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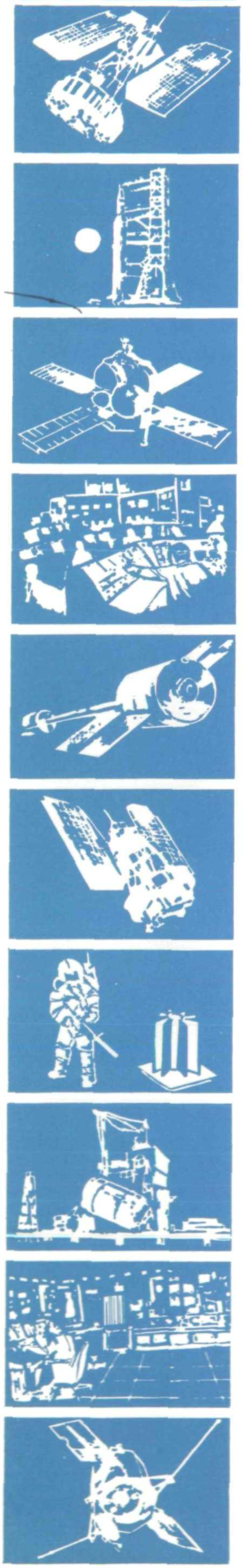

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MAY 21, 1973

Volume I

Final Report

GENERAL ELECTRIC

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Volume I

Final Report

SUBMITTED BY: R W Murray
R.W. MURRAY, PROGRAM MANAGER
ENVIRONMENTAL SYSTEMS

SUBMITTED TO: REUBEN E. TAYLOR, TECHNICAL MONITOR
URBAN SYSTEMS PROJECT OFFICE
NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

SPACE DIVISION
Valley Forge Space Center
P O Box 8555 • Philadelphia, Penna 19101

GENERAL ELECTRIC

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R. W. Murray
Program Manager

ABSTRACT

This report is the result of a comprehensive study of advanced water recovery and solid waste processing techniques employed in both aerospace and domestic or commercial applications. A systems approach was used to synthesize a prototype system design of an advanced water treatment/waste processing system. Household water use characteristics were studied and modified through the use of low water use devices and a limited amount of water reuse. This modified household system was then used as a baseline system for development of several water treatment waste processing systems employing advanced techniques. A hybrid of these systems was next developed and a preliminary design was generated to define system and hardware functions.

Supporting data on each of the processes investigated is provided in the appendix portion of this report, Volume II.

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SUMMARY

INTRODUCTION

This report details the procedures used to develop a prototype design of an advanced water recovery/solid waste processing system. Household water use habits were reviewed to determine the factors affecting water demand. This information was then used to develop a baseline system or concept which resulted in greatly reduced water usage with minimal impact on the life style of the user. Following the establishment of the baseline system and the domestic water demands, a typical community was defined to be used as the design basis for the development of the water recovery system. An in-depth study of advanced wastewater treatment processes and systems was next made to provide background information for the final system selection and design.

Appendices are provided (under separate cover) as part of this report which present more detailed information on specific areas of interest than has been given in the body of the report.

SECTION 1

Water demand criteria were established and categorized as having either a direct or indirect impact on water use rates. Numerous surveys on the subject of water use were reviewed and are summarized in the report. Based on these surveys a representative figure for daily water consumption for a household of four persons was found to be 255 gallons. This is the figure reported by the Federal Water Quality Administration and has been selected in this study on the basis of its general agreement with other studies. For the purpose of maintaining consistency with other ongoing work in this field, the breakdown into functional water use also follows FWQA recommendations.

The effects of water pricing on water use were also studied. It was found that for design purposes the commonly accepted value for domestic water consumption in a metered water system is 100 gallons per capita day. Flat rate water demand allows a 50 percent increase in the average quantities for design purposes.

Water use habits for a conventional household were studied to develop a time based water demand curve or hydrograph. This graph was used as a reference for development of a baseline concept employing water recycling and conservation techniques.

Equipment and devices for low water usage were surveyed and are presented in the report. A study of monitoring and control equipment for maintaining water quality was also made. A listing of equipment is presented for monitoring and control of the following water quality variables:

1. pH
2. Specific Ions
3. Conductivity
4. Particulates
5. Organic Materials
6. Residual Chlorine

The list includes manufacturer's operating characteristics and price ranges for the equipment. A study was made to determine the composition of household waste waters from a conventional household. Data on the composition of wastewater from conventional kitchens, bathrooms and laundries as well as toilets are presented along with total wastewater composition as follows:

1.	BOD	229 mg/l
2.	Total Residue	776 mg/l
3.	Nonfilterable Residue	260 mg/l
4.	Dissolved Solids	425 mg/l

This data was extensively used in the subsequent determination of the composition of wastewater from the baseline and advanced systems.

To assess the impact of dwelling type (apartment, mobile home, conventional house) on water demand, a discussion of the unique characteristics of each of these dwelling types is presented along with a brief discussion on the implementation of a baseline system into these dwellings.

SECTION 2

Prerequisite to developing a baseline concept or system it was necessary to establish guidelines to assure that the system would be acceptable for integration into the "typical home." The guidelines considered included:

1. The lifestyle of the home occupants will be minimally impacted, where aesthetics are not affected and the change can be rationalized as "reasonable" to achieve resultant savings.

2. In stressing water saving devices and procedures capital costs are offset by operational costs, where possible. The reasoning for this is that in dealing with "typical" situations, the running costs will be determined as a proportion of system used by the occupants. By relating added costs to operating procedures, the capital costs are reduced in favor of incentivized charges. In later years as water costs become somewhat more accountable, incentives may contribute more realistically to resource conservation.

3. Reuse schemes are proposed for those household functions not involving direct body contact on the premise that water cloudiness or other technically acceptable aesthetic disadvantages will be minimized when camouflaged by a closed cycle appliance.

Sources of water waste within the home were identified and discussed including that due to the performance of discontinuous water use functions and the dwell time necessary to achieve water temperature stability. Areas of water use which are seemingly amenable to water reuse such as toilet flushing and appliances such as clothes washers were also investigated for inclusion into the baseline system.

Water conservation was a prime consideration in the development of the baseline system. An investigation was made of low water use devices to determine the effect such devices would have on water use rates. The survey indicated that a shower flow limiting valve would reduce water use for this function by approximately 30 percent and a shallow-trap water closet could reduce toileting water requirements by approximately 40 percent.

Water recirculation was also included in the baseline system study. The reuse of water was considered because many high water consumption household functions require water of less than drinking water quality. For example rinse water from the clothes washing machine could be recirculated for use as wash water in subsequent appliance cycles. Another prime area for water reuse is the toilet flushing function. Water recirculation of course requires that the used water be stored until needed. This storage of used water could result in biological problems which could ultimately affect the sanitation of the entire water system. To prevent the occurrence of these problems, the stored water will be heated or treated with chlorine depending upon the final use for which the water is intended.

A comparison was made between the water and wastewater volumes of the conventional and baseline systems. This comparison indicated that by using the baseline system daily water use was reduced from 255 gallons per day to 98 gallons per day or a reduction of 61 percent.

Of course, in order to achieve this water reduction, some repiping and additional equipment was required over and above that normally found in a conventional household. An estimate of these changes was made and a list of typical equipment requirements was presented.

Economic justification of the baseline system was presented based on a 30 year system life and 7.5 percent interest rate. Two conditions were presented:

1. Condition 1. The typical case, 25,000 population, 4 houses/acre, existing sewers and water service, abundant soft water supply, secondary waste treatment

2. Condition 2. The worst case, 100 home community, 1 house/acre, community based water and waste treatment individual home water softeners, tertiary waste treatment.

Using the cost data for the two cases cited and projecting to the year 2000, it was found that for the typical case the use of the baseline system resulted in an annual loss to the homeowner of $101/year while for the worst case the savings to the homeowner amounted to $1,697/year. Of course, the worst case presented is a truly isolated one; however, there are a large number of locations where the use of the baseline system would be at least moderately attractive.

SECTION 3

An understanding of the processes and potential for advanced waste treatment requires an appreciation of the present technology of primary and secondary wastewater treatment and of the types of pollutants which can be removed only by advanced waste treatment processes. Primary treatment consists of sedimentation for removal of up to 90 percent of the settleable solids and from 40 to 70 percent of the suspended solids from sewage. Secondary treatment processes employ bacterial actions, oxidation and synthesis to remove 90 percent of the suspended solids, 90 percent of the biodegradable organics, 60 percent of the non-biodegradable organics, 50 percent of the nitrogen, 30 percent of the phosphorus and over 99 percent of the pathogenic bacteria and viruses from sewage. Tertiary or advanced wastewater treatment techniques must be employed to remove the remaining pollutants.

Recent developments in the advanced waste treatment area have indicated that, in some instances, advantages can be realized by using advanced processes in place of the primary and secondary treatment. As a result of the study of wastewater treatment processes this is the approach which was employed in selecting the proposed treatment processes. To establish the processes required to adequately treat the wastewater, it is necessary to establish two sets of parameters. The first is the quality of the influent to be treated. From data previously reported, the wastewater was found to contain pollutants of the following types and average levels.

Pollutant Type	Average Value (mg/l)
BOD	229
Total Solids	776
Organic Solids	534
Suspended	(235)
Dissolved	(299)
Inorganic Solids	181
Suspended	(18)
Dissolved	(163)

The second set of parameters to be established define the quality of water or effluent to be discharged from the system. It was decided that, due to the increasing stringency of government standards for effluent water the effluent quality should meet USPHS standards for potable or drinking water.

To provide background information on the functions which must be performed to meet the effluent water quality standards, a brief discription of each of the following functions was provided:

1. Solids Removal
2. Organic Removal
3. Nutrient Removal
4. Inorganic Removal
5. Disinfection

A detailed discussion of each of these functions is presented in Appendices G through K respectively.

SECTION 4

Development of a water recovery waste processing system requires that an estimate be made of the quantity of material to be treated. Since this factor is primarily dependent upon the number of dwelling units it was necessary to establish the expected size of the community for which the system was to be designed.

Selection of a typical community size has been set at 500 dwelling units based upon a survey made for the U.S. Department of Housing and Urban Development of prefabricated housing construction techniques (Ref. 81). Baseline system hydraulic data has been expanded to indicate the daily sewage flow rate as well as the peak flow to be expected from the 500 dwelling units. The daily flow rate was found to be 50,000 gpd while the peak flow was 125 gpm during a 16 hour period of the day. Wastewater composition has been established based upon the water use characteristics of the baseline system.

Wastewater characteristics for the baseline concept were next established as follows:

Quantity		98.5	GPD
BOD		408	mg/l
COD		1133	mg/l
Suspended Solids			
Organic		333	mg/l
Inorganic		105	mg/l
Dissolved Solids			
Organic		541	mg/l
Inorganic		740	mg/l
Total Phosphate		76	
Kjeldahl Nitrogen		131	
Total Plate Count	- 35^oC (MPN/ml)	767×10^6	
Coliform	- 35^oC (MPN/ml)	88×10^6	

Three physico-chemical treatment concepts based upon the baseline system were next developed. Each system is described and an estimate of the cost factors is presented.

Distillation as a water treatment method is also examined because of the process simplicity and the high quality of the water produced when other treatments such as catalytic oxidation are included. Several distillation processes are presented including brief discussions of multiple effect evaporation, multistage flash evaporation, vapor compression distillation and air evaporation techniques. Effectiveness of the techniques reviewed is illustrated by the fact that several of the processes are capable of evaporating 30 pounds of water for each pound of steam supplied. Economically, distillation has been found to be relatively expensive with a cost of more than \$.45 per thousand gallons for large saline water treatment facilities compared to physico-chemical wastewater treatment with a cost of \$.31 to \$.37/1000 gallons for a system of similar size. The major cost of distillation is largely dependent upon the energy source with approximately 50 percent of the cost for conventional plants going to steam production requirements.

Integration of the sewage treatment process with a source of waste heat, such as from electrical power generation and waste incinerator utilities or solar energy will significantly lower or nearly eliminate altogether the cost of operating the distillation process. However, without the prospect of utilities integration, a physico-chemical water treatment process appears more compliant to the design requirements at this time.

Based upon the physico-chemical systems discussed, a study was next made of the compatibility of the various unit processes and a process selection matrix was developed. The matrix was then used to select the proposed system. The physical provisions of the proposed system were next sized based on the baseline hydrograph, and wastewater characteristics and the projected community peak flow rates. Included in the system shown in Figure 1 are a surge receiving station, primary separator reactor for chemical addition, a feed chamber, ultrafiltration stage, ion exchange bed (clinoptilolite) and provisions for chlorination. In addition a centrifuge is provided for primary separator sludge dewatering and an incinerator is provided for solids disposal.

Component design considered three modes of operation as predicted by the community hydrograph. Mode 1 is tailored to the normal waking hours of the community during which time the process flow will be 40 gpm. Mode 2 is a peak flow condition where up to 60 gpm flow is expected. Mode 3 or the low flow mode provides for system flows up to 20 gpm. The components have been sized in accordance with the system requirements. To illustrate the modularity of the proposed system, the hardware is illustrated as being suitable for mounting on two 10 by 40 foot trailers.

The proposed system capital cost is estimated to be \$311,100 while the total operating cost excluding manpower will be approximately \$1.90/Kgal. Total system cost (excluding

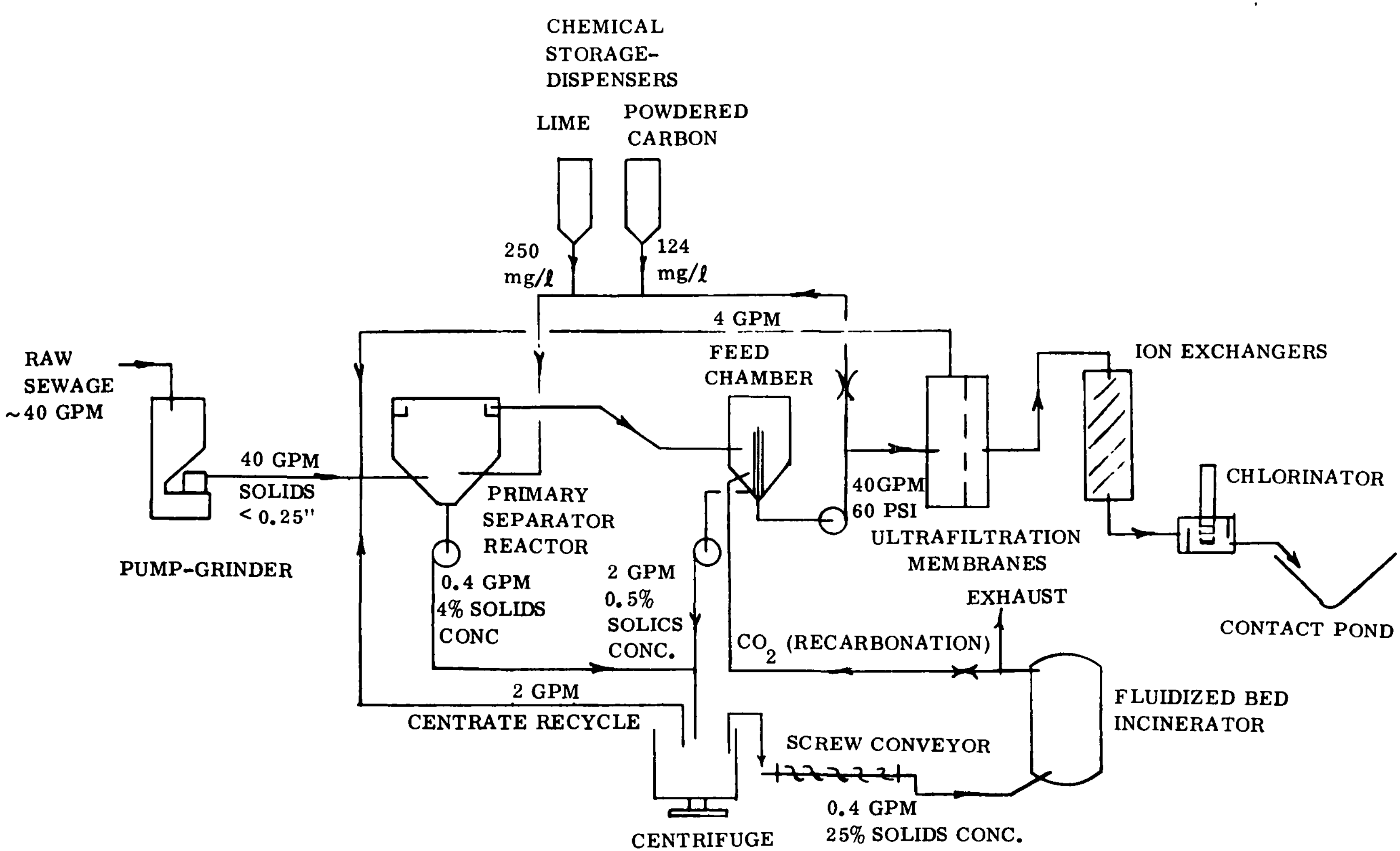


Figure 1. System Schematic

manpower) is estimated to be $3.37/Kgal based upon capital amortization of 7 percent for 25 years.

It is apparent that the proposed system is far more costly than the typical situation and is in fact quite similar to the worst case situation; however, as regulations on water quality become more stringent, the costs of existing systems will most certainly increase, thereby making the proposed system more economically acceptable. For the present however, the water costs for the proposed system would amount to approximately $10.00/month per apartment which does not seem unreasonably high for both water and sewage treatment.

RESULTS AND CONCLUSIONS

During the course of the study it became increasingly apparent that the selection of a single wastewater treatment concept is subject to a great many variables for which information leading to a fixed solution was not readily available. While much work has been done in the study of advanced waste treatment systems, information relating to the interrelationship between processes is difficult to obtain and is mainly left to the personal judgement of the system designer. Due to this condition, it is recommended that a test bed approach be utilized to characterize various sewage treatment, water management control and integration approaches prior to synthesis of an optimal system design. This approach is not completely foreign to the wastewater treatment industry. Field tests are frequently made with laboratory type apparatus to evaluate the effectiveness of a particular process in treating water from a wastewater source. These tests provide information on the degree of treatment required, system size, operating costs, etc.

Instrumentation was quickly identified as an area in need of advances in the state of the art. While the equipment available is suitable for cursory analysis to determine the presence of specific pollutants or the effects of specific treatment there does not seem to be equipment available to provide a complete water analysis on a short time basis. Especially important in systems involving water reuse after treatment is the test for bacterial and viral contamination. There is no real time or near real time device for making this type of analysis.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1
HOUSEHOLD WATER USE

1.1 WATER DEMAND (QUANTITY) CRITERIA

There are at present no precise means for defining a "design to" number representative of the volume of water required by every user of public water supplies. Definition of this elusive design requirement would require a very sophisticated study to mathematically derive a model inclusive of all relationships influencing the need for fresh water by the residential sector. In the absence of this rigorous mathematical model the results of studies conducted over the last ten years must be the source of the empirically oriented model as they dissect our modern domestic society for the characteristics most indicative of present and future water use based on statistical averaging for each of the following parameters which have been characterized as those having a direct impact upon water use rates and those indirectly influencing use rates.

Direct:

1. Economic standard of the home/community
2. Number of dwelling unit occupants and their ages
3. Regional location (environmental conditions)
4. Type of domestic wastewater removal system
5. Water pricing policy - measurement method
6. Dwelling type and provisions

Indirect:

1. Awareness of natural resource limitations
2. Commitment to ecologic improvement
3. Political and legislative status quo

As the objective of the program deals exclusively with creating a technical/economic concept, the indirect influences will be infused only where public acceptability to usage of the proposed concept is impacted.

A summary table of applicable water use surveys is presented in Figure 1-1 in two forms, actual gallons/function and percentage of total gallons. Studies have also been conducted for reasons other than determining detailed water apportionments, but necessitated estimating the total gallonages used by each dwelling unit (house or apt). These findings are presented in Figure 1-2 for comparison. In establishing the mandatory water requirements, only winter period data is cited; as most references note, since the wastewater quantities are most reflective of household water demand during this period. Although presented in a later section, it is worth noting at this point, the hydrographs of wastewater generation are not directly comparable to water demand. This is attributable to the effects of consumption, appliance, piping and fixture water storage (time lag), plus the attenuation of flows due to damping of local overpressure or back flow (surge) conditions by dwelling plumbing.

Returning to the statistical approaches for defining water use, as listed in the first paragraph of this section each methodology is compared to the actual measurements taken by the researchers (Refs. 1, 2 and 3) to at least find a correlation of quantification methods. The resulting plots are shown in Figure 1-3. Curve I (Reference 4) considered economic levels of home value to predict average water use. The study determined that although water use increased with affluence (ability to afford automatic appliances, entertain guests, etc.), houses equipped with septic tanks used approximately 25% less water regardless of home worth and were more sensitive to the number of house occupants. This relationship is plotted as Curve II. The income level-house value influence is supported by later research (Reference 5) showing a 21% increase in water use. As indicated by the equations for the curves, a minimum amount of water is required, and depending upon the fixtures and automatic appliances included with the house independent of house value or number of occupants. The additional demands are established by the number of occupants. Linaweaver, et. al., (1967) found this number to be 40 gallons while Andrews/Hammond (1970) set this at 30 gallons.

1.2 INFLUENCE OF WATER PRICING ON WATER USE

Residential water supplies are designed for two basic operating conditions, population served and peak demands. The total population projected for an area is usually multiplied by a commonly accepted value of 100 gallons per day for domestic water consumption, however, this value is

FUNCTION / SOURCE	TOILETING		BATHING		KITCHEN		DRINKING		LAUNDRY		LAVATORY-GENERAL CLEANING		TOTAL GALS	DWELLING TYPE
	GALS	%	GALS	%	GALS	%	GALS	%	GALS	%	GALS	%		
REID (1965)[1]	96	41	80	34	18	7	8[2]	3	34	14	12	7	236	HOUSE[3]
MCLAUGHLIN (1968)	70	39	56	31	8	4			30	17	4	2	180	DU AVER.
OLLSON, ET. AL. (1968)	8[4] 67	43	48	31	39	25[5]							154	APT-2.9/DU
REFERENCE BASELINE											8	3		
BAILEY, ET. AL. (1969)	100	39	80	31	15	6	12[2]	5	35	14	5	2	255	HOUSE[3]

NOTES:

1. OUTDOOR USES SUBTRACTED FROM CITED REFERENCE AND PERCENTAGES BASED ON ADJUSTED TOTAL
2. THIS FIGURE INCLUDES KITCHEN TAP USE
3. FOUR INHABITANTS, DISHWASHER, GARBAGE DISPOSAL, CLOTHES WASHER
4. VACUUM TOILETS USED, ESTIMATED CORRECTION TO 22.5 gpcd FOR CONVENTIONAL TOILET BY VACUUM SYSTEM DESIGNER (LILJENDAHL, SANIVAC CORP, ROCHESTER, IND) OR 67 GALS (2.9 OCCUPANTS/APT)
5. THIS FIGURE INCLUDES ALL OTHER APARTMENT USES. APARTMENT HAS NO DISHWASHER , CLOTHES WASHER OR GARBAGE DISPOSAL.

Figure 1-1. Water Use Allocations

SOURCE	APARTMENTS			HOUSES		
	GPD	LOCATION	NO. OF OCCUPANTS	GPD	LOCATION	NO. OF OCCUPANTS
LINAWEAVER, ET AL (1967)		NATIONAL	2.6	203		
LINAWEAVER/GEYER (1964)				195	BALTIMORE, MD.	3.3 3.1
ANDREWS/HAMMOND (1970)				216 181 174	DURHAM, NH EPPING, NH PORTSMOUTH, NH	3.9 5.3 3.8
ANDERSON/WATSON (1967)				274	LOUISVILLE, KY.	6.2
GILBERT ASSOC. (1964)	160	SUBURBAN PHILA, PA.	UNKNOWN			

Figure 1-2. Water Demand Survey

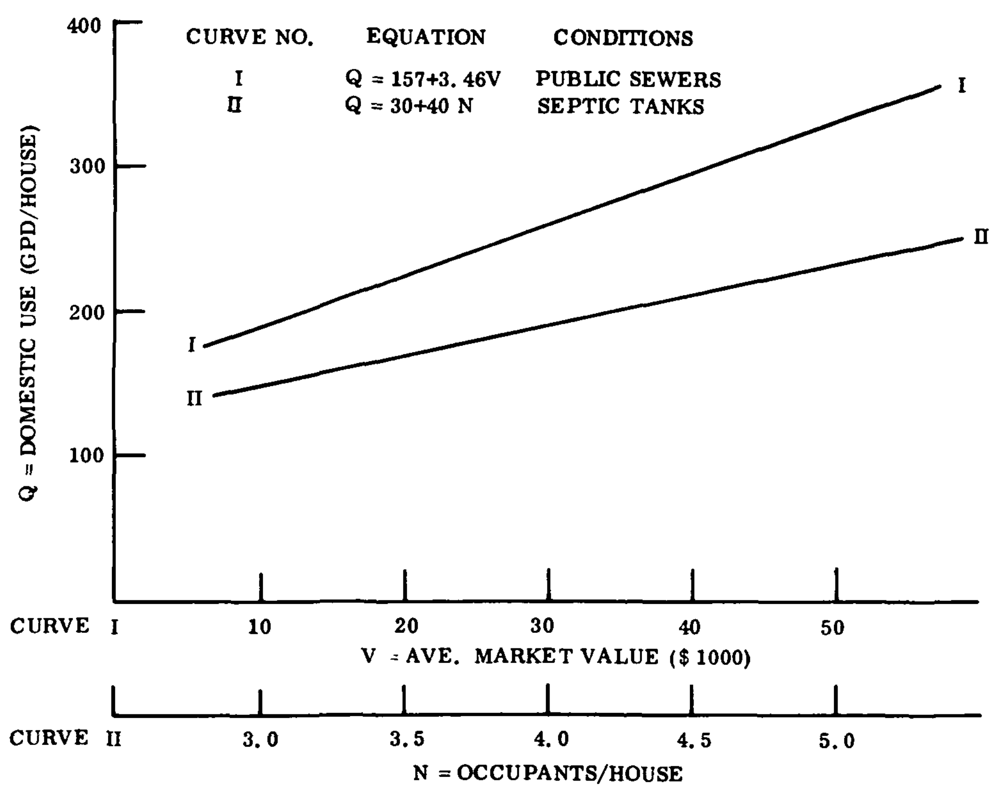


Figure 1-3. Variability of Domestic Water Use

dependent on using a metered service as opposed to a flat rate service. Flat rate water demand allows a 50% increase in average quantities used for design purposes (Reference 6). Peak demands determine the source pressure, storage conditions, and water distribution line sizing in order to guarantee, that under the calculated maximum flows, the curb (delivered) pressure to each residence is at least 30 psi and supports a 15 gpm minimum flow.

In a study of combined sewers conducted by the American Society of Civil Engineers, water demands were analyzed resulting in the curves shown in Figure 1-4 (McPherson, 1967). These variations are consistent with later studies (Andrews/Hammond 1970; Howe/Vaughan, 1972).

Figure 1-4 illustrates the relationships between average long term water demand and maximum hourly and daily and minimum daily water demands. It can be seen that the ratios of peak and minimum demands to average demands (vertical scale) are functions of the number of dwelling units under consideration. However, these ratios remain relatively constant when the number of dwelling units exceeds approximately 10-20. These relationships are useful in designing water services to meet peak loads.

Water pricing will favorably affect water usage if the houses are individually metered. Where unmetered and flat rate services are provided, no incentives exist to prevent careless use or positive maintenance practices.

1.3 HOUSEHOLD HYDROGRAPH

The hypothetical dwelling unit for determining the baseline hydrograph follows the recommendations of Baily, et al (Reference 9). The hypothetical home (Figure 1-5) is equipped with 1-1/2 bathrooms, an automatic washing machine, a dishwasher and a garbage disposal. The two adults and two children living in this home are assumed to use water in average amounts and in an average way. The daily water use of this hypothetical family is shown in the following table.

Function	Total Water Use (1) (Gallons/Day)	Hot Water Used (Gallons/Day)
Dishwasher	15	15
Other Kitchen	12	9
Utility Sink (Cleaning)	5	3.75
Laundry	35	26.25
Bathing	80	60
Lavatory	8	1
Toilet	100	0
Totals	255	115

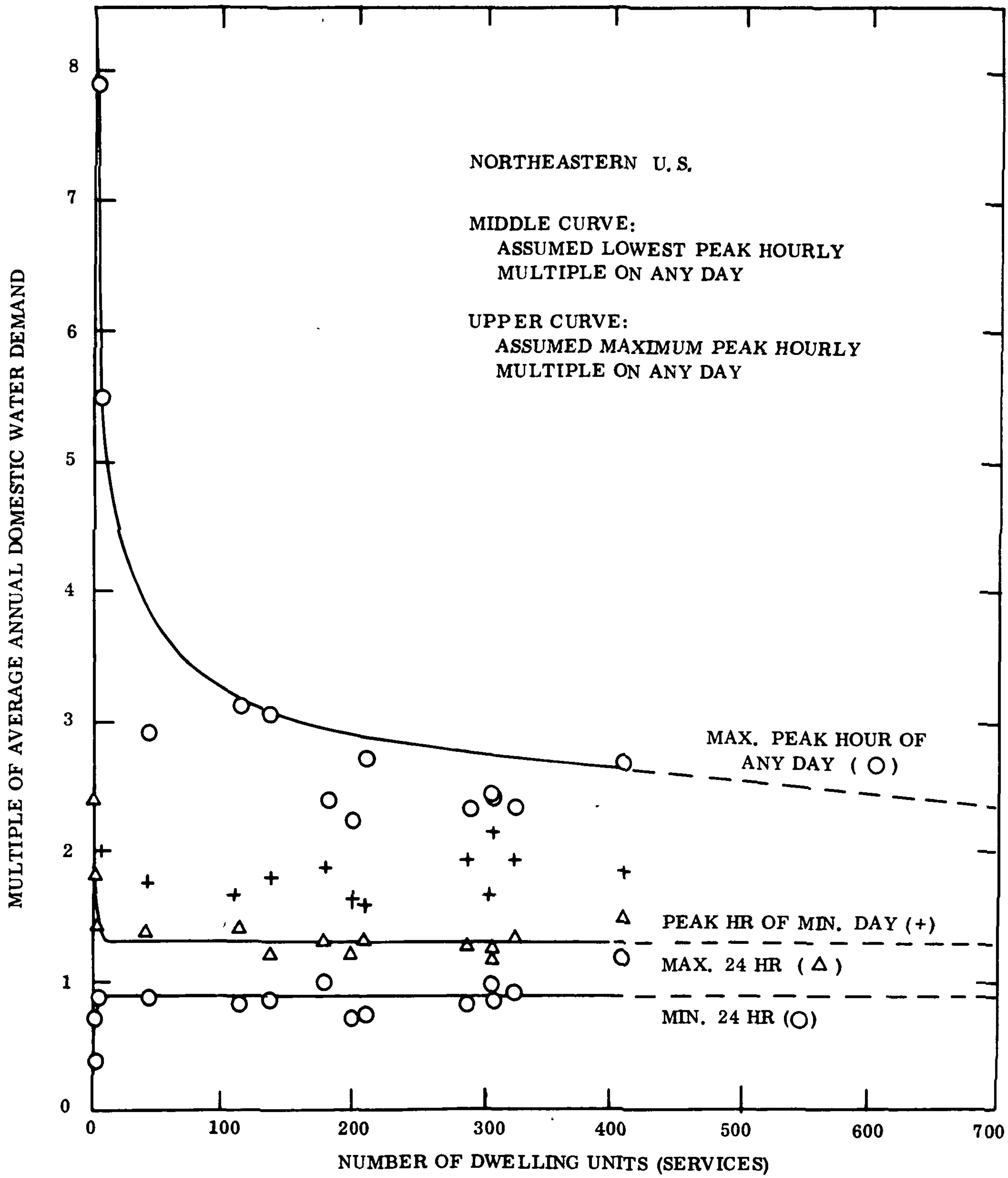


Figure 1-4. Average Annual Domestic Water Demand

Based on Watson's findings (Reference 10), a dishwasher is typically used 1.5 times per day, using 10 gallons of water per use. Use of the garbage disposal has been set at 4 times per day at a flow rate of 3.14 gpm for a total daily water use of 9.3 gpd. This corresponds to 0.73 minutes per use. According to Howe (Reference 11), water use for home automatic washing machines ranges from 32-59 gallons per load. Therefore, it is assumed that 35 gallons per day corresponds to one usage per day. Toilet flushing has been assumed to use 5 gallons per flush corresponding to 20 flushes per day. Further assumptions regarding volume of water per function use and number of uses per day have been directly incorporated into hypothetical hydrograph. The timing of usages is based on a hypothetical water use pattern for the "typical" family.

Flow rates in fixtures and appliances which have been assumed for the various functional water uses are as follows:

Typical Fixture/Appliance

Flow Rate GPM

Function	Hot	Cold	Reference
Toilet		33	(23)
Shower	3.75	1.25	(23, 7)
Cooking (Kitchen)		4	(Max. 4.5(23))
Lavatory		3	(Max. 4.5(23))
Garbage Disposal	3.14		(8)
Cleaning (Utility Sink)	2.25	.75	(23, 7)
Drinking (Kitchen)		1.0	(Max. 4.5(23)
Dishwasher	3		(2-5(23)
Clotheswasher	3 (fill)		
	3 (rinse)	3 (rinse)	(23)

The maximum supply flow which could be expected would be approximately 17 gpm, corresponding to simultaneous use of dishwasher, clotheswasher, shower, and one toilet. This value has not been incorporated into the hypothetical hydrograph, since it is not a "typical" situation. However, maximum possible flow rate must be considered when designing a household water-waste system.

