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GRUMMAN

STUDY OF WATER RECOVERY AND SOLID WASTE PROCESSING FOR AEROSPACE AND DOMESTIC APPLICATIONS

VOLUME II - FINAL REPORT

Prepared Under Contract NAS 9-12503

For The
Manned Spacecraft Center,
National Aeronautics and Space Administration
Houston, Texas

DWR 630-09

STUDY OF WATER RECOVERY AND SOLID WASTE PROCESSING FOR AEROSPACE AND DOMESTIC APPLICATIONS

VOLUME II - FINAL REPORT

By
Charles A. Guarneri
Arnold Reed and
Ronald E. Renman

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FOREWORD

This document was prepared by the Grumman Aerospace Corporation under Contract NAS9-12503 "Water Recovery and Solid Waste Processing for Aerospace and Domestic Applications" for the Urban Systems Project Office at the Manned Spacecraft Center of the National Aeronautics and Space Administration. The Program was administered under the technical direction of Mr. Reuben Taylor.

Information pertaining to water resources was provided by Geraghty and Miller, Consulting Ground and Water Geologists.

An abbreviated description of the contents of this report is contained in Volume I - Final Report Summary.

ABSTRACT

Land development in many parts of the country is discouraged by inadequate water resources or by incompatibilities between water supply and waste treatment plans. Many established areas cannot satisfactorily keep pace with rapidly expanding urban populations for the same reasons. In addition, the cost of additional water supply and waste management in such areas can be extremely high. Practical alternatives to conventional water and waste treatment systems are required in newly constructed or redeveloped communities where such difficulties exist. This report evaluates the manner in which current and advanced technology can be applied to develop practical solutions to existing and emerging water supply and waste disposal problems.

An overview of water resource factors as they affect new community planning, and requirements imposed on residential waste treatment systems are presented. The results of equipment surveys contain information describing: commercially available devices and appliances designed to conserve water; devices and techniques for monitoring water quality and controlling back contamination; and advanced water and waste processing equipment. System concepts are developed and compared on the basis of current and projected costs. Economic evaluations are based on community populations of from 2,000 to 250,000. The most promising system concept is defined in sufficient depth to initiate detailed design.

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INTRODUCTION

During the past decade, the NASA, and aerospace and commercial industries have been concurrently advancing water and waste management technology. This study explores the application of advanced concepts for water recovery and solid waste processing systems for residential use. Its objective is to define a system concept which offers the best potential for near term and future usage. Concepts are developed and evaluated within the context of a total system that would provide all necessary utilities to a "free standing" community. For the purposes of this study a community model consisting of 500 newly constructed low rise apartment units with four (4) occupants per unit was assumed.

The study was initiated with a regional overview of water resource factors as they affect new community planning. Determinations of residential water use and waste generation rates were also made.

Significant reductions in household water flow can readily be achieved by appliances and fixtures currently being used in aircraft, marine, and mobile and remote home applications. A survey of this equipment was conducted. Surveys were made to accumulate data describing currently available water quality monitoring and control equipment, and water and waste processing systems. Aerospace versions of processing equipment were also reviewed to evaluate the contribution that this technology will make in the design and development of advanced systems.

Equipment and operating cost data was accumulated for those processes that were considered appropriate to the community model. Nineteen concepts in four categories based on major process selections were developed. The concepts incorporate varying degrees of water conservation, reuse and reclamation.

They were evaluated by means of a straightforward comparison of total system costs, with some consideration given to water consumption. In order to avoid selection of a concept suitable only for small populations, the comparisons were extended to towns of 25,000 and 250,000. Water hardness was found to produce a significant cost variation as a result of differing detergent and/or water softening needs. Comparisons were therefore made for both hard and soft water areas. Projections were made to the year 2000 to assess any shift in relative cost due to differing rates of increase in the various system components.

Differences in the overall costs of the concepts evaluated are not as dramatic as was anticipated. This is a result of the dominant influence of equipment that is common to all concepts studied such as fixtures, appliances, plumbing and certain waste handling and disposal provisions.

A category of concepts that collects concentrated "black water" (toilet waste) by a vacuum system, thereby allowing it to be incinerated directly, was found to be most economical in both hard and soft water areas. Concepts within this category differ in the extent to which "gray water" (sink, bath and laundry water) is recycled or reused. The more expensive categories either: (1) combine and biologically treat black and gray water or (2) reuse gray water for toilet flushing prior to various forms of treatment. The cost of concepts within the selected category were found to vary with the hardness of the water supply. As water hardness increases, greater degrees of reclamation are favored.

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Site selection for the systems studied will most likely be dictated by water availability. Furthermore, water short areas tend to have greater hardness. As a result, a system concept that: (1) reuses gray water for subsurface landscape irrigation during growing seasons and (2) treats gray water to potable quality for limited household reuse during the remainder of the year, was selected for more detailed definition. The process selected to treat gray water features reverse osmosis membranes. An absolute determination of a system configuration cannot be made in the absence of a specific site location. The system defined nevertheless incorporates features that are appropriate to any application.

A preliminary design of the selected concept was made. Specifications for selected and designed components are presented along with an overall system schematic. The interfaces of the system concept with a total energy system are identified. In an appendix, a cursory review of thermodynamic systems for power genreation and their fuel consumption requirements are given.

SUMMARY/CONCLUSIONS

The following summary is presented in the form of major conclusions derived from each section of the study.

I. Water Resources

- Local geography, geology, hydrology and climate play dominant roles in the development of water and waste management system configurations. Since a site location was not specified for this study, it was necessary in some instances to generalize environmental interfaces.

- Irrigation requirements also influence system design. In an average climate, lawn watering needs exceed gray water production during nearly half of the year. Subsurface gray water irrigation was found to be an effective means of reducing recycle requirements and beneficially disposing of wash waters.

- Water hardness has a significant effect on both household effluent quality and system cost. Reclamation processes soften water, resulting in decreases in detergent and/or softening costs in hard water areas of up to $60 yearly for each family. In general, the water supplies in arid areas are hard. This increases the suitability of recycle systems to water-short areas.

- Present and near term projections of public, medical and legislative attitudes toward water reuse strongly suggest that some restrictions be imposed on the use of recycled waste waters in initial systems. As a result, none of the concepts considered use recycled black water for other than landscape irrigation. Even for this application, the black water is treated first to at least tertiary quality and then applied to the soil via sub-surface watering techniques. Recycled gray water, although potable, is not considered for routine internal consumption. It is used for laundry, bath and irrigation purposes only, in various concepts.

- With the rapidly increasing emphasis on new towns, new communities and planned unit development (PUD), water supply practices will probably change markedly. One effect will be a trend towards reduced per capita consumption through widespread use of low water consumption devices. In addition, the practicality of water recycling in new developments will result in considerable decreases in fresh water usage. However, recycle systems will be more expensive by reason of extra equipment and plumbing. Dividing this increased cost by fewer gallons consumed per capita will make water costs seem to be very high. If recycle systems are economically justified, it will be as a result of savings in sewage treatment and refuse and thermal management.

II. Waste Generation

- Estimates of water-borne and solid waste generation vary widely with such factors as level of affluence, social and personal habits, climate and housing. Empirical data is limited and difficult to correlate.

A recent Swedish experiment, which instrumented apartment buildings, is used as the basis for the water-borne waste generation rates used. Solid waste generation data is based on situations considered representative of the community model employed.

III. Commercial Equipment Surveys

- Household water requirements can be reduced significantly by employing currently available low water use fixtures and appliances at little or no cost or inconvenience to the user.

- Process instruments, capable of adequately monitoring water in a recycle system for bacteria and viruses, are not currently available. Available bacteria monitors have inadequate response times. Virus detection is generally accomplished manually and incubation periods are required. While development work is being undertaken by NASA and industry, purification systems must preclude the need for such instruments. This can be accomplished by closely tracking simpler measurements such as pasteurization and sterilization temperatures or bactericide concentrations.

IV. Applicable Aerospace Technology

- A wide variety of development programs have been undertaken by NASA and the aerospace industry as a result of the criticality of efficient water and waste management to the design of advanced manned spacecraft. For the most part, resultant systems contain processes that were originally developed for less demanding industrial and commercial applications.

  Evaluations revealed that much of the sophistication of aerospace adaptations of water and waste treatment processes is a result of unique requirements for: zero gravity operation, extremely high reliability and minimum weight, volume and power utilization. Great emphasis is placed on systems integration as a means by which spacecraft penalties can be held to absolute minimums. Extensive manned test programs are conducted to evaluate "closed loop" systems. Since there are practical limits on achieving reliability, in-flight maintenance provisions are designed into critical spacecraft systems. Much of the technology developed to adapt water recovery processes to spacecraft requirements, are relevant to the development of advanced integrated urban utilities systems, especially in the detailed design and implementation phases.

V. Community Model

- The physical layout of self-contained communities such as the one studied should carefully consider the requirements of utilities systems. This is particularly important from the standpoints of centralizing processing equipment and simplifying collection and distribution networks (a significant cost element).

VI. Cost Evaluation Data

- Processes such as distillation and pyrolysis are competitive with physical-chemical treatment only if waste heat is readily available when required. While utilization of the community's power generation waste heat appears appropriate, difficulties arise due to mismatches in availability and demand caused by extreme climates or seasonal changes. Since power generation, heating and air conditioning are the primary elements in overall thermal energy management, their system configurations must be generally defined prior to evaluating the integration of thermal water recovery processes.

- Vacuum sewers are less expensive than gravity sewers on the community site, particularly for reduced flows when black and gray waters are handled separately. This is a result of gravity sewer requirements for larger diameter pipes and for increasing slopes to handle lower flows. Based on filled-pipe operation, vacuum sewers are even less expensive if gray water alone is collected. This type of operation is appropriate only for gray water.

- Water should not be recycled for household reuse if there are community water needs that can be satisfied by waste waters (i.e. irrigation, scrubber water, heat transport fluid, commercial and industrial use).

- Storm water collection and disposal systems should be given strong consideration as a relatively cost free means of conveying and disposing of residual gray water and other treated waste waters. Storm water handling requirements are normally more demanding than those of treated waste water.

- Incineration is the most site-independent means of disposing of refuse and sludges. It is also most appropriate to total energy management systems.

VII. Integrated System Concepts

- Differences in the overall cost of the concepts evaluated are not as dramatic as was anticipated. This is a result of the dominant influence of equipment that is common to all systems studied (i.e. fixtures and appliances, plumbing, waste handling, incineration, etc.)

- Reclamation and reuse is not cost effective in soft water areas having a plentiful, good quality water supply. It appears, however, that it is a practical alternative to conventional approaches in newly constructed or redeveloped communities where water supply and/or waste disposal problems exist.

- The economic value of direct reuse (e.g. dish and clothes washer rinse water used in subsequent wash cycles) is marginal. It is nonetheless included in the selected configuration in consideration of water-short site locations.

- Concepts that collect concentrated black water by a vacuum system and incinerate it directly are most economical in both hard and soft water areas. System concepts that either combine and biologically treat black and gray water, or reuse gray water for toilet flushing prior to treatment, were found to be more expensive.

- Consideration of areas with water resource and waste disposal problems led to the selection of a system characterized by the following:

  - Water conservation: vacuum toilet, flow limiting shower heads and faucets, and front loading clothes washing machines (lower water usage).

  - Direct reuse: dish and clothes rinse water reused for subsequent wash cycles.

  - Waste water collection and transport: separate vacuum collection and transport of gray and black water - common vacuum source.

  - Waste water processing:

    Separate incineration of concentrated black water and refuse with heat recovery for power generation.

    Subsurface gray water irrigation in growing seasons - treatment to potable quality for limited household reuse during remainder of the year.

The system minimizes water recovery requirements by reducing household use and by recycling only when there is no need for water of less than potable quality.

VIII. Preliminary Design

The preliminary design developed by this study is generally applicable to all regions of the country. It is compatible with a wide variety of total energy systems and offers distinct advantages when the two systems are integrated.

- Although the preliminary design was not priced in detail, cost estimates were made for numerous concepts, preparatory to its selection. The concept which is the basis for the preliminary design is:

  - 13% less costly in 1972 for soft water areas,

  - 26% less costly in 1972 for hard water areas,

  - 20% less costly in 2000 for soft water areas,

  - 29% less costly in 2000 for hard water areas

  than a conventional water and waste management system. The concept requires

  - 56% less water for a 500 dwelling unit community

  - 63% less water for towns of 25,000 and 250,000 people.

  The concept produces

  - 86% less treated sewage outfall for towns of 25,000 and 250,000 people.

- Aside from the potential cost savings of a water and waste management system that makes use of up-to-date technology and a systems approach, houseing developments can benefit by substantial reductions in their ecological impact. They can be located on land that is prospectively cheaper. Housing can also be situated in better compliance with planned economic development in water-short regions or those that have pollution problems.

RECOMMENDATIONS

Water and Solid Waste Management

The primary recommendation of this study is the eventual construction and testing of an apartment complex incorporating the water and waste management system concept that is described in the Preliminary Design Section of this report. This would be in compliance with the intended follow-on work that was initially expressed in the statement of work for this program.

The test program would be oriented towards proving the validity of the concept as well as acquiring detailed data, such as: utility requirement profiles, accumulator requirements between subsystems with different and/or variable flow rates, operating and maintenance costs of new or modified subsystems and components, system reliability and resident acceptance of the total system and its components.

Implementation of this recommendation should be the culmination of a series of smaller tests and studies. The recommendations that follow are suggested efforts that could be conducted sequentially or simultaneously. The order of arrangement does not imply any priority ranking. Programs that involve the same type of waste water or strongly interface with other subsystems should be efficiently grouped.

DEVELOPMENT PROGRAMS

Vacuum Collection

The Liljendahl vacuum toilet and ancillary collection equipment have been in very limited commercial service for several years. A survey, discussed in Section III, describes a partial recirculation toilet that uses one-seventh as much water per flush as the Liljendahl toilet. Mating this toilet with a vacuum collection system appears feasible but has not been demonstrated. One of the recommended programs for Vacuum Collection is the experimental evaluation of the use of a partial recirculation toilet with a vacuum collection system.

An additional recommendation is the evaluation of gray water collection in filled sewers using a vacuum as the motive force. The data sought is whether solids settling in the line will be transported by liquid velocity or will an occasional air sweep be required to move settled solids satisfactorily. Energy requirements should also be obtained.

Incineration

A good method of "treating" and disposing of toilet wastes is incineration. With a partial recirculation toilet and possibly a Liljendahl toilet, the black water quantity is sufficiently small that it appears practical to incinerate black water in the fuel nozzle of a power furnace. The relationship of electrical power requirements to the quantity of black water discharged is such that the incremental fuel needed to vaporize and heat the water to furnace temperatures is about 15% to 30%. The additional energy stored in the water vapor can be recovered in a properly designed system. Furthermore, the heat transfer coefficients are higher with humid gases and permit reductions in heat exchanger surface (and cost). A potential problem is the fouling of heat exchangers with ash from the black water wastes. It is recommended that a series of tests be performed to demonstrate feasibility and to establish parametric performance data on nozzles and the power generation components that are exposed to the combustion gases.

Subsurface Gray Water Irrigation

Employing gray water for landscape irrigation provides multiple benefits by reducing fresh water requirements and problems associated with final disposal of used water. Because of aesthetic appearance and the possibility of health hazards, it is inappropriate to spray this water onto lawn surfaces. Two subsurface irrigation methods---trickle and moisture barrier irrigation---have been used with fresh water, but not with gray water. The two methods should be evaluated with gray water (settled and unsettled), in various types of soil, with several types of vegetation and in several climates.

Water Recovery

Reverse osmosis appears to offer economic advantages in reclamation of water from gray water. A number of tests are recommended to demonstrate the suitability of this process and to obtain operating data with the specific type of water to be used as input. They are the determination of:

- operating characteristics of sand core supported membranes, processing gray water without pretreatment.
- The effects on membrane life of various yield percentages (product water divided by input).
- The efficiency of membrane cleaning techniques when fouled by gray water.
- The effectiveness of the membranes as bacterial barriers.

ANALYTICAL STUDIES

Generation of Load Profiles

Past and present studies of integrated systems have used averaged system values in specific situations which represent the maximum and minimum condition of a particular parameter. An example is the use of the average cooling load for the peak of the hottest day of the summer in say three regions of the country. What effect the cooling load has at specific hours on the integrated system is not determined, nor is the effect of cooling (or heating) requirements on individual days.

In order to ascertain an integrated system's requirements and benefits with any realism, daily and annual load profiles must be established for: electrical power, heating, cooling, water consumption and waste generation for specific or generalized locations. This suggested program is a prerequisite for the effective performance of the next recommendation.

Total Energy Concept Development

Total energy systems have been designed and built in the past. Some are still operating while others have failed economically. The first part of this recommendation is the execution of a survey that would correlate thermodynamic considerations with economic success of failure. The second part is the creation of numerous concepts for power generation and heat utilization, using various thermodynamic cycles. Optimization of the thermal parameters would be performed. The concepts would be tested for appropriate performance in residential use.

I WATER RESOURCES

WATER SUPPLY

A number of water resources factors are significant in the context of new community planning.

In the selection of a new community location, one of the initial matters for consideration is the question of water supply. The source of supply has to be clearly defined together with such matters as the quality of water, the methods of diversion, treatment and distribution. Providing there is a suitable source of water, the developer would have to establish his right to use the supply. This right would depend on the water-rights doctrine in effect in the particular state or region. The predominant water rights doctrine together with the regions of water surplus and deficiency on a nationwide basis are shown in Figure 1[1].

