 VSS(20),TSS(20),ALK(20),CPERK(15),ECF(15),O20(10),RPSIN(10),
     4 QOUT(2),VFLD(10),SRET(2),XML(2),DFG(10),URS(10)
      KTYPE=6
      LIST=6
      KARD=5
      READ(KARD,809) KRUNS,(NRUN(J),J=1,KRUNS)
      DO 25 IRUN=1,KRUNS
      DO 300 I=1,20
      Q(I)=0.0
      SOC(I)=0.0
      SNBC(I)=0.0
      SON(I)=0.0
      SOP(I)=0.0
      SFM(I)=0.0
      DOC(I)=0.0
      DNBC(I)=0.0
      DN(I)=0.0
      DP(I)=0.0
      DFM(I)=0.0
      SBOD(I)=0.0
      DBOD(I)=0.0
      VSS(I)=0.0
      TSS(I)=0.0
  300 ALK(I)=0.0
      DO 400 I=1,15
      CCOST(I)=0.0
      COSTO(I)=0.0
      ACOST(I)=0.0
      AOCOS(I)=0.0
      CCPCT(I)=0.0
      AOCPCT(I)=0.0
  400 CPERK(I)=0.0
      ASB=0.0
C......READ AND PRINT INPUT DATA FOR RUN..........
      WRITE(LIST,840) NRUN(IRUN)
      READ(KARD,114) (NFORK(I),I=1,10)
      WRITE(LIST,870) (NFORK(I),I=1,10)
      READ(KARD,101) SOC(20),SNBC(20),SON(20),SOP(20),SFM(20),DOC(20),
     1DNBC(20),DN(20),DP(20),DFM(20),ALK(20)
      WRITE(LIST,871) SOC(20),SNBC(20),SON(20),SOP(20),SFM(20),DOC(20),
     1DNBC(20),DN(20),DP(20),DFM(20),ALK(20)
      VSS(20)=SOC(20)*2.13
      TSS(20)=VSS(20)+SFM(20)
      SBOD(20)=(SOC(20)-SNBC(20))*1.87
      DBOD(20)=(DOC(20)-DNBC(20))*1.87
      TBOD20=SBOD(20)+DBOD(20)
      READ(KARD,102) URFS,     XRSS,CAER2,AEFF2,DO,CKWH,AF,GSS,
```

```
     1TRR,TSS(12),GTH,GSTH,ERR,TSS(15),WRE,GE,GES,TDIG,TD,
     2TSS(16),SBL
      WRITE(LIST,872) URPS,     XRSS,CAER2,AEFF2,DO,CKWH,AF,GSS,
     1TRR,TSS(12),GTH,GSTH,ERR,TSS(15),WRE,GE,GES,TDIG,TD,
     2TSS(16),SBL
      READ(KARD,801) BCI,SVI
      WRITE(LIST,873) BCI,SVI
      CIFC = BCI/554.4
      CIFO = BCI/634.4
      CCL2=.08
      DCL2=8.
C.......READ AND PRINT INPUT DATA FOR CASES..........
      READ(KARD,107) NUR,(URS(I),I=1,NUR)
      WRITE(LIST,874) NUR,(URS(I),I=1,NUR)
      READ(KARD,107) NTMP,(DEG(I),I=1,NTMP)
      WRITE(LIST,874) NTMP,(DEG(I),I=1,NTMP)
      READ(KARD,107) NAS,(ASS(I),I=1,NAS)
      WRITE(LIST,874) NAS,(ASS(I),I=1,NAS)
      READ(KARD,107) NBOD,(EMBOD(J),J=1,NBOD)
      WRITE(LIST,874) NBOD,(EMBOD(J),J=1,NBOD)
      READ(KARD,802) NQ,(QDOT(J),QBARE(J),J=1,NQ)
      WRITE(LIST,875)NQ,(QDOT(J),QBARE(J),J=1,NQ)
      READ(KARD,107)NFR,(RPSIN(J),J=1,NFR)
      WRITE(LIST,874) NFR,(RPSIN(J),J=1,NFR)
      READ (KARD,107) NVFL,(VFLD(J),J=1,NVFL)
      WRITE (LIST,874) NVFL,(VFLD(J),J=1,NVFL)
C..........START 7 DO LOOPS..........
       NCASE=1
      DO 25 LF=1,NFR
      FRPS=RPSIN(LF)
      DO 25 NU=1,NUR
      URSS=URS(NU)
      DO 25 NTM=1,NTMP
      DEGC=DEG(NTM)
   80 DO25I=1,NAS
      XMLSS=ASS(I)
      DO25K=1,NBOD
      BOD5=EMBOD(K)
      DO 25 NV=1,NVFL
      VFL=VFLD(NV)
      DO 25 LQ=1,NQ
      IFLOW=1
      NIT(1)=0
      NIT(2)=0
      NBFLAG=0
C..........REENTRY FOR QBARE..........
  901 IF(IFLOW-1) 902,902,903
  902 Q(20)=QDOT(LQ)
      GO TO 904
  903 Q(20)=QBARE(LQ)
  904 UBAR=QBARE(LQ)/QDOT(LQ)
  908 LOOPS=6
C     MIX STREAMS NINE AND TWENTY
   67 IF(LOOPS-6) 66,65,66
   65 Q(9)=0.0
```

```
   66 TEMP1=Q(20)/(Q(20)+Q(9))
      TEMP2=Q(9)/(Q(20)+Q(9))
      SOC(1)=TEMP1*SOC(20)+TEMP2*SOC(9)
      SON(1)=TEMP1*SON(20)+TEMP2*SON(9)
      SOP(1)=TEMP1*SOP(20)+TEMP2*SOP(9)
      SNBC(1)=TEMP1*SNBC(20)+TEMP2*SNBC(9)
      SFM(1)=TEMP1*SFM(20)+TEMP2*SFM(9)
      DOC(1)=TEMP1*DOC(20)+TEMP2*DOC(9)
      DNBC(1)=TEMP1*DNBC(20)+TEMP2*DNBC(9)
      DN(1)=TEMP1*DN(20)+TEMP2*DN(9)
      DP(1)=TEMP1*DP(20)+TEMP2*DP(9)
      DFM(1)=TEMP1*DFM(20)+TEMP2*DFM(9)
      ALK(1)=TEMP1*ALK(20)+TEMP2*ALK(9)
      Q(1)=Q(20)+Q(9)
      VSS(1)=SOC(1)*2.13
      TSS(1)=VSS(1)+SFM(1)
      SBOD(1)=(SOC(1)-SNBC(1))*1.87
      DBOD(1)=(DOC(1)-DNBC(1))*1.87
C     PRIMARY SETTLER PERFORMANCE
      IF (NFORK(5)) 1091,1091,1092
 1092 Q(8)=0.
      Q(2)=Q(1)
      TEMP1=1.
      GO TO 1093
 1091 Q(8)=FRPS*Q(1)/URPS
      Q(2)=Q(1)-Q(8)
      TEMP1=(1.-FRPS)*Q(1)/Q(2)
 1093 SOC(2)=TEMP1*SOC(1)
      SNBC(2)=TEMP1*SNBC(1)
      SON(2)=TEMP1*SON(1)
      SOP(2)=TEMP1*SOP(1)
      SFM(2)=TEMP1*SFM(1)
      DOC(2)=DOC(1)
      DNBC(2)=DNBC(1)
      DN(2)=DN(1)
      DP(2)=DP(1)
      DFM(2)=DFM(1)
      VSS(2)=SOC(2)*2.13
      TSS(2)=VSS(2)+SFM(2)
      SBOD(2)=(SOC(2)-SNBC(2))*1.87
      DBOD(2)=(DOC(2)-DNBC(2))*1.87
      BOD2=SBOD(2)+DBOD(2)
      DBOD2=DBOD(2)
      IF (NFORK(5)) 1094,1094,1000
 1094 TEMP1=FRPS*Q(1)/Q(8)
      SOC(8)=TEMP1*SOC(1)
      SNBC(8)=TEMP1*SNBC(1)
      SON(8)=TEMP1*SON(1)
      SOP(8)=TEMP1*SOP(1)
      SFM(8)=TEMP1*SFM(1)
      DOC(8)=DOC(2)
      DNBC(8)=DNBC(2)
      DN(8)=DN(2)
      DP(8)=DP(2)
      DFM(8)=DFM(2)
```

```
      VSS(8)=SOC(8)*2.13
      TSS(8)=VSS(8)+SFM(8)
      SBOD(8)=(SOC(8)-SNBC(8))*1.87
      DBOD(8)=(DOC(8)-DNBC(8))*1.87
C     AERATOR PERFORMANCE
 1000 CEDR=.18*1.047**(DEGC-20.)
      CAER=CAER2*1.047**(DEGC-20.)
      SMAX=1200000./SVI
      IF (URSS*XMLSS-SMAX) 86,86,85
   85 URSS=SMAX/XMLSS
   86 SA=XMLSS/1000.
      IF(IFLOW-1) 905,905,906
  905 TA=(BOD2-BOD5)/(BOD5*CAER*SA*24.)
      VAER=Q(2)*TA
      IF (VAER-.0372) 1001,1001,1002
 1001 NAER=1
      GO TO 907
 1002 IF (Q(20)-200.) 1003,1003,1006
 1003 VAMAX = 1.
      GO TO 1008
 1006 VAMAX = Q(20)/200.
      IF (VAMAX-6.) 1008,1008,1007
 1007 VAMAX = 6.
 1008 IF (VAER-VAMAX) 1004,1004,1005
 1004 NAER=2
      GO TO 907
 1005 NAER=IFIX(VAER/VAMAX+0.99999)
      GO TO 907
  906 TA=VAER/Q(2)
      XMLSS=1000.*(BOD2-BOD5)/(BOD5*CAER*24.*TA)
  907 CONTINUE
      XRSS=556.1*GSS**.4942/XMLSS**1.8165/(TA*24.)**.4386
      ASMAX=BOD5/XRSS/.685
      ASMIN=0.0
      IF(ASMAX-XMLSS)50,50,70
   70 ASMAX=XMLSS
   50 XMLAS=(ASMAX+ASMIN)/2.0
   42 FOOD=SBOD(2)+DBOD2
      FMAX=FOOD
      N=1
      GO TO 8
    7 ERROR=FMAX-FMIN
      TOL=.10
      IF(ERROR-TOL)21,21,19
   19 FOOD=(FMIN+FMAX)/2.0
    4 IF(FOOD-DBOD(2))5,5,6
    5 DBOD(4)=DBOD(2)-FOOD
      SBOD(4)=SBOD(2)
      GO TO 8
    6 SBOD(4)=(SBOD(2)+DBOD(2)-FOOD)*.70
      DBOD(4)=.233*SBOD(4)
    8 TEMP1=(.65*FOOD/XMLAS)-XRSS
      Q(7)=(Q(2)*TEMP1-CEDR*VAER)/(URSS-XRSS)
   20 Q(5)=Q(2)-Q(7)
      N=N+1
```

```
      IF(N-2)23,23,22
   22 TEMP2=XRSS*Q(5)+URSS*Q(7)
      XMLBS=Q(2)*SBOD(4)/TEMP2/.80
      SBOD(5)=(XMLAS*.685+XMLBS*.80)*XRSS
      DBOD(5)=DBOD(4)
      TBOD5=SBOD(5)+DBOD(5)
      GO TO 24
   23 TBOD5=XMLAS*XRSS*.685
   24 IF(TBOD5-BOD5)10,10,15
   10 IF(N-3)11,12,13
   11 FMIN=(CEDF*VAER/Q(2)+XRSS)*XMLAS/.65
      FOOD=FMIN
      GO TO 4
   12 WRITE(KTYPE, 307) NCASE
  307 FORMAT(/* DEMAND MLASS CANNOT BE HELD, CASE *,I3)
      GO TO 984
   13 FMAX=FOOD
      GO TO 7
   15 IF(N-3)16,18,17
   16 WRITE(KTYPE,306) NCASE
  306 FORMAT(/* BOD5 DEMAND CANNOT BE ACHIEVED, CASE *,I3)
      GO TO 984
   17 FMIN=FOOD
   18 GO TO 7
   21 CONTINUE
      XLNBS=SNBC(2)*Q(2)*2.13/TEMP2
      XMLIS=Q(2)*SFM(2)/TEMP2
      XMLDS=(.12*Q(2)*FOOD/TEMP2)-.185*XMLAS
      TEMP1=XMLAS+XMLBS+XLNBS+XMLDS+XMLIS
      TEMP2=TEMP1-XMLSS
      TOL=5.0
      IF(ABS(TEMP2)-TOL)41,41,51
   51 IF(TEMP2)52,52,53
   52 ASMIN=XMLAS
      GO TO 50
   53 ASMAX=XMLAS
      GO TO 50
   41 CONTINUE
      SOC(5)=(XMLDS+XMLAS)*XRSS/2.46+(XMLBS+XLNBS)*XRSS/2.33
      SOC(7)=SOC(5)*URSS/XRSS
      SNBC(5)=XLNBS*XRSS/2.33+(XMLDS+.185*XMLAS)*XRSS/2.46
      SNBC(7)=SNBC(5)*URSS/XRSS
      TEMP2=XRSS*XMLAS/2.46
      SON(5)=.234*TEMP2+(SOC(5)-TEMP2)/10.
      TEMP2=TEMP2*URSS/XRSS
      SON(7)=.234*TEMP2+(SON(7)-TEMP2)/10.
      SOP(5)=SOC(5)*.01
      SOP(7)=SOC(7)*.01
      SFM(5)=XMLIS*XRSS
      SFM(7)=XMLIS*URSS
      DOC(5)=DNBC(2)+DBOD(4)/1.87
      DNBC(5)=DNBC(2)
      DOC(7)=DOC(5)
      DNBC(7)=DNBC(5)
      DN(5)=(Q(2)*(SON(2)+DN(2))-(SON(5)*Q(5)+SON(7)*Q(7)))/(Q(5)+Q(7))
```