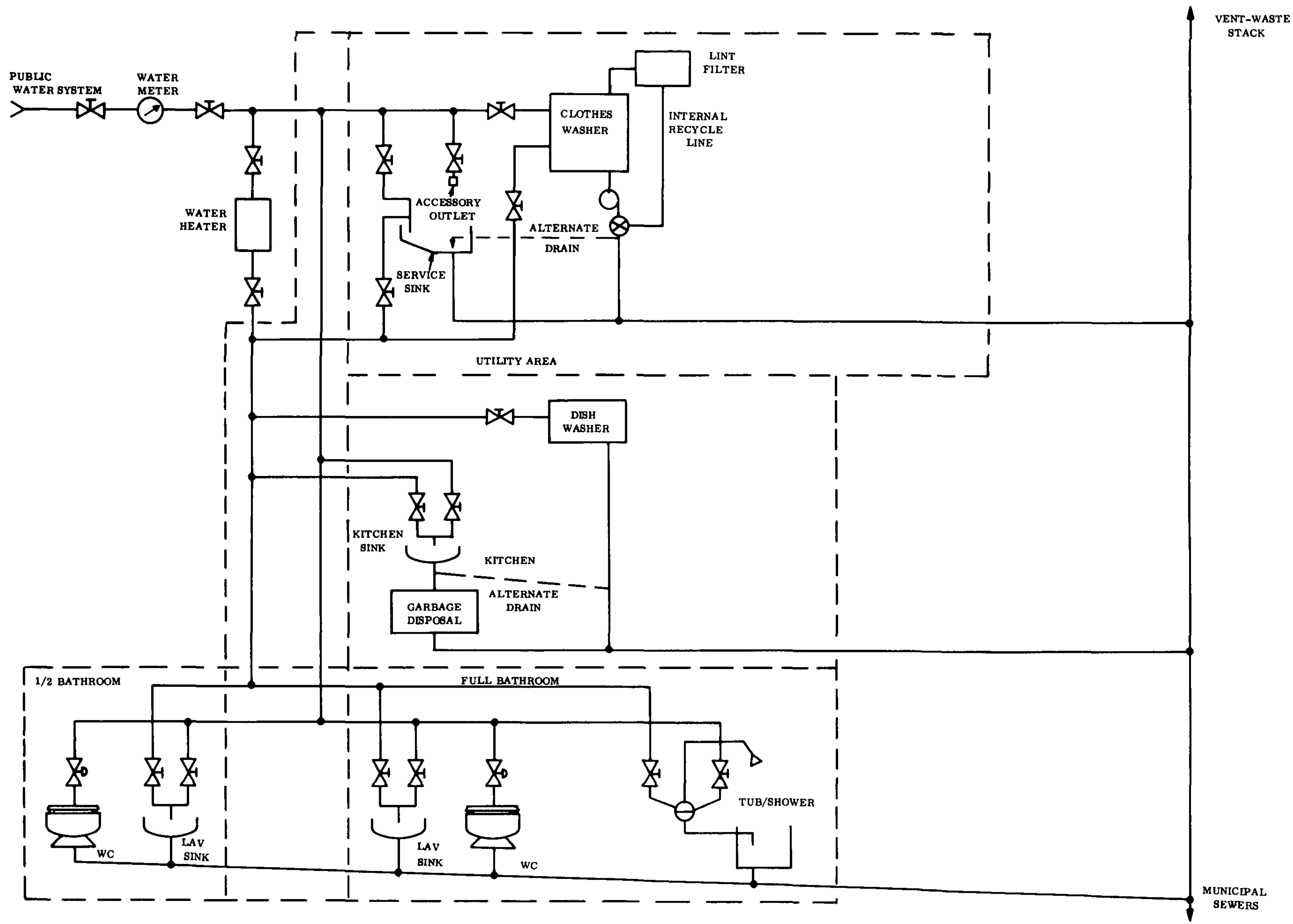


Figure 1-5. Conventional System

In most cases, waste flows will closely follow supply flows. In certain appliances, such as washing machines, pump-out rates may be higher than supply rates. Waste flow rates for toilets (black water) may be as high as 50 gpm. High instantaneous waste flows will most likely have to be buffered by a holding tank in the waste treatment system. The derived instantaneous hydrograph is presented in tabular form in Appendix A and a 15-minute hydrograph, more useful for system criteria, is shown in Figure 1-6.

1.4 EQUIPMENT AND DEVICES FOR LOW WATER USAGE

This paragraph presents the results of investigating presently available hardware capable of improving water use efficiency. The survey is divided into items, such as appliances, that are self-regulating and devices that, when used in a system provides some measurable benefit. The hardware identified is presented in Table 1-1. The table covers those designs having a measurable effect on low water usage.

1.5 MONITORING AND CONTROL EQUIPMENT

A very large number of undesirable and potentially dangerous substances must be controlled or eliminated in a water supply system for the water to be suitable for its intended uses. The primary purpose is to protect the health of the users. Reliability of the treatment and supply system is the major line of defense against intrusion of unwanted substances. Water monitoring and sampling and analysis assure that failure of sufficient treatment will be detected, and also provide information for control of the treatment system.

In a household water reuse system, automatic monitoring and control are necessary. The limited availability and reliability of on-line continuous monitors, as well as their high cost, make the choice of an optimum system essential.

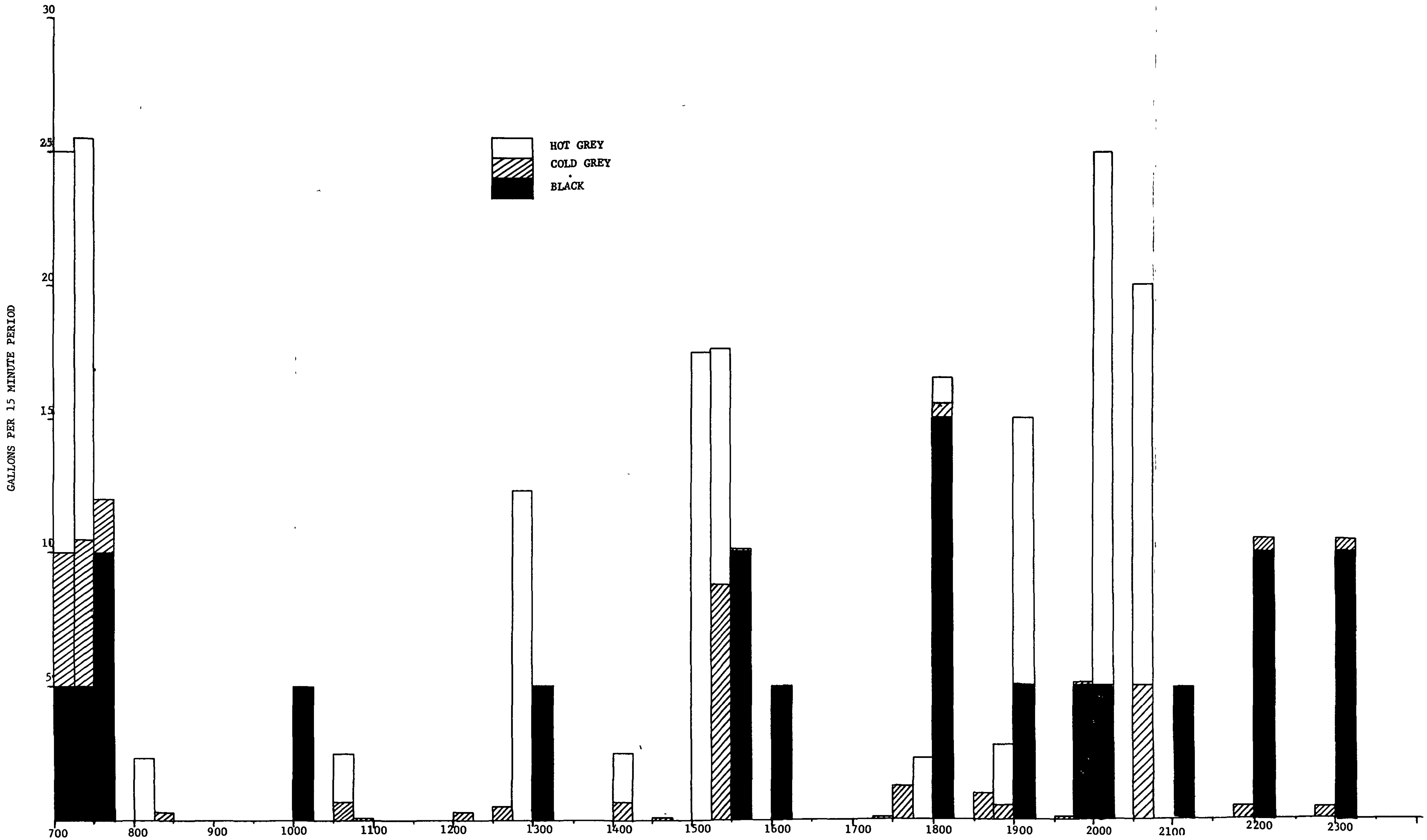


Figure 1-6. Household Hydrograph - 15 Minute Flows

Table 1-1. Low Water Use Equipment/Devices

Name	Operating Principal	Water Use Impact	Source (Example)	Remarks
I. Appliances				
Clothes Washer Dishwasher	Pre-set operating cycle	Rationed water as function of items to be washed	General Electric Co.	User selects Load equivalent to water quantities
II. Fixtures				
Commodes				
Vacuum	Suction assisted waste transfer	1-2 quarts/flush	Sanivac Corp.	
Shallow Trap	Surge to initiate syphonic drain	3 gallons/flush	Eljer Plumbing Ware	
Dual Flush	Two volumes (1 for feces, 1 for urine)	1-1/4 gallons for urine, 2-1/2 gal for feces	L. G. Virsberg Co., Sweden	
Recirculating	Chlorinated (or equal) flushwater with tank	Repeated use of flushwater for toileting	Raritan	Used on airplanes, boats
Urinal (Male/Female)	Purge well and transfer liquid wastes	1 gallon/flush	Crane Co.	
Shallow Bathtub	Reduced depth/sidewall width	Approx. 8-10 gallons Less than full-sized tube	American Standard	Used on mobile homes
III. Devices				
Valves-				
Flow Limiting Ports (Restrictors)	Included orifice to restrict flow	Limit water flows to calculated Maximum G. P. M.	Kohler	Orifice assembly can be installed with in-line valve
Spring-Close Stem	Self-closing stem when handle is released	Stops water flow when hand(s) is occupied with scrubbing, etc., eliminates unmonitored water use savings of 50% are possible	Eljer Plumbing Ware	Can be timed to close after a set flow period
Attachments-				
Aerators	Aerate water steam to extend moisture coverage by transition of liquid to liquid/gas mix	For wetting surfaces, less water is required. 25% savings have been estimated	American Standard	
Shower Heads	Restricted/aerated sprayer	Limits flow to 4 GPM	Crowley Sales Co.	
Miscellaneous-				
Proximity Switches	Senses hands or body in flow stream path and initiates pre-mixed water stream	Savings of 50%	Fluidic Parts-Cornell Photocells-General Electric Co.	Available in fluidic and electrical parts
Ejectors	Draws second liquid into suction port using line pressure	Allows combined fresh and "used" waters to be dispensed @ 1:4 ratio for reuse applications	Penberthy-Houdaille	
IV. Other				
Incinerator Toilet	Burns all wastes-electric	No water required	Research Products Mfg. Co.	
Hot Water Circulation	Maintain hot water at each hot water tap	Eliminates pipe "warm-up" water waste		

The survey of monitoring and control devices has determined that monitoring should be considered for the following variables:

1. pH
2. Specific Ions
3. Conductivity
4. Particulates
5. Organic Material
6. Residual Chlorine

Conductivity is an indirect measure of the concentration of dissolved inorganics in solution. Particulate matter includes both organic and inorganic species, while organic material includes both particulate and dissolved forms.

Table 1-2 is a listing and description of currently available monitoring and monitoring/control systems involving these variables. Following the table is a list of abbreviations used. Manufacturer's addresses are included as Appendix B. Of the above variables, pH, conductivity, particulate and residual chlorine monitors are well established and reliable. A monitoring-control system for pH generally requires some engineering, and thus the price depends on the application. Complete systems are available for $435 - $1,350.

Conductivity monitoring is simple and reliable. Cost for monitors runs from $125 up, with a control system increasing the cost. Removal of dissolved inorganics will be necessary in a closed cycle water reuse system, and conductivity monitoring would be the most practical method for efficient control.

Particulate matter in treated water is generally measured indirectly by its turbidity. On-line turbidimeters are available for $95 - $ 1,500. These are generally reliable, and many have control capability and/or alarm options.

Residual chlorine provides an indication of the sufficiency of chlorine dosage, and can be used to control dosage for optimum disinfection. Costs for monitoring-control systems range from

Table 1-2. Monitoring and Control Devices (Sheet 1 of 6)

Variable	Manufacturer	Instrument	Cost	Outputs	Accuracy (pH Units)	Drift	Temp Manual	Compensation Auto	Battery	Internal Calibration Std	ORP	Comments (See note on page 1-19)
pH	Analytical Measure	MDLS RC, IC, R4,	$395-545	Voltage, relay, recorder digital								
pH	Leeds & Northrup	pH electrode assembly	$355-990									
pH	Limnetics	MDL. 20 & Cont. Rcdg. Mtr.	$1000	Voltage, recorder								Range is adjustable
pH	Universal Interloc	MDLS. 320-323 pH sensors	$365-595	Voltage								Flow immersion, in-line types, Trans -Analyzer available
pH	Analytical Measurements	Digitrol	$895	With controller, recorder	0.02		X	X		X		
		30	$425	With recorder	0 1		X	X		X		
		707	$145		0 1					X		
		Redox.	$195		0 1					X	X	
pH	Aquatronics	125	$548	W/Controller	0 5			X		X		
		101	$140		0 1				X	X		
		110-R	$475	W/Recorder	0 02		X		X	X		
		120-R	$365	W/Recorder	0 02					X		
pH	A.E S.	5M 1402	$750	W/Controller	0 1	0.1 units/mo		X			X	Range optional
pH	Beckman Instruments	900	-	W/Controller	0 02	0.005/day		X			X	
		940	$810 up	W/Controller	0 02		X	X			X	
		941	$810 up	W/Controller	0 02		X	X			X	
pH	Cambridge Instrument Company	91B	$670	W/Controller	0.1	0.05/day	X				X	
		30C	$284		0.1	0 05/day		X	X		X	Na^+ and K^+ Measurement versions, expanded scale
		90A	$530				X				X	
		28A	$760			0.02/day		X				ORP $790
		28B	$880			0.01/day		X			X	Range any 5 pH units of any 500 mv
pH	Delta Scientific	8012	-	W/Controller				X		X	X	
		1112	$198						X			
		3312	$1285	W/Recorder					X			
		3412	$1465	W/Recorder					X			Temperature measurement
pH	Foxboro	699	$745-770	W/Controller			X	X		X	X	
		Dynalog series 9950	-	W/Controller, recorder		0.05/3 mo.	X	X			X	Adjustable range
pH	Hach	1975	$175			0.05/day	X		X			
		2075	$189			0 05/day	X					
pH	Honeywell	pH Sensor Amplifier	$950			0.01/day		X			X	
pH	Industrial & Mill Supply Company Division Kernco Instrument	RC-9	$555	W/Controller, recorder			X	X				Dual scale
		BC-2	$435	W/Controller			X	X				
		DC-5	$525	Digital		0.02/day	X	X				
		KR-8	$335					X	X		X	
		SR-15	$410				X	X				Expanded scale
pH	KDI Corp	PHA	$900			1% full scale/mo		X	X	X	X	
pH	Martek Instr.	HMS	$750					X	X			
pH	Universal Interloc	1000	$700-1100	W/Controller		0 1/year	X	X		X	X	
		1501	$1350	W/Controller		0 1/year					X	

Table 1-2. Monitoring and Control Devices (Sheet 2 of 6)

Parameter	Manufacturer	Model	Cost	Outputs	mmho Ranges	Temp Comp.	Battery	Intern. Calibration Std.	Comments (See Note on Page)
Conductivity	Aquatronics	305	\$ 265	Rustrak rcdr.	<100, 10000, >10K	Auto	X	X	4 ranges
		310R	485		<100, 10K, >10K	Auto	X	X	4 ranges
		325A	450		<100, 10K, >10K	Manual/auto		X	Control options
Conductivity	AES	SM-1403	700		10K, >10K				Max. drift 1%/mo (med. scale), 3%/mo (high scale
Conductivity	Beckman	RB3	263		<100, 10K, >10K	Manual/auto	X		W/o probe; splashproof version available
		RA-2A	205 872 + (8 days)		<100, 10K,		X	X	Stream and lake survey
		RQ	924 + (31 days	W/recorder	<100, 10K	Manual/auto	X		Spring-wound clock
		DWSM	4070						Deep well solution meter
Conductivity	Cambridge Scientific	HYNAC portable	114		<100, 10K	Auto	X		
Conductivity	Delta Scientific	1114	248		<100, 10K				
		33, 4-01	1325	Rustrak rcdr.	<100, 10K, >10K	Auto	X		
		3414-01	1535	Rustrak rcdr.	<100, 10K, >10K	Auto	X		Measures temperature
Conductivity	Delta Tech. Labs	40-100	105		10K		X		
Conductivity	Hach Chemical	2200	189		10K	Manual	X		5 ranges
		2300	199		10K	Manual			5 ranges
Conductivity	Honeywell Industrial Division		750		10K				
Conductivity	Hydrodyne	72	125		<100K, 10K	Auto		X	3 ranges
Conductivity	Hydrolab	TC	585		10K, >10K		X		Max. drift 0.5% reading/25°C change
Conductivity	KDI Corp.	CDA	860 1095		10K, >10K 10K, >10K	Auto Auto	Optional Optional	X X	Single range, max. drift 1%/mo Dual range, max. drift 1%/mo

Table 1-2. Monitoring and Control Devices (Sheet 3 of 6)

Parameter	Manufacturer	Model	Cost	Outputs	mmho Ranges	Temp. Comp.	Battery	Intern. Calibration Std.	Comments
Conductivity	Myron L.	560B	$ 155-208	Voltage, relay	0-10K	Auto			5 cnd. cells available depending on application; alarm/control optional
		DS meter	108-198		10K	Auto	X		
Conductivity	Leeds & Northrup		100-250						
Conductivity	Universal Interloc	101-115	150-250	Voltage					Flow, immersion types, Model 700MA Transmitter-Analyzer avail. (1,2)
					(ppm)				
Residual Chlorine	BIF	870	-	Control capability	0-1, 0-20	X			
		880	2800-3200	Voltage, relay telemetry, pressure	0-1, 0-2	X			6 ranges
Residual Chlorine	Capital Controls	RR-870	1665	W/recorder, control capability	0-1, 0-10	X			5 ranges
Residual Chlorine	Wallace & Tiernan	Resid. Cl. Anal. for waste water	3400	W/recorder, control capability	0-1, 0-20	X			5 ranges, Total Cl.
		For cooling	2650	W/recorder, control capability	0-2	X			Free Cl.
		For potable water	3150	W/recorder, control capability		X			
Residual Chlorine	Delta Tech. Labs	30-110	615		0.2-10, 0-1000				Control optional
Residual Chlorine	Fischer & Porter	Ancchlor resid. Cl.	$ 2900	W/recorder, control capability	0-1, 0-20	X			
		Chlor-Trol free resid.		Control capability	0-2	X			

Table 1-2. Monitoring and Control Devices (Sheet 4 of 6)

Parameter	Manufacturer	Model	Range	Cost	Outputs	Comments, Water Quality Variables
Specific Ions Specific Ions	AES	1200, 1250, 1400, 1500	Multiple	1000-6250	Volt, amp., digital, relay, telem.	Cond., Cl^-, DO, ORP, pH, solar rad., turbidity, temp., NH_3, Br^-, Ca^{++}, Cr^{+6}, Cu^{+2}, F^-, hardness, hydrazine, I^-, FE^{++}, NO_2, NO_3, PO_4, SO_4, + (1, 2)
Specific Ions	Beckman	J	1 ppb- 10K ppm sev ranges	3255		Na^+, auto temp. comp.
		J	1-1K, 10-10K ppm	1650		Cl^-, auto temp. comp.
		900	0-0.1, 0-100, ppm	1820	Control optional	F^-, auto temp. comp.
		9500	Multiple	1800	Amp., Rcdr., telemetry	Cond., Cl^-, DO, ORP, pH, solar rad., turbid., temp. +
Specific Ions	Calgon	Chemonitor series	1 ppm-100 ppm several ranges 0-.316, 0-3.16 ppm			Na^+ F^-
Specific Ions	Delta Scientific	Series 8000 anal./ contrlr.		2000-6000	Volt, digital, telem., relay	Cond., Cl^-, DO, ORP, pH, solar rad., turbid., temp., NH_3, Br^-, hard., Cl_2, Chromate, Cr^{+6}, Cu^{+2}, CN^-, F^-, hydrazine, Fe^{+2}, I^-, PO_4^{-3}, Flow +
Specific Ions	Foxboro	Ion Selective Meas. System		1000-2100	Amp., rcdr., relay, telemetry	pH, $Cl_2^=$, turb., ORP, cond., Cl^-, CN^-, F^-, Ag^+/S, For process applications depending on specifications
Specific Ions	Hach Chemical	Series CR2, CR		295-475	Volt, relay, rcdr	F^-, silica, PO_4^{-3}, chromate, SO_4, hardness, Fe, Cl_2, hydrazine, Ca, permanganate pH +, monitoring + control
Specific Ions	Honeywell	H_2O Qual. Syst. (4 mdls.)		5000-9000	Volt., relay, rcdr., telemetry	Cond., Cl^-, DO, ORP, pH, solar rad., turbid., temp., level and flow
Specific Ions	Hydrolab Corp.	Surveyor		2200-2500		For water surveys, instrument package has provision for 5 sensors, 16 available, auto temp. comp. Price is for readout system + cable only sonde \$160-372/electrode
Specific Ions	KDI Polytechnic	1-1000		925-1390	Volt., rcdr, tele.	Cond., Cl^-, DO, ORP, pH, solar rad., turbid., temp., Ca^{++}, NO_2, NO_3, F^-, Cu, Pb, Ag, SO_4, Br^-, CN^-, hardness, I^-, perchlorate, throcyanate +
Specific Ions	Leeds + Northrup	Sodium Ion Anal. 7971	.1-10000 ppm/ several ranges		Control options	Nu^+, manual/auto temp. comp., includes analyzer calibrating unit and Model 7070 monitor
Specific Ions	Robertshaw	900		665		
Specific Ions	Technicon	CSM 6	0-100 ppm	31K-34K	Volt, relay, digital, telemetry	NH_3, NO_2, NO_3, PO_4, pH, hardness, phenol, silica, Cu, F^-, Fe, Cr^{+6}, Cl^-, +, rcdr. output
Specific Ions	Union Carbide	Series 1600		5000-9000	Volt, rcdr., digital telemetry	Cond., Cl^-, DO, ORP, pH, turbid, temp. +
Susp. Solids, Turbidity	Agricultural Control System	LT series	0-0.1/0-1000 JTU		Control capability	Forward scatter
Susp. Solids, Turbidity	AES	SM 1414	0-100/0-3000 JTU	975	Opt. control capability	90° scatter
Susp. Solids, Turbidity	Delta Scientific	1115 3115 3215	0-300 JTU 0-1/0-1000 JTU 0-1/0-1000 JTU	95 975 1475		Battery, transmission Battery, transmission Battery, transmission
Susp. Solids, Turbidity	Hach Chemical	1720CR	0-0.2/0-30 JTU	450	Alarms opt. volt relay recorder	90° scatter
		1861	0-0.2/0-5000 JTU	775	Alarms opt. volt relay recorder	Scatter off moving fluid surface
		1889	0-1/0-1000 JTU	575	Alarms opt. volt relay recorder	Scatter off moving fluid surface
Susp. Solids, Trubidity	Honeywell		0-100/0-3000 JTU			90° scatter
Susp. Solids, Turbidity	Keene	Bowser turbid. meter 861	0-5000 JTU			Combination scattering/transmission, used in water filtration plants
Susp. Solids, Turbidity	KDI	TBA	4 ranges 0-2400 JTU	1120		Ratio of transmitter/scattered light
Susp. Solids, Turbidity	Phipps & Bird	St. Louis turbid. meter	0-2 JTU	135		Transmission
Susp. Solids, Turbidity	Photomation	TTD-1	0-10, 0-500 ppm	750		Transmission
Susp. Solids, Turbidity	Photronic	Turbid. phot 200	0-10 ppm	1190(1500)	Relay, rcdr., control capability alarms opt.	Forward scatter
Susp. Solids, Turbidity	GAM-Rad	250	0-5/0-50K ppm	1600	Control capability	90° scatter, transmission mode optional
		370-A	0-1/0-50K ppm	3360	Control capability	90° scatter
Susp. Solids, Turbidity	Jacoby-Turbox	A-2	0-10/0-10000 ppm	1800	Incl. relays	Transmission
Susp. Solids, Turbidity	Lehigh Systems	S. S. monitor	0-100/0-10K ppm	3000	Digital, alarm, printout	System

Table 1-2. Monitoring and Control Devices (Sheet 5 of 6)

Parameter	Manufacturer	Model	Cost	Measured	Mg/1 Range	Operating Principle	Outputs	Comments
Dissolved Carbon/Oxygen Demand	AES	1600	9800 W/rcdr	TOC	0-50/0-4000	Combust in O_2, detection of CO_2	Rcdr, volt, amp, dig	Relay, telemetry, 3 ml/min sample flow
		1610	9800 W/rcdr	TC	0-50/0-4000	Combust in O_2, detection of CO_2	Recorder	Fluidized bed combustor
Dissolved Carbon/Oxygen Demand	Beckman	915	5210-6310	TOC	0-10/0-4000	Comb in O_2 or air, detect. of CO_2	Recorder	20-200 ml sample, 2-4 min. analysis
		Process carbonaceous analyzer	8000	TC	0-50/0-4000	Comb. in air, detect of CO_2	Recorder	
Dissolved Carbon/Oxygen Demand	Ionics	225	8000	TOD	0-200/0-1000	Comb in 200 ppm O_2 in N_2 Detect. of O_2 consumption	Recorder voltage	20 ml sample, 3 min/analysis
Dissolved Carbon/Oxygen Demand	Precision Scientific	Aquarator	5500	COD	0-10/0-30 Mg 02/1	Comb in CO_2, detect. of CO_2		
Dissolved Carbon/Oxygen Demand	Union Carbide	1212M	8740	TC	0-100/0-3000	Comb. in air, N_2 carrier gas, detection of CO_2	Recorder	100 ml sample, 2 min/analysis
		1214	10,000	TOC	0-50/0-5000	Comb. in air, N_2 carrier gas, detection of CO_2	Recorder	100 ml sample, 2 min/analysis
Dissolved Carbon/Oxygen Demand	Oceanogr. Internl	Total C Analyzer	4800-5900	DOC POC PIC	0.2-2 DOC up 5-20 POC up	Wet oxidation under N_2 in sealed ampules by potassium per sulfate, detn of CO_2		
Dissolved Carbon/Oxygen Demand	Parkson Corp.	COD meter	5-6000	COD		Wet oxidation by potas. dichromate	Recorder	
Dissolved Carbon/Oxygen Demand	Technicon	Auto Analyzer II	5800 up	COD	0-20 up	Wet oxidation by potas. dichromate	Recorder	
Dissolved Carbon/Oxygen Demand	RMA Development	Oxymand	3800	BOD	0-100 ml O_2	Follows press. drop from O_2 consumption	Rcdr., volt, relay	Automated BOD for treatment plant control
Dissolved Carbon/Oxygen Demand	Phipps & Bird	Biomand I	7400	BOD		Follows press. drop from O_2 consumption	Recorder	Automated BOD
Dissolved Carbon/Oxygen Demand	Carl G Brimmekamp	Sapromat AG		BOD		Replaces O_2, electrolytically, measures current		Automated BOD
Dissolved Carbon/Oxygen Demand	Aqua Test Corp	Water Qual. Mon.	790/990	Dissolved Orgs	Higher levels	Dual beam UV photometer	Alarm	Dissolved organics measurement adjustable path length

Source of tabulated instrumentation are References 24, 25 and 26.

Table 1-2. Monitoring and Control Devices (Sheet 6 of 6)

ABBREVIATIONS USED IN MONITORING AND CONTROL DEVICES CHART

ORP	Oxidation-reduction potential
Rcdr	Recorder
Cond.	Conductivity
Do	Dissolved Oxygen
volt.	Voltage
amp.	Amperage
telem.	Telemetry
Temp. Comp.	Temperature Compensation
solar rad.	Solar Radiation
turbid.	Turbidity
opt.	Optional
+	Indicates additional variables available
dig.	Digital readout
TOC	Total Organic Carbon
TC	Total Carbon
TOD	Total Oxygen Demand
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
POC	Particulate Organic Carbon
DIC	Dissolved Inorganic Carbon
BOD	Biochemical Oxygen Demand
Comb., Combust.	Combustion
detn.	Determination
Press	Pressure

$2,650 to $3,400. The lack of an automatic, on-line instrument for determining microbiological quality necessitates a highly reliable disinfection control system.

Specific ion electrodes, although desirable, would be very expensive, considering the number of ions of interest. In addition, available sensors tend to foul and require frequent servicing. If treatment of water is designed to remove undesirable ions, monitoring of ions can be accomplished with conductivity sensors, which should reliably guard against usage of water of excessive dissolved inorganic content. Organic content of water must be rigidly controlled in a water reuse system, to prevent tastes, odors, colors and foaming, and to remove toxic substances. Common measures of organic content are BOD (biochemical oxygen demand), COD (chemical oxygen demand), TOC (total organic carbon), and CCE (carbon chloroform extract). Determinations of these quantities cannot be made practically with automated continuous on-line sensors. BOD and CCE determinations are time-consuming, while the others require expensive instrumentation and rarely have been utilized in continuous, on-line manner. A possible alternative is an on-line U-V photometer, which measures organic content by U-V absorption. One manufacturer currently marketing a device on this type is the Aqua Test Corporation. However, to our knowledge, the technique has not yet been utilized to a degree which would indicate its reliability and practicality.

Foaming, caused by surface-active agents such as detergents and soaps, could be a potential problem in a household water reuse system. Foaming could be produced by laundry, dishwasher, shower, kitchen, and lavatory wastewaters containing detergents and soaps, and thus is a general consideration in treatment of grey waters. Adequate reliable removal of foam and its causative agents by a treatment system, along with monitoring of organics in recirculated water, should provide sufficient protection against foaming problems.

Backflow, the siphoning of wastewater from waste to supply piping, is a consideration in any household plumbing system. Cross-connections must be designed out of the system. For protection against backflow, one of the following conditions must be met (Reference 10):

1. A sufficient air gap must exist between the water supply outlet and the maximum possible water or liquid level, <u>or</u>

2. The supply pipe must be equipped with a vacuum breaker, or back-siphonage preventer.

Backflow will not occur across an air gap that is three times the diameter of the smallest waterway in the fitting. Vacuum breakers admit air to the supply pipe whenever a vacuum exists within it. For adequate protection, these devices must operate under a vacuum of as high as 15 inches of mercury.

Bacterial control of treated water can be accomplished in a small installation by addition of low concentrations of halogen compounds, the most common being chlorinating compounds such as:

CA (OC1)	Calcium hypochlorite
Na OC1	Sodium hypochlorite
Ca C1 OC1	Chlorinated lime
$Na\ ))C-C_6H_4-SO_2\ NC1_2$	Halazone

The perferred method of addition of the solutions is by chemical reagent feeders. Stirring should be provided in the contact vessel to promote breakup of bacterial clumps and provide sufficient contact between the chlorine and the microbes. Required dosage of chlorine increases with increased solids and organic content, increased pH level, increased bacterial content, increased ammonia and organic nitrogen content, decreased temperature, and decreased time of contact. Because of the large number of variables, disinfectant dosage is normally controlled by the maintaining of a certain chlorine residual for a specified holding time. A 0.5 mg/1 chlorine residual after 15 minutes is generally sufficient to assure a 99.9% mortality of coliform bacteria. (Reference 11).

Other disinfection techniques, such as ultraviolet irradiation of water films, should be considered along with chlorination. Ozonation, alone or in combination with ultraviolet irradiation, has been gaining popularity in municipal water and wastewater treatment, particularly in Europe. However, the necessity to generate ozone on site makes this process practical only for larger treatment systems. It should be noted that many water and wastewater treatment processes remove bacteria and pathogens from water. Filtration processes are particularly effective. However, a final disinfection process is required to assure mortality of organisms which may pass through the other treatment processes.

1.6 COMPOSITION OF HOUSEHOLD WASTE WATERS

The concentrations of contaminants in total waste waters from individual homes and from different homes vary widely (Reference 12). For the purposes of this study, however, it will be assumed that waste characteristics remain relatively constant for each of the major waste flows. The only comprehensive investigation of waste flows from different household sources has indicated that this is not an unreasonable assumption (Reference 3). The study investigated the composition of waste from kitchens, bathroom grey water, laundry, and vacuum toilets (black water). The kitchens were not equipped with food waste disposers. The important data from that study are summarized in Table 1-3.

In order to estimate concentrations of impurities in the black water from the conventional toilets, the levels in vacuum toilet wastewater have been modified. To account for the greater volume of flush water the conventional toilet (5.0 gal.) as compared with the vacuum toilet (1.7 liters), the concentrations in Table 1-3 have been adjusted.

Additional correction must be made because of the waste materials contributed by a garbage disposal. Garbage disposals were not present in the residences investigated in Reference 3. According to the most comprehensive study thus far made on the subject (Reference 13), the presence of a household food waste disposal does not significantly affect total water use, but does increase levels of BOD, suspended solids, dissolved solids and grease in the total household effluent by 17, 26, 9.3 and 35%, respectively. On the basis of the assumed daily volumes for black, grey and garbage disposal waste-calculated, are assumed to be:

BOD	870 mg/1	Suspended Solids	1375
Total Solids	2345	Dissolved Solids	970

Table 1-3. Composition of Household Wastewaters (2) (waste concentration in mg/l)

Constituent	a) Kitchen (no garbage disposal)	b) Bathroom grey	c) Laundry	a)+b) +c) (no garbage disposal)	Vacuum Toilets
BOD	324 mg/l	76 mg/l	349 mg/l	203 mg/l	2317 mg/l
KMn 04 (Permanganate Value-Chemical Oxygen Demand)	662 mg/l	109 mg/l	872 mg/l	408 mg/l	8508 mg/l
Total P	6.5 mg/l	10.3mg/l	155 mg/l	18.7 mg/l	190 mg/l
Kjeldahl N	11.4 mg/l	5.6 mg/l	23.2 mg/l	8.9 mg/l	1280 mg/l
NH_4 - N	0.7 mg/l	0.4mg/l			
NO_2 - N	0.014	0.01 mg/l			
NO_3 - N	0 mg/l	0 mg/l			
Total Residue (Total Solids)	715 mg/l	356 mg/l	2240 mg/l	666 mg/l	6250 mg/l
Fixed Total Residue (Total inorganic solids)	181 mg/l	193 mg/l	1424 mg/l	303 mg/l	1630 mg/l
Volatile Total Residue (Total organic solids)	534 mg/l	163 mg/l	816 mg/l	379 mg/l	4620 mg/l
Nonfilterable Residue (Total suspended solids)	253 mg/l	49 mg/l	179 mg/l	149 mg/l	3574 mg/l
Fixed Nonfilterable Residue (Inorganic suspended solids)	18 mg/l	12 mg/l	69 mg/l	20 mg/l	560 mg/l
Volatile Nonfilterable Residue (Organic suspended solids)	235 mg/l	37 mg/l	110 mg/l	130 mg/l	3014 mg/l
Total Dissolved Solids	462 mg/l	307mg/l	2071 mg/l	517 mg/l	2676 mg/l
Inorganic Dissolved Solids	163 mg/l	181mg/l	1355 mg/l	283 mg/l	1070 mg/l
Organic Dissolved Solids	299 mg/l	126 mg/l	716 mg/l	234 mg/l	1606 mg/l
pH	7.1	8.0	9.8		8.9
Plate count 35°C (per ml)	8×10^6 /ml	1×10^7 /ml	~ 0[1]		73×10^6
Coliform 35°C	3×10^6 /ml	6×10^5/ml	~ 0[2]		6×10^6/ml
Coliform 44°C	6×10^5/ml	1×10^5/ml	~ 0[2]		5×10^6/ml

1. Levels as high as 10^6 per ml have been found in commercial and domestic laundries. (Reference 44)
2. Coliforms and viruses have been recovered from commercial and domestic laundries. (Reference 44).