Land ownership rights mean that title to the water is implicit with title to the land. Under appropriative rights, the state owns the water and assigns water rights to applicants on a priority ranking basis. In either case, the principle of eminent domain can be exercised.

Development of a water supply might not be compatible with plans for waste disposal if both functions are to be performed within the boundaries of the site. This would be especially important where ground water was to be the source of supply. Frequently, a proposed development could satisfy its water needs from on-site sources but cannot simultaneously meet its waste disposal requirements.

The public attitude with regard to land use and the trend towards land use controls which could be based on limited water supply, will certainly affect the development of new communities. A recent report, "The Quiet Revolution in Land Use Control" prepared for the Commission on Environmental Quality points out that the proposed National Land Use Policy Act requires the states to identify and control development in areas of critical environmental concern. These areas include the protection of key river basins, wet land, shorelines, etc. An idea fundamental to this act is, that land is a resource and not simply a commodity. This point of view makes water a matter of critical environmental concern and a key factor in future land use decisions.

Existing and emerging water resource problems on a nationwide basis are summarized in Table 1, with Figure 2 showing region designations[2]. These data provide a broad regional basis for predicting water-resource problems of the near future. In addition to the general problems of these regions, there are a variety of conditions which may result in local water deficiencies. For example, New York City has outgrown the capabilities of the surrounding region to supply required water quantities. As a result, this community is forced to seek water sources in other river basins. Such encroachment would clearly be at the expense of the future water needs of other communities. Another example is the smaller community which has failed to set aside enough land to take care of its growth requirements and, as a result, will have water supply problems in the future.

For independent new communities (relatively far from existing cities) ground water would probably be the most logical source for the water supply. In this case, the locations for new communities would be limited geographically to the areas of high ground water favorability which are shown in Figures 3 and 4[1]. By reducing the requirements by water management techniques, a site might be developed on less

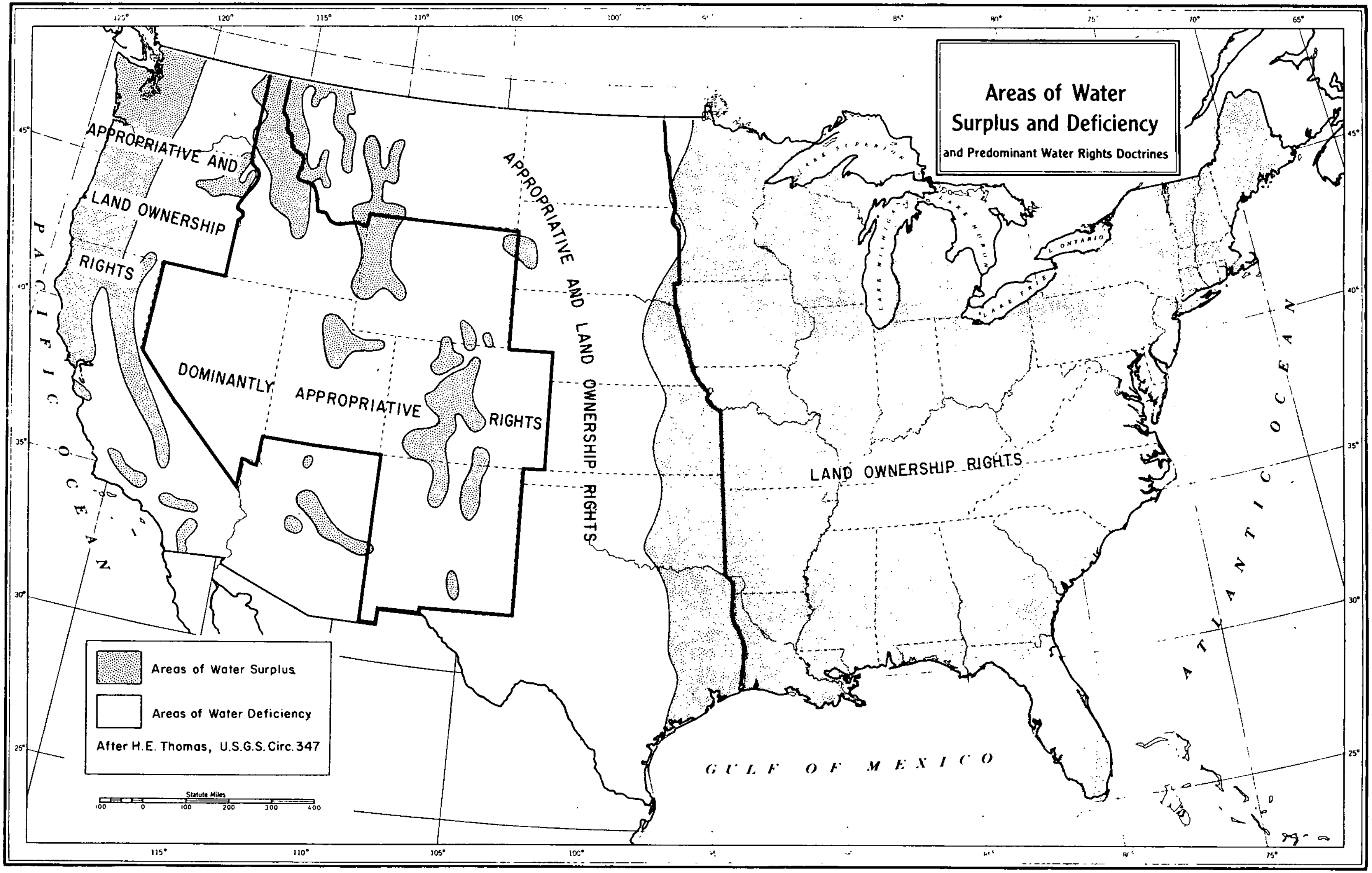

Figure 1 Areas of Water Surplus and Deficiency

TABLE 1 EXISTING AND EMERGING WATER MANAGEMENT[2] PROBLEMS IN THE UNITED STATES

(Source: U. S. Water Resources Council, 1968)

Region	Adequacy of Annual Natural Runoff	Ground-Water Storage Depletion	Water Quality				Flood Damages	Watershed Lands	Beach, Shore, and Riverbank Erosion	Wetlands
			Wastes	Heat	Salinity	Sediment				
North Atlantic	C	C	A	A	D	C	C	C	B	B
South Atlantic-Gulf	D	C	B	C	D	B	B	B	A	A
Great Lakes	C	D	A	A	D	C	D	D	C	C
Ohio	C	D	B	B	D	C	B	C	D	D
Tennessee	D	D	C	C	D	C	C	C	D	D
Upper Mississippi	C	D	B	B	D	C	B	C	B	B
Lower Mississippi	D	D	C	D	D	A	B	B	B	B
Souris-Red-Rainy	B	D	C	D	C	D	B	D	C	B
Missouri	B	B	C	C	C	B	A	B	B	B
Arkansas-White-Red	B	A	C	D	A	B	B	B	A	B
Texas-Gulf	B	A	B	C	B	B	C	B	B	B
Rio Grande	A	A	B	D	A	A	C	B	C	D
Upper Colorado	A	D	C	D	C	B	D	C	D	D
Lower Colorado	A	A	B	D	A	A	C	B	C	D
Great Basin	A	C	B	D	C	C	D	C	D	C
Columbia-North Pacific	C	C	C	B	D	D	B	C	C	B
California	B	B	B	C	B	C	B	B	B	C

A - Severe problem in some areas or major problem in many areas.
B - Major problem in some areas or moderate problem in many areas.
C - Moderate problem in some areas or minor problem in many areas
D - Minor problem in some areas.

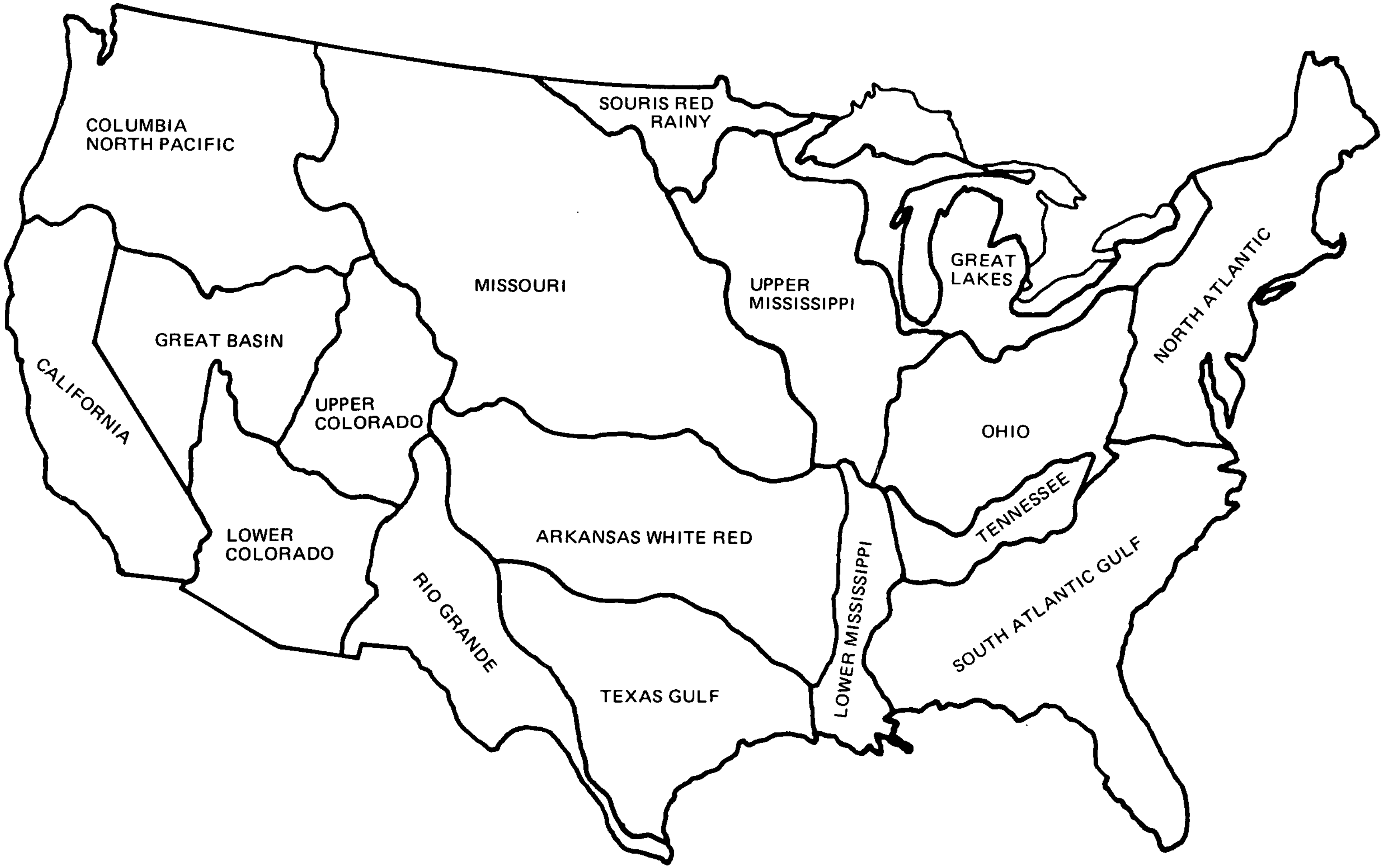

Figure 2 Water Resources Regions for Water Use in the United States

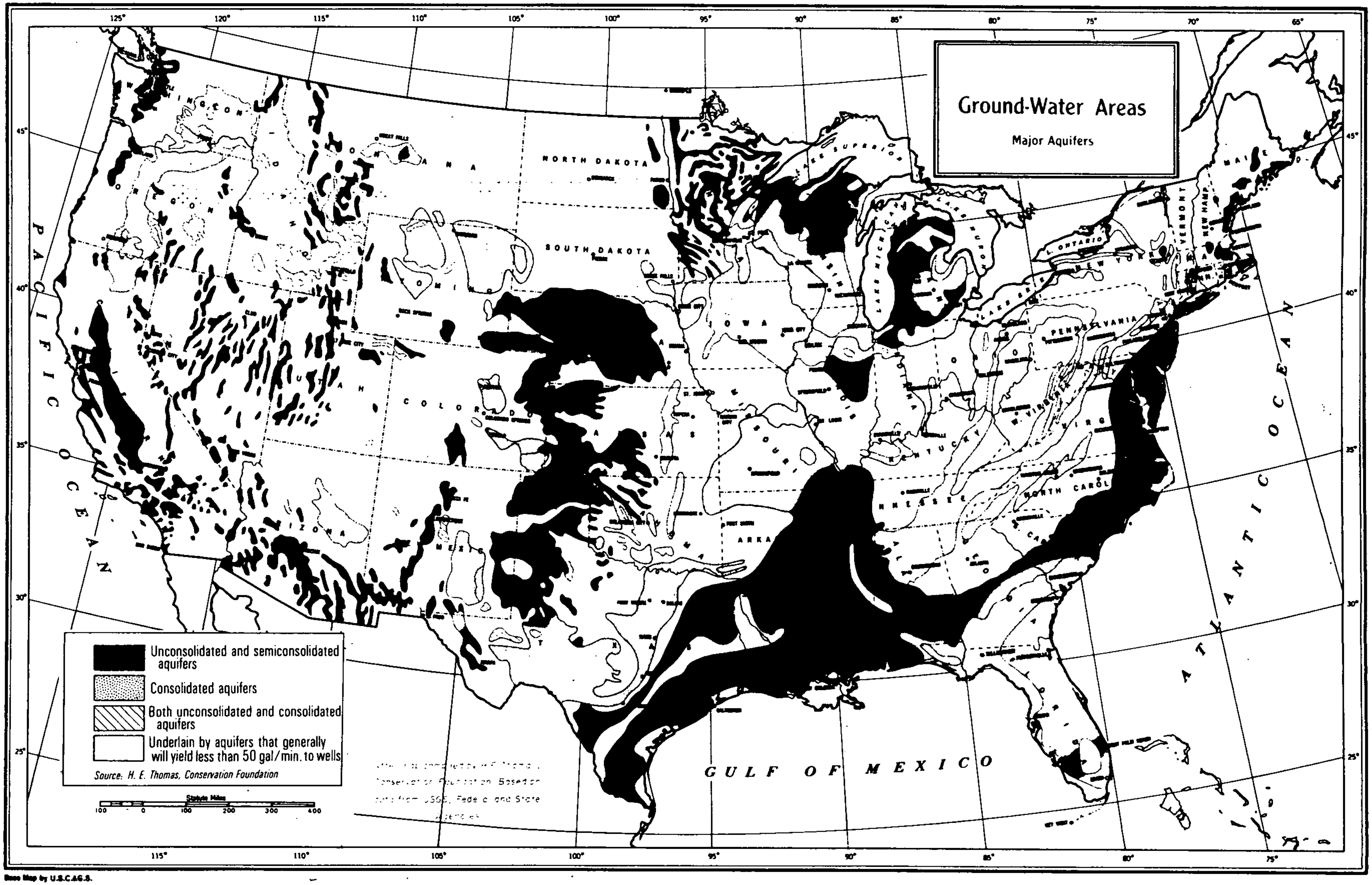

Figure 3 Ground-Water Areas

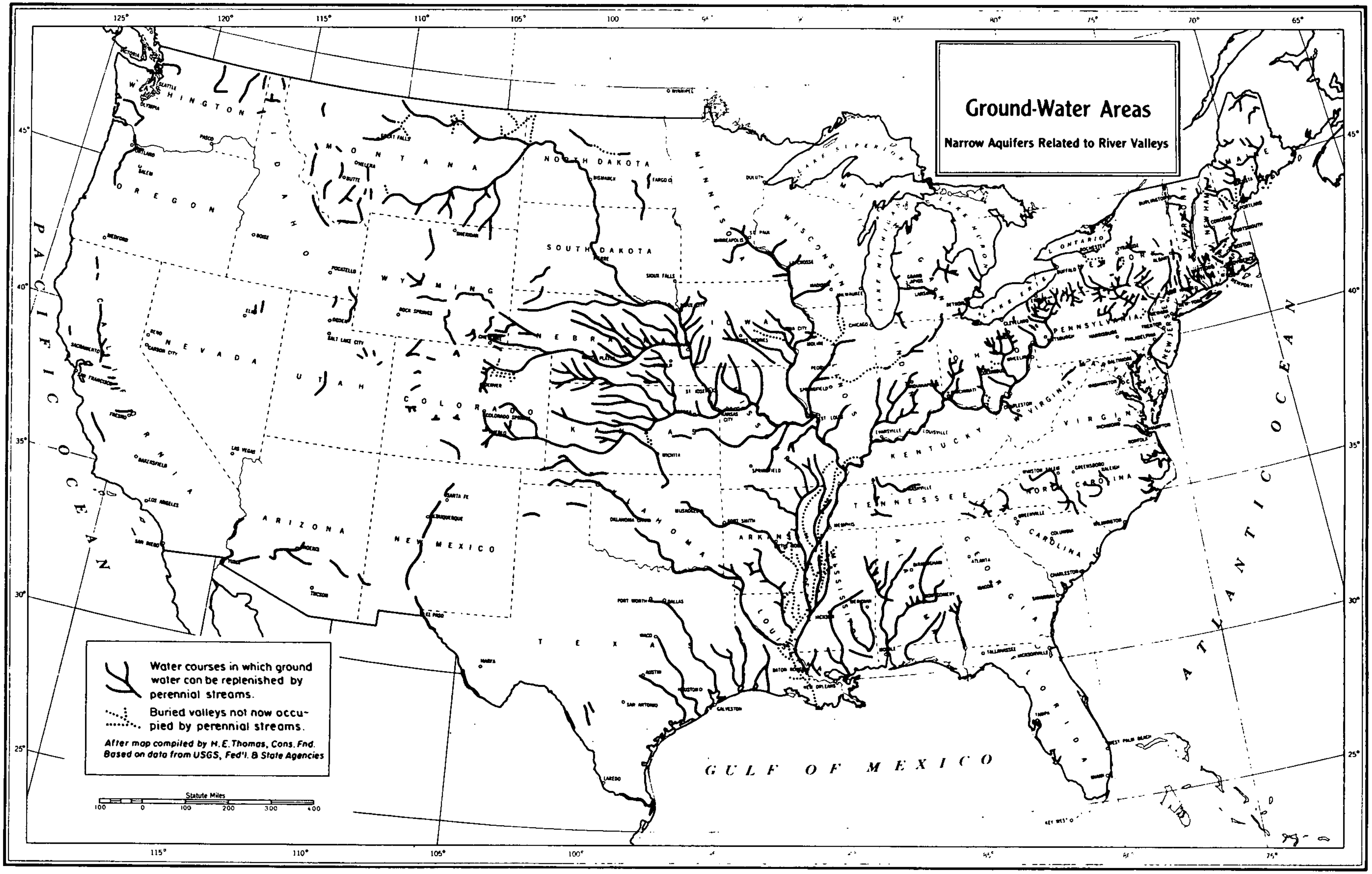

Figure 4 Ground Water Areas

expensive land, that might otherwise be incapable of meeting environmental or water planning requirements.