```
      DN(7)=DN(5)
      DP(5)=(Q(2)*(SOP(2)+DP(2))-(SOP(5)*Q(5)+SOP(7)*Q(7)))/(Q(5)+Q(7))
      DP(7)=DP(5)
      DFM(5)=DFM(2)
      DFM(7) = DFM(2)
      SBOD(7)=(SOC(7)-SNBC(7))*1.87
      DBOD(7)=(DOC(7)-DNBC(7))*1.87
      VSS(5)=SOC(5)*1.90
      TSS(5)=VSS(5)+SFM(5)
      VSS(7)=SOC(7)*1.90
      TSS(7)=VSS(7)+SFM(7)
      TBOD2=SBOD(2)+DBOD(2)
      BODLD(IFLOW)=Q(2)*TBOD2*100/(VAER*XMLSS)
C     IS BOD LOADING GREATER THAN 70
      IF (BODLD-70.) 1075,1075,1070
 1070 PRINT 1071,BOD5,NCASE
 1071 FORMAT (1H0,*BOD LOADING ABOVE 70 AT THIS EFFLUENT BOD OF*,F7.2,
     +1X,*AT CASE NUMBER*,I3)
      GO TO 984
C     CONDITIONS FOR NITRIFICATION
 1075 Q(6)=(Q(2)*(1.-.65*FOOD/XMLAS)+CEDR*VAER)/(URSS-1.)
      Q(4)=Q(2)+Q(6)
      RETUR=Q(6)/Q(2)
      X4X3=(1.+RETUR)/RETUR/URSS
      DN(3)=DN(2)/(1.+RETUR)
      X3Y=DN(3)*.99/(X4X3-1.)
      CNIT=.18*EXP(.116*(DEGC-15.))
      TAN=(1.+RETUR)*(ALOG(X4X3)+4.605/(DN   (3)+X3Y))/CNIT
      VNIT=Q(2)*TAN
      QNIT=Q(20)*(TA/TAN)
      IF(TAN-TA)917,917,916
  917 NIT(IFLOW)=1
      XNH3(IFLOW)=0.0
      XNO3(IFLOW)=0.77*DN(5)
      GO TO 914
  916 XNH3(IFLOW)=0.77*DN(5)
      XNO3(IFLOW)=0.0
  914 CONTINUE
C     AIR REQUIREMENTS
      DOSA=14.16-.3943*DEGC+.007714*DEGC**2-.0000646*DEGC**3
      DOSA=DOSA*1.221
      AEFF=AEFF2 *(DOSA -DO)*1.02**(DEGC-20.)/DOSA
      WFOOD=Q(2)*FOOD*8.33
      WAS=XMLAS*VAER*8.33
      AIRCF=(.577*WFOOD+1.16*CEDR*WAS)/AEFF/.232/.075
      WDN=(Q(5)*DN(5)+Q(7)* DN(7))*8.33
      IF(IFLOW-1)910,910,911
  910 IF(NIT(IFLOW))27,27,26
   26 AIRCF=AIRCF+4.6*WDN/AEFF/.232/.075
   27 BSIZE=AIRCF/1440.
      GO TO 912
  911 IF(NIT(2))912,912,913
  913 AIRCF=AIRCF+4.6*WDN/AEFF/.232/.075
      IF(NIT(2)-NIT(1))918,912,918
  918 IF(BSIZE-AIRCF*(QNIT/Q(20))/1440.)915,915,912
```

```
  915 NBFLAG=1
      BSIZE=AIRCF*(QNTT/Q(20))/1440.
  912 CFRGA=AIRCF/1000000./Q(1)
C     CALCULATE STREAM INTO THICKENER
      Q(10)=Q(7)+Q(8)
      SOC(10)=(SOC(7)*Q(7)+SOC(8)*Q(8))/Q(10)
      SNBC(10)=(SNBC(7)*Q(7)+SNBC(8)*Q(8))/Q(10)
      SON(10)=(SON(7)*Q(7)+SON(8)*Q(8))/Q(10)
      SOP(10)=(SOP(7)*Q(7)+SOP(8)*Q(8))/Q(10)
      SFM(10)=
     1          (SFM(7)*Q(7)+SFM(8)*Q(8))/Q(10)
      DOC(10)=(DOC(7)*Q(7) +DOC(8)*Q(8))/Q(10)
      DNBC(10)=(DNBC(7)*Q(7)+DNBC(8)*Q(8))/Q(10)
      DN(10)=(DN(7)*Q(7)+DN(8)*Q(8))/Q(10)
      DP(10)=(DP(7)*Q(7)+DP(8)*Q(8))/Q(10)
      DFM(10)=(DFM(7)*Q(7)+DFM(8)*Q(8))/Q(10)
      VSS(10)=SOC(10)*2.0
      TSS(10)=VSS(10)+SFM(10)
C     CALCULATE STREAMS FROM THICKENER
      Q(12)=TRR*Q(10)*TSS(10)/TSS(12)
      Q(11)=Q(10)-Q(12)
      TSS(11)=(1.-TRR)*Q(10)*TSS(10)/Q(11)
      TEMP4=TSS(11)/TSS(10)
      SOC(11)=TEMP4*SOC(10)
      VSS(11)=SOC(11)*2.0
      SNBC(11)=TEMP4*SNBC(10)
      SON(11)=TEMP4*SON(10)
      SOP(11)=TEMP4*SOP(10)
      SFM(11)=TEMP4*SFM(10)
      DOC(11)=DOC(10)
      DNBC(11)=DNBC(10)
      DN(11)=DN(10)
      DP(11)=DP(10)
      DFM(11)=DFM(10)
      TEMP3=TSS(12)/TSS(10)
      ATH2=Q(10)*TSS(10)*8.33/GSTH
      SOC(12)=TEMP3*SOC(10)
      SNBC(12)=TEMP3*SNBC(10)
      SON(12)=TEMP3*SON(10)
      SOP(12)=TEMP3*SOP(10)
      SFM(12)=
     1          TEMP3*SFM(10)
      DOC(12)=DOC(10)
      DNBC(12)=DNBC(10)
      DN(12)=DN(10)
      DP(12)=DP(10)
      DFM(12)=DFM(10)
      VSS(12)=SOC(12)*2.0
      ATH1=Q(10)*1000000./GTH
      IF(IFLOW-1)920,920,921
  920 ATHM=AMAX1(ATH1,ATH2)
  921 CONTINUE
C     CALCULATE DIGESTER PERFORMANCE
      C1DIG=.28/EXP(.036*(35.-TDIG))
      C2DIG=700.*EXP(.10*(35.-TDIG))
```

```
      DIG12=SOC(12)-SNBC(12)+DOC(12)-DNBC(12)
      TDM=2.5/C1DIG
      TDOPT=(1.-(C2DIG/(C2DIG+DIG12)**.5))/C1DIG
      TDMIN=AMAX1(TDM,TDOPT)
      IF(TD-TDMIN) 43,43,44
   43 TD=TDMIN
   44 DIG13=C2DIG/(C1DIG*TD-1.)
      TEMP4=(DIG12-DIG13)/(SOC(12)+DOC(12))
      CDF=200.*EXP(.12*(35.-TDIG))
      DF=CDF/(C1DIG*TD-1.)
      SOC(13)=SNBC(12)+DIG13-DF
      DOC(13)=DNBC(12)+DF
      FRDIG=(SOC(12)-SOC(13))/SOC(12)
      SNBC(13)=SNBC(12)
      SON(13)=(1.-TEMP4)*SON(12)
      SOP(13)=(1.-TEMP4)*SOP(12)
      SFM(13)=SFM(12)
      DNBC(13)=DNBC(12)
      DN(13)=DN(12)+.65*SON(12)*TEMP4
      DP(13)=DP(12)+SOP(12)*TEMP4
      DFM(13)=DFM(12)
      IF(IFLOW-1) 923,923,924
  923 VDIG=Q(12)*TD*1000./7.48
  924 CONTINUE
      CH4CF=163.85*(DIG12-DIG13)*Q(12)
      CO2CF=249.9*(DIG12-DIG13)*Q(12)-CH4CF
      VSS(13)=SOC(13)*2.0
      TSS(13)=VSS(13)+SFM(13)
      Q(13)=Q(12)
C     CALCULATE STREAMS FROM SLUDGE WASH
      IF(NFCRK(1))45,45,929
   45 Q(17)=WRF*Q(13)
      QOUT(IFLOW)=Q(5)-Q(17)
      TEMP1=Q(13)*1000000./GF
      TEMP2=Q(13)*TSS(13)*8.33/GFS
      IF(IFLOW-1)925,925,926
  925 AF=AMAX1(TEMP1,TEMP2)
  926 CONTINUE
      Q(15)=EFR*Q(13)*TSS(13)/TSS(15)
      Q(14)=Q(17)+Q(13)-Q(15)
      TSS(14)=Q(13)*((1.-EFR)*TSS(13)+WRF*TSS(5))/Q(14)
      VSS(17)=VSS(5)
      TSS(17)=TSS(5)
      TEMP1=TSS(15)/TSS(13)
      SOC(15)=TEMP1*SOC(13)
      SNBC(15)=TEMP1*SNBC(13)
      SON(15)=TEMP1*SON(13)
      SOP(15)=TEMP1*SOP(13)
      SFM(15)=TEMP1*SFM(13)
      VSS(15)=SOC(15)*2.0
      TEMP2=TSS(14)/TSS(13)
      SOC(14)=TEMP2*SOC(13)
      VSS(14)=SOC(14)*2.0
      SNBC(14)=TEMP2*SNBC(13)
      SON(14)=TEMP2*SON(13)
```

```
      SOP(14)=TEMP2*SOP(13)
      SEM(14)=TEMP2*SEM(13)
      TEMP1=Q(13)/(Q(13)+Q(17))
      TEMP2=Q(17)/(Q(13)+Q(17))
      DOC(14)=TEMP1*DOC(13)+TEMP2*DOC(5)
      DNBC(14)=TEMP1*DNBC(13)+TEMP2*DNBC(5)
      DN(14)=TEMP1*DN(13)+TEMP2*DN(5)
      DP(14)=TEMP1*DP(13)+TEMP2*DP(5)
      DEM(14)=TEMP1*DEM(13)+TEMP2*DEM(5)
      DOC(15)=DOC(14)
      DNBC(15)=DNBC(14)
      DN(15)= DN(14)
      DP(15)=DP(14)
      DEM(15)=DEM(14)
      IF(VNIT-VAER)60,60,61
   60 ALK(5)=ALK(1)+3.57*(DN(5)-DN(2))
      GO TO 62
   61 ALK(5)=ALK(1)
   62 ALK(12)=ALK(5)
      ALK(13)=ALK(12)+(DN(13)-DN(12))*3.57
      ALK(14)=TEMP1*ALK(13)+TEMP2*ALK(5)
      ALK(15)=ALK(14)
      Y1=100.*ALK(15)/TSS(15)
      Y2=VSS(15)/(TSS(15)-VSS(15))
      FECL3=1.08*Y1+2.*Y2
      CFECL3=0.08
C     CALCULATE STREAMS FROM VACUUM FILTER
      WP=88./(TSS(15)/10000.)**.123
      TEMP1=1000000.*(100.-WP)/WP
      Q(16)=Q(15)*(TEMP1-TSS(15))/(TEMP1-TSS(16))
      TSS(18)=8.33*(Q(15)*TSS(15)-Q(16)*TSS(16))
      TEMP2=TSS(18)/TSS(15)
      SOC(18)=TEMP2*SOC(15)
      VSS(18)=SOC(18)*2.0
      SNBC(18)=TEMP2*SNBC(15)
      SON(18)=TEMP2*SON(15)
      SOP(18)=TEMP2*SOP(15)
      VSS(16)=SOC(16)*2.0
      DOC(16)=DOC(15)
      DNBC(16)=DNBC(15)
      DN(16)=DN(15)
      DP(16)=DP(15)
      TEMP3=8.33*(Q(15)-Q(16))
      DEM(18)=DEM(15)*TEMP3
      DP(18)=DP(15)*TEMP3
      DN(18)=DN(15)*TEMP3
      DNBC(18)=DNBC(15)*TEMP3
      DOC(18)=DOC(15)*TEMP3
      TEMP2=TSS(16)/TSS(15)
      SOC(16)=SOC(15)*TEMP2
      SNBC(16)=SNBC(15)*TEMP2
      SON(16)=SON(15)*TEMP2
      SOP(16)=SOP(15)*TEMP2
      SEM(16)=SEM(15)*TEMP2
      DEM(16)=DEM(15)
```