Assuming that 9.3 gallons per day are used in the typical household garbage disposal (Reference 10), the levels of contaminants in kitchen, combined kitchen and bathroom grey and combined kitchen, bathroom grey and laundry wastewaters have been adjusted to account for the presence of a garbage disposal. The results are summarized in Table 1-4.

Table 1-4. Composition of Wastewaters (Typical Conventional Home)

	Kitchen with Garbage Disposal	Kitchen + Bathroom Grey + Laundry	Conventional Toilet	Total Wastewater
BOD	506 mg/l	242 mg/l	209 mg/l	229 mg/l
$KMnO_4$ Value	> 662 mg/l	> 408 mg/l	756 mg/l	
Total P	> 6.5 mg/l	> 18.7mg/l	17 mg/l	
Kjeldahl N	> 11.4 mg/l	> 8.9 mg/l	115 mg/l	
Total Residue	1257 mg/l	763 mg/l	563 mg/l	
a) Fixed	> 181 mg/l	> 303 mg/l	147 mg/l	776 mg/l
b) Volatile	> 534 mg/l	> 379 mg/l	416 mg/l	
Nonfilterable Residue	627 mg/l	220 mg/l	322 mg/l	260 mg/l
a) Fixed	> 18 mg/l	> 20 mg/l	50 mg/l	
b) Volatile	> 235 mg/l	> 130 mg/l	272 mg/l	
Dissolved Solids	630 mg/l	543 mg/l	241 mg/l	425 mg/l
a) Inorganic	> 163 mg/l	> 283 mg/l	97 mg/l	
b) Organic	> 299 mg/l	> 234 mg/l	144 mg/l	
pH	~ 7.1 mg/l			
Total Plate Count 35°C	≥ 800 X 10^6/ml		658 X 10^6/ml	
Coliform 35°C	≥ 301 X 10^6/ml		51 X 10^6 /ml	

The levels of contaminants present in waste waters from the various household sources will obviously vary widely over the course of any day. The primary utility of the information presented herein is to indicate the relative levels and major types of impurities present in the wastewaters. This information will be used in the evaluation of potential recycle/reuse schemes in the baseline and advanced systems.

1.7 WATER DEMANDS BY DWELLING TYPES

There are two essential relationships involved in assessing differences associated with apartments, houses and mobile homes.

The home is the unique dwelling (of the three) in that it is a "full scale" living area whereas the apartment/mobile home units are generally restricted in floor space.

There are, of course, very large apartments available, as there are mobile homes with the same room sizes and numbers as a "typical" single family dwelling, but the average size places the single dwelling first for usable living area space.

The second major relationship is the kinship of the single family dwelling with the mobile home. Both are distinct units, detached (in most cases) from other structures or at least situated in less densely populated sections. This structural and basic social interface differences influence and limit the practicality of certain water-related uses.

1.7.1 APARTMENT WATER USE

1. Current Status - As intimated in Figure 1-2 (Apartments-GPD), the average population of apartments, being less than single dwelling, results in less water use per living unit than other dwelling forms. Per capita water use is also somewhat less because room sizes are small and appliance space is limited. Dishwashers and clothes washers are not commonly found in apartments. Clothes washers, when provided, are installed by the landlord, in a community laundry room located in the basement section of an apartment building. Recently, appliance manufacturers have introduced "mini" clothes washers and dishwashers in the hopes of capturing the apartment dweller market on the premise of eliminating the inconveniences associated with not having a nearby appliance. The advertising shows closet-stored combined washer-dryers and dishwashers that connect to the kitchen sink spout and convert to counterspace when not

required. These new machines in being sized for smaller ("apartment sized") loads use commensurately less water; i.e., 15 gallons for the GE version compared to 30-40 gallons in regular sized machines. The appliance gap, coupled with the lower average accupancy/apartment accounts for the lower total water demand.

2. Projected Water Savings - The baseline concept presented is not amenable to apartment use except for the low water use devices. The bathroom lavatories and showers and the kitchen sink are the only sources of reclaimable water (grey water). In the absence of appliances, or appliances that drain into the sink, no practical recycle scheme is evident due to the intimate utility relationship within the apartment building complex. One outstanding improvement has been successfully proven, the vacuum collection system and low water use toilet patented by J. Liljendahl. A typical system is depicted and wastewater quality evaluated in Reference 3. Essentially, the system accomplished what the marine toilet provides on a ship. Using energy assisted transfer (pressure in the marine toilet, vacuum for the Liljendahl system), solid wastes are carried in smaller lines to a holding tank for subsequent injection into the municipal sewer or treatment/disposal by a packaged plant. If tertiary treatment were provided, a dual water system may be economically feasible for this application (Reference 14).

1.7.2 MOBILE HOME WATER USE

1. Current Status - The same spatial constraints for the apartment apply to the mobile home. It is, in fact, an apartment transformed from the cluster to a separate entity. In addition it also has several unique limitations. The ceiling to floor height is usually seven feet to reduce racking (parallelogramming) induced by highway loads during shipping. Clearance from the floor to the roadbed to meet "over the road" humps, etc., results in a design restriction on installation of the bathroom tub/shower. This fixture is usually a shallow floor design and shorter than conventional tubs, hence water use for bathing is reduced. Again, as in the apartments, water using appliances are not common, although frequently since the mobile home has space outside the living area, these appliances can be found next to the trailer either in a shed or under an awning for protection.

2. Projected Water Savings - Because the mobile home is essentially a scaled down single family dwelling, the baseline concept is applicable where the cited appliances are included.

SECTION 2
BASELINE CONCEPT

2.1 DERIVATION OF BASELINE CONCEPT

The most important factor in deriving the proposed baseline is to create an effective system that would be acceptable for integration into the "typical" home by current standards of aesthetic and socially amenable habits. Realizing this is still a highly subjective topic, the project team, in reviewing most possible schemes, seemed to agree that public acceptance would be lacking for any change where direct body or oral contact of reused water is recommended. This category included reused waters for lavatory sinks, shower/baths, kitchen water and other outlets where water consumption is usual.

The baseline water saving concept for the "typical" dwelling (as defined in Reference 7) is proposed with the following guidelines:

1. The lifestyle of the home occupants will be minimally impacted, where aesthetics are not affected and the change can be rationalized as "reasonable" to achieve resultant savings.

2. In stressing water saving devices and procedures capital costs are offset by operational costs, where possible. The reasoning for this is that in dealing with "typical" situations, the running costs will be determined as a proportion of system used by the occupants. By relating added costs to operating procedures, the capital costs are reduced in favor of incentivized charges. In later years as water costs become somewhat more accountable, incentives may contribute more realistically to resource conservation.

3. Reuse schemes are proposed for those household functions not involving direct body contact on the premise that water cloudiness or other technically acceptable aesthetic disadvantages will be minimized when camouflaged by a closed cycle appliance.

2.1.1 SOURCE OF WATER WASTE

Within the home, water is "wasted," that is, not applied to a desired function because of the following:

1. Performance of discontinuous water related functions. This is exemplified by leaving the water running in a lavatory or shower while applying soap, scrubbing and other actions divorced from the flowing steam. For each water use, this waste is conservatively estimated at 50% the total gallonage allocated to that function.

2. Dwell time for water temperature stability. This waste occurs both for hot water (most common) and cold water. As most homes have one water heater, usually located near the public water supply utility connection, the fixtures (sinks, bath/showers) located remote to the heater must be purged of the residing water, that has lost its heat to the piping/environment, and allowed to flow hot water until the plumbing heat transfer to the pipes supports the hot water outlet temperature. With dwelling hot water at an average of 140-160°F, cold water is usually combined and both taps manipulated until the final water temperature desired is attained. For cold water lines, when the coldest possible water available from the supply is desired, such as for drinking, a similar purging of the "old" water is the usual procedure. Thus, for one or two glasses of water, several gallons may be wasted.

3. Water leakage in pipes and valving. This problem will not be evaluated, as any system when improperly maintained, can result in poor performance.

2.1.2 AREAS OF WATER REUSE POTENTIAL FOR THE BASELINE CONCEPT

1. Toilet Flush Waters. The most significant water use lending to immediate recycle schemes is the amounts and quality required to carry human wastes to the sanitary sewers. In the earlier studies on home use of water, many of the already cited references, single out this function due to its proportion of total gallons ($\sim$ 40%) and minimum water quality requirements (Table 2-1). The project team concurred that a recycle scheme for toilet flushing would be an acceptable candidate for the baseline system provided the water quality standards recommended in the table could be reasonably met.

2. Appliances. The major water-using home appliances are the clothes washer, dishwasher, and garbage disposal. Of these, the garbage disposal uses the least amounts of water - approximately 9 gallons (Ref. 10) with a high concentration of sewage (see Paragraph 1.6) and does not lend itself to practical reclamation. Both the dish and clothes washers have common operational sequences in that they have separate wash and rinse cycles with complete drain of each between refills.

   The clothes washer water quantities, identified in the earlier studies range from 32 to 59 gallons/use divided evenly between the two cycles. The pump utilized to drain the tub also, through an integral valve, causes recycling of the tub waters during wash periods and rinse periods. The drain line is usually attached to a drain pipe or dumps directly into a receptor sink.

Table 2-1. Water Quality Standards for Household Functions

Use / Characteristics	USPHS Drinking Water	Bathing	General Washing-Cleaning	Toilet Flush	Lawn Watering
Extrinsic - (Units)					
Turbidity	5	10	10	20	10
Color	15	15	15	30	15
Odor	3	3	3	6	3
Intrinsic (mg/ℓ or PPM)					
Alkyl Benzene Sulphonate (ABS)	0.5	1.0	2.0		1.0
Silver (Ag)	0.05*	0.05	0.05		0.05
Arsenic (As)	0.01(0.05)*	0.01(0.05)*	0.05		0.05
Barium (Ba)	1.0*	1.0*	2.0		1.0
Boron (Bo)					1.0
Cadmium (Ca)	0.01*	0.01	0.01		0.01
Chloride (Cl)	250	500	500		500
Chromium (Cr)	0.05*	0.05	1.5		0.05
Carbon Chloroform Extract (CCE)	0.2	0.2	0.4		0.4
Cyanide (Cn)	0.01 (0.2)	0.2	0.2		0.2
Fluoride (F)		6.0	6.0		6.0
Lead (Pb)	0.05*	0.05	0.05		0.05
Nitrate (NO_3)	45	90	180		180
Phenols	0.001	0.005	0.01		0.05
Selenium (Se)	0.01*	0.01	0.01		0.01
Sulphates (SO_4)	250	500	500		500
Total Dissolved Solids	500	500	500		1000
Zinc (Zn)	5	10	10		10
Staining Agents					
Manganese (Mn)	0.5	0.05	0.05	0.5	0.5
Iron (Fe)	0.3	1.0	1.0	1.0	1.0
Copper (Cu)	1.0	2.0	2.0	1.0	1.0
Fe + Mn		1.0	1.0	1.0	1.0
Solutions					
pH		6.5-8.3	6.0-8.3		6.5-8.3
Hardness		100	100		
Alkalinity		60	60		

* Indicates Max. Allowable

The dishwasher, located in the kitchen area most often in close proximity to the sink, uses either a hot or cold water tap from the sink water supply. An integral heater raises the incoming water temperature to approximately 140°F before machine start-up is enabled. The wash-rinse sequences do not follow consistently, i.e., there may be sequential wash cycles prior to a rinse cycle.

These appliances eject relatively "clean" rinse waters and, as such, represent candidate contributors to wastewater reclamation and reuse for the baseline concept.

2.2 BASELINE CONCEPT

In formulating the baseline concept for household water and wastewater, primary consideration has been given to reducing water usage. Technological constraints have been observed, so the proposed modifications may be made with currently available hardware or simple modifications of available hardware (Table 2-2). In addition to utilizing devices which directly reduce water use, a limited amount of water recirculation has been incorporated into the baseline system. Economic, health, safety and behavioral restraints have also received due consideration, so the baseline system presented herein is one which could be incorporated practically into a home constructed at the present time. The schematic is shown in Figure 2-1.

2.2.1 LOW WATER USE PLUMBING FIXTURES

The low water use plumbing fixtures which have been incorporated into the baseline water-wastewater system and their estimated water savings are listed below:

Low Water Use Plumbing Fixtures

Fixture	Application	Reduction in Water Use Over Conventional
Limiting flow valve	Shower heads	30% (5 gpm to 35 gpm)
Aerator	Kitchen, lavatory faucets	Incl. in conventional system
Shallow-trap water closet	Toilets	40% (5 to 3 gal/use)
Body weight flow control valve	Shower	50% additional (est.)

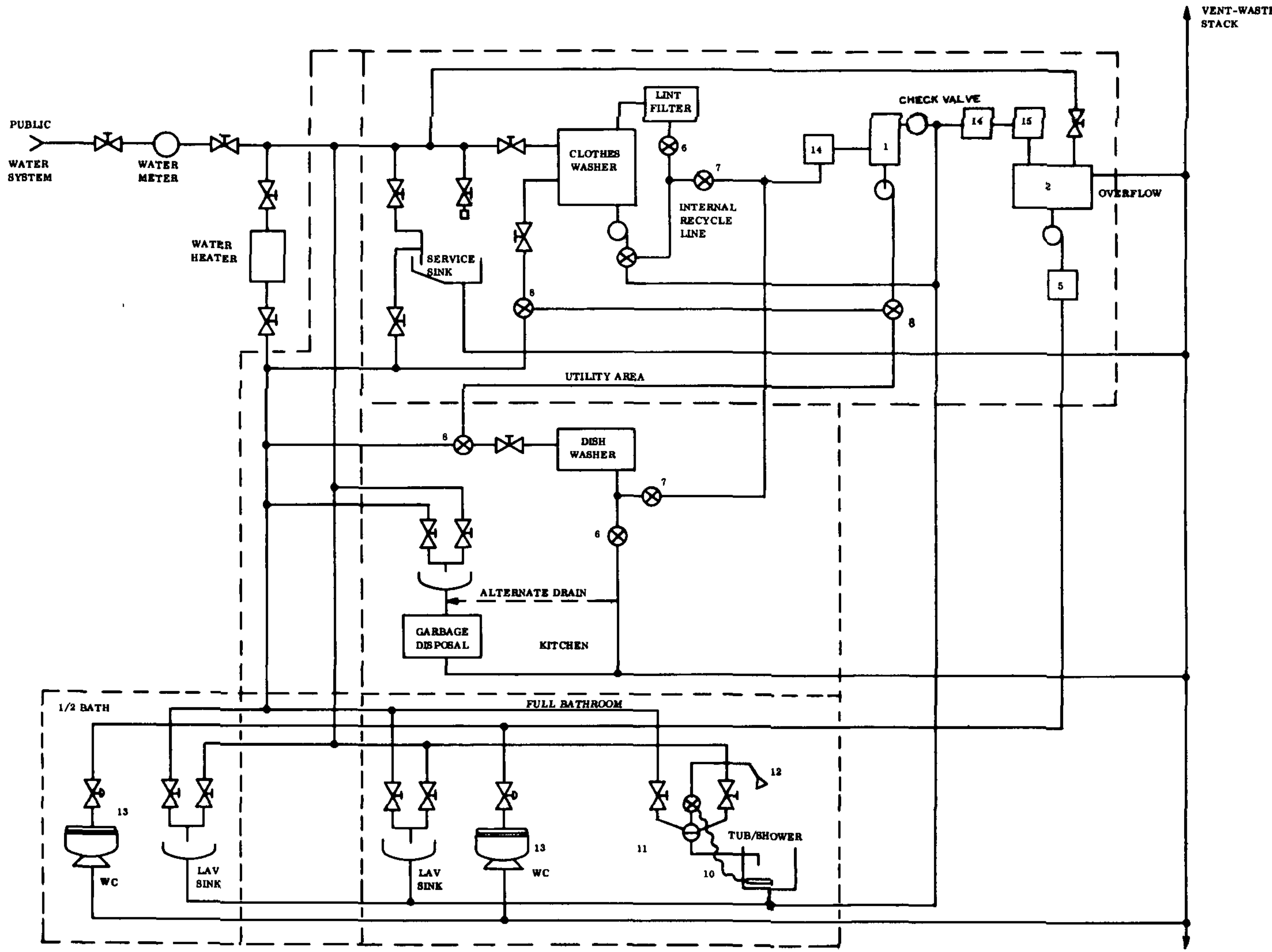
Table 2-2. Hardware Listing

Item No.	Item	Application	Example	Cost
Components				
1	Water heater-30 gal.	appliance reuse water storage	Sears 42K32131N	$49.95
2	Water tank	flush water storage	US Plastic Corp. #05003, 29 gal.	34.00
3	Pump	appliance water pumping	US Plastic Corp. #94101-2-MD	44.50
4	Pump	flush water pumping	Sears 42K2501N	59.95
5	Cartridge filter	filtration of flush water	Serfilco LM020U +30 μ cartridge	40.85
6	2-way solenoid valve, normally open (1")	a) clotheswasher interval recycle line	ASCO 8210C14	60.50
		b) dishwasher drain to sewer	ASCO 8210C14	60.50
7	2-way solenoid valve, normally closed (1")	a) clotheswasher to hot water tank (water heater)	ASCO 8210C4	48.25
		b) dishwasher to hot water tank	ASCO 8210C4	48.25
8	3-way solenoid valve (1/2")	a) clotheswasher hot water supply (recycled water line normally open)	ASCO 831664	67.75
		b) dishwasher hot water supply (recycled water line normally open)	ASCO 831664	67.75
9	Ball cock with float	flush water storage tank fresh water backup supply	Sears 42K2118	3.29
10	Mat	shower flow control	Sears 96K4665H	3.08
	Tubing	shower flow control	2 x Thomas 9561-C43	3.20
	Engineering & Fabrication of above into flow control		mat = 5% of above =	.31
	Tube x tube x tube Connector (1/4")	water pipe - valve - mat tubing connection	Plastic Piping Systems #321309	.87
	Reducing tee (SxSxT) (1/2 x 1/2 x 1/4")	connect tubing to shower supply pipe	Plastic Piping Systems #003505	1.95

Table 2-2. Hardware Listing (Cont)

Item No.	Item	Application	Example	Cost
11	Pneumatic valve	shower flow control	ASCO P210C94	28.00
12	Limiting flow shower head	limiting shower flow to 3.5 gpm	Ref. Gen. Dyn. p62	15.00
13	Shallow flush Water closet (2)	limit flushwater to 3 gal.	Ref. Gen. Dyn. p62	40.00
14	Strainer	pre-hot water storage	Serfilco-brass, 150 mesh	18.00
		pre-flush water storage	Serfilco-brass, 150 mesh	18.00
15	Chlorinator Tablet type	disinfection of toilet flush waters	Diamond Shamrock Corp.	30.00
Piping/Fittings		Material	Installation	
16	1/2" pipe @ $0.35/ft.	26 ft. = 9.10	$1.30/ft. = 34.00	43.10
17	1" pipe @ $0.70/ft.	36 ft. = 25.20	$1.30/ft. = 47.00	72.20
18	1/2" straight-in @ 0.17 x 22	3.70	*	3.70
19	1" straight in @ $0.25 x 22	5.50	*	5.50
20	1" tee @ $0.55 x 3	1.65	*	1.65

* included in sizing connections
(detailed presentation of needed connections is included as Appendix F)



NOTE SEE TABLE 2 2-1 FOR DESCRIPTION OF NUMBERED ITEMS

Figure 2-1. Baseline System

Limiting flow valves restrict the maximum flow through a fixture. A maximum flow rate of 3.5 gpm for a shower head, with a water savings of 30%, is reasonable (Ref. 7). For lavatory and kitchen faucets, maximum flow rates are not utilized as often as in showers, and limiting flow valves would not afford greater water savings than the more conventional faucet aerators, which are also less expensive. It has been estimated that aerators on lavatory and kitchen sink faucets would reduce water consumption by 25% (Ref. 7). However, faucet aerators are quite common, especially in new construction, and have been assumed to be present in a conventional home.

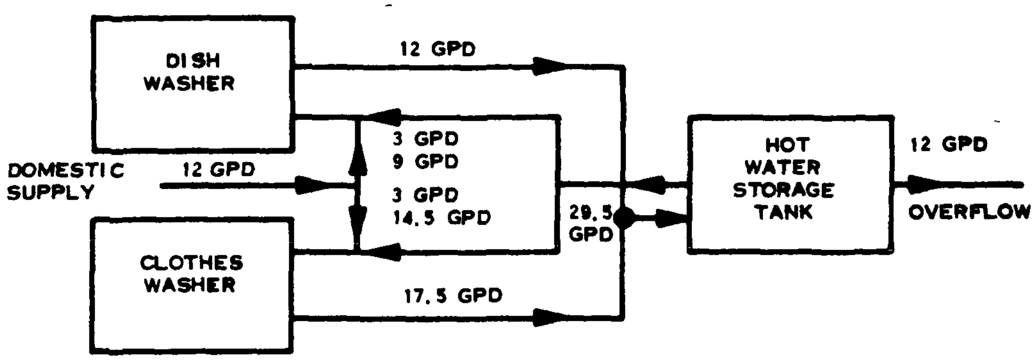
Shallow trap water closets, currently available, would reduce water required per use from the conventional 5 to 3 gallons.

A foot pedal on-off control for a lavatory sink would allow control of flow while washing or performing oral hygiene functions, without the inconvenience of adjusting temperature in combined hot-cold flow, and would free the user's hands to function. This type of control is currently available in commercial applications. Potential water saving, by reducing running of water when not needed, is estimated at 50%, over and above savings afforded by an aerator. However, it has been determined that the added cost of this device mitigates against its use, since it would afford a water saving of only 4 gpd for the typical household. The body weight flow control for the shower is similar in concept. Although not currently commercially available, the system can be fabricated from existing hardware. Water savings are estimated at 50% above those resulting from a flow control valve.

2.2.2 WATER RECIRCULATION

Since many high water consumption household functions require water of less than drinking water quality, recirculation of certain wastewaters has been given consideration. Rinse water from the clothes washing machine and dishwasher are of higher quality than wash water, and should be suitable for use as wash water in these appliances. Rinse water would be diverted through a strainer to a heated water tank, from which the dishwasher would draw wash water directly. The clothes washing machine would either draw water directly (hot water wash), or in combination with cold fresh water (warm water wash).

Water requirements for dishwashers of 2 gallons for washing and 8 gallons for rinsing (Ref. 8) corresponding to 3 gallons of wash water and 12 gallons of rinse water per day, all hot, assuming 1.5 uses per day for a total use of 15 gpd. Clothes washer water use of 35 gallons indicates 17.5 gal/day used for both washing and rinsing cycles. Since data are not available, it will be assumed that 2/3 of washes utilize hot water and 1/3 warm water, corresponding to approximately 14.5 gallons of hot wash water and 3 gallons of cold wash water per day. The water balance for the hot water storage tank is as follows:



The maximum withdrawal from the hot water storage tank would occur when dishwasher and clothes washing machine (hot water wash) are used at approximately the same time. This would amount to 19.5 gallons and the hot water tank has been sized at a nominal 30 gallons to allow a residual for withdrawal of water.

An overflow will be provided to carry the excess water to the second recirculation system. This system will recirculate appliance recirculation tank overflow, clothes-wash water and spent bathroom grey (shower, bath, sink) water to be used for toilet flushing. The system consists of a strainer to remove settleable solids, a tablet-type chlorinator for disinfection and odor control, a storage tank, and a pump to supply the necessary head to deliver water to the shallow-trap water closet through a cartridge-type filter which will remove visible suspended solids. The average daily water balance for the storage tank is as follows:

Function	Inputs	Outputs
Hot water tank overflow	12 gpd	
Shower-bath	41 gpd*	
Lavatory/sink	8 gpd	
Clothes washer	17.5 gpd	
Toilet flush		60 gpd
Total	70.5 gpd	

*assuming an average of 3 showers to 1 bath

Average daily excess input over output = 18.5 gallons. Overflow from the tank will be diverted to the sewer.

On the "average" day, the maximum withdrawal over replacement for any time period occurs between 1520 and 1900 hours, and amounts to 17.5 gallons. If the clothes washing machine is not used, nor is the dishwasher used at mid-day, the maximum withdrawal without replacement would be 27 gallons between 730 and 1900 hours. To provide for sufficient flush water in this nominally maximum situation, the size of the hot water tank has been set at 30 gallons. To provide flush water in the event of an empty flush water tank, a fresh water supply connection is provided to the storage tank as a backup.

2.2.3 WATER QUALITY IN RECIRCULATION SYSTEMS

1. Appliance Water Recirculation. Although information concerning relative levels of contaminants in clothes and dishwasher wash and rinse waters are not available, it is assumed that rinse water will, in general, have significantly lower levels than waste wash water. Filtration will remove solids, and any pathogens not killed by detergents, bleaches or heat and which are not trapped in the filter will be controlled in a clothes washer recycle water by holding the water in the hot water tank at approximately 160°F. Bacterial contamination by pathogens should not be a factor in dishwashers which operate with 180°F water [(1)]. The gradual buildup of dissolved solids which would be a problem in a complete recycle system is avoided since wash waters are being removed from the system.

2. Reuse of Water for Toilet Flushing. Water quality requirements for toilet flushing are less stringent than for other household uses. Recommended criteria are minimum odor, minimum staining properties, and the prevention of serious health hazards (Ref. 7). Chlorination will kill pathogens, while filtration will remove

1. A problem exists in clothes washers because neither the water temperature nor the detergents used under today's home and commercial laundering conditions can be relied on to reduce the number of bacteria in fabrics to a safe level.

solids and reduce turbidity. Chlorine should reduce odors, while odors caused by chlorine itself will be minimized due to the holding time provided by the tank. Staining agents (manganese, copper and iron) are not expected to be present in significant amounts in waters recirculated for toilet flushing. Laundry and shower waste waters have previously been stored and reused for toilet flushing successfully with only filtration for treatment (Ref. 2). There was no foaming problem from detergents and the author concluded that the slight grey color was not objectionable. If research or application indicates that people find the coloration objectionable, flushing water could be colored using dye, as is done in commercial jet aircraft.

Comparison of Water and Wastewater Volumes
Conventional versus Baseline Systems

Function	Fresh Water Use (GPD)				Wastewater (GPD)	
	Conventional		Baseline		Conventional	Baseline
	Total	Hot	Total	Hot		
Toilet	100	0	0	0	100	60
Utility sink	5	3.75	5	3.75	5	5
Kitchen sink	12	9	12	9	12	12
Dishwasher	15	15	12	12	15	3 (+18.5)**
Clotheswasher	35	26.25	20.5	8.75	35	(18.5)**
Lavatory sink	8	1	8	1	8	(18.5)**
Shower-bath*	80	60	41	30.75	80	(18.5)**
Totals	255	115.00	98.5	65.25	255	98.5

* Assuming 3 showers to 1 bath

** 18.5 gpd total excess from these sources discharging to flush water recirculation tank, and overflowing that tank.

It is apparent that the baseline water/wastewater system would reduce total average daily water demand by approximately 61%, hot water demand by approximately 43% and total average daily wastewater flow by approximately 61%.

2.2.4 WATER RECIRCULATION IN THE BASELINE SYSTEM

In the baseline system water recirculation is employed in two applications. Rinse waters from clothes and dishwasher are reused as wash water in these appliances. Wash water is drawn from the tank and forced to the appliances by means of a pump. The rinse waters are strained before entering a hot water storage tank to remove settleable particulates and prevent a buildup of sludge in the storage tank. A strainer will not impose the head loss which a fine filter would. Grit, the fraction of domestic sewage of specific gravity 2.65 which settles rapidly, ranges in particle size from 200μ up (Ref. 10). Organic particulates of specific gravity 1.001 may range below this in size, and could potentially cause a solids buildup in the tank. A study of the application of straining in the treatment of combined sewer flows (Ref. 14) found that a strainer of 105μ opening retained 90% of the settleable material in the flows. Based on Stoke's Law ($V_s = (g/18)\ [(S_s-1)/\gamma]\, d^2$), particles of specific gravity 1.001 and diameters of less than 100 will have a settling velocity of less than 1.47×10^{-4} cm/sec at 71°C (160°F). It is expected that turbulence during inflow and outflow will keep particulates in this size range in suspension and that buildup of solids will not occur in the tank. Therefore, it is recommended that a strainer of maximum sieve opening 105μ (140 Mesh) be incorporated into the recirculation line before the appliance water storage tank.

In the flush water recirculation system, wastewaters from tub/shower, lavatory, clotheswasher wash cycle and hot water tank overflows are recirculated to be used for toilet flushing. In addition to a strainer of maximum sieve opening 105μ to remove settleable solids, a tablet-type chlorinator is included preceding the storage tank for disinfection and odor control. Because appearance of flush water could be an aesthetic factor, visible particulates should be removed from the recirculating water. Filters required to remove small particulates impose a relatively high pressure drop (3 psi new up to 30 psi when spent). The included filter (to remove visible particulates > 40μ) must be placed on the outlet side of the flush water supply pump so that the pump can overcome the head loss inherent in the filter. A cartridge type filter of pore opening 30μ has been chosen to effectively remove visible particulates. The filter is of the replaceable cartridge type.

2.2.5 COMPARISON OF HYDROGRAPHS

The reduced use of fresh water and the resulting wastewater reduction are graphically illustrated in Figures 2-2 and 2-3. These graphs are derived using the "typical" home water use graph (Figure 1-6) developed earlier in the study.

2.3 ECONOMIC ANALYSIS

2.3.1 INTRODUCTION

The purpose of this analysis is to compare the baseline water conservation system's economics with those of a conventional household water and wastewater system.

Two locations will be examined, a typical suburban location with average water and sewage rates, and a "worst case" location in an isolated small community with extremely high water and sewage costs and a need for water softening.

For each situation, the incremental capital and operating costs of the baseline system over the conventional system will be estimated and the net annual cost or benefit calculated.

In addition, the costs for both the conventional and baseline systems will be projected into the future to determine what effect the projected differential price increase of various cost components will have on the comparative costs of the two systems.

2.3.2 BASIC ASSUMPTIONS

Table 2-3 lists the basic assumptions made in this analysis. The home on which cost comparison will be made has the same hypothetical specifications as the home analyzed by the Federal Water Quality Administration (Ref. 7).

To determine the appropriate capital amortization rate, an estimate of 30 years life for the baseline plumbing system and a 7.5% interest rate are used. These factors are based on the terms of a conventional mortgage which would be used to finance a new single family dwelling.

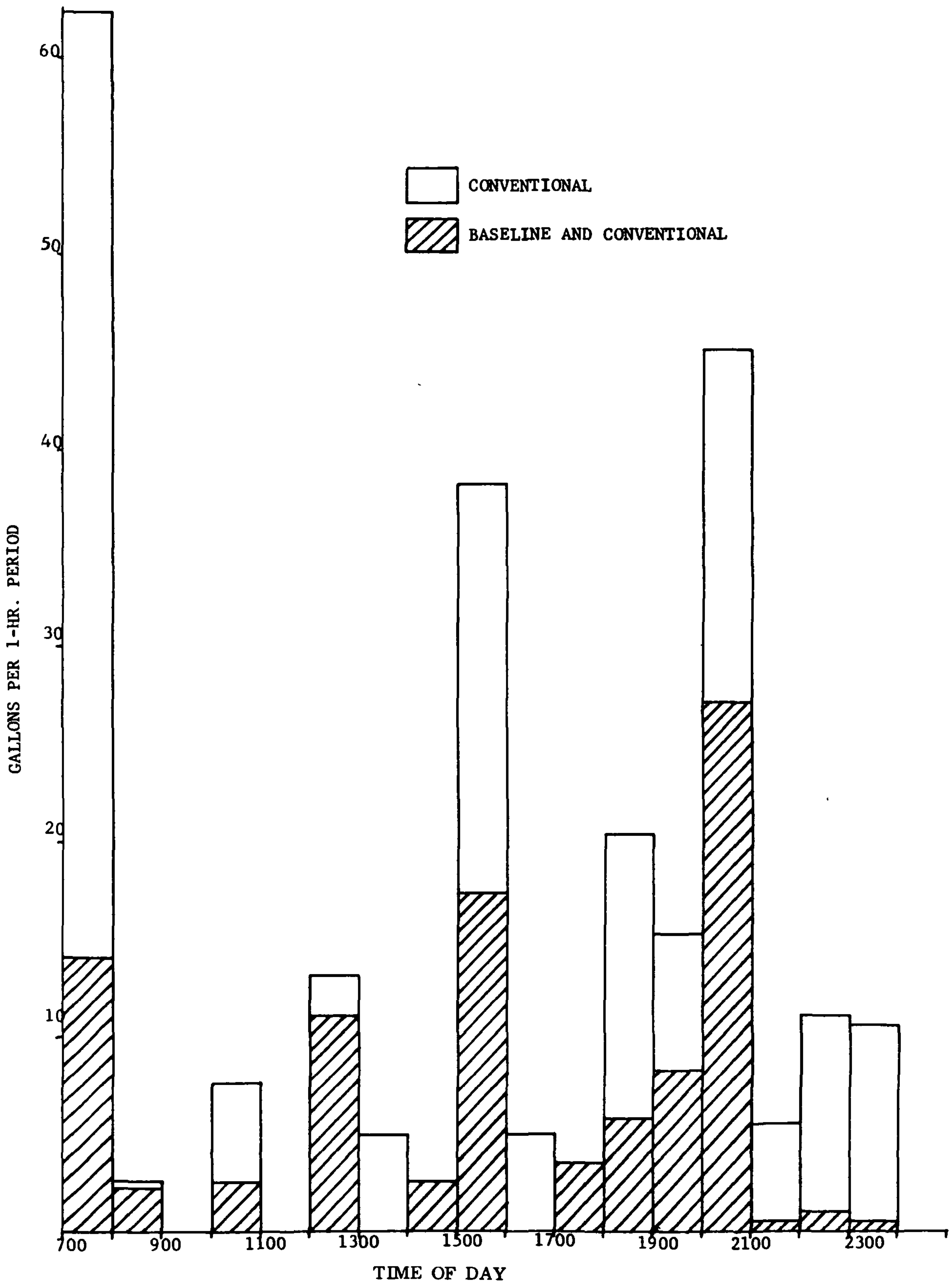


Figure 2-2. Baseline vs. Conventional Municipal Water Demands

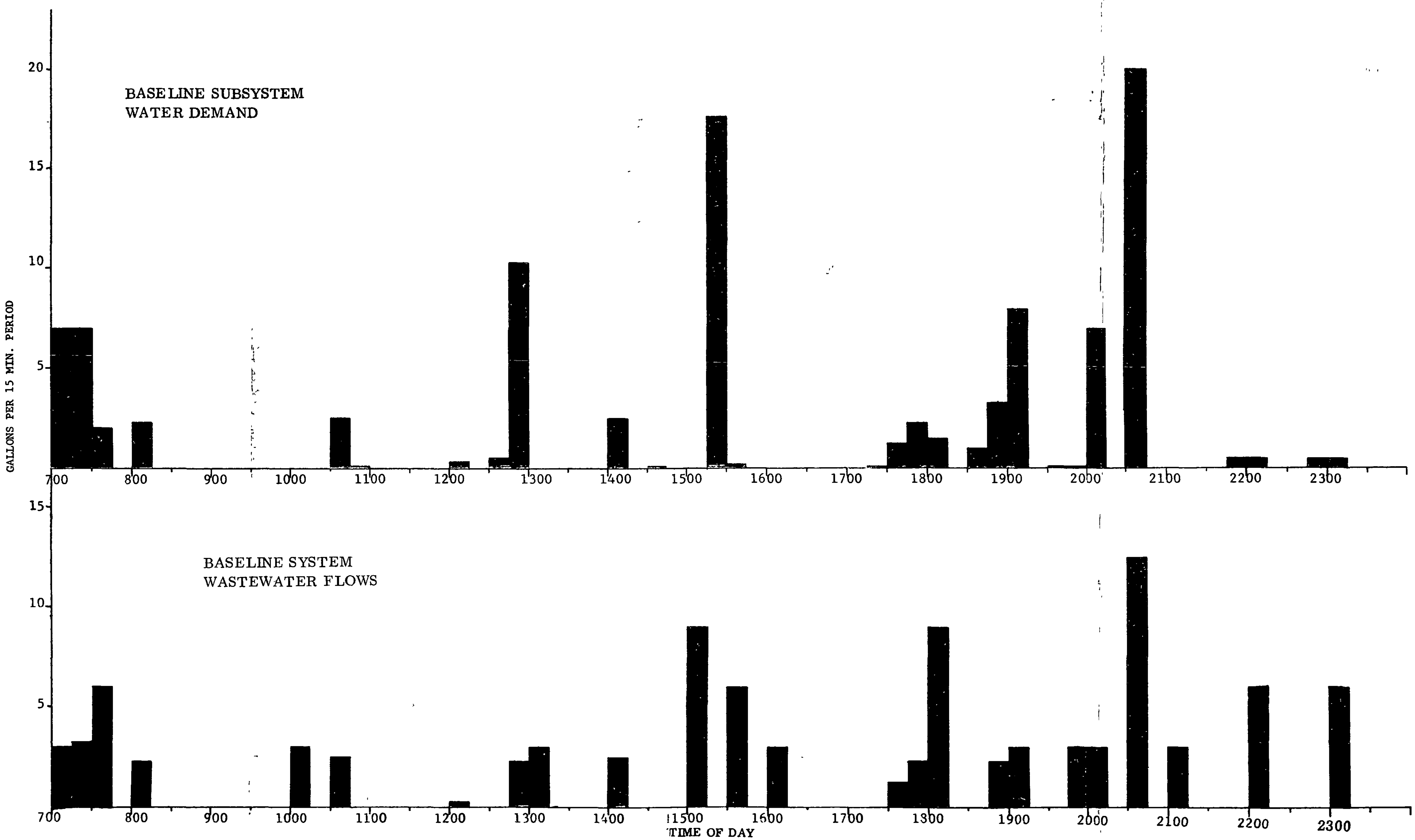


Figure 2-3. Baseline System Municipal Water Demands

All costs used in this analysis have been adjusted to mid-1972 price levels using the appropriate price indexes. Appendix D shows the adjustment calculations.