WATER SUPPLY QUALITY

In 1969, the Bureau of Water Hygiene of the U.S. Public Health Service initiated a Community Water Supply Survey[3] to determine whether potable water supplies met Drinking Water Standards[4]. The 969 systems surveyed represented five percent of the national total and served 12% of the national population. Fifty nine percent of the surveyed systems delivered water that met all the standards. Twenty five percent delivered water that exceeded one or more of the recommended limits but not of the mandatory limits. Exceeding mandatory limits requires rejection of the water. Twenty percent failed to meet 14 of the 30 water quality standards and 16% exceeded mandatory limits. The smaller water supply systems had greater difficulty meeting required quality standards than the larger systems. This was especially true for communities of less than 500 customers. Table 2 gives the constituent limits from the 1962 standards.

It is assumed that new communities will meet existing U.S. Public Health Service Drinking Water Standards and future proposed standards. As an indication of how much material is contained in raw water on a regional basis, Figure 5, showing total dissolved solids (TDS) by state, is included.[1] Although only three states exceeded the recommended limits, treatment for reduction of TDS is usually provided simply to reduce objectionable tastes. Figure 6 shows the hardness of untreated water. Treatment for reduction in hardness is provided to minimize calcium and magnesium scale formation in pipes and equipment, especially where higher temperatures are involved. Naturally, the more material there is in the raw water, the more the finished water will cost.

The distribution of the various natural dissolved chemical constituents in raw water supplies should remain more or less constant with time. However, certain constituents such as chlorides from road deicing, phosphates and nitrates from fertilizers and a number of industrial contaminants are continually added to the water environment. These will certainly have an impact on the quality of water supplies.

The range of concentrations of the most common dissolved chemical constituents present in public water supplies for the 100 largest cities in the United States are given in Table 3 and quality in terms of hardness, total dissolved solids and pH are given in Table 4.[2]

TABLE 2 CONSTITUENTS CONCENTRATION LIMITS FROM THE 1962 U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS[4]

Recommended Limits	
Constituent	Limit
Alkyl benzene sulfonate (measured as methylen-blue-active substances)	0.5 mg/l
Arsenic	0.01 mg/l
Boron	1.0 mg/l*
Chloride	250 mg/l
Color	15 units
Copper	1.0 mg/l
Carbon-chloroform extract (CCE)	0.200 mg/l
Cyanide	0.01 mg/l
Fluoride	
Temp. (ann. avg. max. day, 5 years or more)	
50.0-53.7	1.7 mg/l
53.8-58.3	1.5 mg/l
58.4-63.8	1.3 mg/l
63.9-70.6	1.2 mg/l
70.7-79.2	1.0 mg/l
79.3-90.5	0.8 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Nitrate	45 mg/l
Odor (TON)	3
Phenols	0.001 mg/l
Radium-226	3 μμc/l
Strontium-90	10 μμc/l
Sulfate	250 mg/l
Total dissolved solids (TDS)	500 mg/l
Turbidity	
Untreated	5 units
Treated by more than disinfection	1 unit
Zinc	5 mg/l
* Recommended	

TABLE 2 CONSTITUENTS CONCENTRATION LIMITS FROM THE 1962 U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS[4] (CONT.)

Mandatory Limits	
Constituent	Limit
Arsenic	0.05 mg/l
Barium	1.0 mg/l
Boron	5.0 mg/l*
Cadmium	0.01 mg/l
Chromium (hexavalent)	0.05 mg/l
Coliform organisms (measured by membrane filter technique)	Fails std. if: (a) Arithmetic average of samples collected greater than 1 per 100 ml (b) Two or more samples (5% or more if more than 20 examined) contain densities more than 4/100 ml
Cyanide	0.2 mg/l
Fluoride	
Temp. (ann. avg. max. day - 5 years or more)	
50.0-53.7	2.4 mg/l
53.8-58.3	2.2 mg/l
58.4-63.8	2.0 mg/l
63.9-70.6	1.8 mg/l
70.7-79.2	1.6 mg/l
79.3-90.5	1.4 mg/l
Gross beta activity (in the absence of α or Sr-90)	1.000 $\mu\mu$c/l
Lead	0.05 mg/l
Selenium	0.01 mg/l
Silver	0.05 mg/l

* Recommended

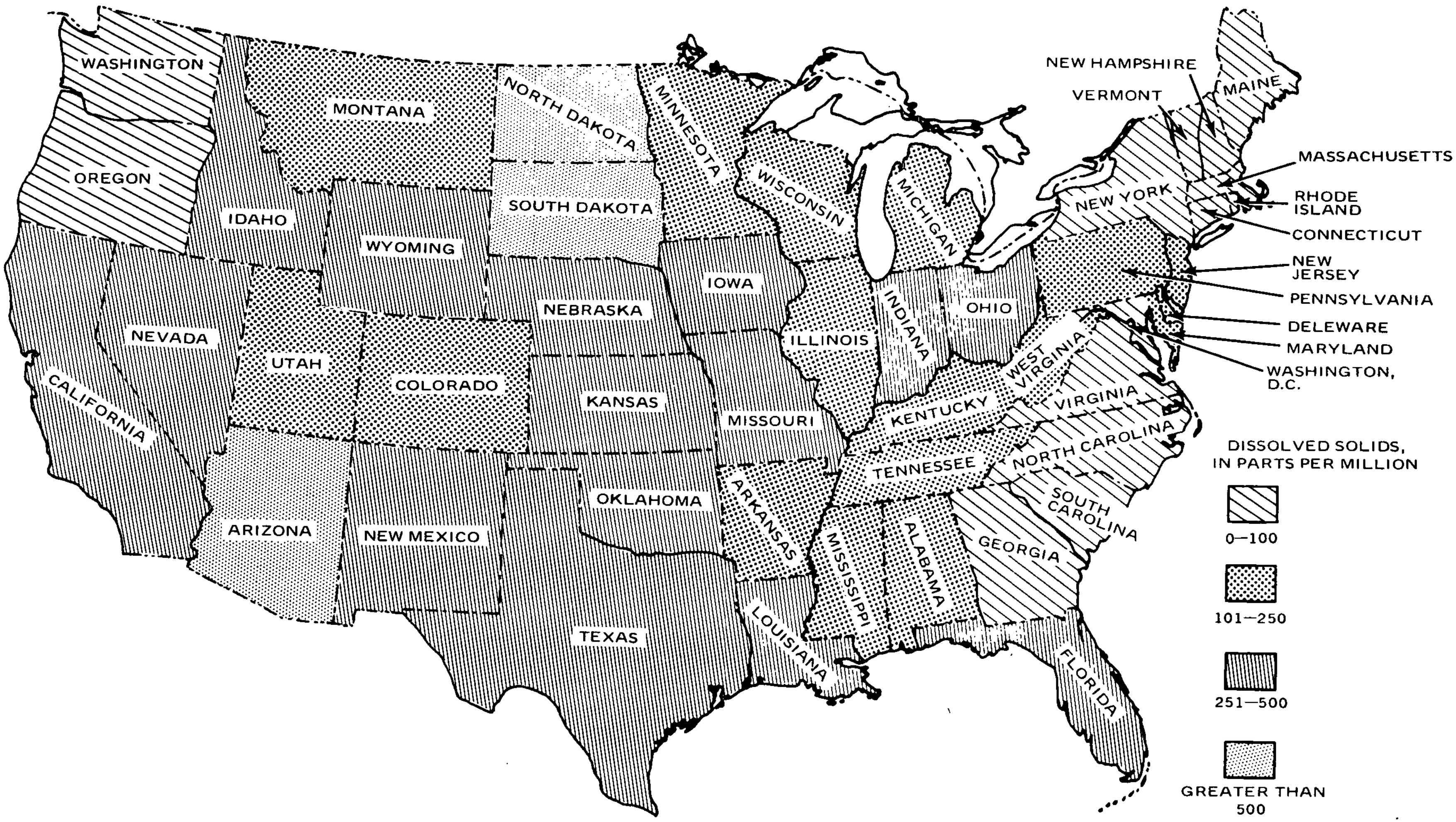

Figure 5 Dissolved Solids in Untreated Public Water Supplies (Average Weighted by Population Served)

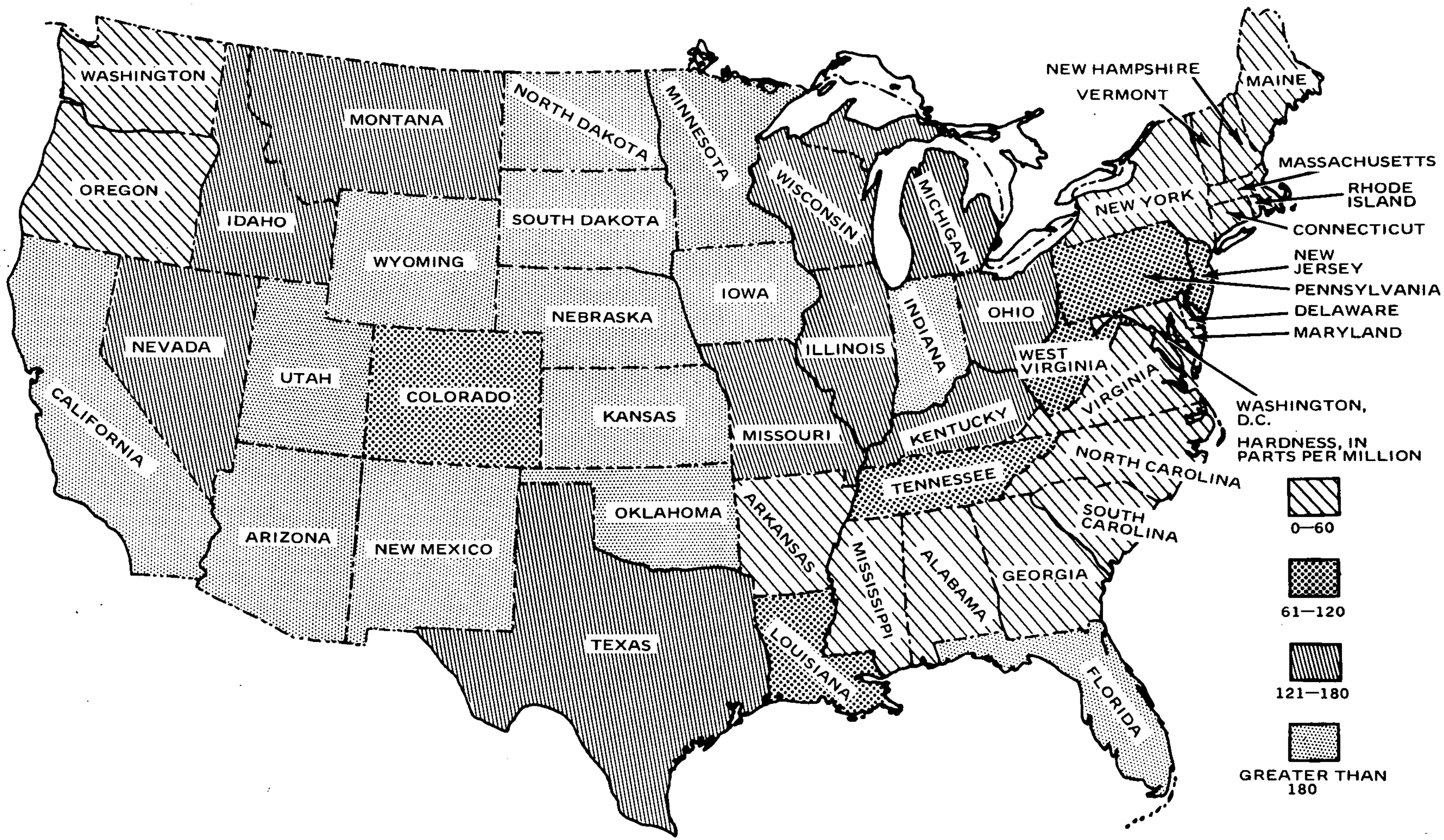

Figure 6 Hardness of Untreated Public Water Supplies (Average Weighted by Population Served)

TABLE 3 RANGE IN QUALITY OF FINISHED WATER IN PUBLIC WATER SUPPLIES OF THE 100 LARGEST CITIES IN THE UNITED STATES[2]

(Source: U. S. Geological Survey)

(Maximum, median, and minimum values as of 1962 are listed. ND means not detected.)

Constituent or Property	Maximum	Median	Minimum
Chemical Analyses (parts per million)			
Silica (SiO_2)	72	7.1	0.0
Iron (Fe)	1.30	.02	.00
Manganese (Mn)	2.50	.00	.00
Calcium (Ca)	145	26	.0
Magnesium (Mg)	120	6.25	.0
Sodium (Na)	198	12	1.1
Potassium (K)	30	1.6	.0
Bicarbonate (HCO_3)	380	46	0
Carbonate (CO_3)	26	0	0
Sulfate (SO_4)	572	26	.0
Chloride (Cl)	540	13	.0
Fluoride (F)	7.0	.4	.0
Nitrate (NO_3)	23	.7	.0
Dissolved Solids	1,580	186	22
Hardness as $CaCO_3$	738	90	0
Noncarbonate Hardness as $CaCO_3$	446	34	0
Specific conductance ..... micromhos at 25°C	1,660	308	18
pH ..... pH units	10.5	7.5	5.0
Color ..... color units	24	2	0
Turbidity	13	0	0
Spectrographic Analyses (micrograms per liter)			
Silver (Ag)	7.0	0.23	ND
Aluminum (Al)	1,500	54	3.3
Boron (B)	590	31	2.5
Barium (Ba)	380	43	1.7
Chromium (Cr)	35	.43	ND
Copper (Cu)	250	8.3	<.61
Iron (Fe)	1,700	43	1.9
Lithium (Li)	170	2.0	ND
Manganese (Mn)	1,100	5.0	ND
Molybdenum (Mo)	68	1.4	ND
Nickel (Ni)	34	<2.7	ND
Lead (Pb)	62	3.7	ND
Rubidium (Rb)	67	1.05	ND
Strontium (Sr)	1,200	110	2.2
Titanium (Ti)	49	<1.5	ND
Vanadium (V)	70	<4.3	ND
Radiochemical Analyses			
Beta Activity ..... picocuries per liter	130	7.2	<1.1
Radium (Ra) ..... do	2.5	<.1	<.1
Uranium (U) ..... micrograms per liter	250	.15	<.1

TABLE 4 QUALITY OF RAW AND TREATED WATER IN PUBLIC WATER SUPPLIES OF THE 100 LARGEST CITIES IN THE UNITED STATES[2]

(Source: U.S. Geological Survey)

(Data as of 1962)

	Raw-Water Supplies[(1)]		Treated-Water Supplies	
	Population Served (millions)	Number of Cities	Population Served (millions)	Number of Cities
Hardness (ppm):				
Less than 61	21	29	23	30
61-120	15	16	22	41
121-180	16	22	11	16
More than 180	8	27	3.7	13
Dissolved Solids (ppm):				
Less than 100	21	27	21	27
101-250	23	38	28	48
251-500	11	29	8	22
More than 500	1.5	6	1	3
pH:				
Less than 7.0	16	18	14	9
7.0-9.0	42	80	38	74
More than 9.0			7	17

(1) A few cities are not included because data are lacking

WATER USE

Reported water consumption rates (per capita per day) vary considerably, most probably because of the different bases on which the data are gathered or presented. Some of the more recent data[5] on residential water consumption indicate an average of 59 gallons per capita per day (gpcd) excluding lawn sprinkling. Consumption ranged from 39 to 127 gpcd and, in the study, correlated most closely with the value of the property. Other findings were: the mean per capita use in areas served exclusively by septic tanks was 47 gpcd; apartment dwellers used 62 gpcd; regions in the east, served by metered public water supplies, used 51 gpcd while similar areas in the west used 67 gpcd; and flat rate areas used 66 gpcd. All of these values exclude lawn sprinkling.