```
      IF (IFLOW-1) 1080,1080,928
C     VARY VF TIME WITH PLANT SIZE
 1080 IF (Q(20)-1.) 1081,1081,1082
 1081 TVF=.2
      GO TO 927
 1082 IF (Q(20)-100.) 1084,1083,1083
 1083 TVF=.8
      GO TO 927
 1084 TVF=0.2*Q(20)**0.30103
  927 AVF=Q(16)*1000000./VFL/TVF/24.
  928 CONTINUE
      Q(9)=Q(11)+Q(14)+Q(16)
      TEMP1=Q(11)/Q(9)
      TEMP2=Q(14)/Q(9)
      TEMP3=Q(16)/Q(9)
      SOC(9)=TEMP1*SOC(11)+TEMP2*SOC(14)+TEMP3*SOC(16)
      SNBC(9)=TEMP1*SNBC(11)+TEMP2*SNBC(14)+TEMP3*SNBC(16)
      SON(9)=TEMP1*SON(11)+TEMP2*SON(14)+TEMP3*SON(16)
      SOP(9)=TEMP1*SOP(11)+TEMP2*SOP(14)+TEMP3*SOP(16)
      SFM(9)=TEMP1*SFM(11)+TEMP2*SFM(14)+TEMP3*SFM(16)
      DOC(9)=TEMP1*DOC(11)+TEMP2*DOC(14)+TEMP3*DOC(16)
      DNBC(9)=TEMP1*DNBC(11)+TEMP2*DNBC(14)+TEMP3*DNBC(16)
      DN(9)=TEMP1*DN(11)+TEMP2*DN(14)+TEMP3*DN(16)
      DP(9)=TEMP1*DP(11)+TEMP2*DP(14)+TEMP3*DP(16)
      DFM(9)=TEMP1*DFM(11)+TEMP2*DFM(14)+TEMP3*DFM(16)
      SBOD(9)=(SOC(9)-SNBC(9))*1.87
      DBOD(9)=(DOC(9)-DNBC(9))*1.87
      SBOD(9)=(SOC(9)-SNBC(9))*1.87
      VSS(9)=SOC(9)*2.0
      TSS(9)=VSS(9)+SFM(9)
 929  LOOPS = LOOPS-1
      IF(LOOPS)46,46,67
C     STORE PARAMETERS FOR PRINT-OUT
   46 CONTINUE
      TOC2=SOC(2)+DOC(2)
      TOC5=SOC(5)+DOC(5)
      TOC7=SOC(7)+DOC(7)
      TBOD2=SBOD(2)+DBOD(2)
      TBOD5=SBOD(5)+DBOD(5)
      EBOD(IFLOW)=TBOD5
      TBODRE(IFLOW)=(1.-TBOD5/TBOD20)*100
      DTEN(IFLOW)=TA*24.0
      TOTSS(IFLOW)=TSS(5)
      SRET(IFLOW)=RETUR
      XML(IFLOW)=XMLSS
      IF(IFLOW-1)930,930,940
C      CALCULATE CAPITAL COSTS
  930 CCOST(1)=14700.*Q(20)**0.625
      IF (NFORK(5)) 1095,1095,1096
 1096 APS=0.0
      CCOST(2)=0.0
      NPS=0
      GO TO 1097
 1095 GPS=(-2780.*ALOG(FRPS)-551.7)
      APS=Q(1)*1000./GPS
```

```
      IF (APS-2.) 932,932,931
  931 IF (APS-30.) 601,601,605
  601 NPS=2
      GO TO 933
  605 NPS=IFIX(APS/30.+0.99999)
      GO TO 933
  932 NPS=1
  933 SPS = APS/NPS
      UCOST2=13.4+5.2*SPS**(-0.9)
      CCOST(2)=UCOST2*APS*1000.
 1097 SAER = VAER/NAER
      UCOST3=175000.+36500.*SAER**(-0.818)
      CCOST(3)=UCOST3*VAER
      CCOST(4)=10570.+5.357*PSIZE
      AFS=Q(4)*1000./GSS
      IF (AFS-2.)  935,935,934
  934 IF (AFS-30.) 610,610,615
  610 NFS=2
      GO TO 936
  615 NFS=IFIX(AFS/30.+0.99999)
      GO TO 936
  935 NFS=1
  936 SFS = AFS/NFS
      UCOST5=12.6+5.35*SFS**(-1.126)
      CCOST(5)=UCOST5*AFS*1000.
      CCOST(6)=3650.+2250.*Q(6)
      CCOST(7)=40000.*Q(20)**.70
      IF (ATHM-200.) 938,938,937
  937 IF (ATHM-50000.) 620,620,625
  620 NTH=2
      GO TO 939
  625 NTH=IFIX(ATHM/50000.+0.99999)
      GO TO 939
  938 NTH=1
  939 STHM = ATHM/NTH
      UCOST8=(18.8+9.1/(EXP(STHM/13300.)))
      CCOST(8)=UCOST8*ATHM
      IF (VDIG-10.) 510,510,505
  505 IF (VDIG-200.) 640,640,645
  640 NDIG=2
      GO TO 515
  645 NDIG=IFIX(VDIG/200.+0.99999)
      GO TO 515
  510 NDIG=1
  515 SDIG = VDIG/NDIG
      UCOST9=5.00/VDIG+1.08+10.7*SDIG**(-0.872)
      CCOST(9)=UCOST9*VDIG*1000.
  525 NAE=1
  530 SAE = AE/NAE
      UCOST0=(18.8+52.0/EXP(SAE/6000.))
      CCOST(10)=UCOST0*AE
      IF (AVF-20.) 545,540,540
  540 IF (AVF-800.) 660,660,665
  660 NVF=2
      GO TO 550
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```
  665 NVF=IFIX(AVF/800.+0.99999)
      GO TO 550
  545 NVF=1
  550 SVF = AVF/NVF
      UCOS11=12800./SVF+372.
      CCOST(11)=UCOS11*AVF
      CALL UNITEX(TSS(18),600000.,8000.,1.,NINC,SINC)
      CCOST(12) = (1570.*SINC **.6)*NINC
      CCOST(14)=9000.*(Q(5)-Q(17))**.469
      CCOST(15)=4400.*Q(20)**.875
   54 CTRP=0.10
      CTGO=.15
      CLAND=.02
      IF(NFCRK(1))48,48,47
   47 ASB=TSS(13)*Q(13)*8.33*30./SBL
      CCOST(10)=0.0
      CCOST(11)=0.0
      CCOST(13)=2.23*ASB
   48 GO TO 56
C     CALCULATE OPERATING COSTS
  940 COSTO(1)=500.*Q(20)+2150.*Q(20)**0.37
      COSTO(2)=1000.*APS+2500.*APS**.5
      COSTO(3)=10000.*VAER+14500.*VAER**.5
      CATRP=AIPOF *365.*CKWH/1830.
      COSTO(4)=CATRP
      IF (NBFLAG) 943,943,942
  942 CCOST(4)=10570.+5.857*PSIZE
  943 CONTINUE
      COSTO(11)=TSS(15)*FECL3*Q(15)*30.40*CFECL3
      COSTO(11)=COSTO(11)+1550.*Q(20)+6450.*Q(20)**.37
      YTONS=.1825*TSS(18)
      IF (YTONS-89444.) 944,944,945
  944 COSTO(12) = 8.05*YTONS
      GO TO 946
  945 COSTO(12)=16.1*YTONS-.00009*YTONS**2.
  946 COSTO(14)=QCL2*(Q(5)-Q(17))*8.33*CCL2*365.
      IF(NFCRK(1))948,948,947
  947 COSTO(9)=80.*VDIG+300.*VDIG**.44
      GO TO 949
  948 COSTO(9)=48.*VDIG+540.*VDIG**.44
  949 DO 941 J=1,15
  941 COSTO(J)=COSTO(J)/1000.*CIEC
C     CALCULATE TOTAL COSTS
   49 DO30J=1,15
   30 CCOST(J)=CCOST(J)*CIEC/1000.
      DO31J=1,15
   31 ACOST(J)=CCOST(J)*AF
      TOTCC=0.0
      DO32J=1,15
   32 TOTCC=TOTCC+CCOST(J)
      CENG=0.08*(1000./TOTCC)**0.146
      CCR=1.+CENG+CTRP+CTGO+CLAND
      TOTCC=TOTCC*CCR
      DO90J=1,15
      ACOST(J)=ACOST(J)*CCR
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```
   90 CCOST(J)=CCOST(J)*COR
      TACOS=0.0
      TCOSTO=0.0
      TOTAO=0.0
      DO 33 J=1,15
      TACOS=TACOS+ACOST(J)
      ACCOS(J)=ACOST(J)+COSTO(J)
      CPERK(J)=ACCOS(J)/Q(20)/3.65
      TOTAO=TOTAO+ACCOS(J)
   33 TCOSTC=TCOSTC+COSTO(J)
      CAPKG=TACOS/Q(20)/3.65
      COPKG=TCOSTO/Q(20)/3.65
      TCOST = TOTAO/Q(20)/3.65
      DO 955 J=1,15
      CCPCT(J) = CCOST(J)*100./TOTCC
  955 ACCPCT(J) = ACCOS(J)*100./TOTAC
   56 WBODPE=(Q(20)*TBOD20-(Q(5)-Q(17))*TBOD5)*8.33
      WTSSPE=(Q(20)*TSS(20)-(Q(5)-Q(17))*TSS(5))*8.33
      CWP=Q(7)*TOC7/Q(2)/TOC2
      CREM = 1.-TOC5*Q(5)/Q(2)/TOC2
      BODRE=1.-TBOD5*Q(5)/Q(2)/TBOD2
      EFF=CREM-CWP
      REMN=1.-(SON(5)+DN(5))*Q(5)/Q(2)/(SON(2)+DN(2))
      REMP=1.-(SOP(5)+DP(5))*Q(5)/Q(2)/(SOP(2)+DP(2))
      IF (IFLOW-1) 68,58,58
   58 CPBOD=TOTAO/WBODPE/0.00365
      CPTSS=TOTAO/WTSSPE/0.00365
   68 CONTINUE
      IF(IFLOW-1) 960,960,961
  960 WRITE(LIST,301)NRUN(IRUN),NCASE
C...........PRINT NFORK(2) STREAM PARAMETERS...........
  961 IF(NFORK(2)) 962,962,966
  962 IF(IFLOW-1) 963,963,964
  963 WRITE(LIST,805)Q(20)
      GO TO 965
  964 WRITE(LIST,806)Q(20)
  965 WRITE(LIST,115)
      WRITE(LIST,302)
      NSTA=1
      WRITE(LIST,313) NSTA,Q(1),SOC(1),SBOD(1),SNBC(1),SON(1),SOP(1),
     1SFM(1),VSS(1),TSS(1)
      WRITE(LIST,304) DOC(1),DBOD(1),DNBC(1),DN(1),DP(1),DFM(1)
      NSTA=2
      WRITE(LIST,313) NSTA,Q(2),SOC(2),SBOD(2),SNBC(2),SON(2),SOP(2),
     1SFM(2),VSS(2),TSS(2)
      WRITE(LIST,304) DOC(2),DBOD(2),DNBC(2),DN(2),DP(2),DFM(2)
      NSTA=8
      WRITE(LIST,313) NSTA,Q(8),SOC(8),SBOD(8),SNBC(8),SON(8),SOP(8),
     1SFM(8),VSS(8),TSS(8)
      WRITE(LIST,304)DOC(8),DBOD(8),DNBC(8),DN(8),DP(8),DFM(8)
      NSTA=5
      WRITE(LIST,313) NSTA,Q(5),SOC(5), SBOD(5),SNBC(5),SON(5),SOP(5),
     1SFM(5),VSS(5),TSS(5)
      WRITE(LIST,304) DOC(5),DBOD(5),DNBC(5),DN(5),DP(5),DFM(5)
      NSTA=7
```