Table 2-3. Basic Assumptions

1. Home Characteristics

   - 6 rooms, single family dwelling
   - 1-1/2 baths
   - 4 occupants; 2 adults, 2 children
   - new construction with specified plumbing as original equipment

2. Typical Location Case

   - 25,000 pop. utility district
   - existing water and sewer lines
   - abundant soft surface water supply
   - average sub-division density, 4 houses/acre
   - secondary waste treatment

3. Worst Location Case

   - existing isolated 100 unit community
   - low density, 1 house/acre
   - community based water and waste treatment
   - tertiary waste treatment
   - individual home water softeners

4. Cost Estimation Factors

   - 30 years life for system
   - 7.5% interest rate for cost of money
   - 1972 price levels

2.3.3 COST PARAMETERS

A number of cost parameters have been taken from the literature or derived to allow calculation of the cost differences between the two systems. Table 2-4 summarizes these parameters. Where the parameter was taken from the literature, the source and price adjustment index used are cited on Table 2-4. Calculations and data sources for those parameters derived are shown in Appendix C.

Table 2-4. Cost Parameters
(all costs at mid-1972 price levels)

Literature Source	Price Adjustment Index	Parameter	$ Value
26	a	typical residential water rate	0.75/1000 Gal
27	a	worst case residential water rate	3.76/1000 Gal
28	a	typical residential sewage rate	0.44/1000 Gal
Appendix C	a	worst case residential sewage rate	2.67/1000 Gal
29	b	electric power	0.022 $/Kwhr
Appendix C	-	home water softening cost	1.77/1000 Gal

Price Indexes

a - U. S Bureau of Labor Statistics - Index for Residential Water and Sewerage Services

b - U. S. Bureau of Labor Statistics - Index for Residential Electric Power

Water and sewage rates for 25,000 population are based on published surveys of U. S. residential rates (Refs. 15, 16). The water rates for a 100-home system is based on a survey by the Farmers Home Administration on small rural water systems (Ref. 17). Energy cost was based on the average U. S. residential electric cost as determined by the Edison Electric Institutue (Ref. 18).

Worst case sewage cost was based on a packaged treatment plant located in a remote location having a low populated density using extended aeration and treating to a tertiary level of 95-98% BOD removal. Sludge disposal and maintenance were based on either private contractor or regional government servicing (see Appendix C).

Softening costs for the worst case were based on use of individual home units treating a hardness of 500 ppm ($CaCO_3$). This level is based on the maximum found in a major U. S. water supply source (Ref. 19).

The purchase and installation costs of the baseline system hardware are listed in Appendix E. Purchase costs were taken from equipment catalogs and direct vendor quotes. Installation costs were derived from a standard cost manual (Ref. 20) based on like or similar hardware.

2.3.4 COST COMPARISON

Table 2-5 summarizes the water, sewage, and electric power reductions which result from the reduced water and wastewater demands, as well as from the reduced hot water heater electricity demand.

Offsetting these savings, however, are the capital and operating costs of the baseline system components. These are detailed in Appendix E and summarized in Table 2-6. These costs represent the increase in costs over the conventional plumbing system which would be incurred in building a new house incorporating the baseline concept.

Table 2-5. Baseline System Cost Savings

	Typical Case			
	Quantity Saved	Unit Cost	Daily $ Savings	Annual $ Savings
Water Supply	156.5 gal/day	0.75/1000 Gal	0.117	43
Waste Treatment	156.5 gal/day	0.44/1000 Gal	0.069	25
Water Heating	6.8 kwh/day	0.022 /kwh	0.150	55
			Total	123
	Worst Case			
Water Supply	156.5 gal/day	5.53/1000 Gal	0.865	310
Waste Treatment	156.5 gal/day	2.67/1000 Gal	0.417	152
Water Heating	6.8 kwh/day	0.022 /kwh	0.150	55
			Total	523

Table 2-6. Baseline System Costs

Capital:		
Material	$ 842	
Installation	469	
	1311	
Amortization Factor	.0846*	
Amortization Cost	$ 111/yr	
Operating		
Filter replacements	$ 4/yr	
Chlorine tablets	20/yr	
Maintenance (3% of capital)	$ 40/yr	
	$ 64/yr	
Total Annual Cost		$ 175/yr

*Amortization factor at 7.5% interest for 30 years

Subtracting the $175/yr. cost of the baseline system from the $123/yr. benefit in the typical case, shows a net loss of $52/yr. However, in the worst case where water and waste treatment are significantly more expensive, the baseline system produces benefits totaling $523/yr. After subtracting the annual cost of the system this leaves $348/yr. net saving for the home owner. While the dollar magnitude of this savings may not appear significant, this cash flow when summed and discounted over the 30-year life of the house has a present worth of approximately $4500.

2.3.5 COST PROJECTIONS

Since it could be many years before the baseline system would be implemented, it is possible that the relative attractiveness of the baseline system and conventional system could change due to a differential shift in the price of the major cost components.

To obtain a feel for what these price shifts might do to the attractiveness of the baseline system, each of the major cost parameters has been projected out to the year 2000 based on the average annual price increase of each parameter during the last ten years. Table 2-7 shows these projections and the source of the price indexes used to make them.

Recalculating the cost comparison using the year 2000 prices, we find in the typical case, the annual loss from using the baseline is increased from $52/yr. to $101/yr. However, in the worst case where the benefits are weighted more towards the more rapidly growing costs of water and waste treatment, the net annual savings are increased from $348/yr. to $1,697/yr. Therefore, the baseline system will become even more attractive in the next 28 years in those locations approaching the worst case situation.

Table 2-7. Cost Parameter Projection

Parameter	Index	62 - 72 Annual Growth	1972 Price	2000 Projected Price
Water and wastewater service - typical case	a	4.8%	$1.19/KG	$4.40/KG
Water and wastewater service - worst case	a	4.8%	$6.43/KG	$23.80/KG
Baseline hardware cost	b	3.0%	$1,312	$3,018
Baseline operation cost	c	4.0%	$64/yr	$192/yr.
Electric power	d	1.5%	$0.022/kwh	$0.033/kwh

Indexes

a Bureau of Labor Statistics - Index for Residential Water and Sewage Services

b Marshall & Swift Equipment Cost Index

c Bureau of Labor Statistics - Consumer Price Index

d Bureau of Labor Statistics - Index for Residential Electric Services

2.3.6 ANALYSIS AND CONCLUSIONS

In a typical situation, the baseline household water reduction system cannot be justified on the basis of its cost savings. At the average U.S. water rate of approximately $0.75/KG, the typical homeowner is paying only $70/yr. for the household's water or $0.18/ton. Waste treatment adds only $0.44/KG.

A water conservation system would clearly save money in the worst case. But, only two utilities in a recent survey of 1,100 U.S. utilities serving over 1,000 population (Ref. 21) had water rates in excess of the $3.76/KG worst case value. These two were the Grand Canyon, Arizona and Nome, Alaska. The Virgin Islands had a comparatively mild $2.00/KG and Galveston, Texas had a very average rate of $0.78/KG. The worst case is quite atypical.

While a survey of small rural water supplies by FHA (Ref. 17) was used as the basis of the worst case water rate, the survey also revealed that the typical household in these areas used only 130 gal/day, compared to the 255 gal/day volume of the typical house. This suggests that people may not place a very high value on much of their current water use, and may be willing and able to reduce it significantly when faced with the alternative of paying several hundred dollars per year additional cost.

Between the typical case and the worst case, lie a large number of possible locations where the baseline system water savings would be moderately attractive. These include isolated homes and small communities located in areas such as the Appalachian Mountains or desert sections of the Southwest where relatively affluent families would have both the desire and ability to pay for abundant water usage in the face of natural scarcity.

While the cost comparisons to date center on individual new homes, it is reasonable to extrapolate the single home's saving to that of a planned unit development incorporating a water conservation system in each unit.

Such an extrapolation has short-comings; for example, if each home reduces its water demand by 50%, the size of the community's water treatment plant must be scaled down accordingly. In doing so, economies of scale will be lost and the unit price of water increased. To establish the savings of the baseline system in such a situation would require a knowledge of not the average cost of water, but of the marginal cost of increment of supply eliminated. Unfortunately, the determination of this cost is beyond the scope of this analysis to estimate.

Another consideration which arises from the possibility of large scale implementation of household water reduction systems is the impact on a region's water resource from reduced household water demand. In most regions of the U. S., household water use constitutes only a small fraction of the total water demand. For example, a recent study (Ref. 22) by the National Water Commission estimated that only 3% of the total U. S. water withdrawals in 1970 were for residential use. The study also reported that over 50% of this residential usage in single family dwellings was for lawn watering. Projection of demands to 2020 by the National Water Commission showed that residential demand will not grow as rapidly as other segments of the demand. Therefore, a reduction in household water use should not have a significant impact on most regions' water source picture through the year 2000.

SECTION 3
ADVANCED WASTEWATER TREATMENT SYSTEMS

3.1 INTRODUCTION - WASTEWATER TREATMENT

An understanding of the processes and potential for advanced treatment requires, first, an appreciation of the present technology of primary and secondary wastewater treatment processes, and, second, of the types of pollutants which can be removed only by advanced treatment.

Primary treatment consists of plain sedimentation for the removal of about 90 percent of the settleable solids from raw sewage. From 40 to 70 percent of the suspended solids are also removed.

Secondary treatment processes reduce the amount of organic matter in sewage through bacterial action, oxidation and synthesis. The most common methods are the trickling filter and the activated sludge processes. These processes, following primary treatment, typically remove 90 percent of suspended solids, 90 percent of biodegradable organics, 60 percent of non-biodegradable organics, 50 percent of nitrogen, 30 percent of phosphorous, and over 99 percent of pathogenic bacteria and viruses.

After secondary treatment, the following impurities usually remain in the effluent:

1. Suspended and colloidal solids.
2. Refractory organic matter that is resistant to biological treatment, such as pesticides, and the products of bacterial metabolism.
3. Plant nutrients, principally phosphorous and nitrogen compounds.
4. Dissolved mineral matter, such as sodium chloride and other mineral salts, all of which are present in an original water supply, but are usually increased by use.
5. Bacteria and viruses, some of them pathogenic.

There has been no process yet devised which is able to remove all contaminants economically in a single step. Several desalting processes remove all pollutants except some of the pathogenic organisms, but these processes are not promising economically for wastewater treatment.

Recent experimental work has indicated the possibility of new approaches in which the advanced treatment process incorporates or replaces the secondary treatment process. Although the technology has been developed and seems ready for full scale operation, it has not yet been incorporated in a full scale plant.

3.2 CONVENTIONAL WASTEWATER TREATMENT PROCESSES

In order to comprehend various treatment system terms and economic impacts, Tables 3-1 to 3-3 are presented. Table 3-1 describes the several treatment process types and their effect on wastes. Table 3-2 presents the average percentage removals attainable by some typical primary-secondary and tertiary treatment methods for the common sewage parameters. Note that both nitrogenous compounds and dissolved minerals, though markedly affected by tertiary treatment processing, still result in high residual levels in the treated wastewater. Table 3-3 presents basic costs for each stage of treatment additively. It should be pointed out that the disinfection process (usually chlorination) is the last treatment function and can follow any of the treatment processes shown if that one were the last process of that plant. The carbon absorption and electrodialysis segments are tertiary treatment functions that cost more than the other treatment processes combined (without brine removal). These economic impacts are typical of most tertiary treatment. Economic factors will be presented in a later section, and are only mentioned here to indicate relative complexity to field a tertiary system.

3.3 ADVANCED WASTEWATER TREATMENT SYSTEM CONSIDERATIONS

Pre-requisite to synthesizing a wastewater treatment-water recovery system is the need to assess current technology status of the latest experimental unit processes capable of integration

Table 3-1. Typical Application Data for Advanced Wastewater Treatment Operations and Processes

Description	Type of wastewater treated*	Removal efficiency, %								Waste for ultimate disposal
		SS	BOD	COD	NH_3	Org N	NO_3	PO_4	TDS	
Physical unit operations										
Air stripping of ammonia	EBT				85–98					None
Filtration										
Multimedium	EBT	80–90	50–70	40–60		20–40				Liquid and sludge
Diatomite bed	EBT	95–99								Sludge
Microstrainers	EBT	50–80	40–70	30–60		20–40				Sludge
Distillation	EBT nitrified + filtration	~99	98–99	95–98		90–98	~99	~99	95–99	Liquid
Flotation	EPT, EBT	60–80				20–30				Sludge
Foam fractionation	EBT	75–90	~70	60–70						Liquid
Freezing	EBT + filtration	95–98	95–99	90–99		90–99	~99	~99	95–99	Liquid
Gas-phase separation	EBT				50–70					None
Land application	EPT, EBT	95–98	90–95	80–90	60–80	80–95	5–15	60–90		None
Reverse osmosis	EBT + filtration	95 98	95–99	90–95	95–99	95–99	95–99	95–99	95–99	Liquid
Sorption	EBT		~50	~40				~99	~10	Liquid and sludge
Chemical unit processes										
Carbon adsorption	EPT, EBT	80–90	70–90	60–75		50–90				Liquid
Chemical precipitation	EBT	60–80	75–90	60–70	5–15	30–50		90–95	~20	Sludge
Chemical precipitation in activated sludge	EPT	80 95	90–95	85–90	30–40	30–40	30–40	30–40	~10	Sludge
Ion exchange	EBT + filtration		40–60	30–50	85–98	80–95	80–90	85–98	†	Liquid
Electrochemical treatment	Raw	80–90	50–60	40–50	80–85	80–85		80–85		Liquid and sludge
Electrodialysis	EBT + filtration + carbon adsorption				30–50		30–50	30–50	~40	Liquid
Oxidation (chlorine)	EBT		80–90	65–70	50–80					None
Reduction	EBT						$NO_3 \rightarrow NH_3$			None
Biological unit processes										
Bacterial assimilation	EPT	80–95	75–95	60–80	30–40	30–40	30–40	10–20		Sludge
Denitrification	Agricultural return water						60–95			None
Harvesting of algae	EBT		50–75	40–60	50–90	50–90	50–90	~50		Algae
Nitrification denitrification	EPT, EBT						60–95			None

* EPT is effluent from preliminary treatment and EBT is effluent from biological treatment
† Varies with type of resin

Table 3-2. Nominal Removal Capability of Several Primary-Secondary-Tertiary Treatment Systems

(Percent removal based on raw waste concentrations)

Parameter	Removal (%)			
	Primary - Secondary		Tertiary	
	Foam Separation	Coagulation-Sedimentation	Granular Activated Carbon Adsorption	Electrodialysis
BOD	93	93	99	99
Total organics	83	85	99	99
Suspended solids	92	99	99	99
"Hard" detergents	85	55	95	98
Total phosphates	30	95	95	97
Total nitrogen	50	50	55	75
Dissolved minerals	5	10	15	50

Table 3-3. Reuse Applications and Costs for Example Water Renovation System

Treatment Sequence	Estimated Cumulative Capital Cost		Estimated Cumulative Operating Cost		Reuse Applications
	300 kgd (K$)	50 kgd (K$)	300 kgd (¢/1,000 gal)	50 kgd (¢/1,000 gal)	
Raw Wastewater	0	0	0	0	None - highly polluting.
↓ Primary Treatment	120.0	27.5	11.5	17.0	Partial pollution control - no direct reuse possible.
↓ Secondary Treatment	230.0	50.0	20.0	27.0	Conventional pollution control; non-food crop irrigation.
↓ Coagulation-Sedimentation	400.0	110.0	23.0	30.0	Improved pollution control, general irrigation supply, low quality industrial supply, recreational water supply, short-term water recharge.
↓ Carbon Adsorption	700.0	220.9	51.0	80.0	Complete organic pollution control, high quality irrigation supply, good quality industrial supply; body-contact recreational supply, long-term groundwater recharge.
↓ Electrodialysis	900.0	260.0	85.0	133.0	Complete organic-inorganic pollution control, high quality industrial supply, indefinite groundwater recharge.
Brine Disposal	4000.0	1700.0	169.0	326.0	
↓ Disinfection	4000.0	1700.0	170.0	327.0	Absolute pollution control, potable water supply
↓ Renovated Water					

Extrapolated from Ref. 39

Table 3-4. Summary of Advanced Wastewater Treatment Processes (Ref. 39)

Process		Scale (GPD)	Status
1.	Adsorption		
1.1	Granular Activated Carbon	14K to 0.5M	Pilot and demonstration
1.2	Fluidized Carbon Beds	7K	Pilot
1.3	Powdered Activated Carbon	15K	Pilot
1.4	Coal	15	Bench scale studies (R&D)
	Ammonia Stripping	100K to 200K	Pilot
	Coagulation		
	Inorganic	7K to 5M	Operational
	Organic	50K to 200M	Operational
	Disinfection		
	Distillation	1000	Pilot
	Electrodialysis	Laboratory studies	R&D
	Filtration		
	Diatomaceous Earth	4K to 250K	Pilot
	Rapid sand and Multimedia	5K to 100K	Pilot
	Flocculation		
	Magnetic		
	Ion Exchange	3K to 15K	Pilot
	Ion Exchange - Organic Removal	Bench-scale	
	Oxidation		
	Catalytic autooxidation	Laboratory studies	R&D
	Light catalyzed chlorine	Laboratory studies	R&D
	Ozonation	240 M	
	Nitrogen Removal		
	Phosphate Removal		
	Mineral Addition	100-1M	Pilot completed
	Reverse Osmosis	3K to 10K	Pilot
DISPOSAL			
	Adsorbate Incineration (carbon regeneration)	300K to 7.5M	Operational
	By-product Recovery	Analysis	R&D
	Coagulant Regeneration		Pilot
	Incineration		
	Wet Oxidation		Operational
	Sludge Conditioning		
	Centrifugation		Pilot
	Filtration		Pilot
	Hydrolysis	Analysis	R&D

to a higher ordered concept. This survey is presented in Table 3-4. Conspicuously absent from this survey are processes involving biological interactions. The following excerpt (from Ref 29) and discussion explain this:

> "It has become apparent over the past several years that achievement of high levels of water quality demanded by progressive water use and reuse requirements, and by requirements for more effective water pollution control, necessitates expanded utilization of advanced technologies for wastewater treatment. Conventional "secondary" biological treatment processes do not provide a completely satisfactory measure for protecting natural waters from pollution by waste discharges.
>
> Well operated modern biological waste treatment plants can provide approximately 90-percent removal of suspended solids and biochemical oxygen demand (BOD). Although the quality of the effluent from such plants has been adequate to meet most discharge regulations and standards in the past, recent increases in both population and in standard of living have resulted, in the face of a relatively fixed total water resource, in more stringent demands, for better water quality and more effective pollution control.
>
> As a result, significant interest has focused over the past decade or so on development of physicochemical processes capable of accomplishing the degree of treatment required by more stringent effluent standards.
>
> However, common philosophy regarding application of advanced physicochemical processes for wastewater treatment generally has centered on providing "tertiary" treatment for wastes which already have undergone conventional "secondary" biological treatment. The addition of tertiary-level physicochemical processes incurs significant additional treatment expenses. Further, the effective operation of a tertiary treatment system depends on consistent and efficient operation of the biological secondary process which remains subject to problems arising from changes in waste composition, from large variations in flow which often have to be diverted, and from the presence of toxic materials which disrupt biological oxidation processes."

The biological treatment process dates back to when septic tanks and cesspools were incepted. The evoluation of sanitary waste treatment advanced the basic principles to the present high capacity (> 100 MGD) plants that serve most minicipalities. Most of these plants were built early in this century and located remotely from the basic urban population on land having no appreciable value. Large primary settling basins and sludge lagoons characterized the basic plant construction. The biological process represents the least expensive operating system since the natural bacterial action provides most of the "treatment" of the wastewaters by parasitically feeding on the organic constituents of the liquids and suspended solids. Settled solids are accumulated and stored to form a concentrated sludge which is subsequently carted away for landfills. During the sludge storage period, anaerobic bacterial colonies form and "digest" the remaining organics producing methane as a byproduct. Many disposal plants capitalize on this using the gas for an energy source to heat, incinerate and/ or control related thermal (combustion/ incineration) processes.

The efficiency of the bacterial reaction is adversely affected by detergents, chlorinated compounds and other chemical products which have come to form home generated sewage. Coupled to this, where combined stormwater and sanitary sewers are installed, stormwater overflow (into these treatment plants) overloads the plant holding capacity and provides high dilution of the process wastewaters, thereby, further reducing the growth of needed active biological colonies.

In large capacity installations the net impact of these chemically strong/ biologically toxic wastes is minimized due to the "averaging" of these wastes with the normal sanitary wastes. Small systems cannot fully realize the benefit of this averaging phenomenon and are severely affected by the intrusion of toxic wastes and flow variations (Ref. 29).

Typical variability found in smaller capacity sewage services are:

1. Toxic materials in the waste
2. Extreme diurnal flow and load variation
3. Requirements for nutrient removal
4. Requirements for rapid start-stop operation

Biological treatment processing does not permit this type of operational performance. The General Electric Company, in embarking on producing a marine waste treatment system quickly ruled out biological systems after reviewing the same operating characteristics except as generated by a ship's crew.

3.4 ADVANCED WASTEWATER TREATMENT FUNCTIONS

In synthesizing any treatment concept, there are basic sewage process parameters to be considered in the development phase. Referring to Table 1-3 and 1-4 the following conventional wastewater composition forms the basis of treatment:

Parameters	Average Value (mg/ℓ)
BOD	229
Total Solids	776
Organic Solids	534
Suspended	(235)
Dissolved	(299)
Inorganic Solids	181
Suspended	(18)
Dissolved	(163)

With approximately 60% of the BOD included in the suspended solids, the remaining 40% are comprised of dissolved matter (organic and chemical). The average content of the mineral (chemical) portion is shown in Figure 3-1. The successful treatment of these wastewater characteristics have been divided into five essential functions for clarity in the study and its presentation. As will be pointed out, where appropriate, there are inter-functional relationships that sometimes serve to link two or more treatment functions by virtue of the operating characteristics of a unit process. These functions and their order of description are:

1. Solids removal (Appendix G)
2. Organic removal (Appendix H)
3. Nutrient removal (Appendix I)
4. Inorganic removal (for reuse) (Appendix J)
5. Disinfection (Appendix K)

Average Components in Domestic Sewage Effluents

Constituent	Approx Build-Up Through One Municipal Use	Normal Range of Build-Up	Representative Secondary Effluent
Ca ($CaCO_3$)	30 ppm	15 - 40	95
Mg ($CaCO_3$)	13	20 - 40	39
Na	55	40 - 700	84
SO_4	25	10 - 40	51
CL	35	20 - 125	50
PO_4	30	15 - 40	30
NO_3	8	0 - 18	8
SiO_2	15	10 - 20	35
ABS	3	1 - 4	3
COD	70	40 - 40	70
BOD	15	9 - 40	15
TDS	250	100 - 500	550
HCO_3	65	-	170
p^H	-	-	7.5

Figure 3-1. Mineral Content of Wastewater

In its elemental form, the waste treatment train should provide capability to accomplish each of these functions. As mentioned above, a unit process can overlap and include several of these steps. An example is chemical precipitation of phosphorus (as phosphate ion), for neutrient removal. The addition of lime (or alum) to a wastewater, not only removes phosphorus (in the sludge), but because the chemical is both a flocculating agent and hydrolyzer, it catalyzes suspended solids to agglomerate for removal by filtration-separation equipment and produces an easily dewatered sludge by liberating bound interstitial waters between solids in the sludge.

The degree of effluent treatment is specified to be compatible with its final disposition, i.e., reuse, recycling, discharge. These standards establish the specific process parameters including chemical additions, point of application, by-product recovery potential and other process unique features influencing performance and operating economics.

3.4.1 SUSPENDED AND COLLOIDAL SOLIDS REMOVAL

The residual suspended and colloidal solids that remain after secondary treatment can be removed by any of several filtration methods, at the relatively low costs of 1 cent to 2 cents per 1000 gallons. It would also remove non-soluble biodegradable organic impurities. These are mostly poorly or non-flocculated bacterial cells, debris from dead cells, and extra-cellular insoluble products of bacterial metabolism. Suspended solids comprise only 20-30 percent of the total organic matter in secondary effluent, but account for most of the biodegradable organic matter present. For example, in one experimental study, removal of 80 percent of the suspended solids resulted in the removal of 81 percent of biodegradable and 30 percent of total organic materials, (Ref. 33). Further, design considerations that are prevalent at the time of construction of secondary treatment cause wide variations in quality of their effluents.

3.4.2 REFRACTORY ORGANIC MATTER REMOVAL

Nonbiodegradable (refractory) organic matter can be reduced to the very low concentrations present in natural water supplies by adsorption by activated carbon. This includes all organic material in solution which resists biological treatment. Most substances in this group have remained unidentified, but such materials as ABS detergents, pesticides, some organic compounds (products of bacterial metabolism), tannins, lignins, and other color imparting substances have been found. Generally, these are high molecular weight compounds. Estimation of concentrations are difficult to make and have not often been reported because of the lack of identification of the substances and the lack of standard measurement techniques that can give unequivocal and reproducible results (Ref. 33). Secondary effluent contains an average concentration of 50 ppm of nondegradable organic matter (Ref. 36).

3.4.3 PLANT NUTRIENT REMOVAL

The principal plant nutrients in secondary effluent (phosphate, nitrate, and ammonia) may induce algae and plant growth. Upon death, the algal cells become food for the bacteria which consume the oxygen dissolved in the water and so may produce septic conditions. The nutrients can be reduced by chemical processes to concentrations that will prevent growth stimulation. Any residual suspended solids are removed at the same time.

These nutrients include inorganic phosphorous and nitrogen compounds. Phosphorous occurs in secondary effluent mainly as the phosphate ion ($PO_4^{\equiv}$). About half of it is introduced into wastewater as a constituent of detergents and other cleaning aids, but some appears as a product of the degradation of organic wastes. Nitrogen occurs as ammonia (NH_3) (or ammonium ion (NH_4^+), nitrate ion (NO_3^-), and nitrite ion (NO_2^-). Their concentrations average about 20, 15, and less than 1 ppm, respectively. Nitrogen is a constituent of organic waste matter and is released in the form of ammonia or ammonium ion upon degradation of the waste. Some of the ammonia is then oxidized and produces nitrite and nitrate ions. A small amount of soluble organic nitrogen may remain in secondary effluent as a result of incomplete degradation.

3.4.4 INORGANIC SUBSTANCES (DISSOLVED MINERALS) REMOVAL

Dissolved mineral concentrations may be reduced from about 850 ppm to the Public Health Service drinking water standards of 500 ppm by electrodialysis, for an additional cost that is in the order of 12 cents per 1000 gallons. Other methods also are available, but at higher cost. Present technology limits this process to a plant size of 10 mgd.

Dissolved mineral matter in sewage are not removed in conventional treatment plants. Usually, about half of the total mineral content originates in municipal water supplies; the remainder is added during use. Minerals occur in solution as ions. Although mineral content of water varies throughout the country, major ionic constituents in secondary effluent average about as follows: sodium (Na^+), 135 ppm; potassium (K^+), 15 ppm; calcium (Ca^{++}), 60 ppm; magnesium (Mg^{++}), 25 ppm; chloride (Cl^-), 130 ppm; bicarbonate (HCO_3^-), 300 ppm; sulfate ($SO_4^=$), 100 ppm; silicate ($SiO_3^=$), 50 ppm (Ref. 37).

These total about 815 ppm. Ammonium, nitrate, and phosphate ions, although classified as nutrients, are actually inorganic substances. If these are included, the total mineral content averages about 875 ppm. In addition to the ions listed, smaller quantities of such ions as ferric iron (Fe^{+++}), copper (Cu^{++}), and zinc (Zn^{++}) occur.

3.4.5 DISINFECTION

Disinfection is usually the means of final purification of liquid waste water following a combination of previous treatment processes. The concern about microbial water quality and low level water transmission of human pathogens (bacteria and viruses) is based upon a presumed inability of water treatment practices to eliminate these pathogenic organisms. In 1969, a task group of the American Water Works Association stated flatly, "There is no doubt that water can be treated so that it is always free from infectious microorganisms. Adequate treatment means clarification (coagulation, sedimentation, and filtration) followed by effective disinfection."

It has been found that under certain circumstances, infectious microorganisms can be transmitted by treated water, but when looked at in depth, the treatments in such cases were inadequate.

Wastewater treatment presents problems not experienced in the treatment of drinking water. Raw sewage entering a waste treatment plant carries large numbers of enteric viruses in addition to bacteria (including coliforms) throughout the year. Primary treatment is generally ineffective in removing bacteria and enteric viruses. Secondary treatment removes most but not all of the organisms of interest.

There is considerable difference of scientific opinion as to the degree of health hazard that remains after the treatment processes are completed. The concensus is one of extreme caution with most scientists agreeing that it has not yet been proven that a health hazard does not exist. However, health officials have expressed the opinion that the probability of bacterial hazard is nil and that the probability of a biological hazard is very low. The concern is based on reports like Sproul <u>et al.</u> (Ref. 38) who have shown that after treatment and chlorination seven virus particles out of some initial 7,000 survived and the claim that these represent a hazard.

A final effective disinfection therefore is required to render all pathogenic microorganisms inactive. Chlorination, surrounded by precautions of ample free residual chlorine with adequate retention time, proper temperature, pH, and clarity of waste water can be relied upon to inactivate pathogenic bacteria and viruses. The relative cost is less than one cent per 1,000 gallons of water treated.

3.5 SUMMARY

There are still problems to overcome before wastewater reclamation, at least for domestic reuse, can become an everyday occurrence. First, the reliability of treatment processes must be improved, and along with this, the rapidity with which analysis of various pollutants can be made must be increased. Until these improvements are possible, it will probably be necessary to impound reclaimed water in reservoirs prior to release to raw water intake at potable water treatment plants.

In the main, the quality of treatment is a function of process reliability and instrumentation. That is, treatment system integrity is a function of unit process capability to continuously perform its designed function and the ability to measure it. The current state-of-the-art in designing treatment systems assumes a nominal throughput and wastewater strength (from pilot studies and sampling studies), and multiplies each by a "peak" factor to size and design the networks and process envelope.

Present bacteriological and virological testing techniques are extremely limited and in need of improvement. Even though extensive virological testing at both Tahoe and Windhoek have indicated no passage of viable virus through the treatment system, it is not certain that passage does not occur due to the difficulty of culturing a great majority of the known viral organisms.

The progressive build-up of dissolved solids is another potential problem in water reclamation. Fortunately, this is a problem which can be solved by current technology, albeit at considerable cost, by such techniques as distillation, ion exchange, reverse osmosis and dialysis. Also, fortunately, the build-up of dissolved solids in most cases is not great due to the natural "blow-down" of dissolved solids from conventional U.S. water systems because of our prevailing rather high consumptive water use practices. The equilibrium concentration of dissolved solids that can be anticipated in any given recycling water system can be rather easily computed for any given moment if proper records are available.

Finally, there must be a cognizance of public reaction to water reuse. The general public will not welcome the idea of drinking their own wastes. Experience has shown that the only way to overcome this rather natural reaction is by means of public education. The establishment of recreational reservoirs such as Indian Creek at the Tahoe project and the Santee Lakes at the Santee project have helped the cause immeasurably. Such reservoirs may well be a vital key to public acceptance of wastewater reclamation; they may also be required unless or until better testing techniques are available to insure an absolute guarantee of safety for domestic reuse.