Another investigation[6] showed the relationships between per capita water consumption as functions of assessed property valuation, education, occupation of principal wage earner, income, age, childrens' age and number of occupants per household. The clearest relationships are those for property valuation, which shows a direct relationship between value and per capita consumption and for number of occupants per household, which shows an inverse relationship with the peak for two occupants. Income, education and occupational status are roughly proportional.

Comparisons of peak hourly flow rates, maximum daily flow rates and average (annual) flow rates, all expressed as gallons per day per dwelling unit, were made for 41 study areas[5]. Maximum daily flow rate ranged from 1.3 to 1.8 times the annual flow rate, with apartments showing a 1.6 ratio. Peak hourly flow rates ranged from 2.6 to 4.9 times the annual flow rate, with apartments showing a 5.2 ratio. The values upon which these ratios are based all exclude lawn sprinkling use.

Several estimates of water distribution internal to a dwelling unit were presented in a study by the General Dynamics Corporation[7] together with their assumed "model" distribution flows. This study is currently being supplemented by continuous monitoring of eight single family dwellings. The most significant finding from the current effort is that average bathing water consumption is less than half the 80 gpcd previously estimated.

The "model" distribution that will be assumed for this study is given in Table 5, presented as average and maximum flow per day for a family of four.

TABLE 5 INTERNAL WATER DISTRIBUTION (GPD)

	Average	Percent	Maximum
Total Intake	196	100	423
Kitchen	23	11.7	38
Laundry/Utility	45	23.0	135
Bathing	40	20.4	120
Lavatory	8	4.1	10
Toilet	80	40.8	120

The maximum water use in the kitchen is created by an additional daily dishwasher operation. Maximum for the laundry/utility is calculated as three machine washings of 35 gallons each plus a threefold usage of utility water. The bathing maximum is taken as a 30 gallon bath (or 7.5 minute shower at 4 gpm) for each member of the family. Lavatory consumption was increased by 25% and toilet water consumption by 50%.

For the average daily flows, the assumed hot water (145^{o}F) percentages are 75% for the kitchen, 35% for the laundry/utility, 50% for bathing, 45% for the lavatory and none for the toilet.

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II WASTE GENERATION

WATER BORNE WASTES

The degree to which water is contaminated during usage is a function of the amount of pollutant and the volume of water to which it is added. Since water quantity is so variable for many processes, the resulting concentrations are likewise variable. In a study where the volume of water is to be deliberately manipulated, it is simpler to use the waste generation rates for the normal household functions.

The waste generation rates expressed as grams per capita-day shown in Table 6, were obtained primarily from a Swedish experiment[1] in an instrumented apartment house. The data in the table was modified to reflect a richer diet and greater use of detergents by Americans. The apartment units contained one or one and a half baths and were occupied by an average of three people. When compared on the basis of contaminant weight per capita-day there is reasonably good agreement with the results obtained from single family dwellings in Louisville, Kentucky[2] and Cincinnati, Ohio[3]. The Swedish data is more comprehensive in that kitchen, bath and toilet effluent quantities were separately defined. The Cincinnati data was obtained from subdivisions averaging four people and one or one and a half bathrooms per home. The home in Louisville was occupied by five people and contained one bathroom.

Evaluations of quality data from a variety of sources have shown that homes having more baths and higher real estate value use more water and produce more contaminants per capita than those having fewer bathrooms and low real estate value. An additional factor affecting water borne wastes is the increasing use of garbage disposal units. Watson[2] evaluated the effects of such devices on water use and combined effluent quality. Interestingly, in two of the three homes evaluated, reductions in per capita water use were evident after installation of food disposer units. It was postulated that less water was used to clean sinks, colanders and garbage cans.

The water borne waste data from Table 6 was modified to reflect the contributions of future homes which can be expected to have higher real estate value, multiple bathrooms and garbage disposal units. The resultant waste generation rates are shown in Table 7.

TABLE 6 WASTE GENERATION RATES, GRAMS PER CAPITA DAY, EXCEPT AS NOTED

Parameters	Kitchen	Lavatory/ Bathing	Laundry/ Utility	Toilet	Combination Of All
COD	34	7	7	72	120
BOD	17	5	3	25	50
Total Solids	36	22	19	53	130
Total Volatile Solids	27	10	7	36	80
Total Fixed Solids	9	12	12	17	50
Total Suspended Solids	13	3	4	30	50
Volatile Suspended Solids	12	2	2	25	41
Fixed Suspended Solids	1	1	2	5	9
Total Phosphate	.01	.01	4	3	7.0
Detergent	.1	Negl.	0.9	-	1.0
NH_3 Nitrogen	0	Negl.	Negl.	10.5	10.5
Grease	7	-	-	-	7
pH	7.2	7.0	9.8	8.9	
Number of Bacteria/Capita-Day:					
Total (Nutrient Agar @ 35°C)	35×10^9	40×10^9	3×10^9	62×10^9	
Coli (@ 35°C)	-	1×10^8	1×10^7	4.8×10^9	

TABLE 7 FUTURE WASTE GENERATION RATES GRAMS PER CAPITA DAY, EXCEPT AS NOTED

Parameters	Kitchen	Lavatory/ Bathing	Laundry/ Utility	Toilet	Combination Of All
COD	34	15	11	86	146
BOD	25	10	5	30	70
Total Solids	55	44	31	66	196
Total Volatile Solids	40	20	11	45	116
Total Fixed Solids	15	24	20	21	80
Total Suspended Solids	20	6	6	37	69
Volatile Suspended Solids	18	4	3	31	56
Fixed Suspended Solids	2	2	3	6	13
Total Phosphate	.1	.01	8	4	12.
Detergent	.2	Negl.	1.2	-	1.4
NH_3 Nitrogen	0	Negl.	Negl.	10.5	10.5
Grease	8	-	-	-	8.
pH	7.2	7.0	9.8	8.9	
Number of Bacteria/Capita-Day:					
Total (Nutrient Agar @ 35°C)	35×10^9	40×10^9	3.0×10^9	77×10^9	
Coli (@ 35°C)	-	1×10^8	1×10^7	6×10^9	

SOLID WASTES

The literature shows that per capita household refuse generation varies widely with level of affluence, social and personal habits, climate and housing. Determinations are often made difficult by conventional collection systems which combine refuse from a variety of sources. Average generation rates as low as 1.5 and as high as 5.0 lbs per capita day are reported. The most frequently cited values fall between 2 and 4 lbs. per person daily. In areas containing housing patterns representative of those to be emphasized in this study (new future communities) values on the order of 3.5 lbs per capita day were found to be most prevalent. The strong influence of seasonal variations on household refuse generation profiles must be accounted for in the evaluation of waste management concepts. The highest peaks are normally experienced in the spring and fall with lesser peaks occurring during the summer months. They are attributable to increased outdoor activities producing large quantities of garden and yard refuse. Figure 7 constructs typical seasonal variations around the selected nominal rate. The profile is based on variations experienced in Hartford, Connecticut and Cincinnati, Ohio[4].

Table 8 quantitatively identifies major component refuse materials. Obtained from the results of a study in Santa Clara, California[5], the data correlates well with other sources[6]. The density of uncompacted domestic refuse varies from 15 to 25 lbs/ft^3. A nominal value of 20 lbs/ft^3 will be used during this study. Chemical analysis, moisture content and calorific value of raw refuse is given in Table 9[5]. Projections of refuse generation depend on the development of technology in the areas of consumer goods packaging, and handling and collection techniques as well as on expected increases in living standards. Recent projections relate refuse generation with household expenditures for durable and non-durable goods. Resultant estimated increases vary from 30 to 40 percent per decade.

For a typical residential community, 0.5 lbs. per capita day is allowed for commercial refuse in addition to the 3.5 pounds for domestic refuse. Of this amount, 3.2 lbs. per capita day is dry and 0.8 lbs. per capita day is liquid.

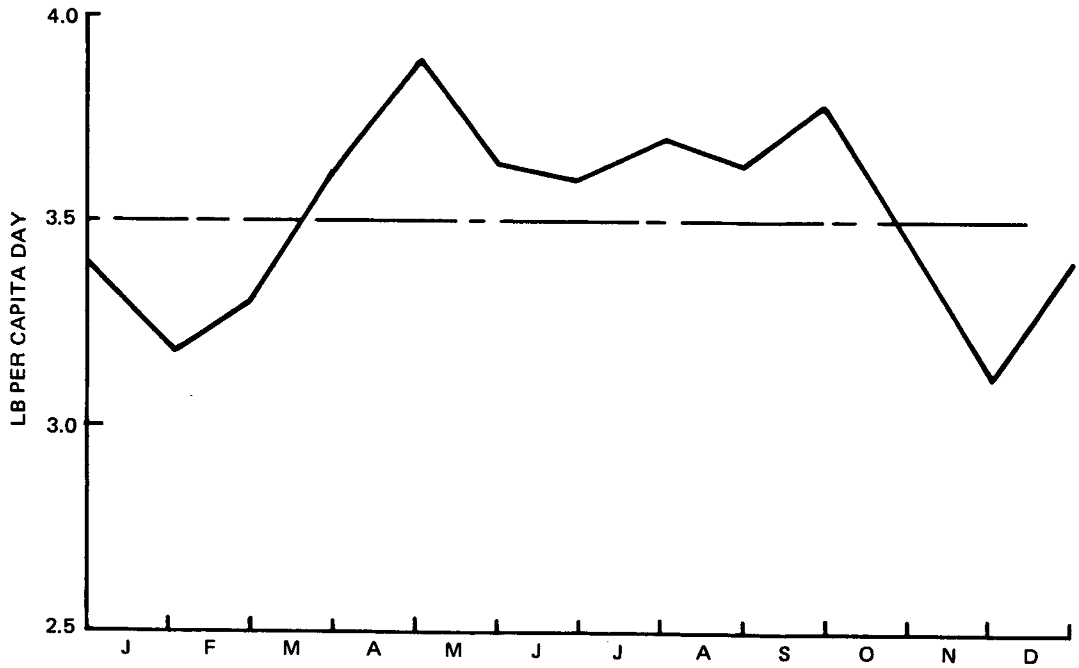

Figure 7 Typical Seasonal Variations in Household Waste Generation

TABLE 8 COMPONENTS OF DOMESTIC REFUSE

Classification	Percentage of Total	Lb/Day/ Person
Garbage	12	0.42
Rubbish		
Paper	50	1.75
Wood	2	0.07
Cloth	2	0.07
Rubber	1	0.04
Leather	1	0.04
Garden Wastes	9	0.31
Metals	8	0.28
Plastics	1	0.04
Ceramics & Glass	7	0.24
Nonclassified	7	0.24
Total	100	3.50

TABLE 9 CHEMICAL ANALYSIS OF RAW REFUSE

Item	Percentage by Weight
Moisture	20.00
Carbon	29.83
Hydrogen	3.99
Oxygen	25.69
Nitrogen	0.37
Sulfur	0.12
Ash and Metal	20.00
Total	100.00

Calorific Value: As fired: 4900 Btu/lb
Drybasis: 6200 Btu/lb
Dryash free basis: 9050 Btu/lb

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III COMMERCIAL EQUIPMENT SURVEYS

LOW WATER CONSUMING EQUIPMENT

A survey was conducted to gather information required to identify and evaluate commercially available equipment designed for low water consumption. The survey form shown in Figure 8 was prepared and distributed to manufacturers of water appliances, plumbing fixtures and devices. The form was intentionally simplified to encourage responses. To some extent the survey duplicated efforts of previous studies. This was nevertheless required to preclude the omission of more recently developed hardware. Although information was received from most of those surveyed (38), responses were in many cases, incomplete. Supplemental information was nevertheless obtained from telephone conversations with manufacturers.

It was apparent that few manufacturers are motivated by water conservation unless user convenience demands it (i.e., trailer, vacation home, and marine equipment) or large savings are visible (i.e., industrial lavatories and office buildings).

All equipment must conform to Federal Specification WW-P-541D which contains general and detailed plumbing fixture requirements. It appears, however, that the detailed specifications are continuously modified to cover new equipment that conforms to general performance, health, safety, and quality requirements. The following paragraphs contain functional and operational descriptions of the equipment surveyed. The manufacturers' names included represent the sources of the information compiled. No implications are made that these manufacturers are the only, best, or recommended sources for the equipment described.

Conventional Toilets

Standard toilets have historically been designed to more than satisfy federal performance and physical appearance specifications for continuous occupancy applications. Typical requirements involve: completeness of flush at prescribed tank levels, back odor prevention traps, minimum bowl water surface areas, air gap back flow prevention and material finishes. Water requirements vary considerably with such factors as detailed trap and water ejection and flush mechanism designs, supply pressure, ball reseat efficiency and the manner in which water is distributed to the tank and bowl. For example, a standard toilet whose specification indicated twenty one (21) quarts per flush was found to perform adequately using about ten (10) quarts in actual use. In any event, it is apparent that the common household unit does not require as much water as is commonly believed.

Shallow Trap Toilet (American Standard)

The shallow trap toilet has the same basis principles of operation and appearance as standard toilets except that it has a more efficient trap design. This allows it to use less water which results in a smaller flush tank.

1. ITEM: ____________________ COMPANY: ____________________

2. DESCRIPTION: ____________________

3. PERFORMANCE:

FLOW VS. PRESSURE: ____________________

FLOW VS. POWER: ____________________

HEAT DISSIPATION: ____________________

WATER REQUIREMENTS: ____________________

NOISE DURING USE: ____________________

ETC: ____________________

4. MAINTENANCE FEATURES: ____________________

5. PHYSICAL CHARACTERISTICS: ____________________

6. OPERATIONAL CONSTRAINTS OR UNIQUE OPERATING INSTRUCTIONS: ____________________

Figure 8 Survey Form

7. COSTS:

INITIAL UNIT PRICE SCHEDULE:* ______________________

INSTALLATION TIME ESTIMATES:

NEW HOMES: ______________________

EXISTING HOMES: ______________________

MAINTENANCE:

REPAIR INTERVAL: ______________________

MATERIALS PER REPAIR: ______________________

HOURS PER REPAIR: ______________________

8. MATERIALS OF CONSTRUCTION LIST:

______	______	______
______	______	______
______	______	______
______	______	______

* Please provide cost per unit based on:

0 to 25, 25 to 100, 100 to 500, over 500

Figure 8 Survey Form (Cont.)

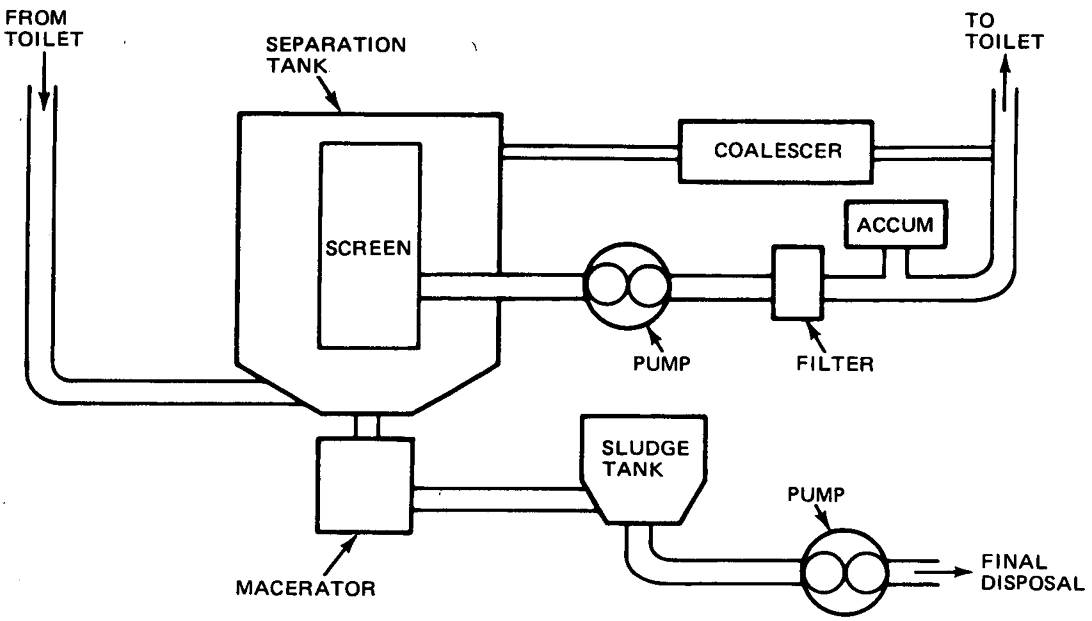
Shallow Trap Toilet (Continued)

Water Requirement	3.5 gallons per cycle
Water Saving	Approximately 30%
Noise	Similar to conventional
Volume	10 - 14 cubic foot envelope
Utility Interfaces	Municipal water supply, waste collection
Floor Space	4 - 6 square feet
Materials	Copper, brass, zinc, plastic, rubber, vitreous china
Isolation Provisions	Water trap to waste system
Odor Control	None (normal)
Cost	
Unit	$80
Installation	$30

Non-Aqueous Recirculation Toilet System (Chrysler Corp.)

This recently developed system uses a non-aqueous liquid (mineral oil) to replace water as the flushing and solids transport fluid. As shown in Figure 9, feces, urine and paper are flushed in the conventional manner and carried to a waste separation tank. As a result of the low density of the mineral oil, waste materials readily settle into a sump at the bottom of the separation tank. Further separation is achieved by screens and the periodic addition of a coalescent. The mineral oil is subsequently filtered, sterilized by the addition of a biocide and recycled. Concentrated wastes are drawn from the separation tank sump, macerated, and pumped to any conventional treatment or disposal system. A flushing fluid life of several years is claimed by the manufacturer.