```
      WRITE(LIST,313) NSTA,Q(7),SOC(7),SBOD(7),SNBC(7),SON(7),SOP(7),
     1SFM(7),VSS(7),TSS(7)
      WRITE(LIST,304) DOC(7),DBOD(7),DNBC(7),DN(7),DP(7),DFM(7)
      NSTA=10
      WRITE(LIST,313) NSTA,Q(10),SOC(10),SBOD(10),SNBC(10),SON(10),
     1SOP(10),SFM(10),VSS(10),TSS(10)
      WRITE(LIST,304) DOC(10),DBOD(10),DNBC(10),DN(10),DP(10),DFM(10)
      NSTA=11
      WRITE(LIST,313) NSTA,Q(11),SOC(11),SBOD(11),SNBC(11),SON(11),
     1SOP(11),SFM(11),VSS(11),TSS(11)
      WRITE(LIST,304) DOC(11),DBOD(11),DNBC(11),DN(11),DP(11),DFM(11)
      NSTA=12
      WRITE(LIST,313) NSTA,Q(12),SOC(12),SBOD(12),SNBC(12),
     1SON(12),SOP(12),
     2SFM(12),VSS(12),TSS(12)
      WRITE(LIST,304) DOC(12),DBOD(12),DNBC(12),DN(12),DP(12),DFM(12)
      NSTA=13
      WRITE(LIST,313) NSTA,Q(13),SOC(13),SBOD(13),SNBC(13),SON(13),
     1SOP(13),SFM(13),VSS(13),TSS(13)
      WRITE(LIST,304) DOC(13),DBOD(13),DNBC(13),DN(13),DP(13),DFM(13)
      NSTA=14
      WRITE(LIST,313) NSTA,Q(14),SOC(14),SBOD(14),SNBC(14),SON(14),
     1SOP(14),SFM(14),VSS(14),TSS(14)
      WRITE(LIST,304) DOC(14),DBOD(14),DNBC(14),DN(14),DP(14),DFM(14)
      NSTA=15
      WRITE(LIST,313) NSTA,Q(15),SOC(15),SBOD(15),SNBC(15),SON(15),
     1SOP(15),SFM(15),VSS(15),TSS(15)
      WRITE(LIST,304) DOC(15),DBOD(15),DNBC(15),DN(15),DP(15),DFM(15)
      NSTA=16
      WRITE(LIST,313) NSTA,Q(16),SOC(16),SBOD(16),SNBC(16),SON(16),
     1SOP(16),SFM(16),VSS(16),TSS(16)
      WRITE(LIST,304) DOC(16),DBOD(16),DNBC(16),DN(16),DP(16),DFM(16)
      NSTA=9
      WRITE(LIST,313) NSTA,Q(9),SOC(9),SBOD(9),SNBC(9),SON(9),SOP(9),
     1SFM(9),VSS(9),TSS(9)
      WRITE(LIST,304) DOC(9),DBOD(9),DNBC(9),DN(9),DP(9),DFM(9)
      NSTA=20
      WRITE(LIST,313) NSTA,Q(20),SOC(20),SBOD(20),SNBC(20),SON(20),
     1SOP(20),SFM(20),VSS(20),TSS(20)
      WRITE(LIST,304) DOC(20),DBOD(20),DNBC(20),DN(20),DP(20),DFM(20)
      WRITE(LIST,116)
      WRITE(LIST,302)
      NSTA=18
      WRITE(LIST,313) NSTA,WP,SOC(18),SBOD(18),SNBC(18),SON(18),SOP(18),
     1SFM(18),VSS(18),TSS(18)
      WRITE(LIST,304) DOC(18),DBOD(18),DNBC(18),DN(18),DP(18),DFM(18)
      WRITE(LIST,831)
C..........PRINT NFOPK(3) OTHER PLANT PARAMETERS..........
  966 IF(NFOPK(3)) 967,967,968
  967 CONTINUE
      WRITE(LIST,105) XMLAS,XMLPS,XLNPS,XMLDS,XMLIS,XMLSS,VAER,
     1VNIT,RETUR,CWP,CPEM,RODRF,REMN,RENF,EFF
      WRITE(LIST,111) EPPS,UPFS,URSS,YPSS,GPS,APS,GSS,AFS,GTH,GSTH,ATHM,
     1TRP,GE,GFS,AE,EPP,WFF
      WRITE(LIST,112) TRIG,TD,VDIG,FPDIG,C1DIG,C2DIG,CH4CF,CO2CF,VEL,
```

```
     1TVF,AVF,FOOD
      WRITE(LIST,113) DEGC,DO,CAFR2,CASF,AFFF2,AFFF,CNIT,CEFF,
     1AIRCF,CFFGA,BSIZE
      WRITE(LIST,118) FECL3,ALK(1),ALK(12),ALK(13),ALK(15)
      WRITE(LIST,807)TA,TAN,ROOLD(IFLOW),SVI,ASR
      WRITE(LIST,808)WROODE,WTSSPE,CNTT
      IF (IFLOW-1) 1043,1043,1042
 1042 WRITE(LIST,700)CENG,CTEP,CTGC,CLAND,CCR
      WRITE(LIST,701)AF
 1043 WRITE(LIST,831)
  968 IF(IFLOW-1) 950,950,951
  950 IFLOW=2
      GO TO 951
  951 CONTINUE
C...........PRINT QDOT,QBARE,UBAR...........
      WRITE(LIST,850)QDOT(LQ)
      WRITE(LIST,851)QBARE(LQ)
      WRITE(LIST,852)UBAR
      IF (NFORK(6)) 985,985,986
C...........PRINT NFORK(6) CERTAIN SELECTED PARAMETERS..........
  985 WRITE(LIST,853)
      WRITE(LIST,854)
      WRITE(LIST,855)FROD(1),FROD(2)
      WRITE(LIST,856)TRODPE(1),TRODPE(2)
      WRITE(LIST,857) ROOLD(1),ROOLD(2)
      WRITE(LIST,858)DTEN(1),DTEN(2)
      WRITE(LIST,859)NIT(1),NIT(2)
      WRITE(LIST,860)XNO3(1),XNO3(2)
      WRITE(LIST,861)XNH3(1),XNH3(2)
      WRITE(LIST,862)TOTSS(1),TOTSS(2)
      WRITE(LIST,863) XML(1),XML(2)
      WRITE(LIST,885) SPET(1),SPET(2)
      WRITE(LIST,886) QOUT(1),QOUT(2)
      WRITE(LIST,887) VEL,VEL
      WRITE(LIST,832)RCI
      WRITE(LIST,833)AF
C...........PRINT NFORK(6) NUMBERS OF EQUIPMENT UNITS..........
      WRITE(LIST,878) NPS,SPS
      WRITE(LIST,879) NAER,SAER
      WRITE(LIST,880) NFS,SFS
      WRITE (LIST,881) NTH,STHM
      WRITE(LIST,882) NDIG,SDIG
      WRITE(LIST,883) NAE,SAE
      WRITE(LIST,884) NVF,SVF
      WRITE (LIST,888) NINC,SINC
C...........PRINT NFORK(4) INDIVIDUAL COMPONENT COSTS..........
  986 IF(NFORK(4)) 980,980,982
  980 WRITE(LIST,810)
      WRITE(LIST,811)
      WRITE(LIST,812) CCOST(1),CCPCT(1),ACCOS(1),CPERK(1),ACCPCT(1)
      WRITE(LIST,813) CCOST(2),CCPCT(2),ACCOS(2),CPERK(2),ACCPCT(2)
      WRITE(LIST,814) CCOST(3),CCPCT(3),ACCOS(3),CPERK(3),ACCPCT(3)
      WRITE(LIST,815) CCOST(4),CCPCT(4),ACCOS(4),CPERK(4),ACCPCT(4)
      WRITE(LIST,816) CCOST(5),CCPCT(5),ACCOS(5),CPERK(5),ACCPCT(5)
      WRITE(LIST,817) CCOST(6),CCPCT(6),ACCOS(6),CPERK(6),ACCPCT(6)
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      WRITE(LIST,818) CCOST(7),CCPCT(7),AOCOS(7),CPERK(7),ACCPCT(7)
      WRITE(LIST,819) CCOST(8),CCPCT(8),AOCOS(8),CPERK(8),ACCPCT(8)
      WRITE(LIST,821) CCOST(10),CCPCT(10),AOCOS(10),CPERK(10),ACCPCT(10)
      WRITE(LIST,822) CCOST(11),CCPCT(11),AOCOS(11),CPERK(11),ACCPCT(11)
      WRITE(LIST,823) CCOST(12),CCPCT(12),AOCOS(12),CPERK(12),ACCPCT(12)
      WRITE(LIST,824) CCOST(13),CCPCT(13),AOCOS(13),CPERK(13),ACCPCT(13)
      WRITE(LIST,825) CCOST(14),CCPCT(14),AOCOS(14),CPERK(14),ACCPCT(14)
      WRITE(LIST,826) CCOST(15),CCPCT(15),AOCOS(15),CPERK(15),ACCPCT(15)
      WRITE(LIST,820) CCOST(9),CCPCT(9),AOCOS(9),CPERK(9),ACCPCT(9)
C..........PRINT TOTAL COST SUMMARY..........
  982 WRITE (LIST,827) TOTCC
      UQDOT=TOTCC/(10.0*QDOT(LO))
      UQBARE=TOTCC/(10.0*QBARE(LO))
      TOTPCT=100.00
      TOCPCT=TCOSTO/TOTAO*100.0
      WRITE(LIST,876) UQDOT,UQBARE
      WRITE (LIST,828) TOTAO,TCOST,TOTPCT
      WRITE(LIST,877) TCOSTO,COPKG,TOCPCT
      WRITE (LIST,829) CPROD
      WRITE (LIST,830) CPISS
      IF(NBFLAG)984,984,983
  983 WRITE(LIST,907)QNIT
  984 NCASE = NCASE+1
      XMLSS=ASS(I)
   25 CONTINUE
      STOP
  101 FORMAT(10F8.4/2F8.4)
  102 FORMAT(3F8.4/5F10.5/5F10.4/5F10.4/5F10.4)
  103 FORMAT(F8.2)
  105 FORMAT(     7X,8HMLASS = F10.4,4X,8HMLBSS = F10.4,3X,
     1 9HMLNBSS = F10.4,4X,8HMLDSS = F10.4,4X,8HMLISS = F10.4/
     2 8X,7HMLSS = F10.4,5X,7HVAER = F10.4,5X,7HVNIT = F10.4,
     3 3X,9HRETURN = F10.4,6X,6HCWR = F10.4/
     4 6X,9HCAPREM = F10.4,3X,9HBODREM = F10.4,3X,9HNITREM = F10.4,
     5 2X,10HPHOSREM = F10.4,6X,6HEFF = F10.4)
  107 FORMAT(I3/(F8.2))
  111 FORMAT(8X,7HERSS = F10.4,5X,7HUESS = F10.4,5X,7HUPSS = F10.4,
     15X,7HXPSS = F10.4/9X,6HGPS = F10.4,6X,6HAPS = F10.4,
     2 6X,6HGSS = F10.4,6X,6HAFS = F10.4/9X,6HGTH = F10.4,
     3 5X,7HGSTH = F10.4,5X,7HATHN = F10.4,6X,6HTFR = F10.4/
     4 10X,5HGF = F10.4,6X,6HGES = F10.4,7X,5HAF = F10.4,
     5 6X,6HEFP = F10.4,6X,6HWPF = F10.4)
  112 FORMAT(8X,7HTDIG = F10.4,7X,5HTD = F10.4,5X,7HVDIG = F10.4,
     1 4X,8HFEDIG = F10.4/7X,8HCTDIG = F10.4,4X,8HC2DIG = F10.4,
     2 3X,9HCH4CFD = F10.4,7X,9HCO2CFD = F10.4/9X,6HVFL = F10.4,
     3 6X,6HTVF = F10.4,6X,6HAVF = F10.4,5X,7HFOCF = F10.4)
  113 FORMAT(8X,7HDEGC = F10.4,7X,5HPC = F10.4,
     1 3X,9HCAEP20 = F10.4,5X,7HCAFP = F10.4/
     2 25X,7X,9HAFFF20 = F10.4,5X,7HAFFF = F10.4/
     325X,5X,7HCNIT = F10.4,5X,7HCEDS = F10.4/
     4 6X,9HAIRCFD = F10.4,3X,9HCFPGAL = F10.4,4X,8HPSIZE = F10.4)
  114 FORMAT(10I1)
  115 FORMAT(25X,4HMG/L,8X,4HMG/L,8X,4HMG/L,8X,4HMG/L,8X,
     1 4HMG/L,8X,4HMG/L,8X,4HMG/L,8X,4HMG/L)
  116 FORMAT(10X,11HPERCENT H20,3X,6HLB/DAY,5Y,6HLB/DAY,7X,
```