SECTION 4
SYSTEM SELECTION AND DESIGN

4.1 INTRODUCTION

This section describes the water treatment processes and developes the operating design criteria for a wastewater treatment system for a community of 500 dwelling units using the baseline system developed in the foregoing sections. Determination of the number of dwelling units is based upon the findings in the report titled: "Developing New Communities," prepared for the U.S. Department of Housing and Urban Development by David A. Crane, Architect and Keyes, Lethbridge and Condon, Architects, Associated Architects and Planners for the Fort Lincoln New Town (Reference 72).

This report, a study of the application of technology innovations to the development of new communities, indicates that, for the majority of prefabricated building systems investigated, the minimum number of dwelling units required/year to amortize construction equipment and sustain economical plant operation is approximately 500. This relatively small number of dwellings presents a challenge to the water/waste treatment system designer due to the minimal effect of averaging of the flow wastes compared to large systems.

4.2 OPERATING DESIGN CRITERIA

The studies conducted in the first segment of this program, derived a household water use reduction scheme that resulted in a characteristic hydrograph of wastewater generation (Figure 2-3) and an estimate of the wastewater composition. These were applicable to the "typical" home without the water use reduction scheme (baseline concept) impacts (Figures 1-3 and 1-4). To be consistent with the objectives of the program, these same efforts have been applied to the household containing the baseline concept (Figure 2-1).

4.2.1 BASELINE CONCEPT HYDROGRAPH

The daily amounts of wastewater generated by each dwelling unit function are:

Function (or source)	Quantity (gallons)	
1. Toileting	60	
2. Utility sink	5	
3. Kitchen sink	12	Fixed
4. Dishwasher	3	+ (18.5)(1)
5. Clotheswasher	(18.5)	
6. Lavatory	(18.5)	
7. Shower-bath	(18.5)	

(1) Indicates Combined Overflow into Sewer

Adding item 1 to the combined overflow and dividing by 4 (the typical number of dwelling unit occupants) the general expression for the treatment system wastewater daily flow becomes becomes:

19.6 (served population) + 20 (number of dwelling units)

The household wastewater hydrograph derived earlier in the program has been statistically averaged and scaled to approximate a community water demand profile for the baseline system (Ref. 48). The resulting curve is shown in Figure 4-1 for 500 units and 2000 people.

4.2.2 CAPACITY

The following factors apply to sizing the processing train hydraulically:

1. Assume 80% of total wastewater quantities are generated during normal waking hours (16 hours - 6 a.m. to 10 p.m.)

2. Peak flow ~ 300% of nominal 16 hour average (Figure 1-4)

3. Daily nominal flow ~ 100 GPD (from Section 2)

$$\text{Nominal Capacity (GPM)} = \frac{80\% \times \text{GPD}}{960}$$

$$= 8.3 \times 10^{-4} \times \text{GPD}$$

$$\text{Peak Flow (GPM)} = 300\% \times \text{Nominal Capacity}$$

$$= 2.5 \times 10^{-3} \times \text{GPD}$$

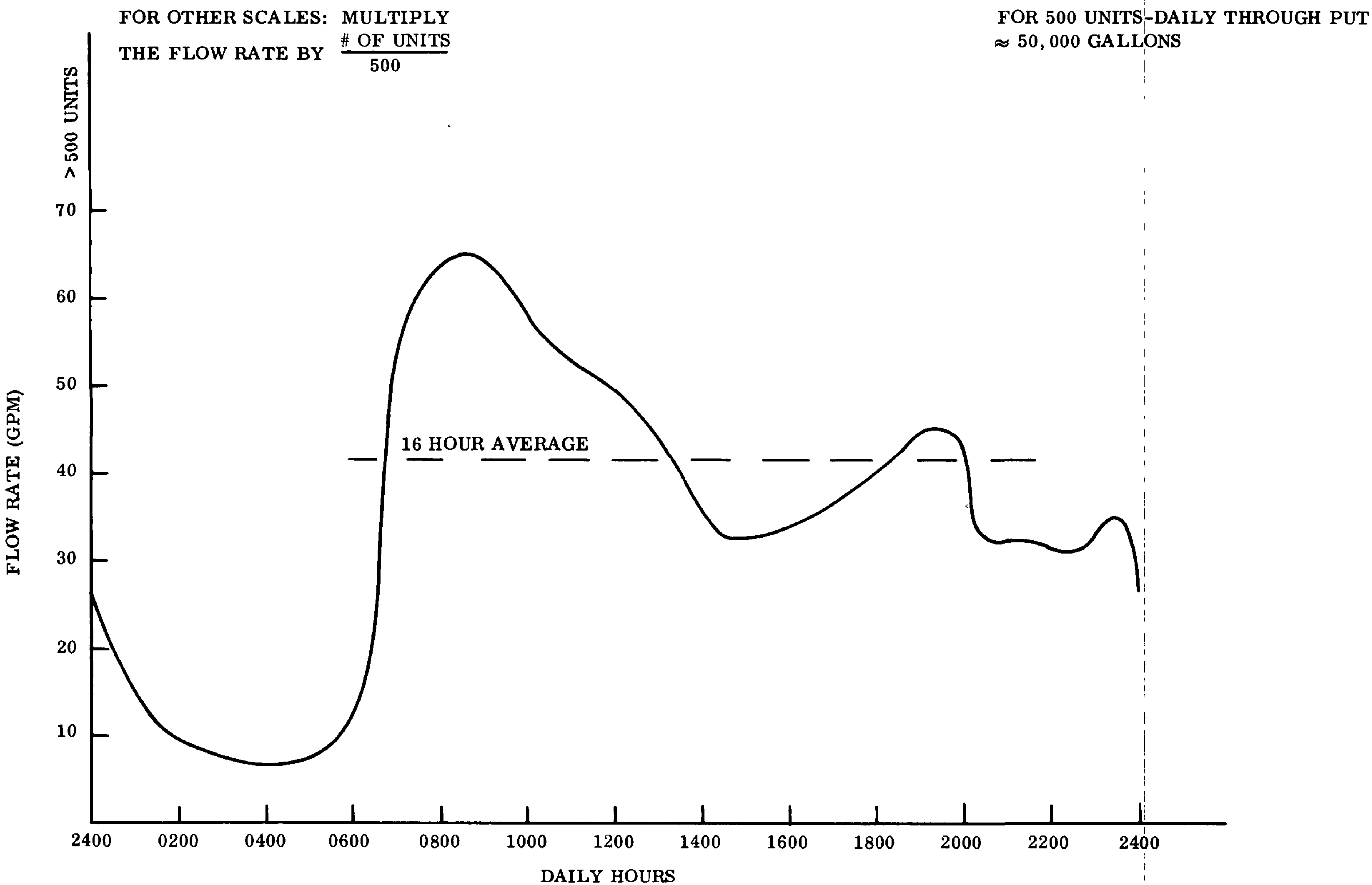


Figure 4-1. Hydrograph of Community Wastewater

Applying these equations to a number of cases results in the following influent values:

Number of Dwellings	Daily Flow (GPD)	Peak Flow (16 Hour Period - GPM)	Nominal Flow (16 Hour Period - GPM)
10	1,000	2.5	0.83
100	10,000	25.0	8.3
500	50,000	125.0	41.6

As shown on the hydrograph, the period of widest variation is from approximately midnight to 2 p.m. with the high flow period comprising about 6 hours during this period. Summing the average inflow for this six hour period, the system must either process or store about 5300 gallons above the 16 hour average processing rate. The peak flow duration is one hour and therefore contributes a maximum added volume of (125-65 GPM) x 60 MIN or 3300 gallons. Therefore, the worst case peak flow loading if superimposed on the high flow curve will require storing or processing 8600 gallons over the six hour period (~25 gpm above average).

4.2.3 WASTEWATER COMPOSITION

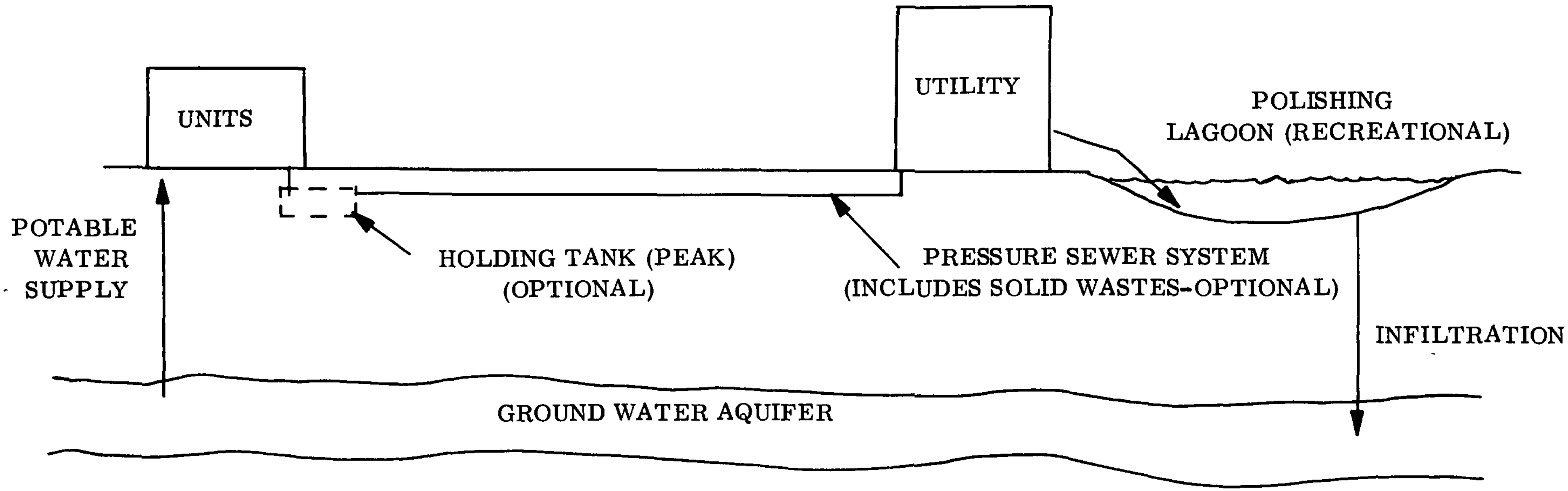
The wastewater emanating from the "typical" household was presented in Section 1. The typical home with the baseline concept included in its water use network will concentrate the wastes in accordance with the reuse functions of the recycled wastewaters. These differences are presented in Table 4-1. Combining these factors results in the wastewater characteristics shown in Table 4-2, and defines the treatment plant process requirements for discharging a product water capable of meeting drinking water standards.

An overall systematic approach to the handling, treatment and return of the wastewater for use can be depicted as shown in Figure 4-2. There are several areas of water related waste management where innovations are technically feasible. These include slurry transport of paper and other combustible solid wastes along with sewage, using pressurized flow, for later separation and combustion in a combined sludge-solid waste incinerator.

Table 4-1. Characterization of Baseline Concept Wastewaters by Function

		A Toileting[1]	B Utility Sink	C Kitchen Sink	D Dishwasher	E Flush Water Tank
Quantity (gpd)		60 (3 gal/flush)	5	12	3	18.5
BOD (mg/1)[3]		348	200	506	324	146[2]
COD (mg/1)		1260	400	662	662	307[2]
SS (mg/1)	Organic	453	100	627	235	8
	Inorganic	83	250		18	4
DS (mg/1)	Organic	240	400	630	299	410
	Inorganic	162	600		163	712
Total P (mg/1)		28	50	6.5	6.5	70
Kjeldahl N (mg/1)		192	15	11.4	11.4	15
Total Plate Conut - 35^oC (MPN/ml)		1097×10^6	--	800×10^6	--	1.1×10^6
Coliform - 35^oC (MPN/ml)		85×10^6	--	301×10^6	--	6.9×10^4
Reference		Sect 1 Pg. 1-25	Assumed	Sect 1 Pg. 1-25	Sect 1 Pg. 1-24	Derived from Data on Baseline Reuse

(1) Assuming fresh water flush; for recycle flush add A & E
(2) Assumes 20% reduction due to chlorine suppression from appliance wastewater inflow to tank
(3) mg/1 = PPM



OPTIONS

- DUAL WATER SYSTEM - TREATED WASTEWATER @ 80 GPD/UNIT
  POTABLE WATER @20 GPD/UNIT
- WATER TREATMENT - (NO AQUIFER) W/WO DUAL WATER SYSTEM
- CONVENTIONAL GRAVITY SEWAGE
- HYBRID SEWER SYSTEM - CONVENTIONAL/ PRESSURE SEWERS W/WO SOLID WASTES
- COMPLETE TREATMENT (NO LAGOON)
- IN-PIPELINE TREATMENT - FLOC AID, DISINFECT/DEODORIZE

Figure 4-2. Operational System Modes

Table 4-2. Total Baseline Concept Wastewater Characteristics*

Quantity (gpd)		98.5
BOD (mg/1)		408
COD (mg/1)		1133
SS (mg/1)	Organic	333
	Inorganic	105
DS (mg/1)	Organic	541
	Inorganic	740
Total P		76
Kjeldahl N		131
Total Plate Count - 35^{o}C (MPN/ml)		767×10^{6}
Coliform - 35^{o}C (MPN/ml)		88×10^{6}

*Assuming recycle flush

This would limit household solid wastes to cans and bottles (easily compressed by commercial trash compactors) for less frequent street collections and more efficient garbage collector packing density. In-pipeline treatment utilizes the sewer piping and flows to initiate any or several time-oriented treatment processes before the wastes arrive at the plant proper. Preliminary time estimates are shown in Figure 4-3. The resulting times do lend to some pretreatment functions such as flocculating. A dual water system can optimize the treated waters according to the projected use (consumptive/non-comsumptive). A review of household water uses shows that about 20% of water uses involve possible consumptive purity (see Paragraph 1.2, Fixed Water Uses). Further study of these water-related interactions should be pursued to ferret out any operating efficiencies gained in an integrated water supply-waste treatment utility.

4.3 ADVANCED WASTEWATER TREATMENT SYSTEMS

Some possible treatment sequences are presented on the following pages with an explanation of their functional performance. Each has certain special features highlighting particular capabilities to point out equipment/technology application potentials.

1. ASSUME 4 HOUSES/ACRE DENSITY ON SQUARE TRACT (1 ACRE = 43,560 FT^2)

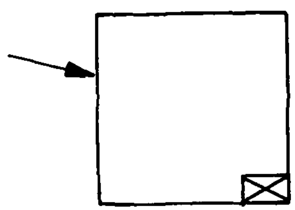
TOTAL AREA

FOR 100 HOUSES: $\frac{100}{4} \doteq$ 25 ACRES

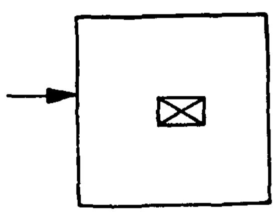
FOR 500 HOUSES: $\frac{500}{4} \doteq$ 125 ACRES

2. TREAT PLANT LOCATIONS

CASE A.



CASE B.



AVE. SEWER LENGTH = MID POINT OF GRID

FOR 100 DU $= \sqrt{(25)(43,560)} = 1045$ FT

FOR 500 DU $= \sqrt{(125)(43,560)} = 2335$ FT

AVE. SEWER LENGTH = 1/2 MID-POINT OF GRID

$= \frac{\text{CASE A}}{2}$

3. MAXIMUM WASTEWATER RESIDENCE TIME WITHIN SEWER

ASSUME MIN. VELOCITY = 1.5 FT/SEC

CASE A	CASE B
100 ~ 26 MIN	~ 13 MIN
500 ~ 58 MIN	~ 29 MIN

Figure 4-3. Sewer Sizing Envelopes

The system employed at Lake Tahoe (Figure 4-4) using lime, begins with phosphorus removal and clarification of the secondary effluent. The spent lime mud is thickened in a gravity thickener, dewatered by centrifuging, and then recalcined in a multiple-hearth furnace for reuse. Phosphorus-rich lime mud is classified in the centrifuge and wasted to the organic sludge system.

The effluent from the lime clarifier flows through an ammonia-stripping tower to a two-stage recarbonation system. Scrubbed stack gases from the lime recalcining and sludge incineration furnaces are used to neutralize the high-pH water. The recarbonated effluent then is pumped to mixed-media filters and carbon columns. Two ballast ponds, each with a capacity of one million gallons float on the system in order to provide flow equalization and supplemental filter backwash water. Spent carbon is withdrawn periodically from the carbon columns, thermally reactivated in a separate multiple hearth furnach, and then returned to the carbon columns. The carbon column effluent is dosed with 2 mg/1 of chlorine and then lifted 1,500 ft (458 m) and piped 27 miles (43.5 km) to Indian Creek Reservoir in Alpine Count, California.

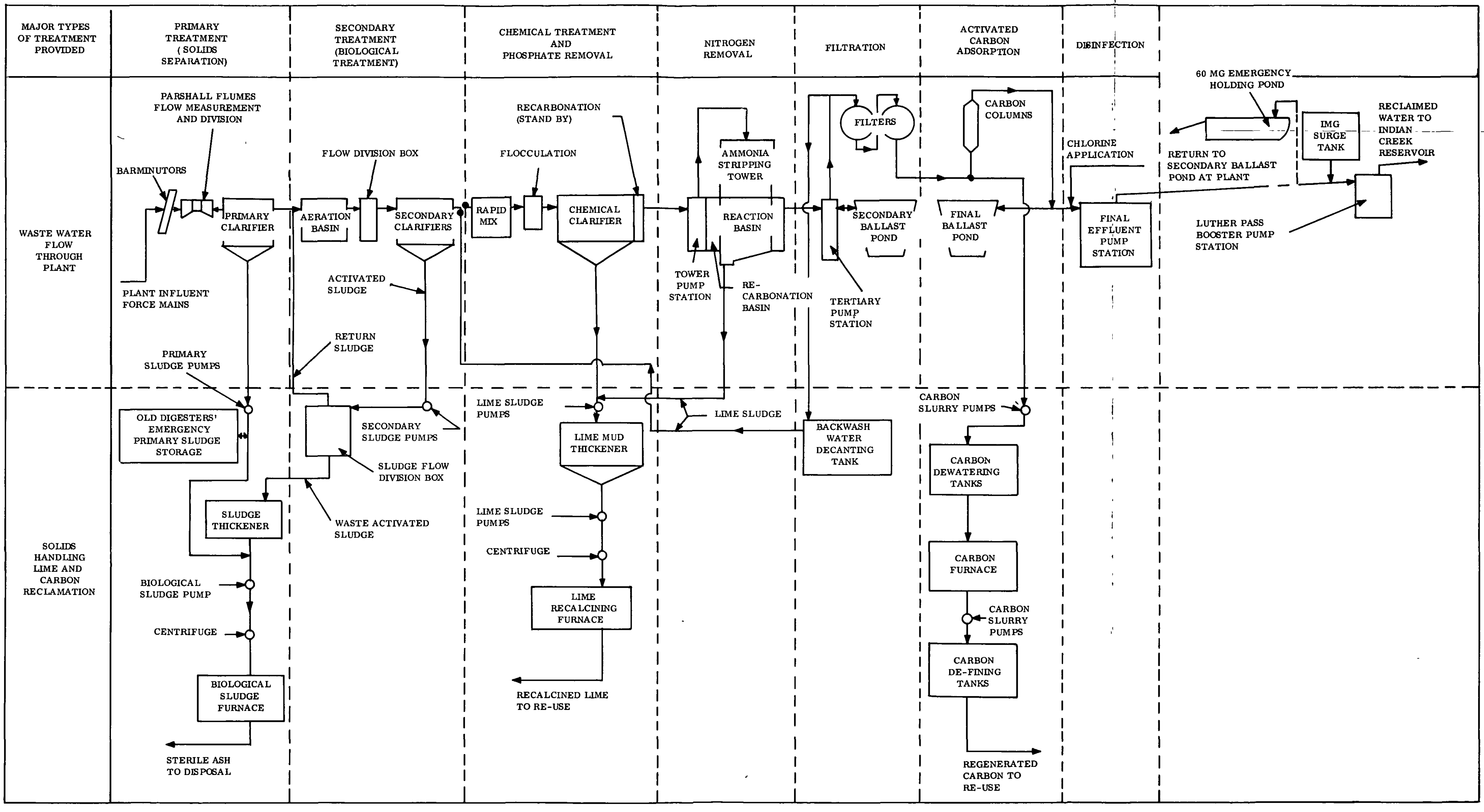


Figure 4-4. Schematic Flow and Process Diagram, South Lake Tahoe, California (Ref. 81)

The system shown in Figure 4-5 contains four major unit processes for wastewater reclamation. In the first process, the raw sewage A entering the system via standard underground sewer lines flows through a wedge-wire screen B, which captures the large and intermediate size solids. The solids removed in this process, as well as those removed in the successive processes, are fed directly into an incinerator unit. From the screen, the waste stream, with gross solids removed, flows into a surge tank C which levels the flow through the remainder of the treatment system.

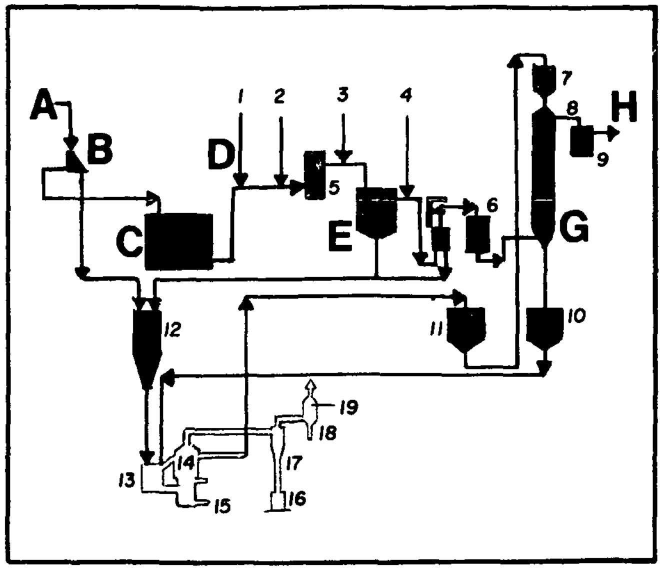
Emerging from the surge tank at an even flow, the stream is treated successively with inorganic coagulants D and precipitants, and polymeric flocculant, to precipitate the phosphate and coagulate the remaining solids which are subsequently settled in a clarifier E.

The clarified stream is treated with a few parts per million of powdered magnetic iron oxide which combines with the remaining suspended solids. This combination is subsequently removed in a magnetic filter F.

Following magnetic filtration, dissolved organics are removed by absorption on granular activated carbon G. (This system is an upflow configuration with pulsed countercurrent operation.) The stream is then chlorinated for the discharge H.

The solids removed in each unit process are fed into a dewatering and incineration system. This same unit is used periodically to thermally regenerate the spent carbon from the adsorption process.

The system illustrated in Figure 4-6 highlights the versatility of centrifuges in conjunction with a conventional secondary treatment process, to concentrate secondary sludge to up to 10% by use of two different types of centrifuges. The digested, washed sludge can be dewatered to a 30% sludge cake depending again on machine selection. Performance envelopes of centrifugal machines can tolerate wide variations in influent solids content and flows making them suitable for small plant installations with rapid start-up and/or changes in process rates to meet plant loading on a dynamic basis (as opposed to large surge tanks).



Community Wastewater Treatment Plant (*AWT CO.)
1—coagulant; 2—pH control, 3—polymetric flocculant; 4—magnetic additive; 5—mixer, 6—adsorber feed, 7—carbon feed, 8—chlorine; 9—chlorine contact; 10—spent carbon; 11—regenerated carbon, 12—sludge hold; 13—sand filter; 14—fluidhearth reactor, 15—blower filter; 16—ash bin; 17—dust cyclone; 18—scrubber; 19—spray water.

Figure 4-5. Community Wastewater Treatment Plant

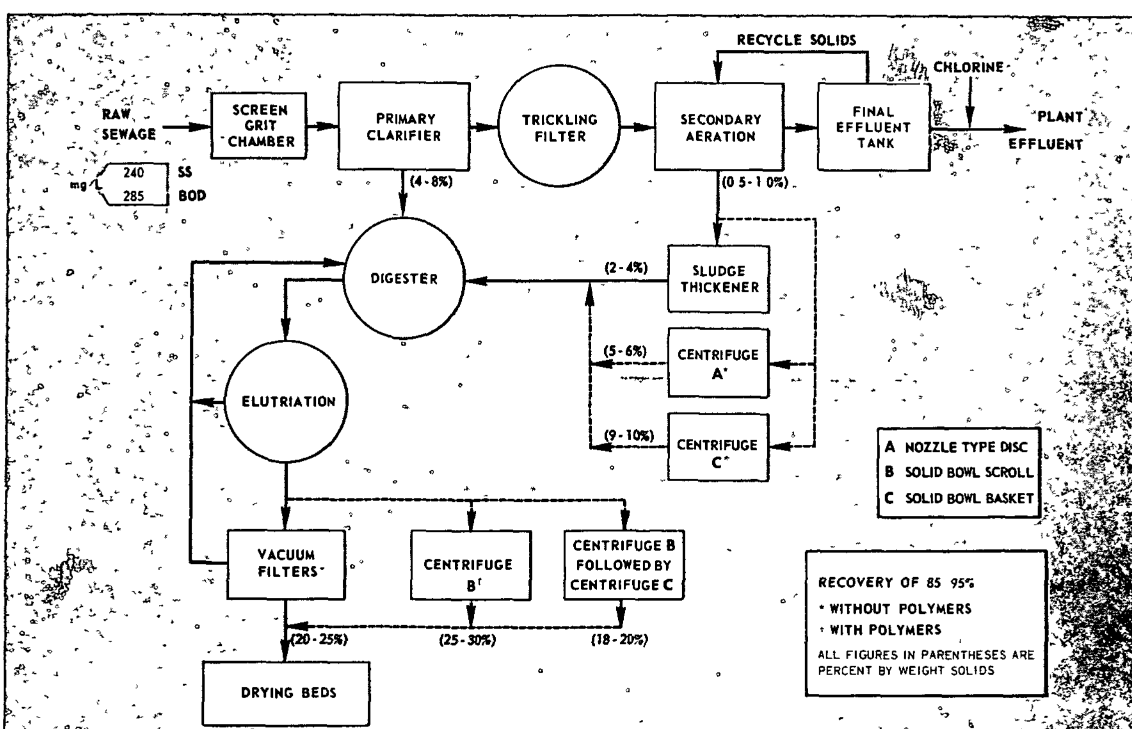


Figure 4-6. Physical Chemical System Using Centrifuges

The cited physical-chemical systems provide examples of the various unit processes that have been mechanized to avoid the shortcomings of biological dependent processes.

A significant advantage of the physicochemical treatment system is the flexibility afforded in plant capacity and to degree of treatment. The physicochemical process permits plant design for modular additions to accommodate increasing requirements for effluent quality. For example, an effluent quality comparable to that obtained from an activated sludge process can be achieved with a carbon adsorption system providing a relatively brief carbon contact period. As requirements for improved effluent quality develop, additional adsorption units simply can be added to provide more contact time, and more effective removal of organic material. Similar flexibility is provided with respect to removal of suspended matter by coagulation and filtration, and removal of phosphates by precipitation. The following sections describe most of the newest methods of advanced treatment available in advanced development. As should become obvious, there are various choices to select from for any preferential waste removal and the chosen treatment system train is based not only on required effluent quality and influent characteristics, but largely on the ingenuity used in matching the unit processes for maximum benefit in an overall design.

Design of a treatment train must produce a desired effluent quality reliably and economically. When compared to the above characteristics of small flows, process selection has to favor techniques able to accept highly variable wastes. The apportionment of economics between capital and operating costs will favor a higher capital cost due to the absence of a fulltime plant operator for these smaller plants. Therefore, automation is justifiable.

4.3.1 CONCEPTUAL PHYSICOCHEMICAL SYSTEMS

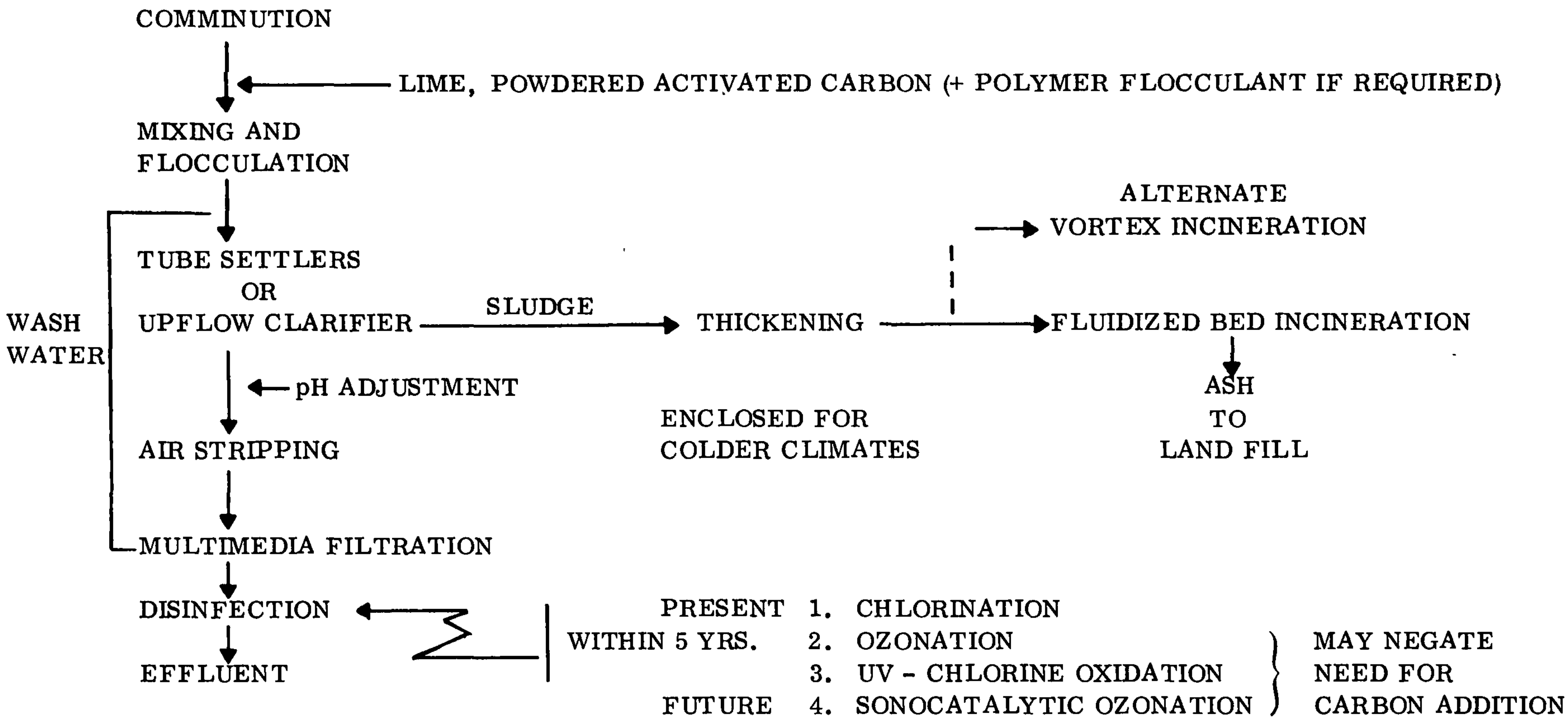
The following concepts are offered as viable alternatives in selecting the ultimate treatment scheme responsive to the hydrograph hydraulic variations and nominal sewage composition delineated in the first section. Each process chain is capable of proportionate operations, that is, includes "tuning" provisions to tailor the applied treatment process to the specific pollutants and their apportioned quantities within the total wastewater. Each system is described and an estimate of the cost factors presented following the technical discussions.

Each of the proposed concepts has several common features. Incoming sewage is comminuted to a maximum size of about 1/2" diameter to maximize surface area exposure to the chemical conditioners and be easily transported without clogging in-line components. If pressure sewering is employed, this function is performed by pump-grinder units located at the residential end of the sewers. Chemical addition, for flocculating suspended solids, raising pH and/or affecting solubles removal can also be dosed while the macerated sewage is in the sewer network. Chemicals added for flocculating require approximately one minute to mix the solution thoroughly and between 15-60 minutes are required to allow floc growth (with gently induced convectives) to occur with subsequent separation of suspended matter by gravimetric and/or filtration equipment. The actual detention times are determined by jar and pilot tests to establish chemical dosage rates, flocculating time constants, sludge characteristics and solids removal percentages, however, average values for design purposes will be used for these operating characteristics.

4.3.1.1 System Concept 1

As depicted in Figure 4-7, this concept is a least risk approach in that the treatment principles and equipment have been successfully applied in various locations. Further, as a test bed, this scheme can be easily modified to include substitute unit processes for performance impact experiments using newer advanced techniques.

The incoming wastewater is dosed with lime to both raise the solution pH (for phosphate precipitation) and form flocs for suspended solids separation. Powdered activated carbon is added to adsorb the soluble organic matter. Should suspended solids removals be inadequate with the lime addition, a polymeric flocculant will be dosed (at about 0.3 to 0.5 mg/1) to further ensure capture of the "fines" (smaller suspended particles). This solution will be clarified in an upflow clarifier sized to retain the mix for 15-30 minutes. For the changing solids loads, a tube (or Lamella) settler module contained within the clarifier geometry will easily remove the required suspended solids and form a sludge comprised of the sewage, spent powdered carbon, and lime composites at about 5% solids concentration. This sludge will be



ESTIMATED AVERAGE REMOVAL EFFICIENCIES

		BASELINE SEWAGE EST. EFFLUENT PPM	
BOD	95% (99)	20	(4)
COD	95% (99)	56	(11)
TSS	99%	4	
P	95%	1-2	
N	~100%	6	
COLIFORMS		<100 MPN/ml	

( )
WITH
ADVANCED DISINFECTION
TECHNIQUES 2, 3, OR 4

Figure 4-7. System Concept 1

processed through a centrifuge to dewater the solids before incineration. Incineration by aspirating the sludge into a vortex stream of hot gases (vortex incinerator) or injection into a fluidized sand bed incinerator completes the solids handling portion of this system. An inert, sterile ash comprised of lime, carbon and any minerals (inorganics) can be periodically removed for disposal.