Four models are being developed to service the daily requirements of 12, 110, 260 or 410 people. Units are being built and evaluated for the Navy (for shipboard use) for commercial tug boats, for the Air Force and for the EPA (land based operation).



Water Requirement			None		
Capacity/Dimensions/Cost					
Model	Cost	Capacity (people)	Length	Width	Depth
A	$12K	12	< 80"	< 36"	< 41"
B	$18.5K	110	80"	36"	41"
C	$25.5K	260	95"	48"	51"
D	$33K	410	95"	60"	60"
Noise			TBD		
Interfaces			Connects to existing toilets 120/240 VA.C., > 1 H.P.		
Maintenance			Requires changing filter materials and adding coalescent, biocide and make-up mineral oil.		

Operation cost approximately 2 cents per flush including expendables, power and maintenance.

Figure 9 Non Aqueous Recirculation

Vacuum Toilet System (AIRVAC/National Homes Corp.)

Developed in Sweden and commonly referred to as the Liljendahl system, vacuum toilets have been used in a limited number of large scale applications in Europe for the past decade. The system relies on the use of a vacuum rather than water to transport toilet wastes. The use of water is limited to that required for bowl cleaning (approximately 1/3 gallon per flush).

The overall design includes a toilet assembly, and a remote vacuum collection system. The toilet is an ordinary appearing vitrified china bowl, with a discharge valve for separating the vacuum source from the water in the bowl. A flushing mechanism controls the discharge valve and a water supply valve. The water valve also acts as a check valve and contains a vacuum breaker to prevent back siphonage (see Figure 10).

The vacuum collection system contains a collection tank, vacuum tank, redundant vacuum pumps and redundant pumps for discharge to sewer. The plumbing is commonly 2 inch diameter plastic piping. Plumbing contains traps to permit transport of wastes in slug form.

Before the flush cycle begins there is about 0.2 gallons of water in the bowl. On flushing, the contents of bowl are pushed by atmospheric air into vacuum plumbing. At the same time water sprays from a ring to wash the bowl. In three seconds the outlet valve closes and water continues to fill the bowl to the required level.

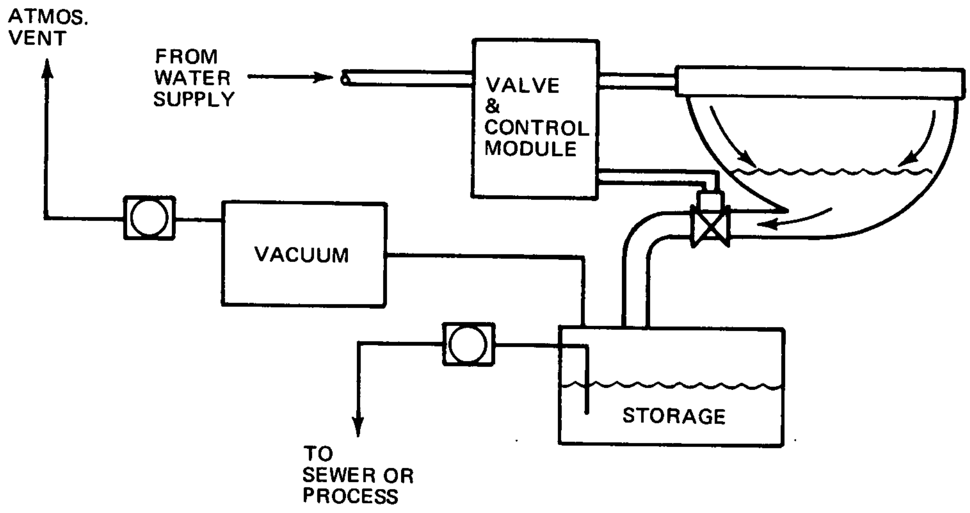


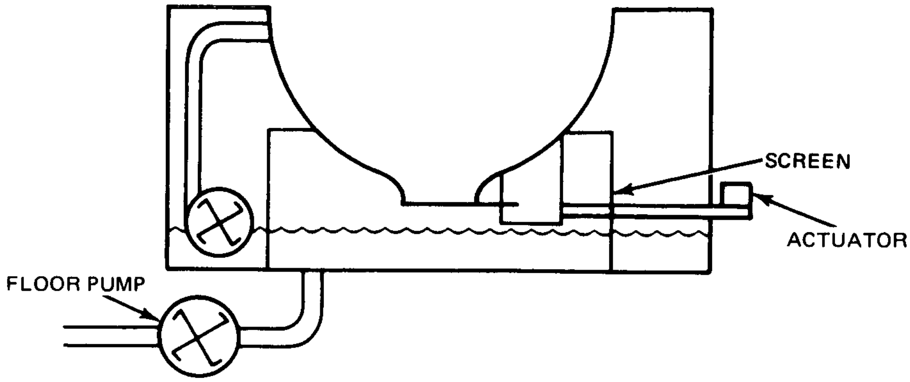
Figure 10 Vacuum Toilet

Water Requirement	1/3 gallon per cycle
Water Supply Pressure	20 PSIG min., 40 PSIG normal
Atmospheric Air Utiliz.	3.5 cubic feet/flush
Vacuum Required	13.5 to 18 inches of Hg. Vac.
Noise	Higher than conventional toilet, for three (3) seconds.
Volume	TBD
Utility Interfaces	Water supply, pump discharge to sewer, air vent.
Isolation Provisions	Water traps, vac. breaker
Odor Control	At toilet; same as conventional. From storage tank; vent to roof.
Material	Fiberglass tank PVC or ABS piping Iron body commercial pumps Rubber seals, vitrified china toilet
Constraints	Minimum of 12" Hg. Vac. is required in collection pipes downstream of discharge valve. Plumbing install-ation requires traps and special consideration at joints.
Maintenance	Probably more frequent bowl cleaning. Approximately 1 hour/year for hardware repair.
Cost	Vacuum toilet \$150 (1-500) Plumbing (single family) \$1400

Figure 10 Vacuum Toilet (Cont.)

Recirculating Toilet (Monogram Industries)

Recirculating toilets are used extensively in aircraft, marine, and mobile and vacation home applications. A 100% recirculation configuration is illustrated schematically in Figure 11. The toilet is charged with several gallons of water. The flush cycle is electrically initiated and timed (typically for several seconds). Flush-water is pumped through a self cleaning filter to remove solid material (feces and paper) which settle into a holding tank. The filtered mixture of urine and water is chemically treated to kill bacteria and prevent odors during repeated use. Home units are occasionally installed so that they may be periodically drained into a conventional sewer system. A slide valve, which remains closed when flushed, isolates sewer gases from the home. From 35 to 80 flushes can be accommodated with an initial fill between 1.5 and 4 gallons. The toilet is drained, rinsed and recharged with water and chemicals when the unit capacity is reached.

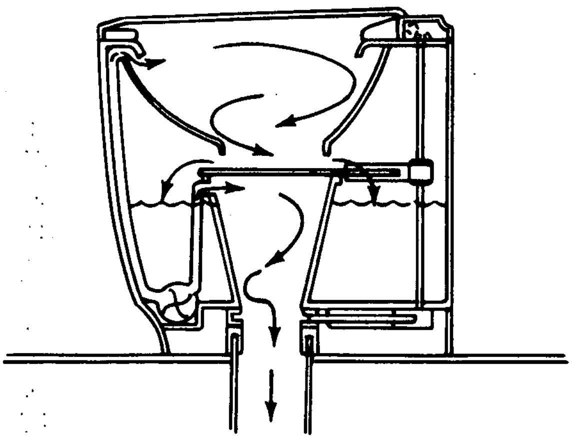


Water requirement (initial fill)	1.5 to 4 gallons
Capacity, storage	3.5 to 8 gallons
Flushes per initial fill	35 to 80
Flush cycle	9 seconds
Circulating pump capacity	12 GPM
Floor pump capacity (max.)	13 GPM at 5 ft. of water
Floor pump capacity (min.)	6 GPM at 40 ft. of water
Noise	TBD
Volume (max.)	19" high x 18" wide x 20" deep
Interfaces	
Electrical	12 V.D.C., 9 amp (max.) 115 VA.C., 5 amp (max.)
Materials	Plastic, stainless steel
Cost, unit (80 flush with pump out)	$220
Cost, unit (50 flush with pump out)	$220
Cost, installation	$25

Figure 11 Recirculating Toilet (100%)

Partial Recirculating Toilet (Sherwood Products)

A partial recirculating toilet, in the process of being marketed, is illustrated in Figure 12. When not in use the lower and upper valves are closed. A positive seal exists between the sewer line and the toilet. When the lid is opened, the upper valve opens to expose the secondary funnel for waste deposition. Closing the lid automatically starts the flushing cycle. The upper valve closes while the lower valve latches open to dump the waste material. A forceful rinse cleans the bowl and is recaptured. A high speed jet of approximately 6 ounces rises the secondary funnel to the waste disposal line. The automatically timed cycle causes the lower valve to form a water seal. The valves are actuated by the lid so as to be independent of electrical power.

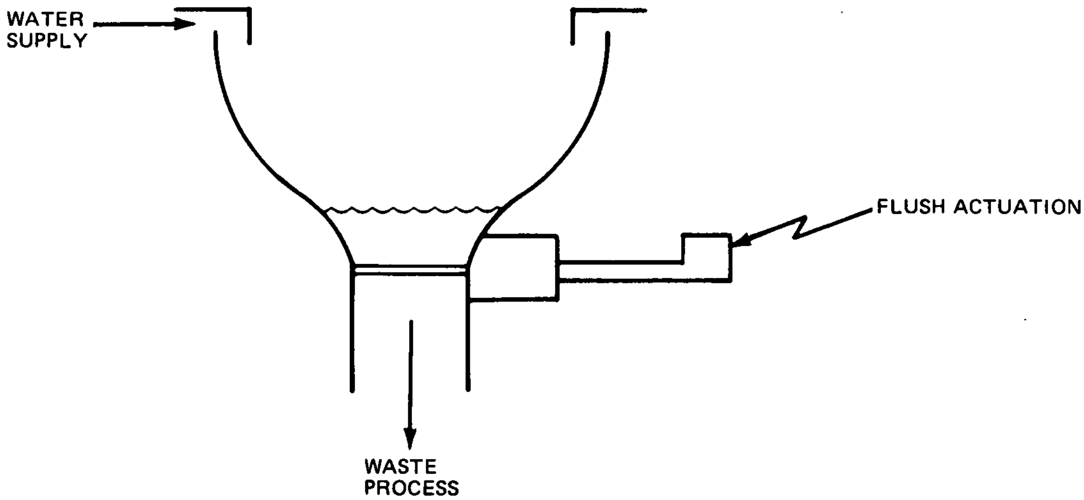


Water - initial fill	3.5 gallons
Water consumption/flush	.333 pounds
Noise	TBD
Volume	18" high x 17" wide x 19" deep
Interfaces	
Electrical	12 V.D.C.
Materials	Plastic, teflon
Cost, unit	$198
Cost, installation	$30

Figure 12 Partial Recirculating Toilet

Direct Flush Toilet (Monogram Industries)

Direct flush toilets are designed to conserve water by utilizing a higher pressure and thereby achieving a more efficient flush. As shown in Figure 13, this is accomplished by obtaining water directly from the supply system. Gravity flush tanks are replaced by foot or hand operated valves. Flush duration is either preset or manually determined by the user. Two basic types of direct flush toilets are available. A commercial type employs a conventional water trap. A vacation home type achieves additional water savings by substituting a mechanically actuated slide valve to perform the sewer isolation function. The valve is only opened during the flush cycle. Direct flush units employing mechanical traps can effectively flush liquid wastes with as little as one pint of water.

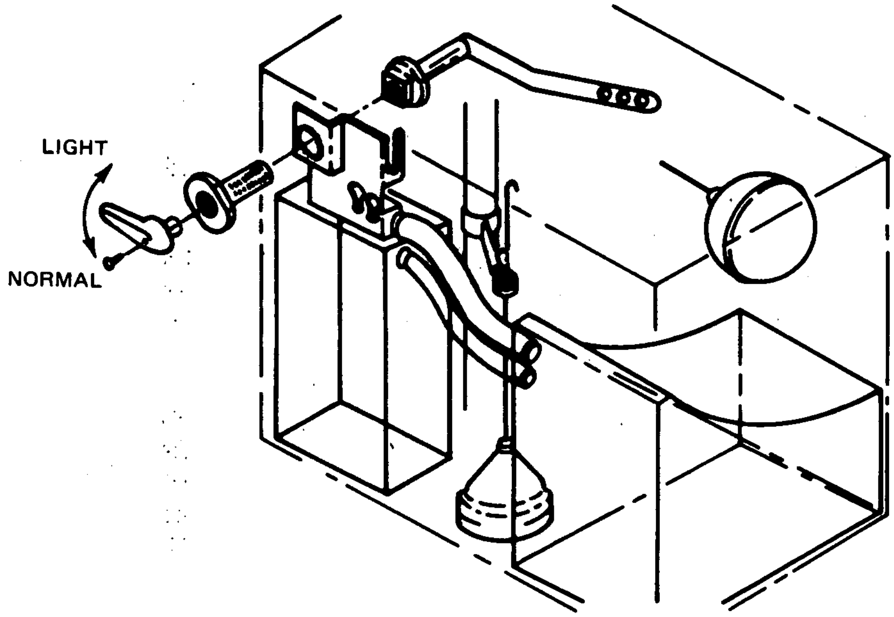


Water consumption	0.12 to 0.48 gal/flush
Noise	TBD
Volume	18" high x 15" wide x 19" deep
Isolation Provision	Water and valve, vacuum breaker
Material	Plastic, vitreous china, stainless steel

Figure 13 Direct Flush (Vacation Home)

Dual Flush Conversion Devices (Water Saver, Inc.)

The survey uncovered simple, inexpensive devices capable of converting a standard toilet to a dual flush toilet. One such device was installed and evaluated by GAC in a local home. As shown in Figure 14, it consists of open bottomed plastic water displacement tanks and a cycle selection mechanism. A downward stroke on the handle permits all of the toilet water to flush the bowl. An upward stroke prevents water contained in the plastic tanks (one gallon) from entering the bowl. The device is designed to fit into standard toilet tanks and is compatible with common ball floats and refill valves. The only constraints found are that (1) the user must hold the handle long enough to complete the flush, and (2) there appears to be insufficient installation space for reliable operation with the new "flap seat" valves being used in some toilets.



Water Savings per Light Flush	1 gallon or 20 % per day
Volume	0.15 $feet^3$
Noise	Same as conventional toilet
Utility Interfaces	Fits within existing toilet tanks and replaces handle and lever.
Materials	Stainless steel, zinc die cast, polyethylene.
Installation Time	10 minutes
Cost	0 to 50 $14 each Over 1000 $9 each

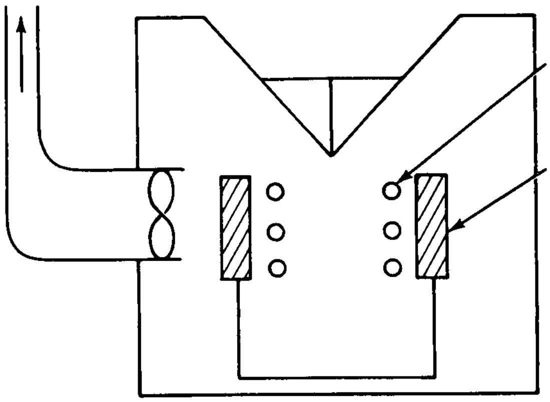
Figure 14 Dual Flush Toilet Device

Incinerator Toilet (Research Products)

Incinerator toilets are widely used in marine, vacation home and a variety of remote site applications. They are available in electrical, gas or oil fired configurations. Wastes are deposited either directly into a firebox or into hinged or rotating holding pans normally lined with disposable paper liners. Units are designed to incinerate from a single to multiple loads. Multiple load units are normally equipped with spring devices that automatically actuate the incinerator cycle.

Design details vary in attempts to achieve better ways of controlling odors, increasing thermal efficiency, safety and convenience and decreasing solids residues. Evaluations of existing units by GAC have revealed odor control to be a major shortcoming of incinerator toilets.

A typical cross section of these devices is shown in Figure 15.



Capacity	1 to 6 persons
Cycle time	35 minutes
Air Flow	200 cfm at 120 VA.C.
Noise	TBD
Volume	20 1/2" high x 15" wide x 23 1/4" deep
Interfaces	
Electrical	120/240 VA.C., 120/208 VA.C.
Power	1900 Watts at 208 VA.C.
Vent Pipe	4 inches
Odor control	Incineration temperature, catalyst, air dilution
Material	Stainless steel, fiberglass
Maintenance	Ash removal
Cost, unit	$645
Cost, installation	$25

Figure 15 Incinerator Toilet

Garbage Grinder (General Electric)

The average garbage grinder provides for continuous or batch feed grinding of food wastes including items such as bones and corn cobs. The units receive food directly from sinks and a dishwasher drain. Impellers and shredding rings provide the grinding functions. Anti-jam provisions and circuit breakers are incorporated with automatic and manual resetting. A drain is provided for sewer discharge. Sound reducing provisions are incorporated.

The overall kitchen flow may not always increase due to this appliance. Reference (2) in the Section II indicates that the flow for a small home increased whereas for larger expensive homes it decreased. The latter may be due to reduced use of water for garbage related cleaning. See Figure 16.