```
     1 6HLB/DAY,6X,6HLB/DAY,6X,6HLB/DAY,6X,6HLB/DAY,7X,6HLB/DAY,
     26X,6HLB/DAY)
 118 FORMAT(7X,8HFECL3 = F10.4,3X,9HALK(1) = E10.4,2X,
     1 10HALK(12) = E10.4,2X,10HALK(13) = F10.4,2X,10HALK(15) = F10.4)
 301 FORMAT(1H1/* RUN NO. *,I3,*, CASE NO. *,I3,11X,
     1*LKR-GOLD2 ACTIVATED SLUDGE PROCESS CALCULATION*,17X ,*DEC. 1970*,
     2//)
 302 FORMAT(1X,7HSTATION,6X,3HMGD,7X,6HCARBON,7X,3HBOD,6X,
     1 10HNBIOCARBON,3X,8HNITROGEN,3X,10HPHOSPHORUS,1X,12HFIXED MATTER,
     2 5X,3HVSS,9X,3HTSS/)
 303 FORMAT(1X,3HSOL,I4,7F12.4)
 304 FORMAT(1X,3HDIS,16X,6F12.4/)
 309 FORMAT(2X,12HCHLORINATION,14X,E10.4,6X,E10.4,7X,E10.4,
     18X,E10.4,7X,E10.4/2X,16HSITE DEVELOPMENT,10X,E10.4,6X,E10.4,
     27X,E10.4,8X,E10.4,7X,E10.4/)
 313 FORMAT(1X,3HSOL,I4,9F12.4)
 700 FORMAT(6X,7HCCENG = E10.4,2X,7HCTPE = E10.4,2X,7HCTGC = E10.4,
     12X,8HCLAND = E10.4,2X,6HCCR = E10.4)
 701 FORMAT(6X,5HAF = E10.4)
 801 FORMAT (2F8.2)
 802 FORMAT(I3/(2F8.2))
 803 FORMAT(/* BLOWER SIZE SET BY NITRIFICATION AT QNIT = *F8.3* MGD*/)
 805 FORMAT(* CONDITIONS AT DESIGN FLOW RATE, QPCT = *,F8.3,
     1* MILLION GALLONS/DAY*,//)
 806 FORMAT(     * CONDITIONS AT EXPECTED AVERAGE FLOW, QBARE = *,F8.3,
     1* MILLION GALLONS/DAY*,//)
 807 FORMAT(10X,*TA = *,F10.4,6X,*TAN = *,E10.4,4X,*BOOLD = *,F10.4,6X,
     1*SVI = *,F10.4,6X,*ASR = *,E10.4)
 808  FORMAT(6X,9HWBODRE = F10.4,3X,9HWTSSRE = E10.4,5X,7HCNIT = E10.4)
 809 FORMAT(I3)
 810 FORMAT(1H0, *COMPONENT OR ITEM      CAPITAL COSTS       AMORT. PLUS
     1OPERATING COSTS*)
 811 FORMAT(20X,*K-DOLLARS  PERCENT   K-$/YEAR  CENTS/KGAL  PERCENT*,/)
 812 FORMAT(* PRELIM. TREATMENT *,F10.3,F8.2,F12.3,F11.4,F9.2)
 813 FORMAT(* PRIMARY SETTLER   *,F10.3,F8.2,F12.3,F11.4,F9.2)
 814 FORMAT(* AERATOR          *,F10.3,F8.2,F12.3,F11.4,F9.2)
 815 FORMAT(* AIR BLOWERS      *,F10.3,F8.2,F12.3,F11.4,F9.2)
 816 FORMAT(* FINAL SETTLER    *,F10.3,F8.2,F12.3,F11.4,F9.2)
 817 FORMAT(* SLUDGE RET. PUMPS *,F10.3,F8.2,F12.3,F11.4,F9.2)
 818 FORMAT(* CONTROL HOUSE    *,F10.3,F8.2,F12.3,F11.4,F9.2)
 819 FORMAT(* SLUDGE THICKENER  *,F10.3,F8.2,F12.3,F11.4,F9.2)
 820 FORMAT(* DIGESTER         *,F10.3,F8.2,F12.3,F11.4,F9.2)
 821 FORMAT(* SLUDGE ELUTRIATION*,F10.3,F8.2,F12.3,F11.4,F9.2)
 822 FORMAT(* VACUUM FILTRATION *,F10.3,F8.2,F12.3,F11.4,F9.2)
 823 FORMAT(* SLUDGE INCIN.    *,F10.3,F8.2,F12.3,F11.4,F9.2)
 824 FORMAT(* SLUDGE DRYING BEDS*,F10.3,F8.2,F12.3,F11.4,F9.2)
 825 FORMAT(* CHLORINATION     *,F10.3,F8.2,F12.3,F11.4,F9.2)
 826 FORMAT(* SITE DEVELOPMENT  *,F10.3,F8.2,F12.3,F11.4,F9.2/)
 827 FORMAT(* TOT. CAPITAL COST *, F10.3)
 828 FORMAT(* TOTAL AMORTIZATION AND OPERATION COST*,F11.3,F11.4,F9.2)
 829 FORMAT(* CENTS PER POUND OF BOD REMOVED = *,F8.4)
 830 FORMAT(* CENTS PER POUND OF TSS REMOVED = *,F8.4)
 831 FORMAT (1H1)
 832 FORMAT(/,* BUILDING COST INDEX = *,F5.1)
 833 FORMAT(* AMORTIZATION FACTOR = *,F7.5)
```

```
  840 FORMAT(1H1,*..... INPUT DATA, RUN *,I3/)
  850 FORMAT (*  QDOT = *,F9.3,* MILLION GALLONS/DAY*)
  851 FORMAT (* QBARE = *,F9.3,* MILLION GALLONS/DAY*)
  852 FORMAT(*  URAP = *,F4.3)
  853 FORMAT(23X,*CONDITIONS AT*)
  854 FORMAT(* PARAMETER*,17X, *QDOT      QBARE   UNITS*,/)
  855 FORMAT(* EFFLUENT BOD*,F14.2,F10.2,*   MG/L OXYGEN*)
  856 FORMAT(* BOD REMOVAL*,F15.2,F10.2,*   PERCENT*)
  857 FORMAT(* BOD LOADING*,F15.2,F10.2,*   LB/DAY BOD PER 100 LB MLSS*)
  858 FORMAT(* AER. DETEN. TIME*,F10.2,F10.2,*   HOURS*)
  859 FORMAT(* NITRIFICATION*I11,I10,*      (1=YES, 0=NO)*)
  860 FORMAT(* EFFLUENT NITRATE* ,F10.2,F10.2,*   MG/L NITROGEN*)
  861 FORMAT(* EFFLUENT NH3-N*,F12.2,F10.2,*   MG/L NITROGEN*)
  862 FORMAT(* EFFLUENT TSS*,F14.2,F10.2,*   MG/L MASS*)
  863 FORMAT(* MIXED LIQUOR SS*,F9.0,F10.0,*     MG/L MASS*)
  870 FORMAT(1X,10I1)
  871 FORMAT (1X,9F8.4,4X,F8.4/1X,2F8.4)
  872 FORMAT (1X,3F8.4/1X,5F12.5/3(1X,5F12.4/))
  873 FORMAT(1X,2F8.2)
  874 FORMAT(1X,I3/(1X,F8.2))
  875 FORMAT(1X,I3/(1X,2F8.2))
  876 FORMAT(3X,*AS CENTS/GPD OF*,/,1H ,13X,*QDOT *,F10.3,/,1H ,12X,
     +*QBARE *,F10.3)
  877 FORMAT(3X,*OPERATING COST ONLY*,16X,F11.3,F11.4,F9.2)
  878 FORMAT(1H0,*NUMBER OF *,20X,*SIZE OF EACH*,5X,*UNITS*,/,1H ,
     +*PRIMARY SETTLERS*,3X,I4,6X,F10.3,7X,*SF*)
  879 FORMAT (1H ,*AERATORS*,11X,I4,6X,F10.3,7X,*MILLION GAL*)
  880 FORMAT (1H ,*FINAL SETTLERS*,5X,I4,6X,F10.3,7X,*SF*)
  881 FORMAT (1H ,*THICKENERS*,9X,I4,6X,F10.3,7X,*SF*)
  882 FORMAT (1H ,*DIGESTERS*,10X,I4,6X,F10.3,7X,*CF*)
  883 FORMAT (1H ,*ELUTRIATION TANKS*,2X,I4,6X,F10.3,7X,*SF*)
  884 FORMAT (1H ,*VACUUM FILTERS*,5X,I4,6X,F10.3,7X,*SF*)
  885 FORMAT (1H ,*SLUDGE RETURN*,F13.2,F10.2,3X,*FRACTION*)
  886 FORMAT (1H ,*DISCHARGE*,5X,F12.2,F10.2,3X,*MILLION GAL/DAY*)
  887 FORMAT (1H ,*VAC. FILT. LOADING*,F8.2,F10.2,3X,*GAL/HR-SF*)
  888 FORMAT (1H ,*INCINERATORS*,7X,I4,6X,F10.3,7X,*LBS/DAY*)
      END
      FUNCTION AMAX1 (A,B)
      AMAX1=A
      IF (A - B) 10,20,20
   10 AMAX1=B
   20 RETURN
      END
      SUBROUTINE UNITEX(QDOTU,QMAX,QMIN,F,NUNITS,QUNIT)
C------------FAIL-SAFE DESIGN WITH EXEMPTION------------
C    SIZE AND LEAST NUMBER OF UNITS TO PRODUCE AT LEAST QDOTU OR F*QDOTU
C    WITH ONE UNIT OUT. AT LEAST TWO UNITS, EXCEPT IF TWO OF MIN.
C    AVAILABLE SIZE GIVE MORE THAN TRIPLE QDOTU, THEN ONE UNIT, AND
C    DESIGN IS NOT FAIL-SAFE.
C
      QUNIT = QMIN
      IF (3*QDOTU-2*QMIN) 50,70,70
   50 NUNITS = 1
      WRITE (6,55)
   55 FORMAT (*----DESIGN NOT FAIL-SAFE, VIA EXEMPTION.----*)
```

NOTE: Some minor changes have been subsequently made to format specifications between 879 and 888.