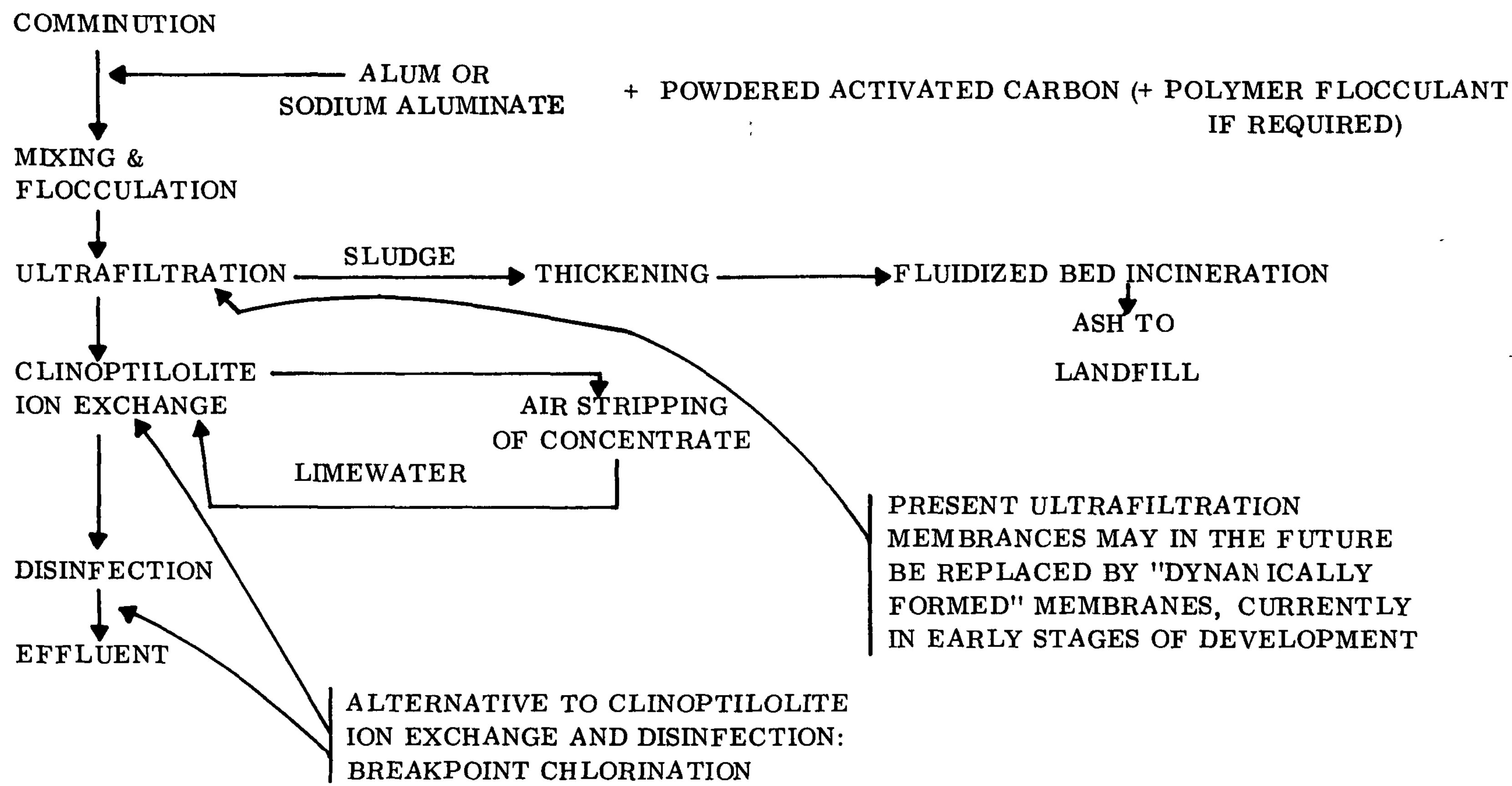
Following clarification, the wastewater pH is adjusted (if required) to between 10.5-11.5 for air stripping of ammonia-nitrogen. A final pass through a multimedia filter removes any residual solids. Disinfection is achieved by adding chlorine until a chlorine residual of at least 0.1 mg/l is measured after a 20-30 minute contact time prior to discharge.

4.3.1.2 System Concept 2

The second concept (Figure 4-8), is actually an evolutionary advance of the first system in that the clarification is accomplished by a membrane technique which removes 99% of the suspended matter and nitrogen (as ammonium ion) is selectively removed by clinoptilolite, a naturally occurring ion exchange media. The pH of the solution is then adjusted to 5.5-6.5 by the addition of alum. This pH level is required to provide optimum phosphorus precipitation. Alum is used instead of lime to retard hydrolyzing the organic matter to smaller mole weight particulates thereby creating a denser sludge with less fines and therefore less likely to cause fouling of the membrane. The sludge being dense is amenable to a fluidized bed incinerator at concentrations to 35% solids. Backwashing, using a high pH solution (limewater) is used to regenerate the clinoptilolite and to restore the ion balance while purging the bed of concentrated ammonium ion which is removed to a small air stripping tower. Again, disinfection is accomplished by chlorination.

4.3.1.3 System Concept 3

As in System 2, the third concept (Figure 4-9) employs alum to flocculate the suspended solids and precipitate phosphorus. The solids separator for this system is the moving bed filter which provides 85% solids removal and raw sludge with about 3% solids concentration. The carbon columns provide the remaining suspended removals along with adsorption of the soluble organics. Contact time required through the carbon bed media is 30 minutes. Spent carbon can be regenerated by the incinerator during quiescent periods. Breakpoint chlorination



ESTIMATED AVERAGE REMOVAL EFFICIENCIES

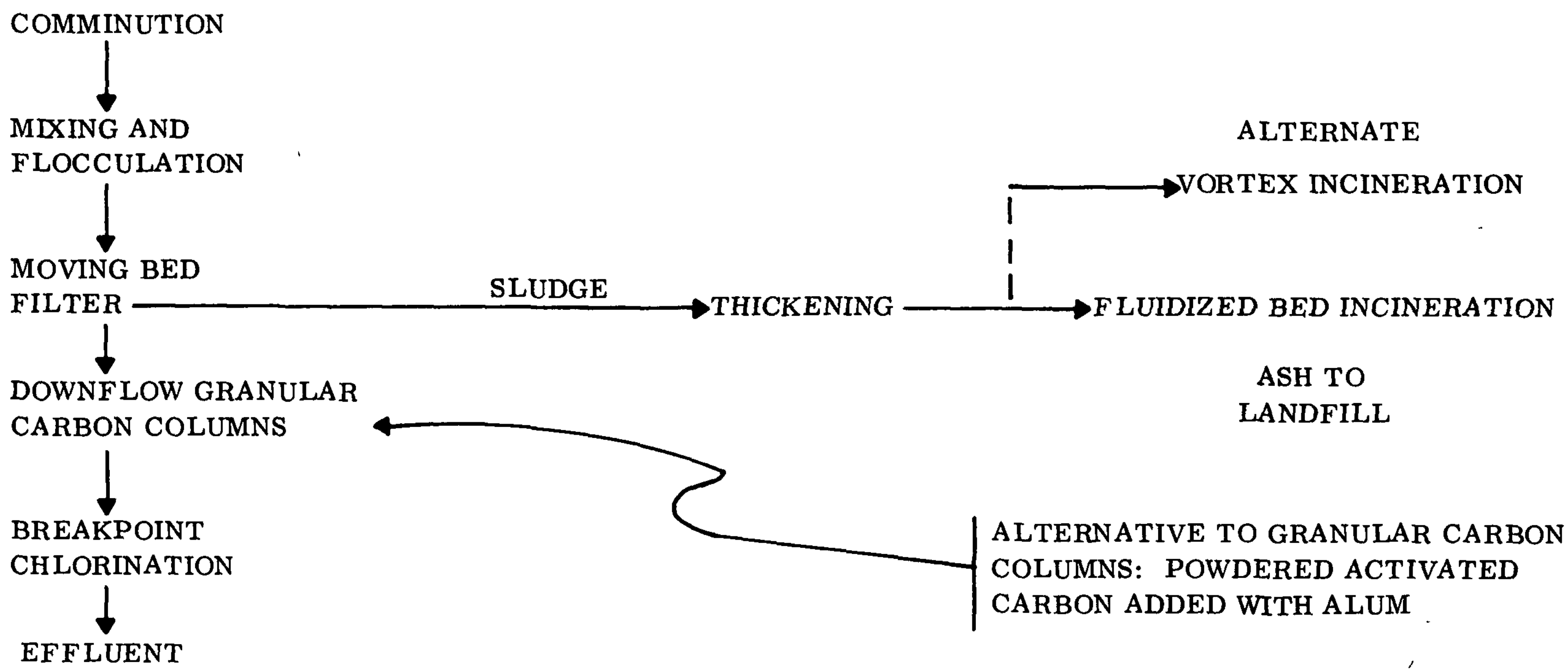
		EFFLUENT PPM (BASELINE SEWAGE)	
BOD	96%	16	SAME IMPACT AS SYSTEM 1
COD	96%	45	
TSS	100%	0	
P	98%	< 1	
N	98% (80–90%)	~ 2 (10–20)	
COLIFORMS	100%	0	

Figure 4-8. System Concept 2

requires the wastewater pH to be between 7-8 (normal sewage range) and the ammonia content measured and known. Chlorine is dosed at a molar ratio of 2:1, chlorine to ammonia. At this ratio, the ammonia is destroyed, and the chlorine is completely oxidized. The resulting wastewater is disinfected, free of adverse taste and odors and nitrogen (as ammonia) is reduced 60-80%.

4.3.1.4 Conceptual Systems Economic Considerations

The concepts presented represent an amalgam of unit processes capable of inclusion in several system concepts. In selecting any of these, the ingenuity of the designer as well as the specific operating features play an important part in proposing any one treatment train to meet a set of effluent quality requirements. Certainly the economic factors involved are the major non-technical contributions to the selection process.



ESTIMATED AVERAGE REMOVAL EFFICIENCIES		EFFLUENT PPM (BASELINE SEWAGE)
BOD	95%	20
COD	95%	56
TSS	99%	4
P	95+%	1-2
N	80-90%	10-20
COLIFORMS	~100%	<100 MPN/ml

Figure 4-9. System Concept 3

Each of the unit processes included in the three concepts described in Section 4, 2.1 are evaluated in Table 4-3. All processes were sized for a 100,000 gal/day flow with waste concentrations of: Bod = 200 mg/1, TSS = 250 mg/1. The installed capital cost and operating costs are estimated for each process at its typical performance level as specified in the table. Capital cost is amortized using an assumed equipment life of 25 years and an interest rate of 7%. Cost estimates do not include operating manpower or periodic maintenance and overhead. Advanced instrumentation and controls are also excluded.

While cost estimates are believed to accurately indicate the relative economics of each process alternative, the absolute level of accuracy is low due to the lack information operating experience with AWT processes in small scale plants.

4.3.2 DISTILLATION SYSTEMS

Distillation is perhaps the simplest and most widely accepted method of purifying water. The process provides highly efficient separation of both organic and inorganic dissolved and suspended solids. Conversion of saline water is perhaps the most widespread application of distillation as a water recover process. Table 4-4 provides information on typical facilities and the type of distillation process employed. A comparison of saline water conversion and wastewater conversion indicates that saline water contains a much higher % of dissolved solid than wastewater and as a result, scaling and boiling point elevation should be less for wastewater conversion than has been experienced in saline water conversion. (Ref 73).

Reference 79, reporting on a survey of the wastewater characteristics of 22 large cities in the United States states that, of the 13 cities supplying data on both calcium and phosphate in wastewater, eight have enough phosphate to precipitate calcium as whitlockite or hydroxophate indicating that in many cases no chemical pretreatment may be necessary to prevent scaling in the distillation apparatus.

Volatile contaminants such as ammonia gas and low molecular weight organic acids occurring in wastewater can be controlled by a preliminary evaporation step or by pH adjustment prior to distillation followed by charcoal filtration of the condensate (Ref 78). An even simpler

Table 4-3. Conceptual Systems Process Economics

Process	Installed Capital Cost ($)	Operating and Amortization Costs ($/KG)[f]	Performance (% Removal)	Type of Influent	Literature References
1. Primary Settling	20,000	0.05	TSS - 55%	Raw Sewage	54, 55, 62
2. Micro-Straining	40,000	0.10	TSS - 70%	Secondary Eff.	56
3. Ultrafiltration	175,000	1.90	TSS - 100%	Secondary Eff.	32, 54, 61
4. Rapid Sand Filter	40,000	0.10	TSS - 75%	Secondary Eff.	54
5. Moving Bed Filter	40,000	0.10	TSS - 83%	Raw Sewage	30, 55
6. Lime Coagulation[a, c]	27,000	0.10	TSS - 90% BOD- 50% P - 90%	Secondary Eff.	55, 56, 57, 62
7. Ferric Chloride Coagulation[a]	31,000	0.13	TSS - 90% BOD- 50% P - 90%	Secondary Eff.	55, 57, 62
8. Alum Coagulation[a]	31,000	0.17	TSS - 90% BOD- 50% P - 90%	Secondary Eff.	55, 57, 62
9. Trickling Filter	15,000	0.15	BOD- 85%	Primary Eff.	54, 58, 60, 67
10. Activated Carbon Column[e]	75,000	0.80	BOD- 90% TSS - 90%	Primary Eff.	56
11. Activated Carbon Powder[b, e]	19,000	0.92	BOD- 90%	Primary Eff.	54
12. Ammonia Air Stripping[d]	12,000	0.13	NH_3-N-90%	Secondary Eff.	56
13. Ion Exchange	39,000	0.25	Totan-N-90%	Secondary Eff.	59, 64
14. Ozonation	52,000	0.38	COD- 60%	Secondary Eff.	66
15. Chlorination-Ammonia Removal	41,000	0.30	NH_2-N-99%	Secondary Eff.	62
16. Chlorination Effluent Residual	3,000	0.01	8 mg/l dosage, 15 min. contact	Secondary Eff.	62, 65
17. Centrifuge Sludge Dewater	4,000	0.04	Solids Conc. 2% → 25%	-	63
18. Fluid Bed Sludge Incinerator	34,000	0.09	25% Solids → Ash		63

NOTES

a - Operating cost includes additional sludge disposal
b - Assumes constant influent BOD loading
c - Operating cost includes recarbonation
d - Operating cost does not include pH adjustment
e - Includes neither credit for carbon recovery nor cost for carbon disposal
f - Amortized for 25 years at 7% interest rate

approach which requires no chemical pre-treatment or post-treatment filtering is the use of high temperature (> 1000°F) catalytic oxidation of the distillation vapors. This process, developed for use in conjunction with a vacuum distillation process, is capable of producing high quality water from concentrated solutions of urine, feces, wash water and commode flush water. The process was originally developed for aerospace applications.

Typically the vacuum distillation process operates at less than 120°F and 1.7 psia to minimize volatile production. Scale formation on heated surfaces appears to be minimal based on extensive tests at General Electric (Ref 76). Adjustment of the sewage pH prior to distillation, and charcoal filtration of the condensate will provide high quality water.

Table 4-4. Plants Now Producing Fresh Water by Distillation of Saline Water (Ref.73)

Location	Capacity, mgd	Type	Manufacturer
Kuwait (Persian Gulf)	2.5	Multiple-effect	G. & J. Weir and Westinghouse
"	2.5	Multi-stage flash	Westinghouse
"	0.375	"	Richardson
Aruba (Caribbean)	3.5	Multiple-effect	G. & J. Weir
Curacao (Caribbean)	1	"	"
Nassau (Bahamas)	1.2	" (under contract)	"
Kingley Air Base (Bermuda)	0.225	Recompression	Cleaver-Brooks
Dharan Air Base (Arabia)	0.2	"	"
Pacific Gas and Elec., (Morro Bay, Calif.)	0.15	Multiple-effect	Lummus Co.
Isle of Guernsey	0.6	Multi-stage flash	G. & J. Weir
S. Cal. Edison (Oxnard, Cal.)	0.1	"	Cleaver-Brooks
Aircraft carriers (U.S., each)	0.2	"	All manufacturers
Shell Refinery (Cordon, Venezuela)	1.2	"	—

Several other techniques can be employed to minimize ammonia production and reduce the magnitude of the problem created by volatiles. These processes are described in Appendix H & I.

Several distillation techniques are available including:

- Multiple effect evaporation
- Multi-stage flash evaporation
- Vapor compression distillation
- Air evaporation
- Vacuum distillation

All of these techniques except vacuum distillation involve reuse of the latent heat of evaporization of the steam to improve the process economics. This reuse of thermal energy is not practical with the vacuum distillation process and is extremely limited in the air evaporation process due to the low temperatures and pressures involved.

Effectiveness of the reuse of thermal energy in the processes mentioned is indicated somewhat by the fact that as much as 30 pounds of water can be evaporated per pound of steam supplied in a multiple affect evaporation system having 30 effects or stages. The equipment required for such process efficiencies is of course much more elaborate than if heat conservation techniques were not employed. Careful design and economic consideration must be given to heat exchange equipment in formulating an optimized distillation process since at least 50% of the total cost in conventional distillation is due to the production of steam.

Table 4-5 presents relative costs of distillation plant requirements. (This data should not be used in estimating the operating costs of aplant.)

Table 4-5. Summary of Costs for a Large Distillation Type Waste-Water Purification Plant (Ref 73)

Electric power	1.85
Steam	22.49
Chemicals	0.50
All other costs	26.50
Total	51.34 cents

4.3.2.1 Multiple Effect Evaporation

Multiple Effect Evaporation (Figure 4-10)consist of a series of stages or effects each maintained at a slightly lower pressure and as a result at a lower temperature than the preceding one. As a result, the steam produced in one effect is used to provide the heating medium for the next and therefore for each pound of steam supplied to the first effect there is produced a number of pounds of product water approximately equal to the number of effects. This technique commonly referred to as cascading is illustrated by Figure 4-11.

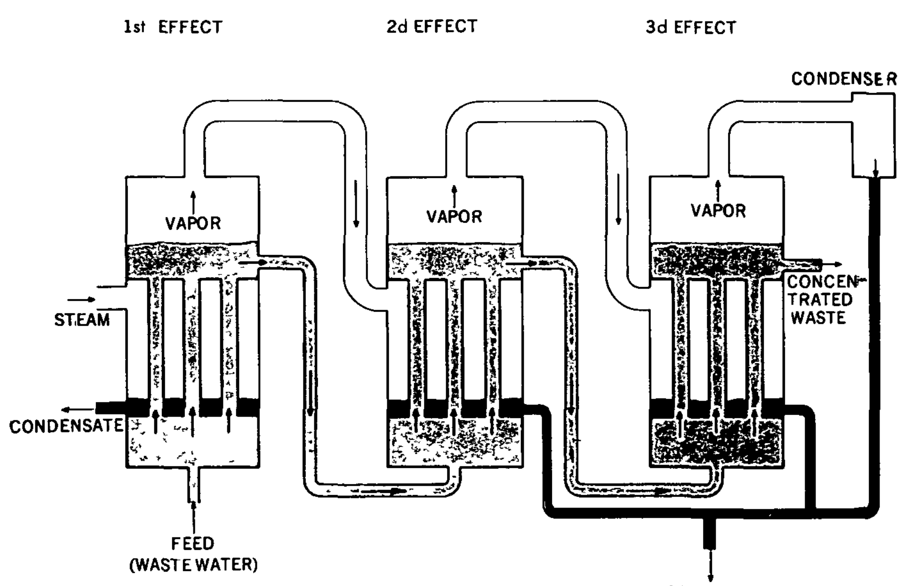


Figure 4-10. Schematic Arrangement of Multiple-Effect Evaporator (Ref 77)

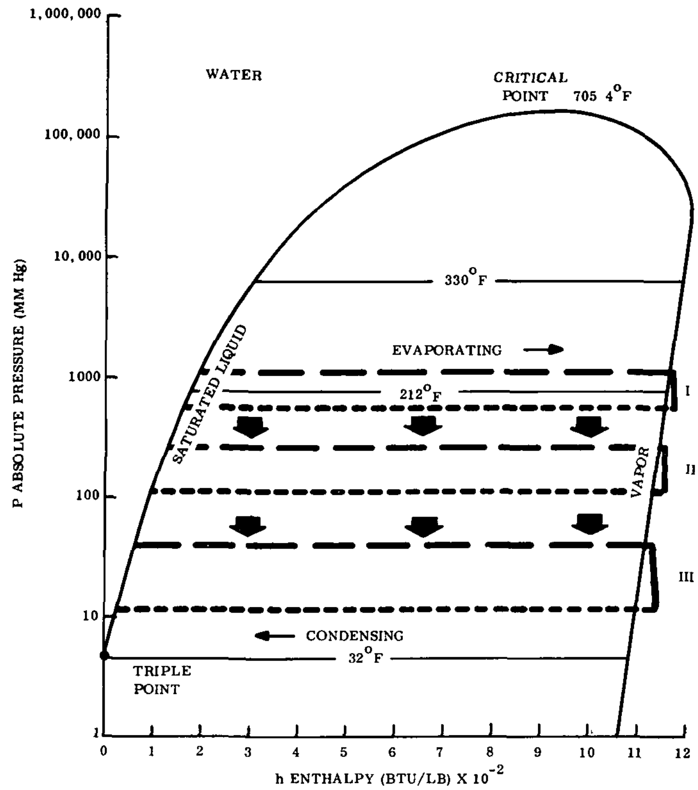


Figure 4-11. Pressure - Enthalpy Diagram Multiple Effect Evaporation Reaction

4.3.2.2 Multi-stage Flash Evaporation

Multi-stage Flash Evaporation (Figure 4-12) processes are arranged to provide evaporation in a number of stages at successively lower temperatures. Feedwater is heated by the heat of condensation so only a small amount of heat is required to flash the liquid to steam in the first stage. System economy is dependent upon the number of stages and the temperature rise of the feedwater.

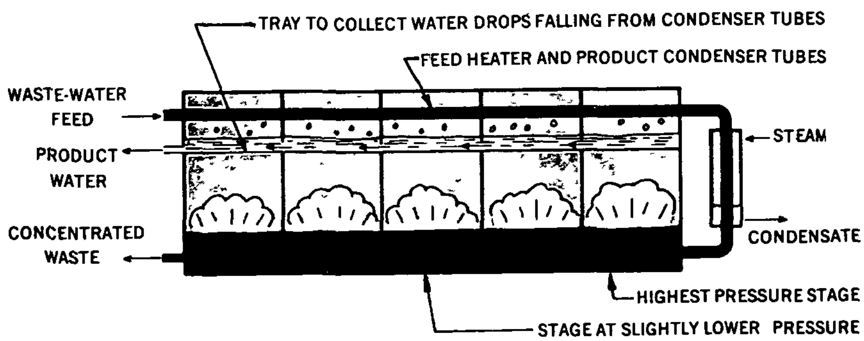


Figure 4-12. Schematic Arrangement of Multistage-Flash Evaporator (Ref 77)

4.3.2.3 Vapor Compression Distillation

Mechanical compression is employed to provide for re-use of heat in the vapor compression distillation process (Figure 4-13). In this technique the temperature of the steam is increased by increasing the pressure of the steam mechanically. The temperature is increased sufficiently to permit transfer of the heat of condensation of the steam to evaporate additional water. Figure 4-14 is a pressure enthalpy diagram of the vapor compression process.

4.3.2.4 Air Evaporation

The air evaporation process is a hybrid of a system developed to the prototype stage and being considered for long term spacecraft missions. The original system employs a vacuum distillation process which permits the evaporation of water at approximately $100^{o}F$ to minimize the release of volatile contaminants into the water vapor. In the air evaporation process, (Figure 4-15) water is evaporated at a temperature of approximately $100^{o}F$ by exposing it to a stream of heated air at low relative humidity. The moisture laden air is then passed through a catalytic oxidation unit which operates at about $1000^{o}F$ where both the air and the water are sterilized and impurities are oxidized. The water vapor is next condensed giving up the heat of condensation to the feedwater and the air can then be recirculated or discharged. This system provides the opportunity for widespread integration into other utility systems since waste heat down to $140^{o}F$ may be used to heat the water being evaporated. The heated air stream can be used for domestic heating and also can be applied to other systems such as absorption refrigeration.

4.3.2.5 Process Economics

Purification of waste water by distillation is affected by three main factors:

1. Supply of heat energy
2. Energy conservation
3. Heat exchange equipment design.

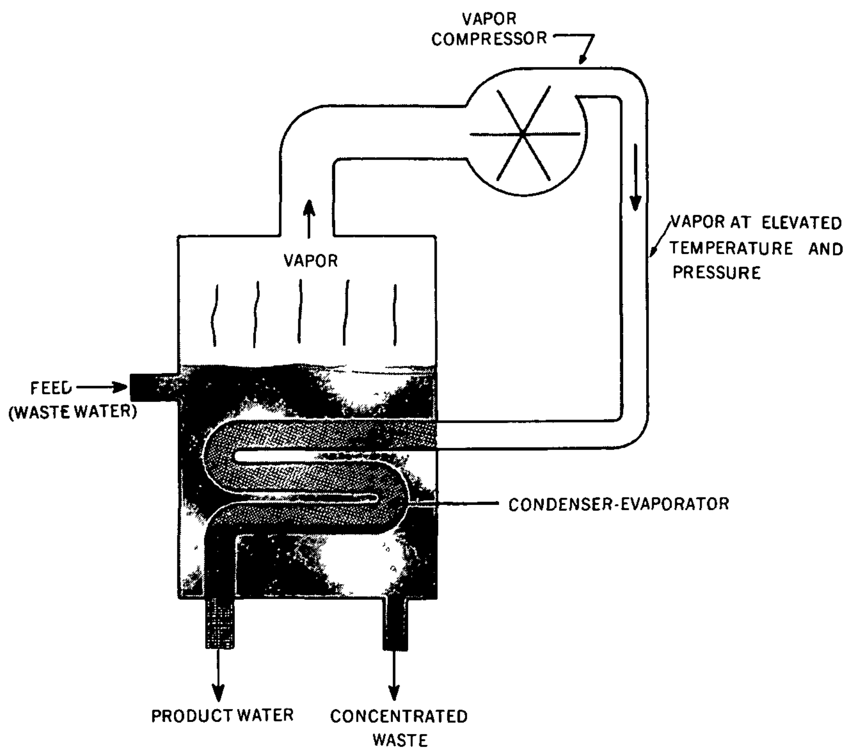


Figure 4-13. Vapor Compression Distillation

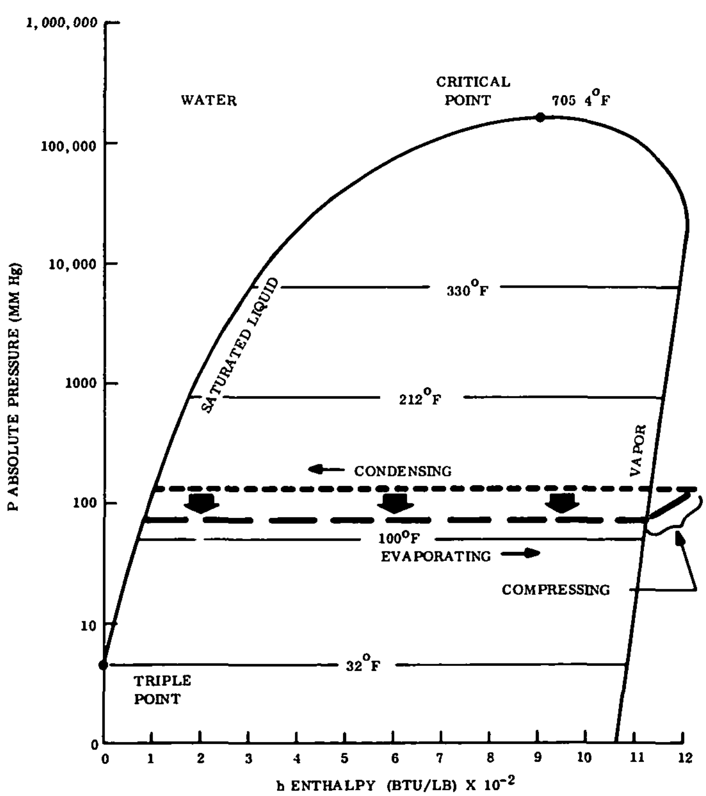


Figure 4-14. Pressure Enthalpy Diagram Vapor Compression Distillation Reaction

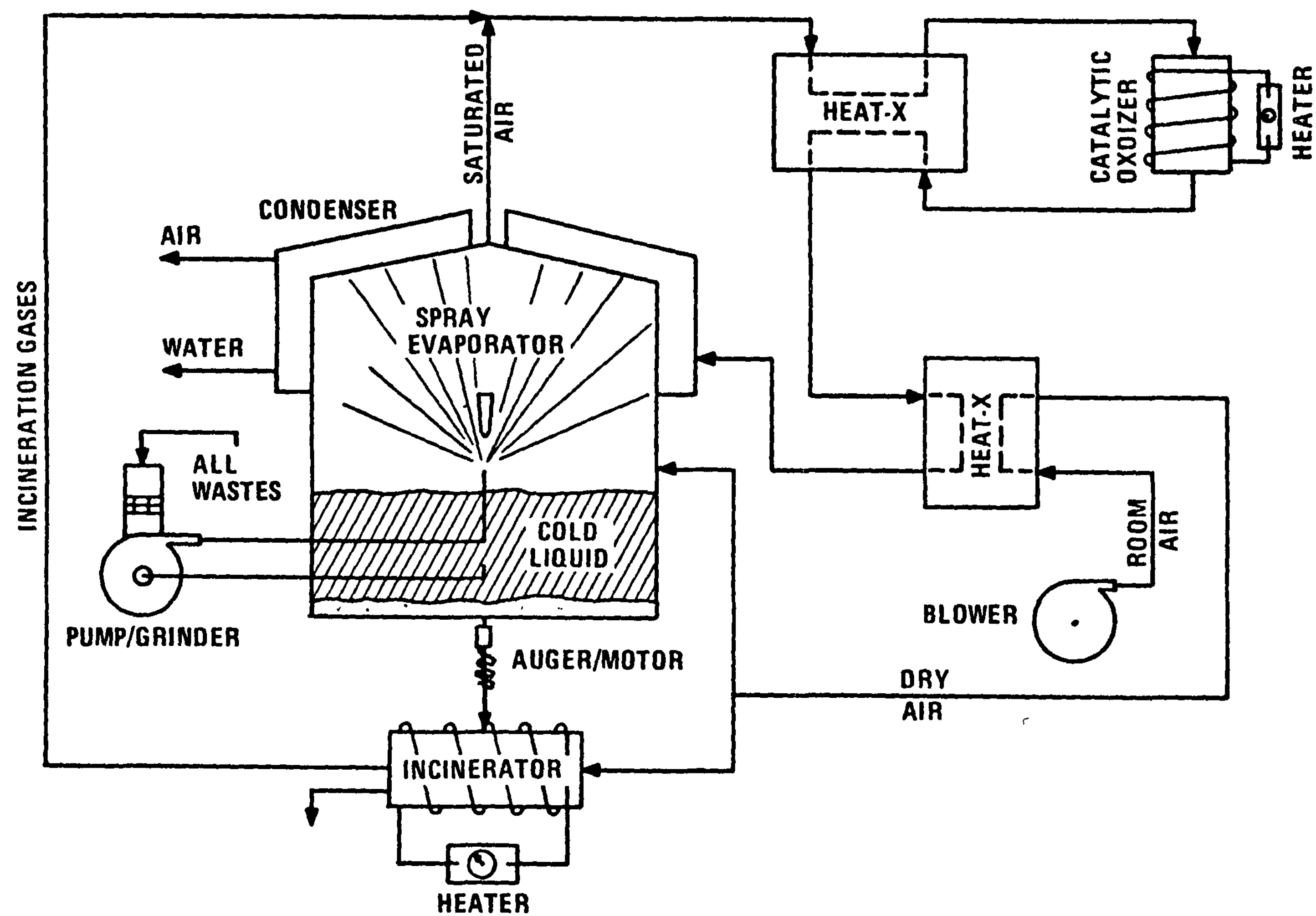


Figure 4-15. Recuperative Air Evaporator Concept

Steam has been the principal source of heat energy for distillation processes, although several other sources have been considered recently including solar and nuclear energy.

Solar distillation generally employs large basins of water covered by clear plastic film. Solar energy passes through the film to the water and the resultant vapor is contained by and condensed on the film and collected. Experience to date with the process indicates that production rates of 0.10 gallons per ft^2 per day can be obtained at radiation intensities of 2000 BTU per ft^2 per day. This rate indicates that approximately 42% of the energy is effectively utilized. It is estimated that for a plant to produce 50,000 gal per day of purified water a surface area of approximately 500,000 ft^2 is required at solar radiation intensities of 2000 BTU per ft^2 per day.

Much is yet to be learned about this technique, particulary in the area of materials durability and methods of increasing system efficiency. One recent development by NASA in the materials for solar collectors offers an absorptivity/emissivity ratio in excess of 10. The development could eliminate the need to orient the collector toward the sun and would also permit operation on cloudy days.

The economics of distillation as an advanced wastewater treatment process and for that matter the techniques involved have, to date, been based on an extrapolation of data obtained from operation of saline water conversion plants. It has been estimated that the costs for distillation of wastewater could be between 7 and 20% lower than that for saline water due to the possibility of using process temperatures up to 350°F.

Nuclear power is also being considered as an energy source for the production of steam but at the present time no economic advantage can be realized when the process is compared to ordinary steam generation when part of the steam cost can be charged to power generation. System size is an important factor in the consideration of nuclear power as an energy source. It is estimated that the cost of steam in a 370 megawatt pressurized light water reactor, capable of producing 50 mgd, would be 37 cents per 1000 pounds.

Table 4-6 (Ref 79) indicates the costs of saline water recovery are between 53.6 and 45.3 cents/1000 gal for a 10 mgd plant.

Table 4-7 (Ref 80) lists five advanced wastewater treatment along with the product water quality and possible applications.

Table 4-8 (Ref 80) presents the costs involved in producing water by each of the five processes. By comparing the costs in Table 4-8 with those shown in Table 4-6 it can be seen that distillation costs are 30% to 45% higher than the costs of physico-chemical processes capable of producing potable water. Worthy of note here is the consideration of the use of waste heat for an energy source for the distillation process.

Future housing developments being envisioned are almost completely independent of outside utility requirements. Modular utility systems with provisions for supplying heat, electricity, air conditioning, water and sewage and waste disposal are being considered. In such a concept, a key consideration must, of course, be the degree of integration which can be obtained between the utility systems.

For example, if waste heat is available as the result of any other utility process it may be utilized to operate a distillation type water recovery system. The distillation processes can then in turn be used to provide both hot and cold water for household use and may even be employed in home heating and air conditioning applications,or there are numerous other possible arrangements for an integrated utility approach.

This widespread integration is one way in which a distillation process can become competitive with the more conventional methods of water treatment.

Table 4-6. Operating Costs of Desalination Plants
(Annual Production - 10 mgd for 330 days per year)

Type Plant	Multiple Effect $	Thermocompression Multiple Effect $
Amortization at 7.4%	556,000	529,000
Maintenance, material, and labor at 2.6%	195,000	186,000
Fuel at 30¢/10^6 BTU	832,000	576,000
Operating and supervisory labor	135,000	135,000
Supplies	50,000	50,000
TOTAL	$ 1,768,000	$ 1,496,000
Cost of distilled water, ¢/1,000 gal	53.6	45.3

Table 4-7. Summary of Treatment Plant Cases

Case	Process	Product Quality and Possible Use
1	Preliminary and secondary treatment, disinfection	Meets most pollution laws: discharge to receiving bodies, some low-level agricultural supply
2	Case 1 plus sand filtration	Improved pollution control: low-quality industrial and agricultural supply
3	Case 1 plus activated carbon treatment	Complete organic pollution control: good-quality industrial and agricultural supply, ground water recharge supply
4	Case 1 plus lime treatment, ammonia stripping, and activated carbon treatment	Complete organic and nutrient-removal pollution control: high-quality industrial and agricultural supply, potable water supply
5	Case 1 plus activated carbon treatment and electrodialysis	Complete organic and inorganicpollution control except where complete nutrient removal required: most water uses including potable water supply.