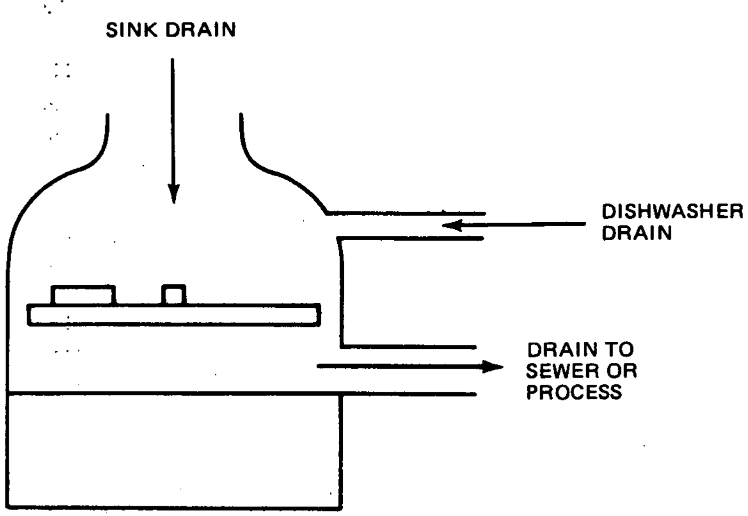


Figure 16 Garbage Disposal

GARBAGE DISPOSAL (Continued)

Water Requirement (Average)	3 gallons per day
Water Flow Rate	2 to 4 GPM
Water Temperature	Cold
Time (Min.)	0.5 to 1.5
Maximum Drain Pumping Head	8 feet
Noise	80 DBA
Volume	0.53 cubic feet (8.5" Dia. x 16.5) max.
Interfaces	Sink and dishwasher supply, sewer drain 120 V A.C., 60 Cyc., 7.5 AMP., 1/2 H.P.
Materials (Exposed to Water)	Stainless steel, polyester, polypropylene, cast tool steel.
Installation Time	30 minutes (new homes)
Cost	$29 to $89
Waste Composition	Food particles, grease

Household Refuse Compactor (Whirlpool)

Residential compactors are designed as free standing appliances to be installed in kitchen work counters.

The lower portion of the compactor is a drawer, into which a special paper bag is fitted for receiving kitchen wastes and refuse. The drawer is pulled out and wastes are dropped into the bag. The drawer is then closed, causing the deposited wastes to be automatically sprayed with an odor reducing solution. When the drawer is fully and properly closed, a starting button is pushed thus energizing the compacting ram mechanism. Two power screws operate the ram, which is said to transmit 2,000 lbs of force to a 6" x 12" ram plate or an equivalent pressure of about 28 psi to the loose refuse in the drawer. The final density is at least three times the initial density. The energizing button can be locked out with a special key to prevent tampering by children. The maker states that "almost all household items can be put in the unit, including bottles, cartons, food wastes, and aerosol cans."

Capacity	1 1/2 cubic foot of compacted material
Waste density, average (before compacting)	20 #/ft^3 (16 to 26)
Compaction ratio	3 to 1
Noise	70 DBA (max.)
Volume, package	9" x 16" x 18"
Power	1/3 H.P.
Expendables	
Bags per family week	1.5
Aerosol (cans/family year)	3
Cost, expendables	
Bags, ($ dozen)	3.60
Aerosol ($/can)	1.00
Cost, unit (includes installation)	$230

Clothes Washing Machines (Westinghouse)

Common Top Loader

The average clothes washer is a top loader, reversing agitator type. A complete cycle includes one wash and one rinse fill in addition to spray rinses. Water quantities and temperature selections are provided for compatibility with various detergents and fabrics, especially permanent press items.

Filtration designs for removing lint and miscellaneous solids vary considerably. Backflushable filter elements trap solids and then flush them to the sewer or processing system. Other designs that retain solids for manual removal are perforated plastic trays, plastic bristles and wire mesh. Provisions are also made for automatically dispensing bleach and fabric softeners. Some specialized units contain water level controls which are adjusted as a function of load size.

E

TOP LOADERS (Continued)

Water Requirement (range)	30 to 60 gallons per full cycle
Water Requirement (average)	45 gallons per full cycle
Water Requirement (small load)	13 gallons per full cycle
Water Supply Pressure	30 to 120 psi
Supply Flow GPM	4 to 6
Discharge Flow GPM	12 to 20
Supply Temperature (Cold to Hot)	50^{o} to 160^{o}F
Cycle Time to Fill (Minutes)	8
Cycle Time to Drain (Minutes)	2
Total Cycle Time (Minutes)	40
Maximum Drain Pumping Head	8 to 12 feet
Noise	Water fill spray, start of agitation, initiation of stop.
Volume	15 cubic feet
Floor Space	6.4 square feet (29" x 25")
Interfaces	120 V.A.C., 60 Cyc., 15 AMP, 1/2 H.P. Hot/cold water, drain
Materials	Porcelain, polypropylene
Filtration	Perforated tray, Nylon fingers Back wash filter
Installation Time	30 minutes
Cost, Unit (installed)	$190 and up

Front Loaders

Front loading, tumbler type washing machines were the first to be mass produced in this country. Discussions with manufacturers indicate that they are more efficient and more effective than their top loading agitator type counterparts. Equivalent cleaning is claimed with up to 50 percent less detergent and somewhat less water. In addition to being more efficient, tumbling is less damaging to fabrics than agitation. Top loading machines on the other hand offer some convenience benefits (less effort to load and unload, better visibility). Top and front loading machines with equivalent optional equipment are comparably priced.

Water Requirement	30 gallons per full cycle
Water Supply Pressure	30 to 100 psi
Supply Flow GPM	4 to 6
Discharge Flow GPM	12 to 20
Supply Temperature (Cold to Hot)	50°F to 160°F
Cycle Time to fill (Min)	8
Cycle Time to Drain (Min)	2
Total Cycle Time (Min)	40
Maximum Drain Pumping Head	8 to 12 feet
Use Rate	1 to 3 times per day
Noise	Water fill spray, start of agitation, initiation of stop.
Volume	15 cubic feet
Floor Space	6.4 square feet (29" x 25")
Interfaces	120 V.A.C., 60 Cyc., 15 AMP, 1/2 H.P. Hot/cold water, drain
Materials	Porcelain, polypropylene
Filtration	Nylon fingers Back wash filter
Installation Time	30 minutes
Cost, unit (install. included)	$200 and up

Washing Machine Water Reuse

Clothes washing machines capable of reusing washwater have been commercially available for some time. Promoted on the basis of saving detergent (not water), their acceptance by the public has been extremely poor. Water and detergent are simply pumped to a holding tank (usually a utility tank adjacent to the machine) after the wash cycle. At the beginning of a subsequent cycle approximately 90 - 95% of the stored washwater is pumped back into the water. Less than total reuse permits the removal of settled solids. The machine is otherwise identical to conventional models. In its current form this feature requires a homeowner supplied holding tank or tub. The machine does not include provisions for reheating or sterilization. The absence of sterility could produce objectionable odors when washes are not performed frequently. For these reasons, and those of general inconvenience and lack of motivation, customer reaction has been almost totally negative.

Where water, rather than detergent savings are desired a similar arrangement could store rinse water for use in the following wash cycle. This would reduce problems associated with water quality. For future applications, machines could be produced with integral pumps, controls, holding tanks and heaters.

Shower Flow Restrictors (American Standard)

Shower flow restrictors take the form of flow regulators or orifice restrictors. They can be purchased as part of the shower head assembly.

Water Requirement	2 GPM or lower
Water Supply Pressure	80 PSI to as low as 1.5 PSI
Water Saving	Approximately 10%
Noise	Similar to conventional
Utility Interfaces	Municipal water supply
Size	Negligible
Materials	Variable
Isolation Provisions	Not required
Installation Time	5 minutes
Cost	

Dish Washing Machines (Whirlpool)

A typical dishwasher contains two trays and two rotating spray arms. It is front loaded and provides for automatic dispensing of detergents and wetting agents.

The machine is filled with hot water only. A heating element provides heat, compatible with the selected operating cycles, (e.g., rinse, soak, single wash, double wash, sanitize).

The filter element is a perforated plastic sheet, which is backwashed to sewer lines after each wash and rinse. Dishes are dried via electrically heated air.

Water Requirement	12.5 to 16 gallons per cycle
Water Requirement (Minimum)	10 gallons per single wash
Water Supply Pressure	15 to 120 PSI
Temperature	140 to 160°F
Supply Flow GPM	1.6 to 2.5
Discharge Flow GPM	4.5 to 7.5
Supply Temperature °F	140 to 160°F
Cycle Time to Fill	1.5 Minutes
Cycle Time to Drain	1.5 Minutes
Cycle Time	Approx. 60/minutes normal
Maximum Drain Pumping Head	15 feet
Noise	TBD
Volume	12 cubic feet
Floor Space	4.2 square foot (24" x 25")
Interfaces	Water supply, sewer drain 120 VA.C., 60 Cyc., 12.6 AMP.
Materials (Exposed to Water)	Porcelain
Filtration	Perforated Plate (Back Wash)
Installation Time	30 Minutes
Cost	$160 to $300
Constraints	Cycle time impacted by water supply temperature
Waste Composition	Foot particles, grease

WATER QUALITY MONITORING EQUIPMENT

Instrumentation for monitoring water treatment and sewage treatment plants are necessary for efficient operation. When renovated water is recycled from one system to the other, instrumentation is mandatory to assure health safety. Instruments are available in several styles based upon ruggedness, dependability, stability, service and calibration requirements. "Process instruments" are built and housed for long uninterrupted service in chemical plants, oil refineries and sewage treatment plants. Usually the sensor is at some distance from the readout/recorder. "Laboratory instruments" which are also called scientific instruments, are usually much more sensitive and versatile but require frequent calibration by skilled operators. The indicator is normally located with the sensor. Between these are a range of instruments with intermediate characteristics. They are often used for pilot plants or semi-works testing. Some of them are designed for routine testing of large numbers of samples with lesser accuracy than scientific instruments.

Since the monitoring requirements for water recycle equipment will be more stringent than that for sewage treatment plants, only process instrumentation should be considered. Unfortunately, process instruments do not cover all the parameters that require measurement. Some of the more delicate apparatus may be improved and made more durable as the need develops while other parameters will have to await state-of-the-art advancements in sensing methods.

A survey of available process instruments from the leading manufacturers was made. Not all the equipment is made by the manufacturer selling it. Sensors and other components are purchased in order to sell instrumentation "systems". The trend has been to provide the customer with a complete instrumentation service comprised of system design of sensors, transmitters, indicators, recorders, controllers, instrument panels and even analog or digital computers. In addition, the vendor usually includes installation, maintenance and servicing. This puts responsibility for successful operation in one company. Table 10 shows the availability of various instruments from manufacturers surveyed.

Water Quality Parameters

pH

Electrodes for pH measurements are readily available, technically well developed, accurate, reliable, stable and operate unattended for long periods. Occasional removal of fouling growth and recharging of the reference electrode are needed. Various methods of sealing the essentially glass electrodes into a pressure retaining mounting are used.

Chemical Species

Drinking water standards specify limitations on chemical concentrations allowed. Because the normal supply resource is such a large accumulation of water, the chemical characteristics change very gradually, if at all. Analysis of chemical species need only to be performed at regular, infrequent intervals. Manual tests are adequate for this purpose. In systems utilizing artificial recycle, the rate of change for chemical species are much more rapid for several reasons. Instead of having one original source of water (precipitation), the system has two (precipitation and sewage). Sewage contains some chemical species that can be orders of magnitude greater than those contained in rainwater even after it leaches material from

TABLE 10 WATER QUALITY EQUIPMENT SURVEY

MANUFACTURERS Process Instruments	pH	Ion Conc.	Particulate Contamination	Dissolved Solids	Organic Levels	Foam Detection	Bacteria Detection	Bacteria Control	System Work	Flow	Level	Temp.	D.O.	Recorders Controllers	Computer Control
Beckman	X	F, Cl	Turb.	Cond.	TOC/ORP					X	X	X	X	X	
BIF	X									X	X			X	
Bristol	X									X	X	X		X	
Fischer & Porter								Cl_2		X	X			X	
Foxboro	X	CN, F, S, Ag, Cl, Cu, Na, Hardness			ORP	X			X	X	X	X		X	X
General Electric									X						
Honeywell	X	Cl	Turb.	Cond.	ORP				X	X	X	X	X	X	X
Leeds & Northrop	X	Na		Cond.	ORP					X	X	X	X	X	
Westinghouse									X	X	X			X	X
Non-Process Instruments															
Ionics Inc.					TOD										
Precision Scientific	X				COD										
Hach	X		Turb.												
Gam Rad			Turb.												
Photronic			Turb.												
Ex-Cell-O Corp.			Turb.												
Comrol Lab.				Cond.											
AES/Raytheon					TOC*										
Union Carbide					TC										

* Continuous instrument expected available by the end of the year.

Ag Silver
Cl Chloride
Cl_2 Chlorine
CN Cyanide
Cu Copper

F fluoride
Na Sodium
S Sulfur
COD - Chemical Oxygen Demand
Cond. - Conductivity

TC - Total Carbon
TOC - Total Organic Carbon
TOD - Total Oxygen Demand
Turb. - Turbidity
ORP - Oxidation - Reduction Potential

the ground. Furthermore, sewage chemical concentrations can change rapidly. With a high degree of recycle, the water resource becomes that which is contained in the system rather than the watershed or ground water supply. The result is that the water resource is many orders of magnitude smaller, thereby allowing still more rapid changes in chemical species concentration. It becomes obvious that continuous on-line monitoring will be needed for chemical species in water recycle systems.

The 1962 PHS standards for drinking water (Table 2 in Water Supply section) lists undesired chemical species which when present in excess may require the use of an alternate supply source or simply rejection of the water as being potable. Most of these species are inorganic ions. There are three classes of instruments which can determine ionic concentrations: absorption spectrophotometers, automated wet chemical instruments and specific ion electrodes.

Atomic absorption spectrophotometers are used to determine metal cations down to very low concentrations in water. However, the detection limit is inadequate for three metals, marginal for two and acceptable for six. The machine examines for only one metal at a time and is not applicable as a process instrument for a number of other reasons. Cations whose maximum limits are below detection limits of the instrument, require evaporation of the water to increase concentrations. Changing of a specific cation lamp requires time for stabilization and calibration. The basic price of the current versions of this instrument is about $10,000 and automatic sequencing for various cations would greatly increase the price.

The wet chemical instruments are automated versions of manual analytical tests. Some of them operate on a continuous flow stream with continuous readouts. The continuous instruments are limited to about 10 chemical species with only the chlorine monitor being used regularly in full scale sewage works. None of these are built in the typical process instrument style.

Specific ion electrode instruments have been adapted from the scientific instrument area by process instrument manufacturers. The ions that can be monitored so far are (1) sodium and fluoride, (2) chloride, cyanide, copper 2+, silver and sulfide, (3) divalent cations (water hardness). Electrodes for group one are selective by reason of the crystalline material covering the electrical lead. Group two electrodes are specific because of the electrode material. The third group employs liquid ion-exchange solutions which react with the desired chemical species. A membrane retains the fluids.

Another specific ion that can be monitored but whose specific electrode is not yet available in a process instrument version, is the nitrate ion electrode. This electrode is satisfactory for drinking water where the chloride ion concentration is low.

Dissolved Solids

According to standard analytical procedures, dissolved solids include solids in true solution and colloidal particles that pass through a specified filter. Current filter recommendations are for filters having pore sizes between 200 and 450 millimicrons ($m\mu$). Colloids range from one to 1000 $m\mu$.

The chemicals in true solution are further categorized as organic and inorganic. The organic chemicals are normally included with particulate organics as the organic level, measured by biochemical oxygen demand (BOD) or chemical oxygen demand (COD) etc. Thus the term dissolved solids is usually applied to true solutions of inorganic salts, since inorganic particulates in domestic sewage are innocuous with respect to sewage treatment or dischage into receiving waters. Another justification for excluding very fine inorganic particulates is that their mass is quite small. In an industrial waste containing filterable solids, there will probably be a tremendously larger mass of solids that will not pass through a filter. Therefore, the larger particles will characterize the stream and the very small ones will be considered insignificant.

Dissolved inorganic chemicals are monitored by process instruments as conductivity (or resistivity) as an <u>indication</u> of concentration. In spite of the many inherent errors in this approach, this measurement is usually adequate for most purposes. In a recycle system, conductivity monitoring in the purified stream would be adequate measurement of dissolved (inorganic) solids concentration. For concentrated waste streams conductivity loses its correlative value. If concentrated waste streams require monitoring, it would be necessary to use some other characteristic such as specific gravity.

Conductivity instruments are well developed and are available from several process instrument manufacturers.

Particulate Contamination

Accurate, meaningful information about particulate contamination in a fluid being continuously monitored has long been elusive. The standard analytical procedure for particulate determination calls for weighing of solids retained by a fine filter which has passed a known volume of liquid. The weight of the extremely small particles that pass through the filter are an insignificant percentage of total weight. The filtration/weighing technique is not amenable to adaptation for continuous monitoring. Instead, optical methods are used.

Various approaches to measuring turbidity have been tried to correlate turbidity with mass of particulates. Since the biochemical effect of a contaminant is a function of mass, this is the parameter that is correctly sought. The techniques that have been used are: absorbance (the inverse of transmittance); forward scatter; side scatter (nephelometry); back scatter and combinations of these. The color of the fluid itself affects all these measurements. In attempts to overcome fouling of the optics, windshield wipers, jet streams, bleed streams, falling films and overflowing surfaces are used.