```
      RETURN
   70 NUNITS = MAX0(INT(F*QDOTU/QMAX+2.-1E-9),INT(QDOTU/QMAX+1.-1E-9))
      IF (NUNITS-2) 80,90,90
   80 NUNITS = 2
   90 QUNIT = AMAX1(F*QDOTU/(NUNITS-1),QDOTU/NUNITS)
      IF (QUNIT-QMIN) 100,110,110
  100 QUNIT = QMIN
  110 RETURN
      END
```

NAMES OF VARIABLES

In the original GOLD Report (52) the variables are listed and defined, and in addition there are some variables in the program listing which are not listed and defined. The following listing of additional variables does not include those occurring in the list of variables or in the program listing in Reference 52. In other words, it includes only those variables which were added during the GOLD1 and GOLD2 modifications.

AOCPCT(i)	Percentage of the total amortization and operating cost attributable to the ith process.
BCI	Building Cost Index.
BODLD(i)	BOD loading for IFLOW = i, lb/day of BOD in Stream 2 per 100 lb MLSS in Aerator.
CCPCT(i)	Percentage of the total capital cost attributable to the ith process.
CIFC	Cost index factor for capital costs.
CIFO	Cost index factor for operating costs.
CPBOD	Cents/lb of BOD removed, amort. + op. cost.
CPTSS	Cents/lb of TSS removed, amort. + op. cost.
DEG	Array to hold DEGC values.
DTEN(i)	Value of TA when IFLOW = i (hours) (Aerator detention time).
EBOD(i)	Effluent BOD concentration for IFLOW = i, mg/l oxygen.
IFLOW	Flow index, IFLOW = 1 when Q(20) = QDOT, IFLOW = 2 when Q(20) = QBARE.
IRUN	DO loop index for runs.
KARD	Logical unit designator for card reader, (5) in system used.
KRUNS	Number of runs to be made.
KTYPE	Logical unit designator for printer, (6) in system used.
LF	DO loop index for FRPS loop.

CHAPTER 6

CONVENTIONAL OR REUSE? A COST COMPARISON FOR MUNICIPAL REUSE IN SAN ANTONIO IN THE YEAR 2000

COST OF INDIVIDUAL COMPONENTS OF THE SYSTEM

Note: The comparative costs developed in this chapter are for facilities and operations to meet the 2000 capability and average production, but installed and operated at 1969 cost levels. It is obvious that if a complete system were installed in 1969 not all the separate facilities would have a 2000 target year. Some might be built for 2020. Others might be built for 1980 with a plan for supplementing them in 1980. This would bring about differences in cost which might affect the comparative costs. However, to explore staging of this complex system is far beyond the resources of this project, which seeks preliminary comparisons.

Surface Water Reservoirs

It had been the decision of the AACOG Steering Committee to allocate to water supply the costs of owning and operating reservoirs in proportion as the conservation storage is to the total storage. It was understood that this gives about the same results as the incremental cost method. This policy was used in costing on this project although we did not find the time to explore the quantitative validity of it.

Previous studies have developed methods for generalizing on required reservoir sizes and costs in various regions of the country and for various yields as expressed as fractions of average stream flow (40, 41, 43). Application of this general estimating method gives costs of owning and operating reservoirs in Texas, 1969, in the range of about 0.6 to 2.5¢/Kgal of yield when this is at a 100 mgd level, and 1-5¢/Kgal at a 10 mgd level, the range in the figures being the range between yields of 5% and 80% of average stream flow.

Information was obtained on the estimated costs and yields of the three specific reservoirs involved in the Cuero scheme (37, 56, 57, 58). The data and computations are presented in Table 29. The table shows storage volumes necessary to allocate costs in the above policy. The percent allocated to water supply is based on the conservation and flood control storages. This has the effect of proportioning the sediment storage among the two actual water uses. The percent allocated to water supply for Cibolo is the average for two sets of storage figures for Cibolo which differed slightly. The investment was adjusted to 1969 by the USBR Earth Dam Index. The withdrawals for this project were those developed in Chapter 3, and shown is the percentage of the yield which this represents. The OMR costs shown are taken from the generalized costs developed in

TABLE 29

RESERVOIR COSTS

	Cuero I + II	Cibolo	Goliad
Capacity, Kaf			
Sediment	50	28	42
Conservation	2,816	172	958
Flood control	843	218	702
Sub-total C + FC	3,659	390	1,660
Total	3,709	418	1,702
% allocated to W.S.	76.7	45.6	57.7
Yield 2020, mgd	216.8	21.3	102.1
Investment, 1969, m$	150	34.2	61
Withdrawal this project	127.7	21.3	113.1
% of yield	58.8	100.	100.+
OMR, 1969 K$/yr	150	70	111
Capital recovery, K$/yr	6,840	1,560	2,780
Total annual cost	6,990	1,630	2,890
Allocated to W.S.	5,360	744	1,670
Cost, ¢/Kgal	6.75	9.55	4.49
Annual cost, S.A. supply K$/yr	3,150	744	1,670
S.A. share of investment, m$	67.7	15.6	35.2

References 40 and 43. OMR costs for Cibolo are found in Reference 58 in magnitude of about three times the generalized OMR cost. However, the generalized costs are retained because they come from actual or estimated OMR costs on a reasonably large number of reservoirs. The capital recovery is based on 100 years life, 4.5% interest, no taxes and no insurance. The total annual cost was allocated to water supply in proportion as the percent of storage allocated to water supply. The costs allocated to water supply were allocated to the San Antonio supply in proportion as the withdrawal for the San Antonio supply was to the total yield.

It is seen that the costs so allocated and based on actual construction cost estimates are about twice those which would have been obtained from the generalized study. Of course, a high accuracy cannot be expected from a generalized prediction of reservoir size for a given firm yield and reservoir costs as a function of size considering the topographical and hydrological variability over the nation. Thus, it is preferable to use actual cost estimates for actual reservoirs at known sites, as is done here, if these are available.

Pipeline Conveyance

Chapter 4 presents a computer program for costing conveyance by pipeline. This was used to compute the cost for the following lines under flow conditions as given in Table 33, beyond:

Cuero-Cibolo-Hildebrand
Goliad to Victoria
Rilling to Hildebrand

Hildebrand refers to the distribution storage tank on Hildebrand Avenue in San Antonio which is the terminus of other conveyance systems that have been investigated. Rilling is the site of the Rilling Road sewage treatment plant.

The parameter values used were as follows:

Elevations

Cuero	242.5 ft msl (mean sea level)
Cibolo	400.1
Hildebrand	830.0
Goliad	200.0
Victoria	50.0
High point between Goliad and Victoria	220.0
Rilling	579.75

Distances

Cuero to Cibolo	34.2 miles
Cibolo to Hildebrand	38.3
Goliad to Victoria	28.35
Rilling to Hildebrand	10.0

Construction and Terrain Factors

Cibolo to Hildebrand	1.05
Rilling to Hildebrand	1.2
Others	1.0
Pipeline life	75 years
Pump station life	25 years
Interest rate	4.5%
Tax rate	1%
Insurance	1%
Labor price	3.00 $/hr
Payroll extras factor	.45
Temperature	21.5°C
Head limit on pump station	300 ft (feet)
Wire-to-water efficiency	.75
Pipe roughness	0.0003 ft

For most of these pump station systems the energy price became approximately 1¢/Kwh; except for the pumped-assisted segment into Victoria where because of the low energy consumption the price became about 4¢/Kwh. However, the effect on conveyance cost is minimal because the actual energy consumption is so small. The complete printout for the Cuero-Cibolo-Hildebrand line has been shown in Chapter 4.

Comparison of Conveyance Costs with Previous Engineering Study

For Texas Water Development Board (TWDB) there had been prepared a preliminary engineering study (36) which included the Cuero-Cibolo-Hildebrand pipeline conveyance system. The engineering report, which also covered the Lake Austin to San Antonio conveyance system, largely canal, produced costs which are much lower than those used in the present study, in ¢/Kgal 6.15, 4.92, and 4.34 for 100, 200, and 300 thousand acre feet per year (Kafy) respectively, with electricity at 3 mils, 200 Kafy is approximately 179 mgd and may be compared with the Cuero-Cibolo-Hildebrand costs in this study for 149 mgd of 13.4¢/Kgal.

The ground rules given by TWDB for their study were quite different from those judged realistic for the present study. Some of them were as follows:

	TWDB	This Study
Utilization factor	1.0	Ca .5
Pipeline life	50 years	75
Pump station life	50 years	25
Interest rate	3.5%	4.5
Insurance	0	1.0
In lieu of taxes	0	1.0
Energy price	3 mils	Ca 10 mils
Pump efficiency	.85	(.75)

Also, TWDB took slightly different elevations for the pipeline termini as follows:

Cuero	230	242.5
Cibolo	390	401

In addition, of course, the TWDB year is 1966 or 1967, the present study year 1969. The present case contains the generalized pump station and pipeline costs for Texas while the TWDB study used their own set of costs, some of which were specified to them by TWDB. Taken together with the fact that the present study QBARE is 149 compared to the TWDB 179 most of these differences in ground rules act to make the TWDB unit cost less than the present study cost.

To check the two systems under conditions as nearly identical as possible the program was run with data corresponding to the TWDB cases for 100, 200, and 300 Kafy. That is, changes in the data were made for elevations, QDOT and QBARE, equipment life, interest rate, taxes and insurance, energy price and pump efficiency (wire-to-water efficiency taken as .806). All other data were left the same as they had been in the Cuero-Cibolo-Hildebrand case including the terrain factors and construction factors, the water temperature and the year, 1969. It was not possible to use the TWDB year 1967 because the cost index projections used are not valid prior to 1968. The comparison is shown in Table 30.

While it was not possible to compute the case for 1967 it is possible to roughly adjust the TWDB data to 1969 by utilizing the Building Cost Index for San Antonio in the two years, 732 and 629. The TWDB figures adjusted in this rough manner are shown in the corresponding columns in the table in parentheses.

It is seen that thus adjusted the TWDB and present study costs agree within a maximum difference of about 7%. The present study is about 6.5% low at 100 Kafy (thousand acre feet per year), about 7.3% high at 300 Kafy and within about .35% at 200 Kafy. It happens that 200 Kafy is the case closest to the real case studied in this project. TWDB has 5.72¢/Kgal and the present study has 5.70.

TABLE 30

COMPARISON TWDB (1967) VS. PRESENT STUDY (1969)
CUERO-CIBOLO-HILDEBRAND

	Segment 1 Cuero-Cibolo		Segment 2 Cibolo-Hildebrand	
	TWDB	Present Study	TWDB	Present Study
100 Kafy				
Pipe diam, in. (inches)	66	58.3	66	58.3
Maximum pressure class	250	150	200	150
Number pump stations	1	2	2	3
Head, pump station	383	266	352,348	285
Total Costs				
Investment, m$ 1967	37.5	-		
Investment, m$ 1969	(43.6)	32.0		
Total production cost, K$/yr	1,912	2,190		
Total production cost, ¢/Kgal 1967	6.15	-		
Total production cost, ¢/Kgal 1969	(7.15)	6.72		
200 Kafy				
Pipe diam, in.	84	77.0	84	76.5
Maximum pressure class	250	150	200	150
Number pump stations	1	2	2	3
Head, pump station	434	257	360,365	283
Total Costs				
Investment, m$ 1967	56.5	-		
Investment, m$ 1969	(77.4)	54.2		
Total production cost, K$/yr	3,371	3,719		
Total production cost, ¢/Kgal 1967	4.92	-		
Total production cost, ¢/Kgal 1969	(5.72)	5.70		
300 Kafy				
Pipe diam, in.	102	93.7	102	89.5
Maximum pressure class	250	150	200	150
Number pump stations	1	2	2	3
Head, pump station	399	212	335,335	271
Total Costs				
Investment, m$ 1967	73.7	-		
Investment, m$ 1969	(85.7)	75.1		
Total production cost, K$/yr	4,565	5,138		
Total production cost, ¢/Kgal 1967	4.34	-		
Total production cost, ¢/Kgal 1969	(5.05)	5.45		

The TWDB pipe sizes are somewhat larger than those of the present study and the total horsepower of the pump stations somewhat less. The TWDB total investment is greater than in the present study and the operating cost less. Part of the difference in operating cost comes about because the TWDB costs for OMR on pipeline and OMR on pump station are considerably lower than the present study costs. For both of these the TWDB study used the ground rules laid down by TWDB. We believe the present study costs for these are nearer to the experienced costs. TWDB is able to use a smaller number of pump stations because it allows a pump station head higher than the present study constraint. If the present study constraint for limiting head on pump station had been 430 feet instead of 300 feet the number of pump stations would have been the same as the TWDB number. However, a limiting head of 400 feet would not have changed the present study. The higher limiting head allowed by TWDB in part explains the higher maximum pressure class which they use, but some of this also could be engineering judgment on the service required regarding backfill conditions, water hammer, etc. which are not plugged into the present study computer program (and which are probably beyond the capabilities of a computer program).

Ground Water Withdrawal

Table 31 shows the investment cost experience on four San Antonio well stations constructed between 1959 and 1968. Two of the stations are secondary stations not having high service pumps or reservoirs, and two are primary stations for which it is seen the unit investment in reservoirs and building make a large contribution to the total investment. The primary and the secondary stations do not lie on the same unit investment curve. The investment relation for the primary station is:

Investment, $ = 237,281*(mgd well pump capability)**.55984

TABLE 31

INVESTMENT IN RECENT SAN ANTONIO WELL STATIONS

Station	Maltz-berger	Wurzbach	34th Street	Basin
Installed, capability, mgd				
Well pumps	10	20	30	75
High service pumps	0	0	33	90
Number of wells	2	4	3	7
Number of high service pumps	0	0	4	6
Number of reservoirs	0	0	1	1
1968 investment, K$	222.6	210.1	1,593	2,660
Unit investments, ¢/gpd				
Reservoirs	0	0	1.05	.42
HS pumps	0	0	.42	.43
Wells and well pumps	1.98	.81	.67	.75
Site preparation, bldg,* general	.00	.02	2.56	1.71
Total including land	2.23	1.05	5.30	3.56

*building

The 1968 costs for the entire City Water Board system shows a unit energy consumption of 1.44 Kwh/Kgal for the well stations, an OMR cost for these of .248¢/Kgal and an energy price of .802¢/Kwh.

The computations for costs were made with a small computer program (GWBXR, not listed) using the above investment relation, a firming factor (installed capability/firm capability) of 1.4, energy use of 1.44 Kwh/Kgal, energy price of 0.8¢/Kgal, OMR cost of 0.25¢/Kgal, and with the maximum size pump station of 75 mgd installed capability. The well station life was taken as 50 years, interest 4.5%, taxes and insurance 2%.

Under these conditions and at a 40% utilization factor the cost of ground water produced in San Antonio is about 3.8¢/Kgal in the mains. The availability of ground water delivered at this low price, of course, is unfavorable for the economics of reuse in San Antonio.