Table 4-8. Cost of Water Summary, ¢/1000 Gal.

	Case 1	Case 2	Case 3	Case 4	Case 5
Fuel	0.3	0.3	0.4	1.6	0.4
Electricity	1.3	1.6	1.7	2.3	3.1
Chemicals:					
Coagulants	2.1	3.0	3.0	3.0	3.0
Lime	---	---	---	1.0	---
Sulfuric Acid	---	---	---	---	1.9
Chlorine	0.5	0.5	0.5	0.3	0.3
Supplies and Maintenance Materials					
Activated Carbon	---	---	0.7	0.4	0.7
ED Membranes	---	---	---	---	2.7
Other	1.0	1.2	1.3	1.9	2.0
Inert Solids Disposal	0.2	0.2	0.2	0.6	0.2
Brine Disposal	---	---	---	---	1.9
Operating and Maintenance	3.9	4.4	4.4	4.9	5.5
Insurance	0.5	0.6	0.6	1.0	1.0
Amortization	6.7	8.8	9.2	13.6	14.2
Interest on Working Capital	0.2	0.2	0.3	0.4	0.5
TOTALS	16.7	20.8	22.3	31.0	37.4

4.4 RECOMMENDED SYSTEM SELECTION

The matrices included in this section indicate the performance and economic contributions represented by the unit processes comprising the three physico chemical concepts developed. Because the ultimate advanced wastewater treatment systems are still in various stages of development, the project team considered generating an integrated design of segmentable unit processes as being in the best interests of evolving improvements, as new technology solutions become available for practical applications. Therefore, the compatibility match of these unit processes to other treatment trains is evaluated. The final selection of the system proposed for preliminary design emphasizes the commonality to adapt, within a wastewater treatment system, to the other more advanced developments anticipated for near-future applications.

4.4.1 UNIT PROCESS COMPATIBILITY

The matrix shown in Figure 4-16 interrelates the composite list of unit processes derived from the three system concepts. By designating each functional connection by a symbol, the commonality and alternative selections are apparent. Those dependent unit processes are related by an "x" designation, with non-impacted relationships shown by an "N" to indicate compatible, but non-dependent relationships. The listing can be grouped into functional categories as follows:

Functions	Unit Process
1. Solids Removal	Comminution Chemical Addition* Mixing Tube Settlers/Clarifiers Ultra Filtration Moving Bed Filter
2. Organic Removal	Chemical Addition* Down Flow Carbon Columns
3. Nutrient Removal	Chemical Addition* pH Adjustment Ion Exchange Breakpoint Chlorination** Air Stripping

	COMMINUTION	CHEMICAL ADDITION	LIME	ALUM-IRON	POLYMERS	POWDERED CARBON	MIXING	TUBE SETTLERS/CLARIFIERS	ULTRAFILTRATION	MOVING BED FILTER	pH ADJUSTMENT	AIR STRIPPING	ION EXCHANGE	BREAKPOINT CHLORINATION	DOWNFLOW CARBON COLUMNS	MULTIMEDIA FILTRATION	CHLORINATION	VORTEX INCINERATOR	FLUIDIZED BED INCINERATOR	SLUDGE THICKENER
COMMINUTION	-																			
CHEMICAL ADDITION	X	-																		
LIME			-																	
ALUM-IRON				-																
POLYMERS			⊗	⊗	-															
POWDERED CARBON			⊗	⊗		-														
MIXING	X	X	⊗	⊗	X	X	-													
TUBE SETTLERS/CLARIFIERS	X	X	⊗	⊗	X	X	X	-												
ULTRAFILTRATION	X	X	⊗	⊗		X	X		-											
MOVING BED FILTER	X	X	⊗	⊗	X	X	X			-										
pH ADJUSTMENT	X	X	X		N	N	X	N	N	N	-									
AIR STRIPPING	N	X	X		N	N	N	N	N	N	X	-								
ION EXCHANGE	N	N			N	N	N	N	N	N	X	X	-							
BREAKPOINT CHLORINATION	N	N		⊗	N	N	N	N	N	N	⊗			-						
DOWN FLOW CARBON COLUMNS	N	N	⊗	⊗	⊗		N	N	N	N		N	N	N	-					
MULTI-MEDIA FILTRATION	N	X	⊗	⊗	N	X	N	N			N	N	N	N		-				
CHLORINATION	N	N	⊗	⊗	N	N	N	N	N	N	N	N	N	X	N (1)		-			
VORTEX INCINERATOR	X	X	⊗	⊗	N	N	N	⊗	⊗	⊗	N	N	N	N	N	N (2)	N	-		
FLUIDIZED BED INCINERATION	X	X	⊗	⊗	N	N	N	⊗	⊗	⊗	N	N	N	N	N	N (2)	N		-	
SLUDGE THICKENER	X	X	X		N	N	N	N	N	N	N	N	N	N	N (3)	N	N		⊗	-

LEGEND

X - COMPATIBLE OR REQUIRED
O - OPTIONAL
O-O - ALTERNATIVE
N - NO IMPACT

(1) FINAL DOSAGE TO BALANCE N REMOVAL DOSAGE
(2) PRODUCES LOW CONCENTRATION SLUDGE
(3) FUNCTION OF REGENERATION OF COLUMN/BED

Figure 4-16. Unit Process Compatibility Matrix

Function	Unit Process
4. Inorganic Removal	Chemical addition* Ion Exchange
5. Waste Products Disposal	Sludge Thickening Vortex Incineration Fluidized Bed Incineration
6. Disinfection	Breakpoint Chlorination** Chlorination

*Some of the chemicals identified are synergistic to provide and/or catalyze several functions
**Partially satisfies disinfection requirements

4.4.2 PROPOSED SYSTEM CONCEPT RATIONALE

Referring to the unit process compatibility matrix (Figure 4-16), it is apparent that the first function (solids removal) has a high functional interdependence between the chemical added and the separation methods, with definite influence on nutrient removal performance.

4.4.2.1 Plant Headworks

Floating solids and grease will be intercepted in the plant headworks where chemical treatment to facilitate flocculation is performed. The chemical treatment is provided in conjunction with a comminution stage which reduces the solids particle size prior to passage into the macerator pump inlet. The macerator pump performs three functions; the forced movement of the waste stream, improved chemical mixing and reduction of the solids particle size.

4.4.2.2 Solids Separation

Of the three filter methods of choice, one is gravimetric and the other two are mechanical. Tube settlers (clarifiers) are less sensitive to widely varying influent solids loads but have a lower "fines" capture thereby requiring a back-up filter scheme for secondary solids. System Concept 1 (Figure 4-7) utilizes a multi-media filter. The most promising advanced filtering technique is ultrafiltration employing a dynamically formed membrane in place of the synthetic membranes now in pilot plants. The development of rapidly forming a "natural" membrane should significantly reduce the operating and maintenance costs of such systems. Therefore, the proposed advanced concept will employ this method for wastewater solids removal. A holding tank will be used to attenuate the incoming flow and permit adequate contact time for agglomeration-sedimentation of primary solids thereby reducing membrane fouling by the larger solids and membrane maintenance (reforming new membrane structure). The ultrafiltration membrane module will be fed by a pressure boosting pump supplied from the holding tank. The combined sludge, from the membrane solids rejection flow and separated solids in the holding tank are transported to a dewatering centrifuge for further concentrating. The clarified wastewater is now ready for final treatment. In conjunction with the added chemical(s), the filtered wastewater contains some phosphorous and essentially all nitrogenous forms (ammonia, nitrate ion).

4.4.2.3 Final Wastewater Processing

Specific identification of chemicals added to the raw sewage was deferred until this section since equipment selection for treating the soluble pollutants is dependent upon the solution characteristics as modified by the added chemicals. For lime treatment, the solution pH will be raised to between 10.5 and 11.5. At this pH, the nitrates are converted to the ammonium ion while the phosphates are precipitated along with calcium carbonate and magnesium (as magnesium hydroxide). The remaining "fines" are hydrolyzed to mole weights of between 200-500 M.W. Lime dosage and resulting phosphorus removals are shown in Figures 4-17 and 4-18. Since reuse and/or reclamation for domestic use is an objective, iron salts can, in addition to floccing solids and reducing phosphorus, add staining agents, discoloration and possible iron residuals in the effluent. For alum or sodium aluminate, the dosage rate is determined by phosphate content and providing sufficient hydrolysis products of the metal, as opposed to pH control for lime. Good clarification usually follows with alum dosages ranging from 150-300 mg/1. Addition of alum will lower the pH of wastewater because of neutralization of alkalinity and release of carbon dioxide. The extent of pH reduction will depend principally on the alkalinity of the wastewater and is directly proportional to dosage. Most wastewaters contain sufficient alkalinity so that even large dosages will not lower the pH to below about 6.0. Optimum pH for phosphorus removal (as $Al\ PO_4$) is within the range of 5.5 to 6.5.

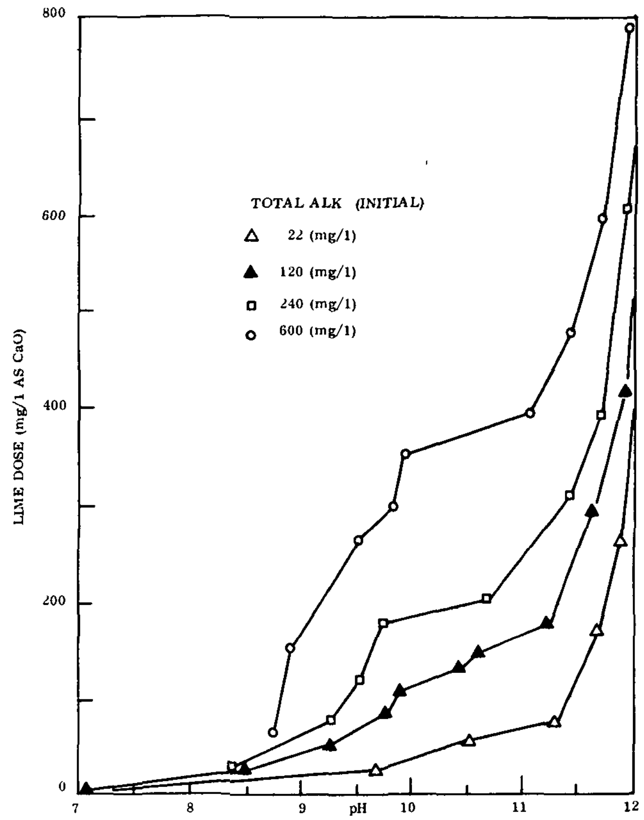


Figure 4-17. Alkalinity, Lime Dose, and pH

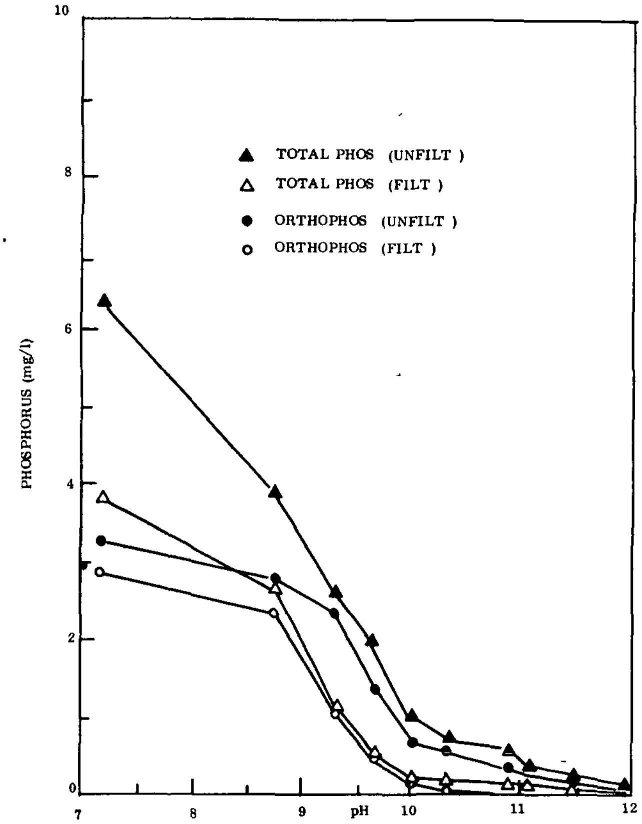


Figure 4-18. Lime Precipitation and Phosphorus Removal from Raw Wastewater

The cost factors for alum and lime are indicated below. The cost of thickening and disposal must provide for the differing amounts of chemical quantities present in the sludge, hence more sludge to dispose of. These values are unit costs and reveal the relative difference.

	Alum	Lime
Chemical ($ /k gal)	0.095	0.026
Recarbonation ($/k gal)	0.095	0.034
Amortization**	0.072	0.063
Function Cost ($/k gal)	0.167	0.097
Thickening* ($/k gal)	0.018 (1.23 lbs/k gal)	0.018 (2.93 lbs/k gal)
	or	
	0.02	0.05
Incinerate	0.02	0.05
Total costs ($/k gal)	0.302	0.223

*thickening by centrifugation-function cost = 0.018 $/lb
**includes capital costs (for 100,000 gpd)

As is obvious from the above total, lime addition for small scale systems seems to be on the order of 26% less costly than alum and is therefore the selected chemical for the proposed system. The impact of using lime influences the remaining unit functions by virtue of the high pH ($\sim$ 10.5) resulting from phosphorus precipitation.

Nitrogen removals can be accomplished by either breakpoint chlorination or air stripping to gain the maximum benefit from the high pH condition of the wastewater. As explained in Appendix I air stripping is temperature sensitive and for colder climates requires that the stripping tower be enclosed and maintained at 50-70^{o}F for best performance. As ammonia is transferred from the wastewater to the scouring air, the air quality is degraded and the free ammonia can be deposited in nearby land masses and waterbodies nullifying the removal on a system level although the specific wastewater treatment is accomplished. Breakpoint chlorination requires close monitoring of the oxidation reaction of the chlorine with the soluble organics which is followed by the formation of chloramines (see Appendix I) at a rate dependent on pH, temperature and interfering substances to the reaction. Because the interrelationships between these parameters are complex and each varies somewhat independently, this method is not considered ready for wastewater treatment applications. For this reason, and the fact that very high solid removals are accomplished by ultrafiltration, ion exchange using clinoptilolite loads is selected as the method for nitrogen (ammonium ion) removal followed by chlorination to complete disinfection of the wastewater. Discharge of effluent is to a man-made pond to assure complete transfer of oxygen for any residual demand. The pond ultimate size may depend on the extent of water reserves required for reclamation and use but should hold about five days equivalent of treated water minimally to allow dissolved oxygen recovery.

The proposed system is schematically shown in Figure 4-19.

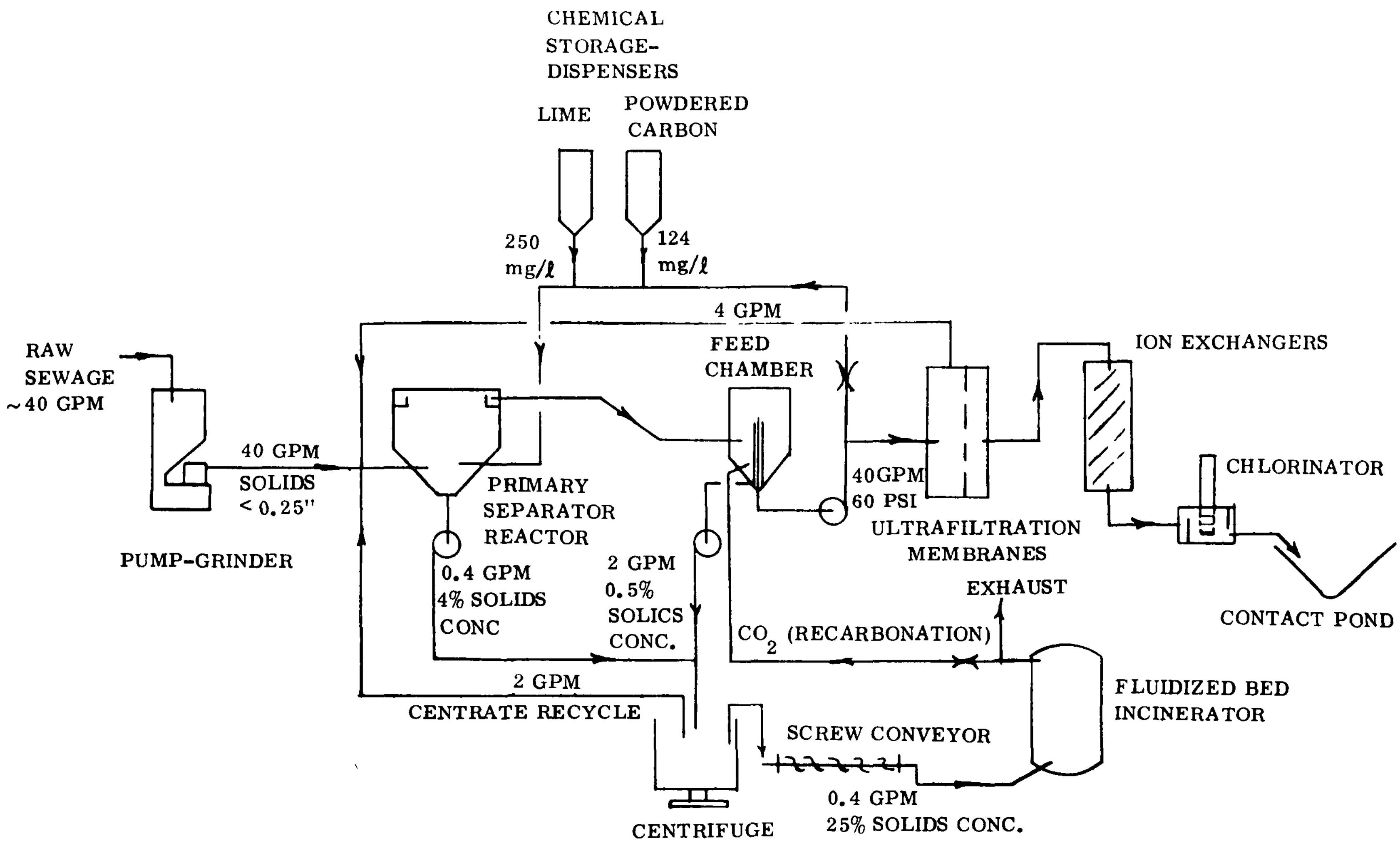


Figure 4-19. System Schematic

4.5 PROPOSED SYSTEM DESIGN

The physical provisions of the proposed system (Figure 4-20) are sized based on the hydrograph (Para. 4.2.1) with peak flow requirements (Para. 4.2.2) and wastewater characteristics derived from implementing the household baseline system (Para. 4.2.3) to the community level.

4.5.1 SURGE-RECEIVING STATION

Operating conditions bearing on this unit are:

	Value	Condition
Incoming flow rates	42 GPM	16 hr nominal
	125 GPM	1 hr peak
	57 GPM	6 hr peak
Chemical contact time*	25 minutes	
Primary separation process flow rates	20 GPM	low flow conditions
	40 GPM	16 hr. nominal
	60 GPM	peak conditions

*Total contact time required is 30 minutes apportioned between receiving chamber, transport pipe, mixing reactor and separator. Initial time budget is:

receiving station	4 min.
transport pipe	1 min.
primary-separator reactor	20 min.
feed chamber	5 min.

1. 2 hour peak inflow: = (1 x 6 hour peak flow + 1 hour peak flow) 60 min
   = 60 (57 + 125)
   = 11,000 gallons

2. 2 hour process reates = 60 (16 hour nominal x 2 hours)
   = 60 (40 x 2)
   = 4,800 gallons

3. Contact time capacity = 25 min (16 hr nominal)
   = 25 (40)
   = 1000 gallons

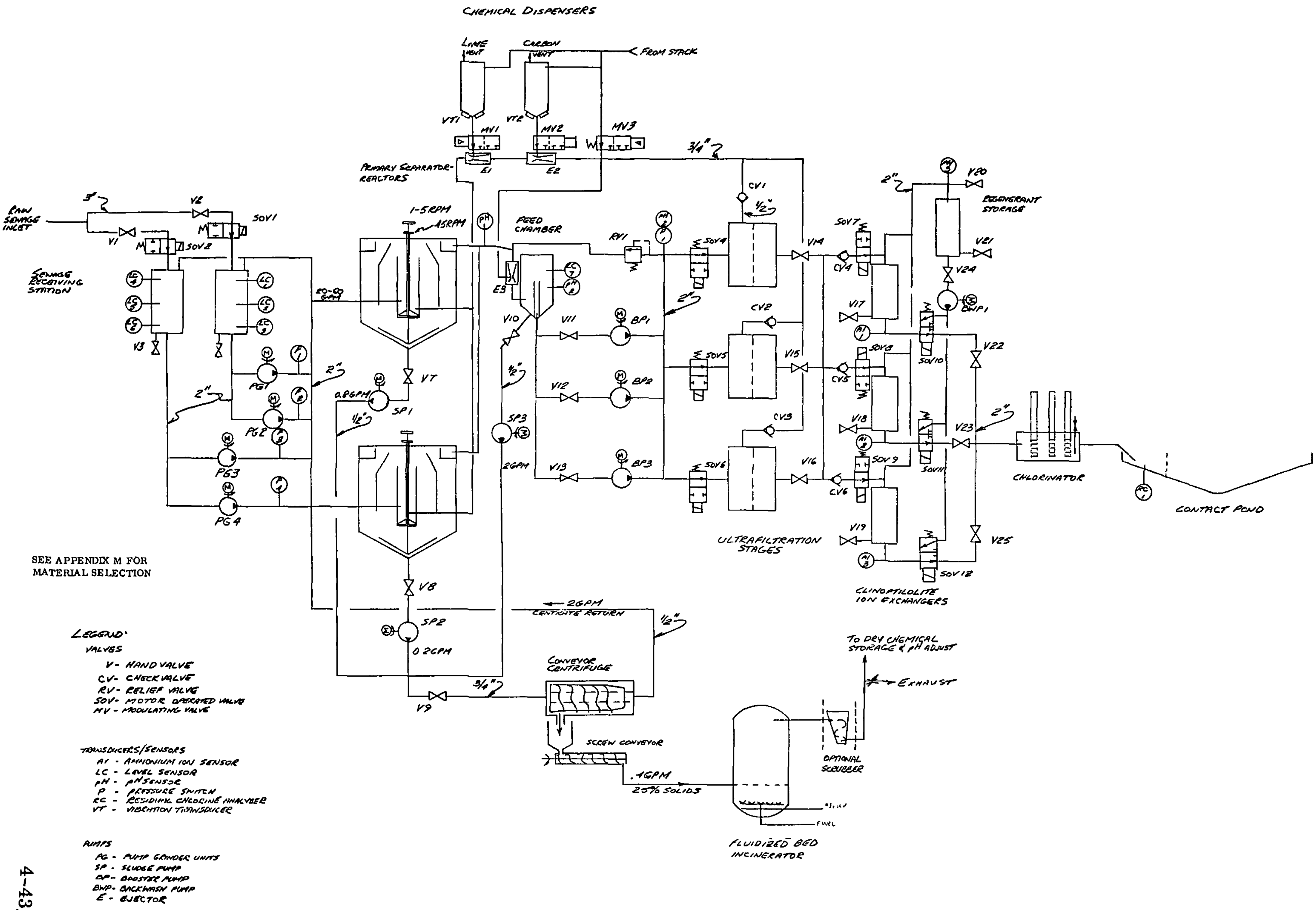


Figure 4-20. Advanced Waste Treatment Proposed System

Allowing 10% for the baffling, agitator and other internal hardware, the total volume is:

$$(7200 + 720) - 134 \quad \frac{ft^3}{gal} \quad = 106 \ ft^3$$

$$\begin{aligned} \text{Tankage required} &= 1 + 3 - 2 \\ &= 1,000 + 1000 - 4800 \\ &= 7200 \text{ gallons} \end{aligned}$$

4.5.2 PRIMARY SEPARATOR REACTOR

Chemical dispensers supply lime and powdered carbon to the primary separator-reactor in proportions dependent on the quantity of wastewater pollutants of interest, solution alkalinity and contact time.

Agitation is required to thoroughly mix the combined lime and powdered carbon slurry with the raw sewage. The agitator speed must assure a circulation capable of providing homogeneity of wastewater/chemicals to raise pH, permit absorption of soluble organics and good flocculation during the holding period. This speed is dependent on the particle size range of the wastewater. Since comminution precedes the chemical addition-initial mixing function; the agitator impeller speed will be established to prevent premature settlement of suspended matter.

4.5.2.1 Lime Addition

As shown in Figure 4-17 the dosage increases with higher alkalinity. The sewage represented by the baseline system should contain approximately 300 ppm (mg/1) alkalinity (from Section I, Para. 2.3). Interpolating between the curves for total alkalinities of 240 and 600 mg/1, it appears that a dosage rate of about 250 ppm of lime is required to raise the solution pH to the needed 10.5-11.0. This will result in 88% removal of Total Phosphorus or 0.88(76) = 66 mg/1 for the baseline wastewater. An additional 10% will precipitate out following the clarifier when the pH is adjusted downward for the ion exchange function.

1. Lime requirements are:

$$\frac{250}{10^6} \times 8.4 \frac{\text{lbs.}}{\text{gal}} \times 50{,}000 \frac{\text{gal}}{\text{day}} = 105 \text{ lbs/day}$$

2. Average lime density = 40 lbs/ft^2, therefore a dispenser for weekly refill would be sized at

   $$105 \text{ lbs/day} \times 7 \text{ days} \div 40 \text{ lbs/ft}^3 = 18.4 \text{ ft}^3$$

4.5.2.2 Powdered Carbon Addition

Assuming 30% of the wastewater BOD is in soluble organic form, carbon addition must be capable of absorbing 0.3 (408) or 123 mg/1. Using an average design value of 1.5 gms BOD/gm Carbon/ (mg/1 BOD) (derived from Ref. 50), the design load for carbon addition is:

$$\frac{123 \text{ mg/1 BOD}}{1.5 \ \dfrac{\text{gm BOD}}{\text{gm Carbon}}} = 82 \text{ mg/1}$$

Since dosage is in raw waste water, total dosage required to overcome inefficiencies and solids interferences = 150% design load x design load = 1.5 x 82 or 123 mg/1 carbon for worst case initial dosages. Using a carbon granule density of 24.5 lbs/ft^3, the weekly carbon storage volume requirement is:

$$\frac{123}{10^6} \times 8.4 \frac{\text{lb}}{\text{gal}} \times 50{,}000 \frac{\text{gal}}{\text{day}} \times 7 \text{ days} \div 24.5 \text{ lbs/ft}^3 = 14.8 \text{ ft}^3$$

4.5.3 FEED CHAMBER

This vessel serves to accumulate any precipitate (of calcium carbonate/magnesium hydroxide) resulting from a downward adjustment of the wastewater pH following primary solids separation and phosphate removal. The wastewater pH is lowered to about 8.5 to protect the ultrafiltration membrane from excessive hydrolitic aging (hardening/clogging) and establish ion exchange conditions for ammonium ion removals. The retention time required for this vessel is 2 minutes for the pH reaction and 5 minutes for precipitate formation and floc formation. Therefore, the tank capacity is:

$$7 \text{ min x peak flow rate x } 0.134 \ \frac{ft^3}{gal} = 7\ (60)\ (0.134) = 56.4\ ft^3$$

4.5.4 ULTRAFILTRATION STAGE

This stage provides final removals of any residual suspended solids including organics, precipitates, and carbon particles not settled in previous clarification equipment. For the 50,000 gpd system, using a membrane average flux of 10.5 gal/ft^2/day (based on the Pikes Peak system) the total membrane area required = $\dfrac{50{,}000\ \frac{gal}{day}}{10.5\ gal/ft^2/day}$ = 4760 ft.^{2} Due to flux decline or the inability to maintain rated flow through the membrane because of increasing blockage, the modules are divided into two units such that the 16 hour nominal flow can be processed through one unit (approximately 40 gpm) while the second unit operates during peak and low flow periods (at approximately 20 gpm). Initially, daily (membrane) washing of each unit is required until the flux decline histogram can be constructed and a realistic maintenance cycle shceduled. Additionally, based on the recorded flux decline of the Pikes Peak unit (Figure 4-21), an additional 10% or 476 ft^3 area will be included and apportioned such that a reserve capability is provided for unscheduled membrane cartridge replacement. Note: This stage is initially proposed using synthetic membrane cartridges (with their present flux rates). Dynamically formed membranes currently in laboratory R&D have an initial flux 9-10 times higher than the synthetic version and should replace the cartridge design when perfected. Equipment density (ft^3 of equipment/ft^2 of membrane area) is estimated at 0.24 therefore:

Total membrane area = 4760 + 476 = 5236 ft^2

Equipment size bogey = 5236 x 0.24 = 1257 ft^3

4.5.5 ION EXCHANGER BED (CLINOPTILOLITE)

This specific exchange media (clinoptilolite) has been under laboratory study by the Environmental Protection Agency for the last two years. The design factors employed herein are as recommended from these limited test results, Reference 51, as modified by the special wastewater characteristics of the baseline sewage. Since the most prevalent sources of ammonia

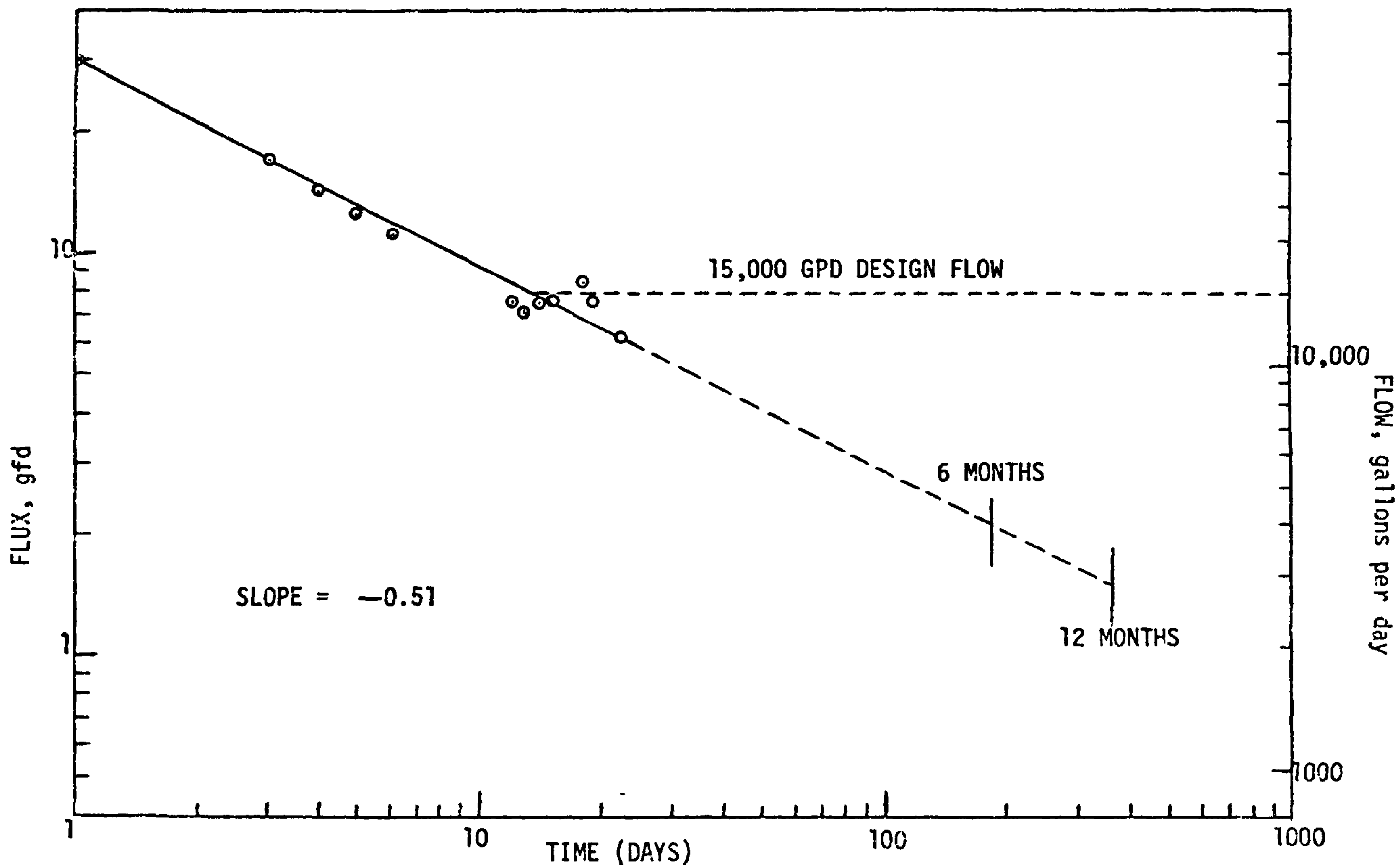


Figure 4-21. Membrane Flux Decline - Pikes Peak Wastewater Treatment System

nitrogen are the toilet and utility sink, the average wastewater characteristics from the typical home is applicable since these wastes are unaffected by the baseline concept. From Table 1-4, the total nitrogenous concentration is approx. 115 mg/1. From Reference 52, the urea content (prevalent source of ammonia) is about 68% of the total dissolved solids. Applying this to the conventional wastewater, the ammonia content is estimated at 78 mg/1 for the black water quantity (60 gal). Therefore, the average household ammonia nitrogen content is the dilution ratio, black water/total wastewater x 78 mg/1 or 60/98.5 x 78.0 = 47.7 mg/1. In reality, this is believed to be high (twice the average domestic sewage content) however, for design purposes, the potential overdesign will result in longer run times between exchange bed regeneration cycles, should the actual loading fall below the derived value. From Reference 51, the required flow is 15 BV/hr* (1.9 gpm/ft^3). To remove all available ammonia (1 mg/1 NH_3 - N in effluent) an exchange value of 0.24 milliequivalents/gram (meq/g) for pH = 8 and 3 ft. bed is required. By increasing the bed depth, ammonia exchange capacity can be increased (at constant flow). Therefore, assuming 90% of remaining ammonia is exchanged in a second 3-ft bed,a value of 0.43 meq/g to saturation is estimated. The overall bed will have an effective capacity of 0.34 meq/g. Total bed volume required = 50,000 $\frac{\text{gal}}{\text{day}}$ $\frac{\text{day}}{1440 \text{ min}}$ $\frac{1}{1.9 \text{ gpm/ft}^3}$ = 18.3 ft^3. From Reference 51, the column throughput is 175 BV or, at 15 BV/hr, a run length of 175/15 $\approx$ 12 hours between regeneration cycles. Assuming a 2 hour regeneration period, the total volume must be increased to 21.5 ft^3 for continuous operations. Regeneration to achieve 95% ammonia elution requires 30 gallons with 0.25 lb. Na Cl/gallon regenerant @ 15 BV/hr. at an adjusted pH of 11.5 (using Na OH addition to regenerant) for approximately 20 BV or $\frac{20}{15}$ = 13 hours. The resin bed must then be rinsed until the exchanger pH is back to 8. Rinsing can use product water to reach a pH of 10, returning the rinsewater at this level to the upstream treatment stages. Continued rinse until the pH is at 8.0 completes the bed regeneration cycle.