Regardless of how well the optical and fouling prevention techniques work, correlation must take into account: size distribution of particles; shape; surface smoothness, reflectivity and color; and shadow effects in higher concentrations. With the extremely wide range of particulate materials in sewage it is difficult to conceive of a good solution to measuring particulate mass by turbidimetry. However, turbidimeters have been and are still used as process instruments for this measurement.

Organic Levels

The standard for organic contamination of wastewater is the biochemical oxygen demand (BOD) test. This test actually measures the oxygen used by bacteria in oxidizing organic chemicals during a five day incubation period. It does not measure the mass of organics present. The test was devised for and is a good measure of the effects of wastes on a receiving stream. If the oxygen is depleted because of the wastes, the water will have an offensive odor and an adverse effect on aquatic life.

In a water recycle system, the accumulated mass of organics present, the actual chemicals and their toxicity are the significant factors. The most appropriate measurement to a recycle situation is total organic carbon (TOC). A zero value for this measurement would preclude toxicity, however, the establishment of a practical maximum allowable level will require extensive investigation. The evaluation would cover the nature of the recycle compounds and the extent of their toxicity.

At present, there are no process instruments capable of continuous TOC analysis. One manufacturer expects to have such a machine available shortly and another within two or three years.

Oxidation-reduction potential (ORP) is sometimes used in a treatment plant to indicate the change in biodegradable organic concentrations into and out of the plant. Since it is not a direct measurement and does not correlate from plant to plant, it is not a universally accepted parameter for organic level measurements.

Foaming Control

Foam is caused by agitation of a gas and a liquid, having a low surface tension. Before the use of detergents, the contaminants in sewage did not lower the surface tension sufficiently to cause difficulties. With the almost universal usage of detergents, excessive foaming took place in rivers and lakes, where sewage effluent was discharged. Reduction of this foaming problem occurred when the detergent industry converted to more biodegradable surfactants. These detergents have apparently eliminated the foaming in receiving waters.

Foam can be a problem in the aeration tank of an activated sludge plant. Most aeration tanks are provided with spray nozzles which utilize sewage effluent to break the foam. Operation of the spray can be continuous, intermittently cycled or manually initiated. For automatic control of the spray, one process instrument manufacturer provides a "switch" consisting of two electrodes which are electrically connected by the foam bridging a gap. Optical sensing of foam height can also be used. There has been no great emphasis on the development of foam sensors since there does not seem to be a great need for them in sewage plants. Most treatment plants have sufficient personnel to attend to the problem.

Back Contamination Control Devices and Techniques[1,2]

The use of renovated wastewater in a system does not necessarily increase the need for back contamination control. The need exists even with conventional water distribution/wastewater collection systems. Probably the greatest influence over back contamination can be exerted in planned new communities where the system is designed at one time and where compliance with regulations are most likely to be met. The requirements and devices for backflow prevention are well established; the problem lies in the consistent application of principles in the design of a system and the understanding and compliance of the system users with these principles.

There are two types of cross connections: direct or pressure type and inlet or gravity type. The pressure type exists where a supplemental pressure source is directly connected to a pipe or tank that is normally supplied with potable water. If the supplemental pressure is higher than that of the water supply and that pressure is applied for an extended duration, then the contents of the pipe or tank can be fed into the water supply system. In a domestic system, this situation can arise where a well is used to supplement city water. If the well is or becomes contaminated it becomes a source of a health hazard.

The gravity type of back contamination is a much more prevalent situation in domestic water supplies. In this situation, the pressure in the line is lower than the pressure of a source of contaminant. In many instances of back contamination, the water supply system was sub-atmospheric in places. Reduced pressure is not a frequent occurrence and by itself is not a hazard. The danger lies in the simultaneous occurrence of reduced pressure, a source of contamination and an opening in the system where the contaminant is located.

Causes of low pressure are: a break in the line, temporary shutdown and repair of a line at other than the highest point, or excessive flow in part of the system such as the use of a fire hydrant. Sources of contamination are due to blockage of a sewer line raising the contaminant liquid level higher than an opening in the supply line and permanently or temporarily submerged supply lines. An example of the first situation exists with underground sprinkling systems. Temporarily submerged lines occur where hoses from a tap feed into a tub, sink or even onto a floor where contaminants can accumulate. Openings in the system are produced by valves opened for use (as in the case of a tub being filled through a submerged hose), defective valves, check valves, etc. and automatically self draining valves for frost-proof operation.

There are five distinct types of piping or mechanical devices that are used to prevent backflow. They are:

- Air Gap - The supply pipe is physically terminated above top rim of the receiving tank, tub, sink, etc. The gap should be at least two pipe diameters but not less than one inch.
- Non-Pressure Vacuum Breaker - This type is also known as atmospheric vacuum breaker or a syphon breaker. It is essentially a tee with a check valve built in. The third opening of the tee is vented to atmosphere. In operation, water pressure opens the check valve causing it to seal the opening to atmosphere. With flow shut off, the valve poppet falls by gravity, opening the tee to atmosphere and sealing off the supply line. Water in the discharge line drains and is replaced by air.

This type of breaker is not used where water pressure is applied for long periods of time nor where there is any back pressure apparent to the breaker. The shut off valve is always upstream and the breaker is mounted at the highest point of the line.

- Pressure Type Vacuum Breaker - This type of breaker is similar in operation to the non-pressure vacuum breaker except that a spring is used to close the check valve and open the atmospheric port. The design permits operation with any back-pressure condition.

- Double Check Valve Assembly - The assembly consists of two spring loaded check valves in series, each acting independently. It has shut off valves both upstream and downstream of the check valve. It can be used where aesthetically objectionable substances may enter the potable water system under back flow conditions. It is not used with systems containing fluids that present a health hazard. Back pressure is an acceptable condition of operation.

- Reduced Pressure Device - This is basically the same as the double check valve assembly with an added relief valve that is operated by the differential pressure across the first check valve. The spring in the check valve produces a pressure drop across the valve even with very low flow. In order for back flow to occur the pressure differential across the check valve would have to be negative with respect to the normal flow direction. Before this occurs, the differential would fall below the minimum acceptable value and the relief valve opens. The greater the tendency for backflow, the more the relief valve opens thereby bleeding off any possible contaminants. This device is used where the fluid that can back flow represents a health hazard. It also works in supply systems with back pressure. The only exception to its use is the case of direct connection to sewage under pressure.

The above devices will satisfactorily protect potable water systems from contamination if they are consistently and prudently designed and installed in a system where the users and repair/maintenance people follow safe practices. Aside from intentional disabling of devices and negligent non-maintenance, probably the greatest danger lies with careless use of temporary interconnections between systems during periods of repair or maintenance. This problem can be minimized through the use of special fittings and line sizes.

Bacterial Control

Present drinking water standards allow up to eight coliform bacteria per 100 ml. A common standard for treated sewage effluent is 240 coliform per 100 ml. It appears that three percent of effluent that meets discharge standards in pure water would meet coliform limits for drinking water. The use of coliform bacteria as an indication of microbial contamination has been acknowledged because in the natural recycle of used water, time is sufficient to allow die off of these bacteria. Implied in this approach is the fact that pathogenic organisms which are parasitic, will die off more rapidly since they are not nutritionally supported by a natural host. In artificial recycle systems, the time interval between use and reuse may be orders of magnitude smaller. The state-of-the-art of killing or controlling bacteria to levels acceptable in artificial recycle systems is adequate. What is needed is an improvement in the degree of treatment to bring it up to the-state-of-the-art.

Of all the methods available for disinfection, chlorination is almost universal in the United States. The use of ozone for disinfection of effluent has had greater usage in Europe and is gradually increasing in this country. A third method that is normally too expensive is heat disinfection. Because no important waterborne disease is caused by sporeforming bacteria or to the heat resistant organisms[3], this method can be very useful in a recycle system where waste heat and heat regenerators are used.

Another potential disinfection method that is commonly used in sewage treatment plants for reasons other than disinfection, is lime precipitation of contaminants. Bacteria are destroyed by the addition of sufficient lime to bring the pH over 11[4]. Lime is also used in softening drinking water and in the ammonia stripping process for removing potential nitrates from sewage effluent. Other methods employ ultra-violet light, silver and copper ions, acids (for low pH) and cationic detergents. They do not appear practical for community systems at the present time because of cost and effectiveness.

There are no process instruments available today which monitor all viable bacteria in water. Two laboratory instruments on the market measure the number or mass of bacteria by indirect methods and are severely limited in capability when the fluid medium varies and there are numerous species of microorganisms present. Their sensitivities are greatly inadequate for monitoring potable water. Their response time can vary up to a half a day.

NASA funded development of a bacteria monitor for aerospace use[5] may well be the procursor of process instruments used in waste water recycle systems. At present, the breadboard instrument needs improvement in sensitivity. The incubation period before readout would be acceptable for larger recycle systems only, where detention times of the purified water are longer. Presumably, the complexity and cost will be reduced during subsequent development.

Virus Control

The major characteristics of viruses that make them so important in a water system that has any possibility of recycle, are: very long survival time even with environments that provide no support; and their great capacity to infect their hosts. Viruses do not multiply outside their hosts but their destruction by natural processes is very slow. A single virus can cause infection, not necessarily illness, where the infected host generates many more viruses that can be disseminated later by various means. Problems associated with viruses are compounded by: the difficulty of detection or assaying quantity, the establishment of the relationship between waterborne viruses and infection, illness and epidemics and the very low concentrations in water supplies.

The technology for virus detection has not even progressed as far as bacterial detection. Techniques are manual and require incubation periods. Efficiency of assay techniques are often less than one percent [6]. Because of the low concentration of viruses, large samples need to be treated to concentrate viruses for detection. A common quantity is 100 gallons. Even if a virus is not detected in this quantity, sample size sufficiency can always be questioned. Currently, there are no automatic instruments, continuous or non-continuous that monitor viruses.

Viruses can be destroyed by chlorine, ozone and heat. Chlorine action on viruses is affected by the same factors that affect its action on bacteria. Organic contaminants present can convert the chlorine to chloramines which are less effective in destroying viruses as they are for bacteria. Ozonation is not yet a common techniques for disinfecting sewage effluent in this country. Thermal destruction which is highly effective, has always been considered too expensive. In total energy systems, the thermal process may become practical.

Conclusions

In order to prevent inadequate instrumentation from limiting the use of otherwise economical waste water recycle systems, several courses of action can be taken. The most obvious path is accelerated research and development of new, better or more appropriate sensing methods and equipment. Increased government funding, redirected objectives and the creation of a large sales market in the water recycle system field may produce the necessary results.

Another avenue of approach is the development of purification processes which will preclude the need for as yet undeveloped, sophisticated instrumentation. Satisfactory operation of these processes may still need monitoring but of the more common type. For example, high temperature destruction of bacteria and viruses could be verified by tracking temperature, with diversion of inadequately sterilized water in case of failure. As a subtask to this course of action is the proof that each process design is sufficient under laboratory and field conditions, which could require more effort than the process development itself. This same subtask is implied as well, in the first course of action, development of improved sensing methods.

For the purpose of this study, adequate instrumentation will be presumed for all recycle methods, although an effort will be made to use those processes that are least dependent upon new instruments.

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5. Witz, S. and Hartung, W. H., Development of a Tape Transport Bacterial Detection System, Final Report No. 1102F Aerojet Medical and Biological Systems, Aerojet-General, February 25, 1972

6. Dr. Safferman, R. S., EPA, National Environmental Research Center, Cincinnati, Ohio, Personal Communication

Manfacturers who provided information contained in this section are:

Toilets	
AIRVAC/National Homes Corp.	Rochester, Indiana
American Standard	New York, New York
Anco Industries	Riverton, New Jersey
Chrysler Corp.	New Orleans, Louisiana
Eljer Plumbing Division	Pittsburgh, Pennsylvania
Koehler Dayton	New Britain, Connecticut
Kohler Company	Kohler, Wisconsin
La Mere Industries	Walworth, Wisconsin
Monogram Industries	Los Angeles, California
Research Products Mfg. Co.	Dallas, Texas
Sherwood Products	San Antonio, Texas
Water Saver, Inc.	Fort Lauderdale, Florida
Faucets and Nozzles	
American Standard	New York, New York
Richard Fife	New York, New York
Clothes and Dishwash Machines	
General Electric	Louisville, Kentucky
Westinghouse Electric	Columbus, Chio
Whirlpool Corporation	Benton Harbor, Michigan
Sewage Treatment	
Cromaglass Corporation	Williamsport, Pennsylvania
Wilson Water Purification	Buffalo, New York
Union Carbide Corporation	New York, New York

F

IV APPLICABLE AEROSPACE TECHNOLOGY

PROCESSES

The criticality of efficient water and waste management to the design of advanced manned spacecraft has motivated NASA and the aerospace industry to undertake a wide variety of development programs. For the most part, resultant systems contain processes that were originally developed for less demanding industrial and commercial applications. For example, reverse osmosis technology was originally developed for the conversion of saline water in areas with water resources problems. Motivated by a requirement to recycle personal hygiene water this technology was expanded by the aerospace community to the point where reverse osmosis is an attractive candidate for domestic washwater treatment.

Evaluations revealed that much of the sophistication of aerospace adaptations of water and waste treatment processes is a result of unique requirements for: zero gravity operation, extremely high reliability and minimum weight, volume and power utilization. Great emphasis is placed on systems integration as a means by which spacecraft penalties can be held to absolute minimums. Extensive manned test programs are conducted to evaluate "closed loop" systems. Since there are practical limits on achieving reliability, in flight maintenance provisions are designed into critical spacecraft systems. Much of the technology developed to adapt water recovery processes to spacecraft requirements are relevant to the design and implementation of advanced integrated urban utilities systems.

LOW WATER CONSUMING EQUIPMENT

In order to compliment the survey of commercially available low water consuming fixtures and appliances, spacecraft devices were evaluated for their domestic potential. In general, their use requires a high degree of motivation that is not achievable in household situations.

Zero Gravity Whole Body Shower

This program consisted of theoretical and experimental investigations to develop low water consuming whole body shower concepts capable of operating in a zero gravity environment. They resulted in the selection of two shower concepts. They differ only in the manner in which they control the flow of water through and extraction from the shower assembly in the absence of gravity forces. The first concept transports and extracts water with a recirculated air flow. After extraction, a liquid/gas separator isolates the water from the airstream, allowing recirculation of air through the blower and back into the shower, and pumping of water into a storage tank. The blower serves a dual purpose of heating the air to a comfortable temperature before it re-enters the stall. The second concept employs a lower air recirculation flow rate necessitating a vacuum device for water extraction. Otherwise the concepts are essentially identical.

The deletion from these concepts of provisions for zero gravity fluid transfer and water/air separation leaves simply a moveable, hand-held, low flow spray nozzle with on-off hand control. It was demonstrated that, with sufficient motivation, effective showering can be acheived with flow rates and total water consumptions on the order of 0.35 gpm and 0.6 gallons respectively. The value of a hand held moveable nozzle with on-off control in reducing water requirements was clearly demonstrated. The inconvenience associated with this approach might not be universally acceptable in domestic situations. A fixed, low flow nozzle with a conveniently located and operated (push button) on-off control offers an attractive compromise. During certain showering procedures (soaping, scrubbing) shower water is normally avoided. A capability to readily stop and reestablish flow (at the desired temperature) appears attractive, regardless of the water savings it would provide.

For the most part, the concepts developed only have application in a zero gravity environment. General showering data will, however, be useful in developing water conservation practices and equipment.

Anal Douche/Air Dry Waste Collection System (Hydro-John)

This program developed a prototype human waste collection system for long duration spacecraft applications. The system features a manually initiated, automatically controlled anal wash and dry cycle for use after defecation. Feces and urine are deposited into the system separately. A steady flow of transport air draws the feces into a blender and the urine into a receptacle. When the user actuates the flush cycle after defecation and micturation, flush water washes his anal area and the urinal. When a small quantity of water has accumulated in the blender it is mixed with the feces to form a slurry which is pumped out of the system. Flush water continues to flow during the pump out cycle thereby washing the user and the collection system. The flush cycle lasts approximately 30 seconds and requires about four (4) pounds of water. The user is then dried by the transport air which is heated to hasten the process.

An obvious attractive feature of this system is its potential for reducing or eliminating the use of toilet tissue for anal wiping. This would reduce solids removal and processing requirements in water reuse systems.

The system also features functionally separate provisions for collecting and transporting feces and urine. As a result, it is of particular interest to recycle concepts that require separation of the basis of solids concentration levels.

Although widely used in other portions of the world, douching is virtually unpracticed in this country. The required change in a most personal hygiene habit is obviously the most serious deficiency of the system. In addition, it is doubtful that all constituents of feces can be removed by douching without some mechanical action. The relatively excessive drying time required would also be generally unacceptable in domestic situations.

Waste Separation, Deactivation by Dehydration and/or Chemical Addition (Dry Johns)

Several programs have developed prototype zero gravity waste collection systems that concentrate and treat feces by either the addition of chemicals or by vacuum drying. Air enters inlet ports just under the seat applying viscous drag forces on the feces and thus transporting it to a motor driven slinger/separator. Rotating tines break up the solid fecal mass and sling it against the container wall where a thin coating is created. Air passes out of the unit through bacteria and odor removing filters. In chemical systems liquid germicides are sprayed onto the feces layer to deactivate microbial growth. In vacuum systems the user actuates a vacuum pump to reduce container pressure to about 1 psia. A vent valve to space vacuum is then opened. The feces are dehydrated to deactivate microbial growth and reduce their weight and volume.