References 40 and 43 present a generalized method for estimating the costs of ground water production. The costs there are 1962 National and include in the investment only the well and the pump, not the high service pumps, building and land. The cost there given for a ten well station with an installed capability of 75 mgd is 2¢/Kgal, but if the investment used there is adjusted to 1968 San Antonio and adjusted for the investment increase attendant upon land, building and high service pumps, a factor as shown in Table 31 of about 4.8, then the so adjusted generalized costs for the comparable San Antonio station come out to 3.5¢/Kgal. Those wishing to use the reference for a general prediction should multiply the capital recovery costs there given by about fivefold to get correct costs for well stations with buildings and high service pumps.

Water Treatment

If surface water were used it would be necessary to treat it in a conventional water treatment plant by coagulation, sedimentation and rapid sand filtration. Reference 59 presents results of a comparative cost engineering audit on treatment plants of this type in sizes of about .5 and 8 mgd. Some additional data on costs in large size plants was used to interpolate the costs in a 230 mgd plant operated at 149 mgd average production. Adjusted to San Antonio 1969 by the Building Cost Index these project an investment of 18.55m$ and an annual production cost of 3,240 K$/yr, about 6¢/Kgal.

Activated Sludge Sewage Treatment

Chapter 5 presents a computer program for costing activated sludge treatment. The exemplary cases run in that chapter are those for the plants actually used in the cost study and the parameter values used will be found in that chapter.

The investment in the existing and under construction plants is already sunk and does not enter into the comparison with advanced waste treatment and reuse. The continuing costs in the three plants if they are used are only the operation costs. The sample printout given in Chapter 5 is that for the new conventional treatment plant which would be required.

The sizes and costs are contained in Table 33, beyond.

Advanced Waste Treatment

Chapter 2 provides a computer program for design and costing of advanced waste treatment by the lime-clinoptilolite-carbon process. The sample printout of the exemplary case given in that chapter are those for the San Antonio 2000 requirements considered as a single central plant. The costs are shown in Table 33, beyond.

Balancing Storage

The monthly average curves of water distributed and sewage collected such as presented in Chapter 3 show no average month in which the water used is less than the sewage collected. If this were also the day-to-day situation the advanced waste treatment plant could operate on the sewage collected and the difference could be made up by a fluctuating ground water pumpage.

However, if there occur individual days on which the sewage collected is greater than the water used then something must be done with that day's excess "raw material." If the system comprises an advanced waste treatment reuse portion in parallel with a conventional treatment discharge portion then presumably the day'e excess could be shunted to the conventional treatment plant and discharged. However, if the system is a complete recycle-no discharge one then a place must be found for the day's excess. Not only must a place be found because of the no discharge-no pollution requirement, but also if any appreciable number of days' excesses are wasted, additional input from ground water must be supplied. Thus, the total system would have to be enlarged to produce this excess which is wasted. To avoid these consequences requires a balancing storage of some sort and of some magnitude.

It is very possible, of course, that in San Antonio this balancing storage could be accomplished by reinjection of the AWT plant product back into the aquifer. San Antonio is sitting on top of a tremendous no-cost storage reservoir.

But most cities are not so fortunately situated as to have a convenient and readily accessible underground storage reservoir at hand. Note that it is not necessary that the city obtain its major supply from ground water. An aquifer storage arrangement could be worked out if the aquifer is available even though the city has a surface water supply.

The alternative to aquifer storage would be a surface reservoir for storage. In any event there would be some cost involved for this balancing storage.

This project has not attempted the assessment of that balancing storage cost primarily because it has not been found possible to work up the extensive data which would be required to determine the magnitude of the balancing storage. Involved is a study similar to a reservoir sizing study, for which the techniques are known. However, the fluctuating input comprises, instead of the data on day-by-day stream flow, the data on day-by-day excess of sewage collected over water used. This, of course, will have many zero days or negative days which count as zero days in the input regime.

This project collected day-by-day data on sewage flows and water flows for a number of corresponding years for San Antonio. The sewage flow data were used in a number of statistical studies including consecutive days of low flow and consecutive days of high flow such as are involved here. The water data were not used because the investigation promised to be a rather major one.

If the quantities involved in each excess event are small the balancing storage could possible be of the order of distribution storage, some of which is normally available on an existing system. The expected frequency of excess events would be greater in the wintertime than in the summertime since in the summer the water use is some three times the sewage collected. It is quite likely, however, that the maximum storage required for an event, which determines the cost, will occur in the springtime months since these are the months of highest rainfall in San Antonio.

Regardless of these speculations this project has not included the cost of balancing storage because it has not determined the magnitude of the storage requirement. It is left as an unknown cost element which is applicable in the reuse scheme, but not in the conventional scheme.

Demineralization and Disposal

As has been described in Chapter 3, the solution to the recycle problem is not yet completely worked out and therefore a complete material balance on the reuse scheme cannot be worked out. It was shown in Chapter 3 that the blend would meet the 500 ppm TDI specification during only two months of the year if there were no demineralization and no discharge.

With a given system any ion might be subject to buildup in the recycling water, that is, in the blend. The RECYCLE Program will provide for computations on about 50 of these and any one of them may prove to be the controlling ion. For illustration let attention be directed to TDI as a controlling parameter. To reduce the TDI to 500 mgpl from the monthly level shown in Chapter 3 it would be necessary to either discharge some water, that is to increase the makeup, or to demineralize some of the return. Our aim in this section will be to make some very rough approximations to the cost of achieving 500 mgpl in the blend under the San Antonio monthly average conditions given in Chapter 3.

If the blend is lowered to 500 mgpl by increasing the discharge that is by increasing the makeup over the levels given in Chapter 3, which will generate a discharge, major changes will have to occur in the system. The amount of increase in the makeup would be quite high because the makeup in the example taken is already at 437 mgpl and therefore not very useful as a diluting water. Also, the ground water supply is not far from its limiting constraints. As will be shown the need for discharge fortunately happens to be the least in those months where the ground water withdrawal is the highest. Nevertheless, if the makeup has to be increased very much it will soon come up against the ground water constraint and thereafter will require a surface water supplement. This, of course, would considerably change the entire picture with respect to reuse. Demineralization seems the preferable alternative if it does not prove too expensive.

It is not possible to arrive at the steady state figures for demineralization without going through the recycle program. However, as a simple approximation Table 32 shows the quantity which would have to be demineralized, by electrodialysis, in order that the blend of Chapter 3 meet the 500 mgpl TDI specification in each month. This has been calculated by simply computing the fraction of the return that would have to be demineralized at 45% removal per stage in order that the blend become 500 mgpl (but not taking into account that the next return would then have a different composition).

TABLE 32

QUANTITIES TO BE DEMINERALIZED (45% REMOVAL)
FOR 500 mgpl IN BLEND

mgd

Month	1st Stage	2nd Stage	Total Return
1	177	46	177
2	162	0	171
3	144	0	172
4	76	0	164
5	96	0	186
6	44	0	180
7	0	0	168
8	0	0	183
9	82	0	189
10	119	0	178
11	176	24	176
12	175	86	175
QDOT	327	159	350
Annual amount processed ÷ 12	104	13	177

During two months it would not be necessary to demineralize at all since the blend is already below 500 mgpl. During three months a 45% removal from the return flow would not be adequate and it would be necessary to demineralize all of the return in a first stage and some of the return in addition in a second stage. This, of course, could actually be done by arranging some of the stacks in series to double-stage the demineralization. The cost computation here, however, computes the costs as if the operation were carried out in two one-stage plants. The design capability for the ED (electrodialysis) plant is taken as 1.85 times the highest monthly average flow. This is actually not correct. The 1.85 factor gives the maximum day in ratio to the maximum month at the 90 percentile level for the total sewage flow. The correct procedure would involve determining this ratio for each month and taking that month giving the highest product of ratio times amount demineralized. This would give a lower QDOT and a lower cost.

The table is to be read as follows: Using January as an illustration, the average total return is 177 mgd. All of this would have to be demineralized in the first stage and 46 mgd would require demineralization in a second stage, leaving 131 mgd to by-pass the second stage. In May, the fifth month, out of 186 mgd average return only 96 mgd would have to be demineralized in the first stage leaving 70 mgd to by-pass demineralization entirely.

Previous work on electrodialysis costs has developed the investment and operating costs for one stage (also for up to six stages) working on water of average ease for demineralization by electrodialysis and in a warm climate such as at San Antonio. The data and costs are from Ionics, Inc. installations and experience and the one stage cost actually applies to demineralization from 900 mgpl to 500 mgpl TDI. The costs for the equivalent 45% removal become slightly higher as the starting TDI becomes lower, considerably higher as it becomes as low as 300 mgpl, and become lower as the concentration becomes higher than 900. However, the cost changes in the starting concentration ranges concerned here are negligible compared to the approximateness of the plant to which the costing is applied.

For a single stage the cost relations are well represented by:

Unit investment, ¢/gpd, (year, region) =

$$\frac{CYCEI}{109.7} * \frac{CYBCIREG}{CYBCINAT} \text{ EXP } \left[\frac{1}{.259739+.0356967*LN(QDOT)} \right] \quad (1)$$

Unit operating cost, C/Kgal (year, region) at UBAR = .9 =

$$\frac{CYBCIREG}{687} * \text{ EXP } \left[\frac{1}{.42406+.0277584*LN(.9*QDOT)} \right] \quad (2)$$

where CYCEI = current year Chemical Engineering Chemical Plant Cost Index

CYBCI = current year BCI, regional and national

The operating cost equation correlates the operating cost in plants of different capabilities in which QBARE is 90% of QDOT. It is not correct to simply apply this relation to situations in which QBARE is the variable in a plant of fixed QDOT capability. In a plant of fixed capability some of the operating costs at UBAR = .9 are fixed and independent of the QBARE and of those that are dependent some are dependent linearly, others not. Cost studies on electrodialysis (e.g. 60) indicate that of the operating costs, for a 10 mgd plant for example, about 10% are fixed and independent of throughput in a given size plant such as labor, lighting, heating, etc. and 90% are independent upon throughput roughly linearly such as energy, membrane replacement, etc. A small computer program was written which would take the production schedule in Table 32 and compute investment and operating costs in which the operating costs according to equation 2 were aportioned as 90% fixed and 10% proportional to QBARE. The resulting investment, 1969 San Antonio, is 42.8 m$ and the annual production cost 7,072 K$/yr. This amounts to 18.6¢/Kgal of feed to the first stage.

When the RECYCLE Program is put to work on demineralization it will be found that the quantities to be demineralized become less than indicated here which has simply taken the required demineralization for one pass to lower the concentration of the return coming from a blend such that it will give 500 mgpl in the blend. However, the blend from which this return came had a concentration greater than 500 mgpl. Not so much demineralization will be required on the return that it is generated from a blend already at 500 mgpl.

In the other direction the cost will be greater by virtue of the limited recovery in demineralization by electrodialysis. Electrodialysis, and also reverse osmosis, are limited in the recovery which can be achieved which is controlled by the concentration built up in the reject liquors. Recoveries of 95% are projected for the San Antonio water. At this rate an additional amount of makeup equalling about 1/20th of the quantity demineralized would be required. This makeup increase would amount to about seven mgd average over the year with 14 mgd being required in the winter months. The production costs of this extra water would have to be added to those shown in Table 33 beyond, but would not increase the total very much. The 14 mgd requirement in the winter months fortunately comes when the makeup demand is low and the total will not exceed the ground water constraint.

Some means of disposal will have to be found for the reject liquor which will have a concentration of the order of 10,000 mgpl in the winter. A pipeline to dispose of this to the Gulf of Mexico would cost about 19 million dollars and the annual disposal costs in it would be of the order of 1,100 K$.

The reader can clearly see that the figures and costs given for demineralization and disposal are of the very roughest sort and only included to give an idea of their general magnitude. A number of alternative demineralization and disposal methods could be considered.