4.5.6 CHLORINATION

Disinfection efficiency is determined by lab tests on the product water to establish the dosage range for chlorine. Since there are three possible process flow rates (peak, nominal, low), the dosage required will be flow rate dependent after the wastewater chlorine demand is established for adequate disinfection (a residual in solution after a 20 minute contact time of ~0.5

*BV/hr = bed Volume/Hour

mg/1 available Cl_2). The method of chlorination proposed is the same as that recommended for the household baseline system (tablet form of calcium hypochlorite with 70% available chlorine). Consumption of these tablets for a 50,000 gpd flow is equivalent to about 0.5 gallon of chlorine daily, for a 10 gm/1 Cl_2 dosage rate or approximately 9.3 lbs. of tabletized chlorine/day.

4.5.7 CENTRIFUGATION

Dewatering will be required for the sludge settled in the primary separator-reactor. This sludge will comprise about 1% of the throughput at an average concentration range of 4 to 10% depending on residence time of sewage in the primary separator-reactor which is a function of the hydrograph variation and the system change in processing rates. For dewatering design, the 4% value will be used. Therefore, the centrifuge loading from the reactor is 1% x 40 gpm = 0.4 gpm @4% solids concentration.

A second sludge source is the feed chamber. This sludge (concentrated calcium and magnesium carbonate plus some organic solids) will have an average concentration of 1/2% and is withdrawn on a demand basis in 20 gallon increments at a 2 gpm rate.

The last sludge source is the rejected waste from the ultrafiltration membrane. This sludge will consist mainly of the fine organic solids remaining in solution and residual powdered carbon. These will be contained in about 10% of total flow or 4 gpm. This source can be returned to the reactor for additional floccing to form a heavier sludge (with the raw sludge) or directed to the centrifuge. Initial design will be to recycle this stream to the reactor. Since this sludge is mainly fine organics, dewatering is difficult and results in high amounts of bound water leading to inefficient incineration. By attempting recycling to the high pH treatment stage further hydrolysis can allow these particles to be absorbed by the powdered carbon.

The centrifuge will therefore accept 0.4 gpm (4% solids) from the reactors and 2 gpm (1/2% solids) for 10 minutes/run, from the feed chamber. The centrifuge should dewater the raw primary sludge to about 30% solids (75% water rejection) or a return centrate flow of 0.3 gpm max. The high mineral content sludge should dewater to about 5% solids (90% water rejection) or a return flow of 1.7 gpm. Totaling, the centrifuge feed water is 2.4 gpm (max. nominal) with a return (centrate) flow of 2.0 gpm and a sludge production rate at 0.4 gpm.

4.5.8 INCINERATOR

The fluidized bed incinerator will accept 0.4 gpm of sludge (max. nominal) with the following characteristics.

Primary sludge - 30% solids (0.4 gpm) comprised of:

	Quantity (mg/1) removed	Sludge (PPM)
Ca CO_3	225	82450
Organics	286	104750
Carbon	243	89000
Phosphorus	66	24150

Secondary sludge - 5% solids (2 gpm) comprised of:

		Sludge @ 5% (PPM)
Phosphorus	7.6	2080
Carbon	27	7340
Organics	123	33650
Ca CO_3	25	6840

Total sludge values are:

Total solids concentration = 25.8%

Composite Characteristics

	Quantity (PPM)	% of Total Solids
Organics	92860	36
Carbon	75370	29
Phosphorus	20460	8
Calcium Carbonate	69740	28

The heat requirements for this sludge is derived in the following analysis:

	% Sludge	Heat Balance (1) (BTU/lb)
Moisture content	74.2	-1770
Dry solids	25.8	
Combustibles		+12,300
Ash @ Cp = 0.2		-288
Calcium Carbonate		-958
Carbon		+14,600

(1) Derived from Ref. 25 on a final temperature of 1500°F

At 0.3 gpm (18 gal/hr) and a sludge specific gravity of 1.14

Heat Balance	Quant (lbs/hr)	Heat Value (MBTU/hr)
Water (s.g. = 1.0)	112.0	-0.20
Dry Solids (s.g. = 1.54)		
Carbon	4.7	-0.07
Ca CO_3	11.9	-0.01
Organics	20.6	+0.25
	149.2	-0.03

The potential gain in heating value due to the high solids concentration is offset by the need to burn the powdered carbon. A net deficit of 30,000 BTU/Hr is evident and will require an auxiliary fuel source. Fuel oil, at a calorific value of 148,000 BTU/gallon handles the needed additional heat plus operating losses (assuming 40% lost heat) with supply flow at about 0.3 gallon/hour. The incinerator sludge feed rate is estimated at 150 lbs/hour nominal. Exhaust gases will be odorless and sterile, however, carbon blow-off may require a stack gas scrubber to remove particulates.

4.6 COMPONENT DESIGN

The component design approach (Figure 4-20) considers system operation in three possible modes, as predicted by the community hydrograph. During the normal waking hours, the predominant process flow will be 40 gpm. During any peak influent conditions, level sensors will control the second process rate by actuating and maintaining a 20 gpm adjunct capability during these periods of high influent hydraulic loading. Following the declining sewage peak flows (after 2 p.m.), level sensors will terminate the 20 gpm system retaining the nominal (40 gpm) capability until the influent declines to the low flow mode (after 10 p.m.) when the 20 gpm system will be again brought on line and the 40 gpm network shutdown. Since modularity is a prerequsite, the overall height of any component shall consider the transport limits of 13.5 ft clearance as a commonly accepted maximum clearance limit for over-the-road transportation. Thus allowing 18 inches roadbed clearance to the underside; 12 feet is a design constraint for the equipment envelope of permanently attached hardware. All states accept 10 foot wide cargo and most states issue road permits for 12 foot wide loads when escorted. The concept design (Figure 4-22) will be baselined for a 10 foot flat-bed trailer, with up to 40 feet of usable packaging length per trailer.

4.6.1 MACERATOR-PUMP RECEIVING CHAMBER

The chamber is sized to absorb and dampen the influent peak flow variations. The maximum variation is between the hours of nominal to peak flow change less the nominal process rate and is equal to 125x(60)-2x(40)x(60) or 2700 gallons. This volume will be directed to two 1320 gallon tanks sized at 4'9" ID x 10 feet high with parallel interconnects (with isolation valves) each containing two 20 gpm pump-grinders at their base. An emergency overflow line to the primary separator-reactor ensures continued operations when pump-breakdown occurs during a nominal or peak flow inlet condition. Outlet piping is sized at 2" IPS.

This diameter provides a fluid velocity of 1.91 and 5.74 ft/sec at 20 and 60 gpm respectively, sufficient to prevent clogging of the lines by the stream suspended matter at either pumping rate. Power required for pumping $= \dfrac{\text{GPM x Head (Ft-}H_2O)}{\text{3960 x Pump Efficiency}}$

$$= \frac{20(80)}{3960(0.8)} = 0.5 \text{ H.P. for each pump}$$

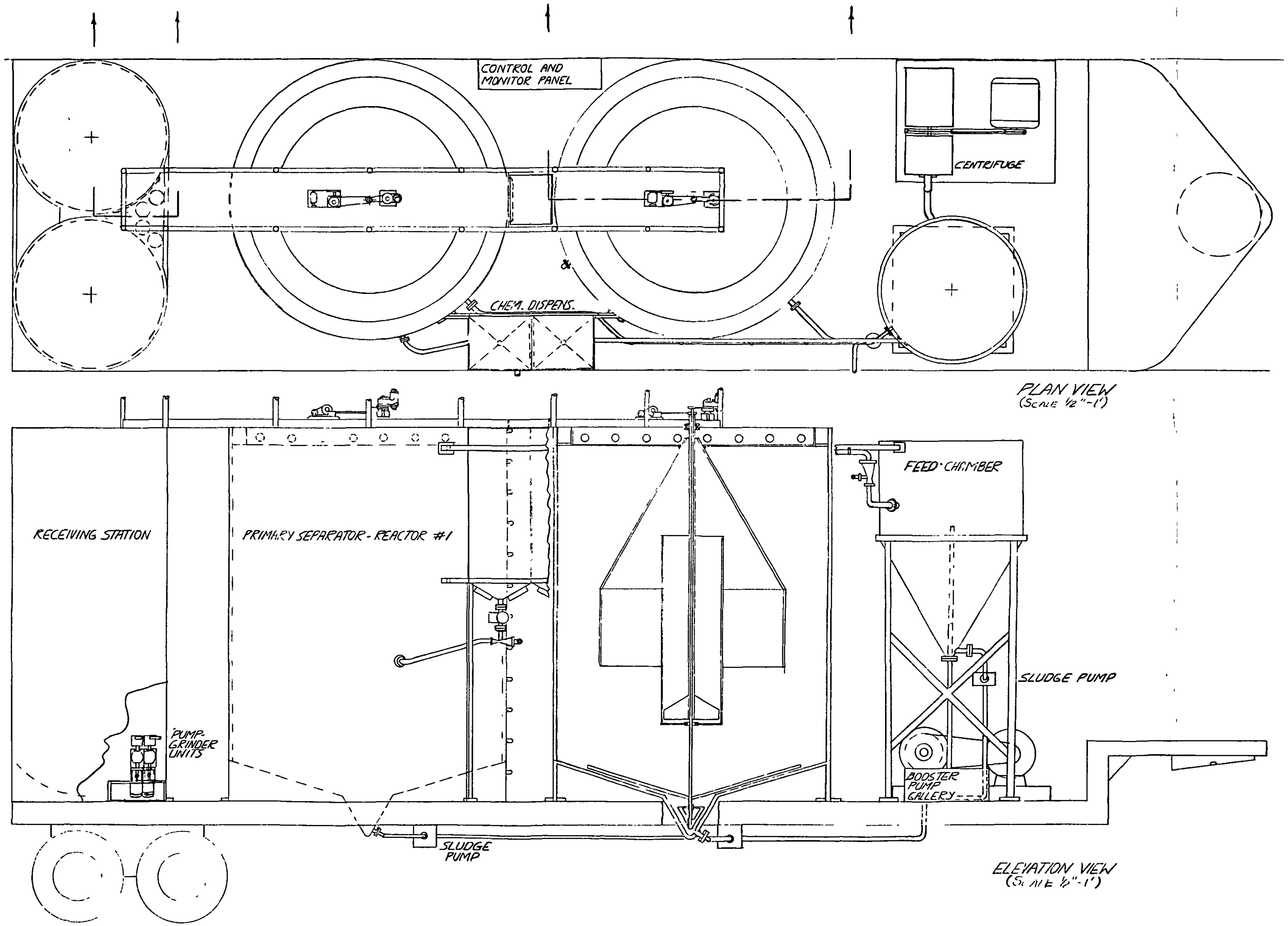


Figure 4-22a. Advanced Waste Treatment System Trailer #1

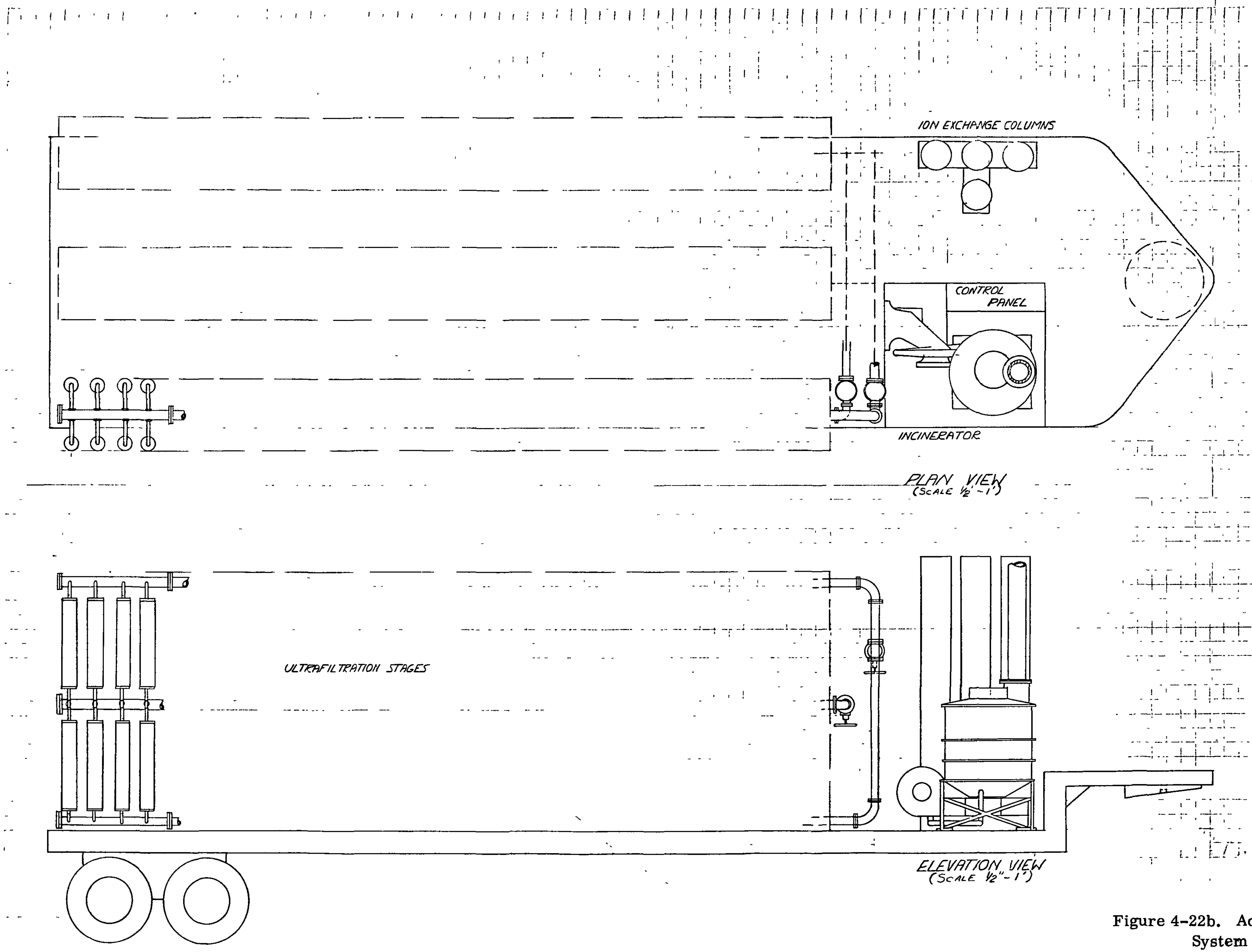


Figure 4-22b. Advanced Waste Treatment System Trailer #2

Level sensors (bubbler types) are mounted along the tanks sidewalls and control operation of the inlet valves and pump-grinder operation as follows:

Tank station - inches from bottom (typical each tank)	Sensor Status	Function Controlled
5	open	processing power-off
	closed	pump-grinder on if STA 44 also closed, process functions activated
44	open	pump-grinder off when STA 5 is open
	closed	pump-grinder on
100	open	pump-grinder off when STA 5 is open
	closed-<10 min after STA 44 closed	inlet valve to other tank opened (if closed), auxiliary ultra-filtration boost pump turned-on

These tanks will be alternately on-line during low flow conditions, to share the operating duty cycles. Inlet piping is sized at 3" IPS to maintain scouring velocities throughout most of the influent flow range (20-125 gpm) anticipated.

4.6.2 PRIMARY SEPARATOR-REACTOR (Figure 4-23)

Using 20 gpm (nominal) and 60 gpm (high) flow rates, the 60 gpm rate is the design limiting value for sizing the separator-reactor. Within this component, the following functions and design impacts are applicable:

Function	Requirement	Design Impact*
Chemical mixing (lime and carbon)	Agitate chemicals with wastewater for 30 seconds	Volume and stirring for 30 sec detention in mixing stage

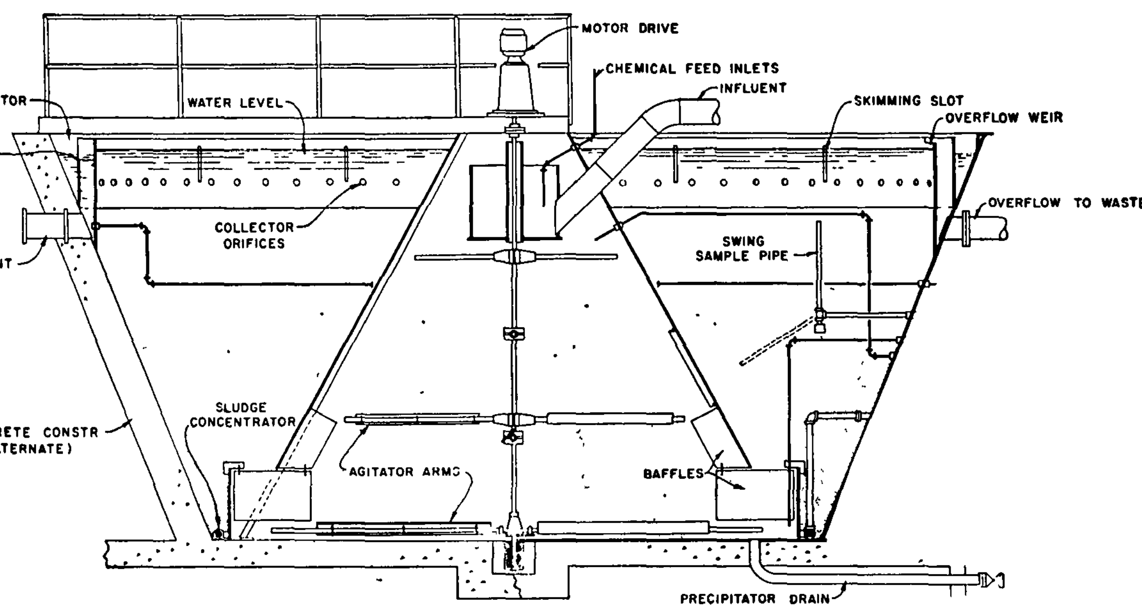


Figure 4-23. Primary Separator - Reactor Concept

Function (Cont)	Requirement	Design Impact*
Flocculation of suspended solids	30 minutes	volume and blending chamber for 30 min. at process flow
Solids separation	2-1/2 hrs for clarification	volume for quiescent chamber at overflow rate of 1200 gpd/ft (Ref 27)
sludge handling	non-interference with separation process	additional volume for raking and sludge accumulation

From the above criteria the following sizes result:

	Gallons	Volume (ft/.)
Chemical mixing chamber volume = 5 min (60 gpm) =	30	4
Flocculating section = 30 min (60 gpm) =	1800	240
Separation section = 60 min (60 gpm) + 90 min (30 gpm)** =	6300	840
Sludge section = 1.0 gpm (30 min) =	30	4

(*) from Ref. 40 except where noted
(**) assumes one of the 2-1/2 hours is at peak flow

The overflow rate determines the minimum area and is 50,000 GPD/1200 GPD/ft = 41.6 ft^2 or a diameter of 7.3 feet minimum. Total gallonage at 8100 will be divided into two separation-reactor units sized at 4000 gallons each (allowing 10% for internal baffles, mechanical equipment, etc). This suggests a unit diameter of about 8'9" for a 10' high tank. Overflow rate at 40 gpm (nominal) flow = 40 GPM x 1440 $\frac{\text{min.}}{\text{day}}$/60.2 ft^2 = 960 gpd/ft^2.

Referring to Figure 4-23, the mixing and floc forming sections extend down from the weir surface level. This sections volume for the proposed concept is 124 ft^3. This results in a truncated conical section at the top, about 9-1/2" diameter and at a depth of 4'8" is at full diameter (6'1") at an included angle of 30^o. The cylindrical section is 2'4' long (1/3 the total depth). Within this section, rapid mixing is required for five minutes after initial chemical introduction. This represents a volume of 5 min x 30 gpm or 150 gals (20 ft^3). The mixing impeller tip speed is 5 ft/sec maximum. The length of this chamber must extend well into the conical section in order to allow solids agglomeration (due to impacts) within the changing velocity gradients as the mixture proceeds down to the sludge blanket located at the bottom surface plane formed by the cylindrical section. Setting the length at 6' , cylinder section diameter is 2'. The relationship between the cylindrical mixing section and the conical chamber is that the fluid velocity is not increased when passing through these sections therefore, the flow areas at the plane of the intersection must be equal or favor the conical section. The remaining volume provides a 2-1/2 hour equivalent separation-settling zone with the overflow weir conducting the wastewater to the feed chamber.

4.6.3 FEED CHAMBER

The high pH incoming wastewater contains carry over precipitates that can be settled out by lowering the pH. Further, the ultrafiltration membrane life (when constructed of synthetics such as cellulose-acetate) is extended by lowering the hydrolysis potential of the solution. The feed chamber, in supplying the booster pumps to the ultrafiltration module, dampens any overflow rate variations providing a minimum constant head. Design parameters require 7 minute retention for pH reaction and precipitate formation. This results in a 420 gallon vessel (60 gpm x 7 min) and allowing 10% for internally mounted equipment is sized at 61.5 ft^3. The height is limited by the overflow weir height and outlet line which is approximately 9-1/2' above the projected installation foundation. Therefore, a 9' height (max) will be used. The required volume yields a major diameter of 4.4 ft. The conical section (30^o angle) contains 22.8 ft^3 and the upper section. 38.7 ft^3 for and overall vessel height of 7.25 ft plus supporting structure.

4.6.4 ULTRAFILTRATION STAGE

As developed in Section 4.5.4, the total membrane area is 5236 ft^2. Available cartridges are sized at 14 ft^2/cartridge and manifolded in groups of eight (112 ft^2/module). Each module requires access from each long side and occupies an envelope of ~4' H. x 3-1/2'L x 2-1/2'D.

Using 10 feet of available height for distribution piping and vertically oriented cartridges, 2 tiers of modules are feasible (224 ft^2 membrane area/3-1/2 ft). For the required system, 23 two tier modules are required. Three rows of eight modules each at 3-1/2 ft/module x 8 modules = 27 feet/each stage is proposed with two stages operating on-line and the third on recycle or maintenance flows (back wash or cartridge replacement). With three galleries of cartridges and a 2' aisleway between rows, overall width is 11-1/2' therefore for over-the-road transfer it may be necessary to disconnect and slide the outer rows toward the center to comply with usual vehicle width limits.

4.6.5 CLINOPTILOLITE ION EXCHANGER

As with the ultrafiltration stages, the ion exchanger columns will be operated in pairs for nominal flow conditions with the third undergoing regeneration or other maintenance. Each bed is sized at 6' deep for down flow ion exchange. A 50% expansion factor is applied to the actual column height to allow for backwash and regeneration using an up-flow system. Therefore, the column height is 9' with each stage containing 6.1 ft^3 of clinoptilolite. Each column is 14" diameter, 9' high. Backwash/regenerant is prepared and stored in a fourth tank of the same size to service up to 2 columns before reconditioning the solution.

4.6.6 CHLORINE DISPENSER

The chlorine tablets are contained within tubes immersed in the flowing stream such that wastewater depth (flow rate) is proportioned to the tablet wetted area. No special design is required as this is a passive device needing only a calibration of residual chlorine to influent coliform count. The housing and tube envelope measures approximately 21' long 14" wide and 30" high (see Figure 4-24).

4.6.7 CENTRIFUGE

The sludge flow rates are very low in comparison to the available centrifugal devices designed for dewatering applications. There is one solid bowl continuous feed machine available capable of performing to the requirements specified. It is a smaller version of the conveyor-type machines described in Appendix G. Typical of centrifugal devices, solids loading variations and feed rates have relatively minor effect on an adjusted centrifuge. Envelope required is 4' wide x 5' long x 1-1/2 high. Inlet size is 3/4" pipe and the sludge discharge is 2" x 6" flange converted to a teflon-lined hopper feeding the sludge incinerator pump. Concentrate discharge is a 2" IPS coupling (see Figure 4-25).

4.6.8 FLUIDIZED BED INCINERATOR

In order to accept the high sludge feed concentration the output flow of the screw conveyor may require some grinding to reduce any caked solids to a size distribution compatible for the mass flow rates of the incinerator. Some laboratory and/or pilot tests will be required by the incinerator vendor to properly size the equipment.

One very attractive improvement in performance economics may be realized if the ash, containing reactivated carbon and lime, can be recovered and recycled to the primary separator-reactor, thereby reducing lime and carbon dispenser feed rates to make-up only the losses.

For additional information on incinerator operation, refer to Appendix L.

4.6.9 CHEMICAL STORAGE/FEED STATION

Since both carbon and lime are readily dispensed in a dry form, the dispensers will be equipped with "dithering" transducers to maintain fluidized flow of the powders into eductors for slurrying into the primary separator-reactor. The dosage rates will be calibrated and metered using gate valves. The hoppers will be lined, galvanized or PVC vessels with weather seals to prevent moisture intrusion which would cause caking of the stored materials.

A portion of the exhaust gases from the incinerator cooling circuit may be circulated to the ullage spaces of these vessels to assure dry conditions prior to gas discharge through positive pressure vents. Since both volumes are approximately the same, the tankage required will be sized for the larger amount and used for both chemicals. The point of injection into the primary separator-reactor is about three feet above the equipment mounting reference plane. The slurry educators, using the ultrafiltration solute reject stream, will

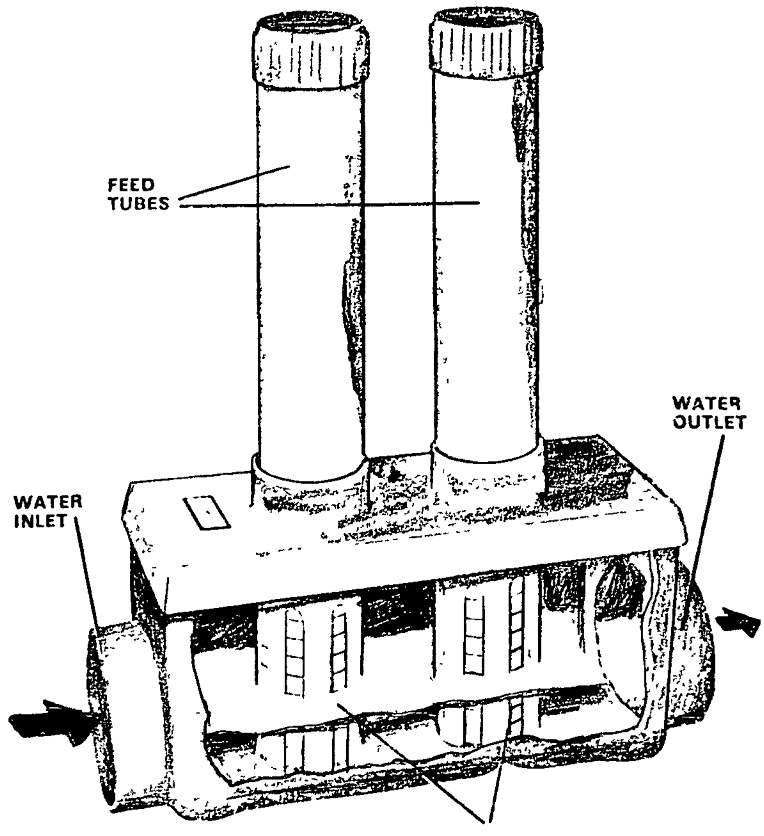


Figure 4-24. Tablet Chlorinator

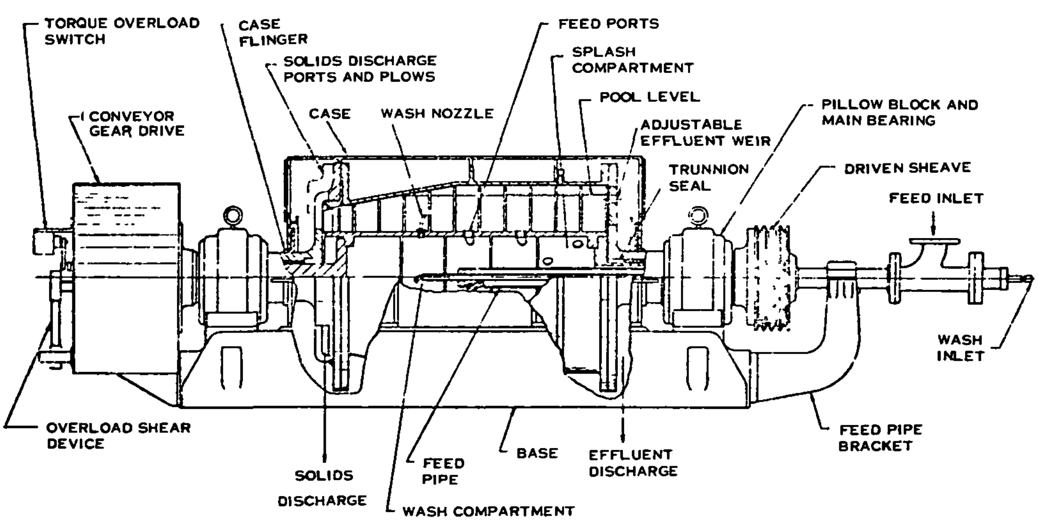


Figure 4-25. Solid Bowl Conveyor Centrifuge

draw a slight vacuum on the chemical feeders to offset the water head (back pressure) of the primary separator-reactor (about 5 feet). The hoppers should be elevated to this level for the dithering system to provide gravity assist to the slurry eductors. Therefore, allowing 2' for refill from above the hoppers, the maximum height available is 5 feet and yields a hopper size of 2' square x 5' high for each chemical.

4.6.10 SUPPORTING HARDWARE

4.6.10.1 Piping

Wastewater, and the chemicals added, challenge most usual piping materials due to the corrosiveness and nature of mixed media in solution. For the proposed system, PVC piping is specified for all systems due to the ease of fabrication (fusion solvent welding), flexibility when vibratory inputs are experienced, and hydraulic advantages offered by the smooth internal surfaces. In general, pipe sizes are selected to conduct the wastewater streams at a minimum flow velocity of 1.5 ft/sec.

4.6.10.2 Valves

As with the piping, valve bodies are PVC wherever shut-off, sampling/drain and isolation valves are required. Seal replacement is the only significant maintenance task as corrosion rates are minimal. Seals and seats can be of viton or teflon.

4.7 PROPOSED SYSTEM ECONOMICS

Table 4-9 summarizes the capital and operating costs of the proposed system at the 50 Kgal/day size proposed for a 500 unit apartment building. The major capital cost elements above and beyond a conventional system are an ultrafiltration stage which contributes 44% of the total capital cost and a sludge incinerator which contributes 18%.

Table 4-9. Water Recovery System Cost Summary (Ref. Appendix M)

Capital Cost:		
Equipment: (installed)		
(a) valves, pumps, pipe	$ 8,100	
(b) clarifiers	52,800	
(c) instrumentation	6,700	
(d) sludge conveyor	5,100	
(e) sludge centrifuge	14,400	
(f) incinerator	46,600	
(g) chlorinator	200	
(h) tankage & vibrators	10,700	
(i) ultrafiltration	112,500	
	257,100	
contractor fee (10%)	25,700	
contingency (10%)	28,300	
total capital cost	$311,100	
Operating Cost:		
(a) activated carbon (123 mg/l)	0.09	$/Kgal
(b) lime (250 mg/l)	0.01	
(c) chlorine	0.04	
(d) ultrafiltration	1.49	
(e) centrifuge (26 lbs/hr)	0.22	
(f) incinerator (26 lbs/hr)	0.05	
total operating cost (excluding labor)	1.90	$/Kgal
(7%, 25 yrs.) capital amortization	1.47	$/Kgal
total system cost	3.37	$/Kgal

The total capital cost of $311,100 includes equipment purchase, installation, contractor fee and contingency. It does not include utilities support, site preparation, or housing, since these elements are presumably already present in the apartment complex. Likewise, there are no provision for sewage collection or water distribution costs since these items are assumed present regardless.

The operating cost estimate of $1.90 $/Kgal includes chemicals, electric power, and fuel oil. Also included is periodic replacement of ultrafiltration membranes. Not included is manpower for operation and maintenance. This cost is uncertain for two reasons. First, there is little operating experience with some of these processes, ultrafiltration in particular. Second, the manpower cost will depend, in part, on the size and availability of the labor force required for normal maintenance throughout the apartment complex. An approximate estimate of the labor cost for operation and maintenance, assuming no excess labor is available, would be about $2.00/Kgal.

In comparing these estimated costs for the proposed system with a conventional system, account must be made for both the waste treatment and the water supply benefits supplied, as well as the less tangible benefit of no water pollutant emission.

Referring to the cost criteria developed as part of the baseline system definition, the "typical" rate for both water and sewage service was found to be 1.19 $/Kgal. This rate was based on tie-in to a utility district serving 25,000 population. A "worst case" rate for an isolated rural community using ground water supply and tertiary waste treatment was found to be $8.20/Kgal. Of this amount, $2.67 represents sewer costs which are not applicable to the apartment complex. The adjusted worst case cost is therefore $5.53/Kgal.

In comparing these costs with the estimated proposed system cost of 3.37 to 5.37 $/Kgal., it is apparent that the proposed system is far more costly than the typical case and approximates the worst case utility cost which is seldom found.

However, another perspective on the proposed system's cost can also be taken. Even with its high capital cost, the proposed system would add only 4% to the construction cost of a typical 500 unit apartment. Such a cost could conceivably be offset by the land price differential between sites with and without the alternative of conventional utility support.

Likewise, the operating and capital amortization cost, though much higher than a conventional system, is still within reason, since \$3.37/Kgal comes to approximately 10\$/mo. per apartment.

In the final analysis, the economic feasibility of the proposed system will be influenced by whether the high treatment level provided is a realistic requirement and whether another, less expensive, system can be synthesized to meet the same performance criteria.

4.8 SYNOPSIS

It should be recognized that many of the processes used in advanced waste treament (such as sedimentation, coagulation, filtration, chlorination, activated carbon, aeration and demineralization) also are used, to varying degrees, in treatment of alternative sources of water supply with which reuse should be compared. Thus, it is not simply a case of comparing the cost of advanced treatment for reuse with the cost of an alternative means of physically supplying water. They must be compared on a common basis. If the alternative supply source includes treatment, the treatment cost must be added to it to compare with a reuse source. Similarly, of course, any cost of conveyance to bring a reuse supply to a common point with an alternative source must be included in the reuse cost.

It is quite conceivable, therefore, that the net cost of advanced treatment to make water available for reuse will be quite small. In effect, the net advanced treatment costs are equal to its total costs less the treatment costs of the alternative supply, plus or minus any difference in conveyance costs to bring alternative supplies to a common point.

SECTION 5

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