Sewage Conveyance

Early in the project AACOG (Alamo Area Council of Governments) had a need for costs of sewers. Neither the AACOG need nor this project involved the small sizes of sewers in the collection system, since for this project the collection system would be required for either the conventional system or the reuse system. Accordingly, it was decided that the cut-off point for the study would be a 12 inch sewer, which has a capability of about two mgd. Sewer costs as a function of depth and diameter were worked out as described beyond for those purposes. The sewer costs were not actually used in the project because at the present stage we have only compared a single AWT plant with a single conventional plant both tentatively at the Rilling site. Accordingly, the conveyance system, i.e. the trunk and interceptor lines, would be the same for both alternatives.

There was prepared (61) a correlation of bid tabulations from about 20 bids throughout the nation on concrete reinforced sewers all deregionalized and adjusted to a WPC-S National Cost Index of a 127.04 corresponding to March 1968. The bid items correlated were simply those items giving per linear foot costs for various sizes of sewer pipe. In addition to these items the total bid normally contains also such additional items as paving, structures, rock excavation, highway crossing, engineering, etc.

The data, supplied as curves for 15, 21, 27, 33, 48 and 60 inch sewers and various depths of cut, were correlated by multiple regression analysis on the Cartesian equations, the best resulting predictive equations being as follows:

for 12' to less than 30":

$$\ln (\$/\text{foot}) = 1.48019+0.0412173*ID+0.0268722*DEPTH$$

$$\sigma = 1.05$$

for 30" and up:

$$\ln (\$/\text{foot}) = 2.28733+0.0227985*ID+0.0134408*DEPTH$$

$$\sigma = 1.028$$

The σ ratios shown above are not the true σ ratios for the original data points. Rather they are the σ ratios for the selected points of the curve used in generating the multivariate regression. They thus indicate how closely the predictive equations reproduce the curves rather than how closely they reproduce the original point data. (The σ ratio is the anti-log of the standard deviation in log units and corresponds to the ratio of the 84th percentile point to the 50th percentile point.)

Obviously the total cost of an installed sewer per linear foot must be obtained from the above predictive equations by multiplying the predicted $/foot cost by some factor which incorporates the other bid items. To develop such a factor, data were obtained on recent bids for sewers in San Antonio, specifically the Alpha, Beta, Gamma and Delta segments of the Olmos outfall and two versions of the Salado outfall with different joint types, the average of the two lowest bids being used in each case. The ratios of the local bids to the predictive equation (for San Antonio area in the year of bidding) fell in two groups, one group around 2.0 and the other around 1.5 (actually 1.98, 2.33, 2.18, 1.44, 1.48, 1.49).

Various manipulations were made in the attempt to correlate these ratios. The conclusion was that the ratio was not correlated with the amount of rock excavation and not with the average depth of cut but it did follow a measure "degree of city streets" measured by the square yard of base supplied for pavement per linear foot of sewer. The ratios around 1.5 occurred when this measure was less than 0.2; those around 2.0 when this measure was above 0.6. Further exploration indicated that it was not the cost of the pavement itself or the culture involved which brought about the difference in the ratios. Rather the bidders had increased the per linear foot items on their bids to bring about the difference.

It was concluded that sewer costing for the project, for San Antonio, would be accomplished by multiplying the predictive equation by 2.0 or 1.5 depending on the qualitative judgement of the terrain as being largely in city streets or largely in open country, respectively.

The final results for San Antonio sewer costs are accordingly expressed as follows:

if ID 12" to less than 30":

unit cost $/l.f. =

$$\text{STREET}^* \left[\text{EXP}(1.48019+0.0412173^*\text{ID}+0.0268722^*\text{Depth}) \right] * \frac{\text{WPC-S(Yr, Region)}}{127.04}$$

if ID 30" and up:

unit cost, $/l.f. =

$$\text{STREET}^* \left[\text{EXP}(2.28733+0.0227985^*\text{ID}+0.0134408^*\text{Depth}) \right] * \frac{\text{WPC-S(Yr, Region)}}{127.04}$$

STREET = 2.0 if largely through city streets,
1.5 if largely in open country.

EXP = e raised to the power indicated in parentheses.

ID = nominal inside diameter of pipe, inches.

DEPTH = average depth of cut below surface, feet.

WPC-S(Yr, Region) = EPA sewer cost indexes for the indicated year and indicated region.

YR = year of prediction

REGION = the one of the 20-Cities regions surrounding the ENR (Engineering News Record) 20 cities cost indexes which has been set out by U.S. Public Health Service for regionalizing cost indexes.

127.04 = the WPC-S national index for March 1968. Basis of the original correlation.

It will readily be recognized that this correlation of sewer costs, based on only 20 bids, must be purely provisional. Through the Construction Grants activity EPA must have much more data on individual sewer installations which could be used for an analysis which would give much more secure predictive equations, of the same stature as those developed for pipelines and mentioned in Chapter 4.

COMPLETE SYSTEM COSTS

Table 33 shows the summary of the components for the conventional and the reuse systems, the quantities as developed in Chapter 3 and the costs as developed in the immediately preceding sections.

The costs for the Cuero to San Antonio conveyance are a little high since they have been computed for conveyance of the whole 149 mgd from Cuero. Actually 127.7 is conveyed from Cuero to Cibolo, and 149 from Cibolo to San Antonio. The total cost for the 149 mgd of surface water delivered is 25.7¢/Kgal and delivered and treated 31.6¢/Kgal.

The cost of the new ground water supply is 3.4¢/Kgal, and 3.8¢/Kgal for the slightly smaller quantity involved in the reuse scheme. For production from the existing ground water facilities only the operating costs are shown, 1.4¢/Kgal, since the capital investment is already sunk and must be borne with either scheme. On this basis, i.e. eliminating the amortization on the existing ground water facilities, the total make-up water delivered and treated is 341 mgd for the conventional case at about 15¢/Kgal and 164 mgd for the reuse case at about 2¢/Kgal. The differential between the conventional and the reuse schemes amounts to 17.4 m$/yr.

For conventional sewage treatment in the existing or under construction plants again only the operating cost is shown since the capital cost must be borne by both schemes. The so computed cost for conventional sewage treatment is 5.8 m$/yr.

Advanced waste treatment is applied to 177 mgd at the unit cost of 23.8¢/Kgal, total cost 15.3 m$/yr in a plant which requires a capital investment of 86 m$. The return conveyance for this water is accomplished for 3.3¢/Kgal.

The very rough figures on demineralization by electrodialysis show a cost of about 18¢/Kgal. The relatively small fraction of reject from electrodialysis, still amounting to seven mgd, adds 1.1 m$/yr for conveyance to the Gulf for disposal.

The balancing storage which may be required in the reuse scheme is not accounted for.

In total, the items accounted for involve an investment of about 264 m$ for the conventional scheme at an over-all 19.5¢/Kgal for a total annual cost of 24.4 m$. The corresponding investment for the reuse scheme is considerably less, only 169 m$ but the annual cost is greater, 26.8 m$/yr at 21.6¢/Kgal.

TABLE 33
COST SUMMARY

	Conventional					AWT Reuse				
	QDOT mgd	QBARE mgd	New Capital m$	Annual Cost K$	¢/Kgal	QDOT mgd	QBARE mgd	New Capital m$	Annual Cost K$	¢/Kgal
Share of reservoir cost Cuero		127.7	67.7	3,150	6.8	-	-	0	0	
Cibolo	230	21.3	15.6	744	9.5					
Surface water conveyance Cuero and Cibolo to S.A.	230	149	67.7	7,268	13.4	-	-	0	0	
Surface water Goliad to Victoria	141.4	113.1	15.1	1,157	2.8	-	-	0	0	
Share of reservoir cost Goliad		113.1	35.2	1,670	4.0					
Total surface water, delivered		149	201.3	13,989	25.7					
Water treatment	230	149	18.6	3,240	6.1	-	-	0	0	
Total surface water delivered & treated		149	219.9	17,229	31.6					
GW withdrawal, new	107	47	5.7	584	3.4	102	39	5.5	533	3.8
Old, operating only	333	145	0	742	1.4	333	125	0	640	1.4
Total water delivered and treated		341		18,555	(14.9)		164		1,173	(2.0)
Sewage treatment, new	234	118	38.5	4,721	11.0					
	80	40.7	0	704	4.7	-	-	0	0	
Old, operating only	24	12.2	0	244	5.5					
	12	6.1	0	138	6.2					
AWTLCC	-	-	0	0		350	177	86.1	15,352	23.8
Return conveyance Rilling to Hildebrand	-	-	0	0		350	177	15.7	2,138	3.3
Balancing storage	-	-	0	0		required, not considered yet				
Demineralization (very rough) 1st stage	-	-	0	0		327	104)	(42.8)	(7,073)	(18.6)
2nd stage						159	13)			
Disposal to Gulf (very rough)						(14)	(7)	(19)	(1,100)	(44)
Total		341	264.1	24,362	19.5		341	169.1	26,836	21.6

Reuse, in these first approximating computations, proves more expensive than conventional supply for San Antonio, but the surprising thing is how close it comes to being competitive, the difference in cost being about 10%. This is so close that any real economic choice would have to await a more refined estimate.

Various criticisms, of course, will be directed for or against one or the other of the alternatives.

Most important the Cuero-Cibolo supply is probably not the cheapest supplemental supply for San Antonio. Since this comprises over half the total cost, if the alternatives do indeed prove to be cheaper then, of course, the substitution will lower the over-all cost of the conventional system.

Working in the other direction is the very likely possibility that by the year 2000 a standard conventional treatment plant will no longer produce an effluent that is allowable for discharge. This will mean that the sewage treatment process will have to be carried on a higher level of performance, possibly involving actually some of the AWT processes in a tertiary stage. Such extra performance would, of course, involve additional costs.

Although the conventional sewage treatment plant designed and costed in this study does have the capability to meet the maximum day's demand under steady state conditions, it is very likely that even so designed the plant cannot be operated to continuously meet the standards under the fluctuating flow conditions actually encountered. The AWT counterpart, however, in the physical-chemical process used, is much more capable of rapid operating changes to handle fluctuating demands... which was one of the reasons for choosing it.

One of the reasons for the occasional (and indeed more than occasional) poor performance of conventional biological treatment plants is the high degree of flow fluctuation resulting from storm flows in combined sewers. EPA has a whole series of projects investigating the economics of separating combined sewers so as to be able to segregate to storm flow portion and in some cases to store it for bleeding off to the treatment plant thus evening out the flow and improving the treatment plant performance. The "uncombining" of combined sewage systems, the provision of a separate storm sewer system, particularly the provision of damping storage for storm flows requires a tremendous investment. Work of many years ago in Boston, for example, came to the conclusion that storm flows could not be handled even with sewer pipes ten times the normal size. To make conventional biological sewage treatment achieve 90% removal 100% of the time would require a very large additional expenditure for some such scheme, not taken into account here.

It is quite likely that the cost of the AWT process will be reduced by further technological development of this relatively new process. Information on performance of activated carbon treatment obtained since the design of the AWT process strongly indicates that the filters may be dispensed with and this will cut about 1.5¢/Kgal from the cost. If demineralization is to be required anyway this will achieve removal of inorganic ions including NH_4 and in that case possibly the clinoptilolite ion exchange stage of AWT could be dispensed with with a resultant saving of some 7¢/Kgal. However, this is not so easily accomplished since the month-to-month fraction of the AWT product demineralized fluctuates from 100% to 0%.

This project studied a reuse system in which the advanced waste treatment was accomplished in a single plant, thus requiring a return conveyance expense. This return conveyance expense could be cut to practically zero and the sewage conveyance cost reduced by having a number of decentralized AWT plants. However, the numbers suggest that this probably would not be economic because the return conveyance cost is only about 14% of the AWT cost and it is likely that the increase in unit cost in the smaller size plants would be considerably more than this difference.

Finally, some will probably wish to look for the recovery of the "values" from the seven mgd of 10,000 mgpl reject from the demineralization.

Over the entire scheme, of course, looms the hard fact of the present day that public acceptance of reuse would be less than wholehearted. Indeed, although direct reuse is practiced in one or two places in the world it is very unlikely that direct reuse with processes at their present performance would be accepted as safe by the public health authorities. This project has compared the economics in the year 2000 on the assumption that by that time the processes will have proven their safety and the product will have achieved public acceptance.

CHAPTER 7

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CHAPTER 8

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27 Abstract

Computer programs were developed for the preliminary design and costing of wastewater renovation by the lime-clinoptilolite-carbon processes of advanced waste treatment; for activated sludge treatment; and for pipeline conveyance of water. These together with methods of algorithms or lesser depth for other processes were used to cost water supply and waste treatment under conditions expected in San Antonio in the year 2000 for two extreme alternatives, one importation of surface water according to the Texas Water Plan and conventional water treatment, waste treatment and disposal by discharge; the other completely closed recycle, discharging no waste water and reusing all the waste water after treating it to make it reusable. The unit costs for these two extremes were about 20¢/kilogallon of water used and the reuse scheme was only 10% more costly than the conventional scheme, i.e. well within the expected error of the estimates. It was shown that the seasonality of the water consumption in the face of non-seasonality of the sewage produced has an important bearing on the design and cost of reuse systems.

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