Containers are typically sized for a few hundred man-days of operation. Containers are designed to be replaceable should it be required by extended mission durations.

Once provisions for zero gravity operation are deleted these systems become essentially the same as chemical and concentrating toilets extensively used in aircraft, marine and mobile home applications. Urine/feces separation schemes may, however, be of interest to some recycle concepts. In addition, data acquired in some of these programs should be of value in selecting germicidal agents for domestic systems.

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2. Reville, J. J. ; and Murray, R. W., "Development of a Prototype Waste Collection System (the Hydro-John)" NASA Contract NAS 9-9741, General Electric Company, February 1970.

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V COMMUNITY MODEL

In order to make a consistent assessment of the various concepts, a housing model is required. An apartment complex, similar to that used by NASA in a recent report on Advanced Housing Development is used. The basic characteristics of the model are:

- population of 2000
- five hundred apartment units
- twenty-six apartment buildings
- average of almost 20 units per building
- fifty-two acres total
- twenty-five acres of landscaping
- layout of buildings as shown in Figure 17
- level terrain

To avoid limiting the evaluation to small populations, the economic analyses are conducted for "towns" of 25,000 and 250,000 people as well as the community of 2000. The towns are comprised of 12-1/2 and 125 model communities tightly surrounding a central district as shown in Figure 18 and 19. While it is recognized that larger towns would not be layed out in this manner, the models provide a convenient and representative means of evaluating larger populations. Again, the terrain is assumed to be level. The lines between buildings and communities shown in the figures are discussed later in the report.

The equipment for processing water, waste water and refuse is always considered to be central to the population under study. That is, for a population of 2000, the water reclamation equipment, refuse incinerator, etc. is located on site. For 25,000 or 250,000 people, this equipment is in the center of town.

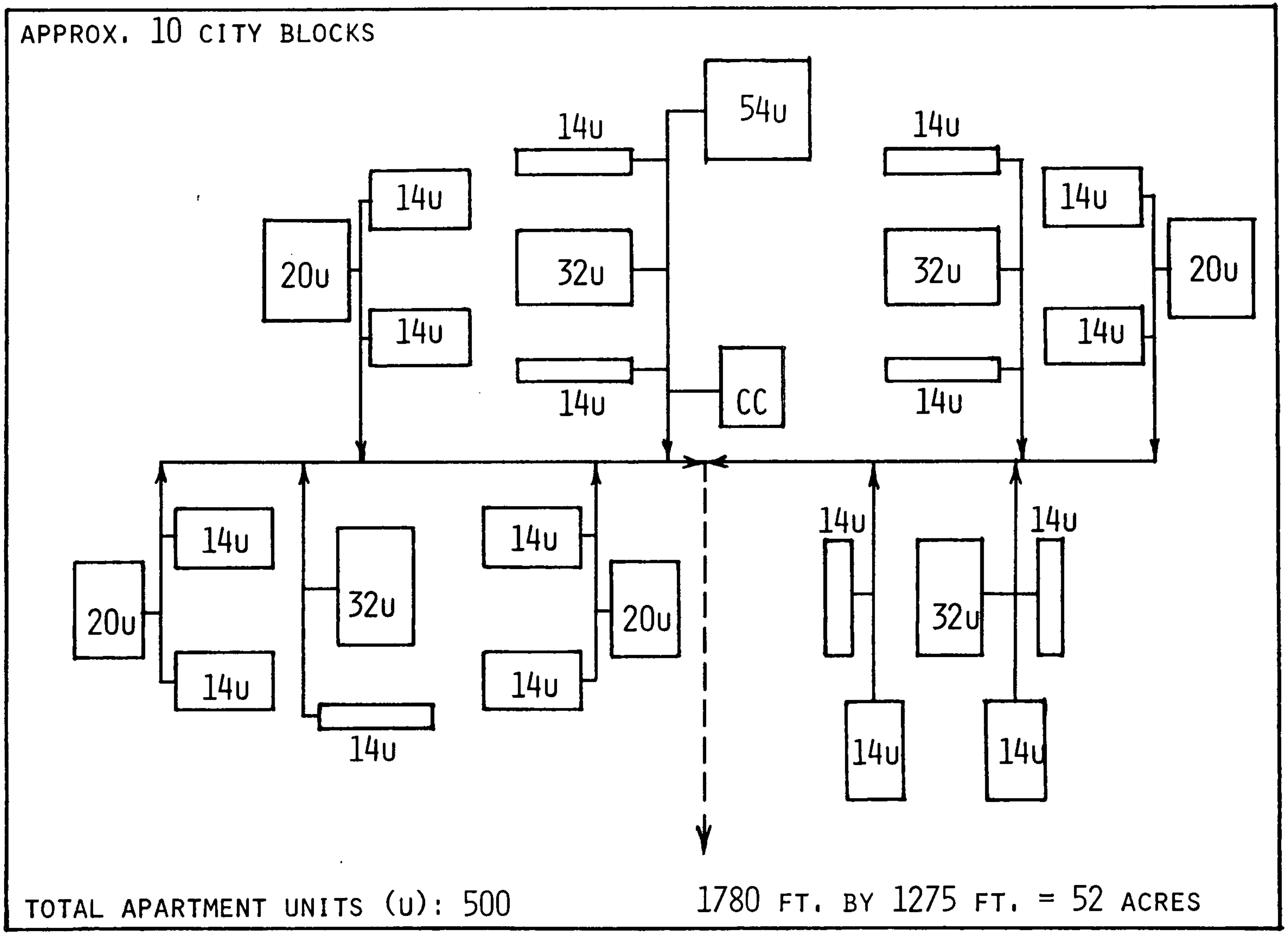

Figure 17 Community Model - 2000 Population

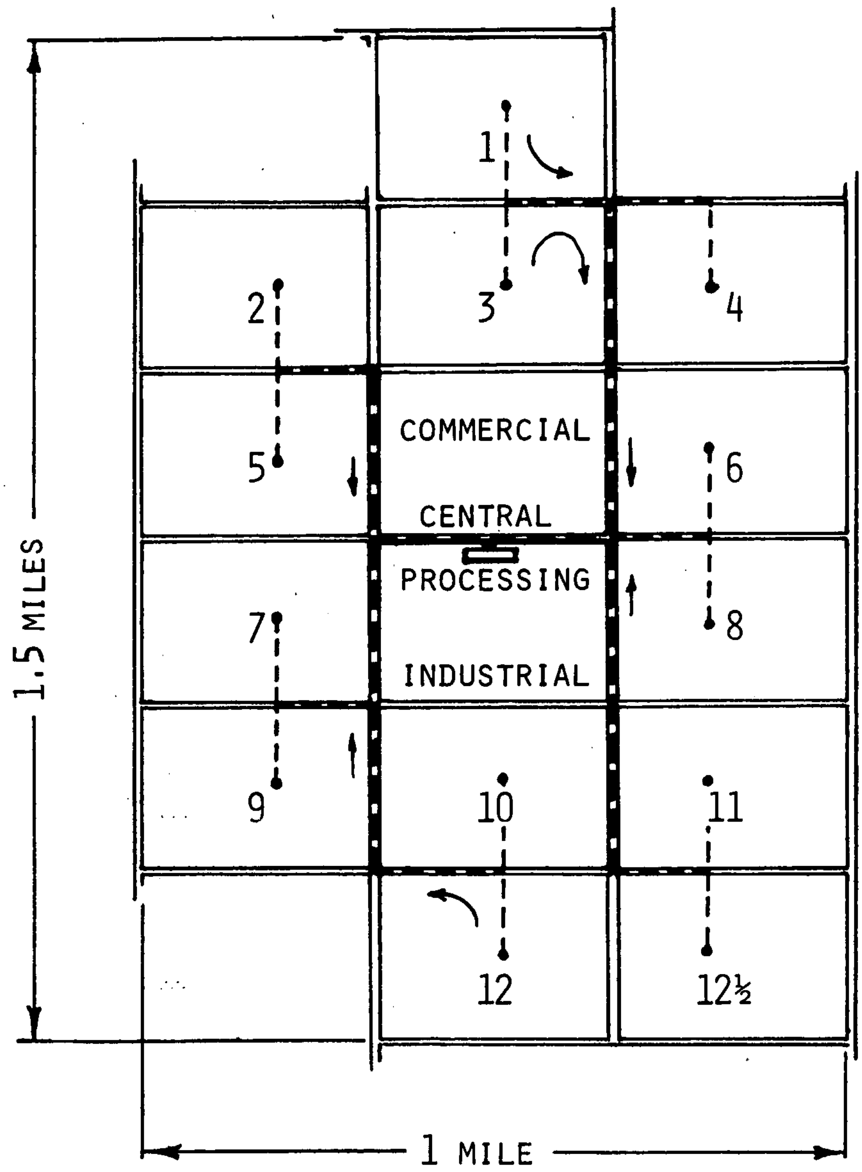

Figure 18 Town Model - 25,000 Population

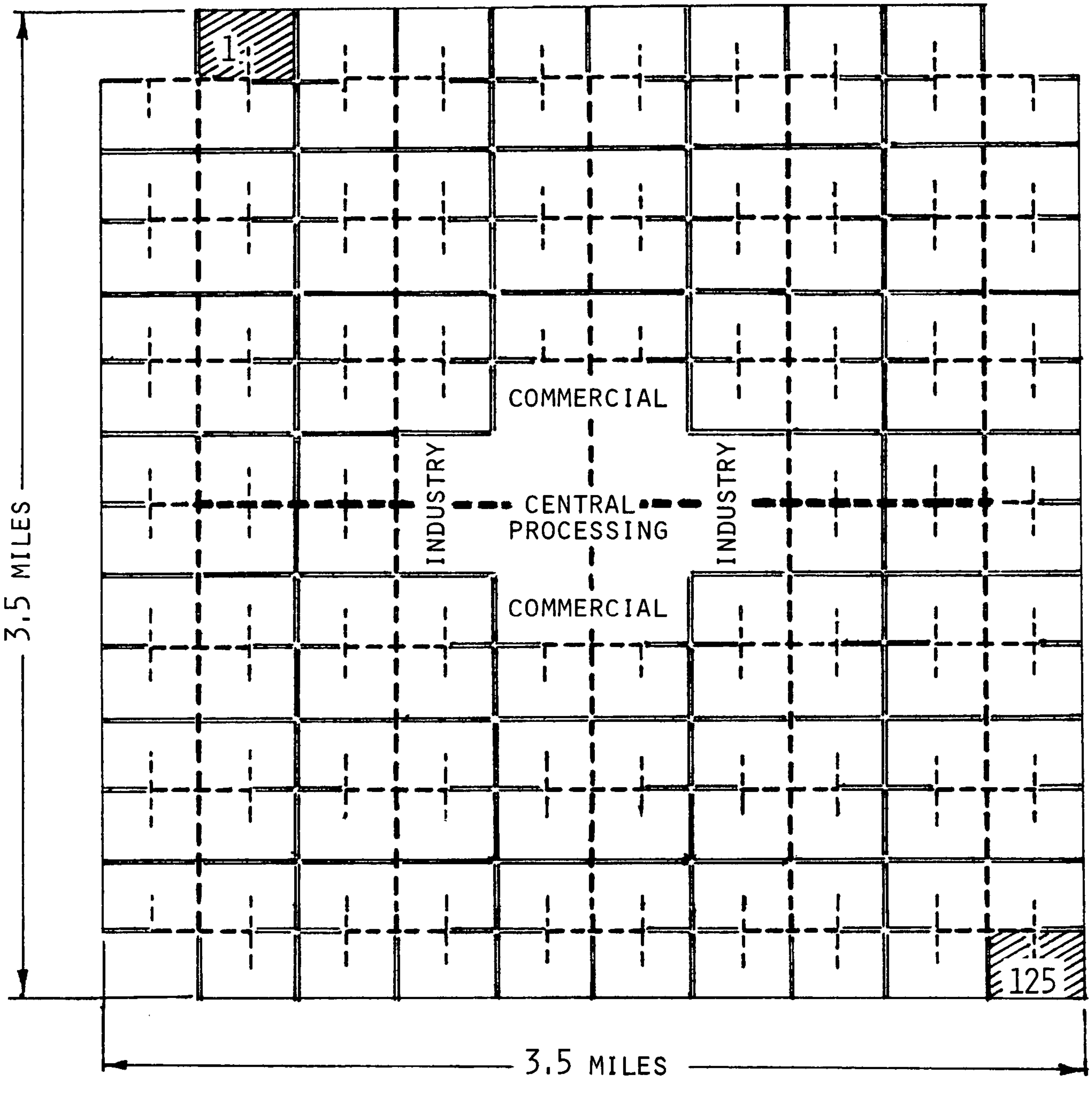

Figure 19 Town Model - 250,000 Population

VI COST EVALUATION DATA

GENERAL COST FACTORS

There are many variables which affect the estimated current and future costs of water and solid waste management. Their significance and the methods used in dealing with them are discussed below.

Subsidies

The federal government, and to a lesser extent, state governments contribute funds to municipalities to alleviate the high cost of local sewage treatment facilities, but not water supply systems. Since the governmental funds originate with the taxpayer, he shares in the cost of all treatment facilities. If the government's percentage of cost sharing were constant over a long period of time, say fifty years, each taxpayer would be paying his share for the total cost of local treatment facilities. Private developers of new towns are not eligible for government subsidy, leaving those residents with the full burden of sewerage costs. For the purpose of this study, subsidies will not be taken into account.

Cost of Finance

That portion of construction costs that are contributed by a local municipality are obtained through the sale of bonds. The interest and amortization (debt service) of bonds for the treatment plant alone usually cost more than the operation and maintenance of the plant. For sewers, the debt service accounts for nearly all of the annual cost. For water supply systems, the capital costs are usually covered by bonds and the operating costs by usage charges.

The variables that affect the annual cost of finance are the years to bond maturity (at which time the bond is redeemed) and the interest rate. Both of these factors are governed by the bond market, credit rating of the municipality and the type of bond.[1]

The bond market is determined by prime interest rates and the quantity of bonds in circulation at the time. It is suggested by the FWPCA[2] (now EPA) that increased construction of waste water facilities abetted by augmented federal funds may drive up interest costs in the bond market. Figure 20 shows market fluctuations in interest rates for municipal bonds.

Using a conservative interest rate of 5% and an average equipment life of 30 years, the Capital Recovery Factor (CRF), is 0.065. This means that for every $1000 borrowed, $65.00 per year (for 30 years) is required to pay interest and retire the debt. There are a number of minor elements of finance that make the CRF inexact, but the potential error in forecasting interest rates overshadows them. For this report, the CRF of 0.065 will be used.

Cost Index

Construction costs have been rising steadily since the mid 1930's. The rate of increase varies with the years, geographical area and is somewhat different for various types of construction. The Evaluation and Resource Control Section of the Environmental Protection Agency's Division of Municipal Waste Water Program, generates a monthly cost index for both sewers and sewage treatment plant construction[3]. The index is maintained for each of 20 cities throughout the country with the national index as an average of the city indices. These indices have been generated since 1961.

The cost index is a tool for converting cost guidelines and estimating procedures established for some period in the past to current costs. A cost established for a particular year divided by the index for that year will equal an equivalent cost in some other year divided by its index. The national average index will generally be used in this study since the greatest deviation in 1967 (for New York City) is only +16% for treatment plants and +27% for sewers. Other indeterminate factors make this deviation insignificant.

Another important use of the cost index is the future projected costs for construction. Figure 21 shows past and projected index values, estimated from slopes during previous historical, economic periods. The cost index for sewers rose at a rate of 8.7% from 1968 to 1971. The projected index rises at a rate of 4.6% from 1971 to 1982. For the Cost Summary for the year 2000, used in the Concept Evaluation Section, a minimum rate of 3% per year (general price index slope for the past 20 years) and a maximum of 5% per year will be used. Assigned values will be based on complexity of the item evaluated, with sewer construction taken as the maximum.

Local Site Effects

All data, equations and graphs published for estimating construction and operating costs are averaged. Sampling for statistical information may be wide, narrow, or limited by some arbitrary classification but the results are always presented as averages.

For the same type of treatment plant, for example, construction costs vary around some mean, with unusual situations requiring as little as one third to as much as three times the norm. Operating costs vary by a maximum ratio of two. Average construction costs of different types of treatment plants can be as little as one seventh the cost of a conventional activated sludge plant. Collection sewers and interceptors also vary by a maximum ratio of three.

The local site has a profound effect on construction costs as well as the type of treatment permissible. This would hold true even with uniform codes, regulations and specifications for treatment. The factors involved in local sites are too numerous to discuss in this study, especially since they must be ignored for generalized conclusions. Examples of disturbing factors are: topography, type of soil, type of subsurface geology, labor rates, climate, precipitation, distance from site to water source, manufacturing centers and raw material sources.

Industrial Sewage

Although this study is directed at residential water and sewage, larger treatment plants accept more and more industrial sewage as the size of the community increases. This is evident in graphs showing sewage flow versus population served[4]. The actual amount of industrial sewage is relatively small; orders of magnitude different from the discharges expected from a steel mill or an oil refinery. No special attention will be given to reclaiming water from industrial wastes in keeping with the generalized approach of this study. In new communities, the quantity and quality of industrial waste waters will be approximately known and can then be included in overall water management planning.

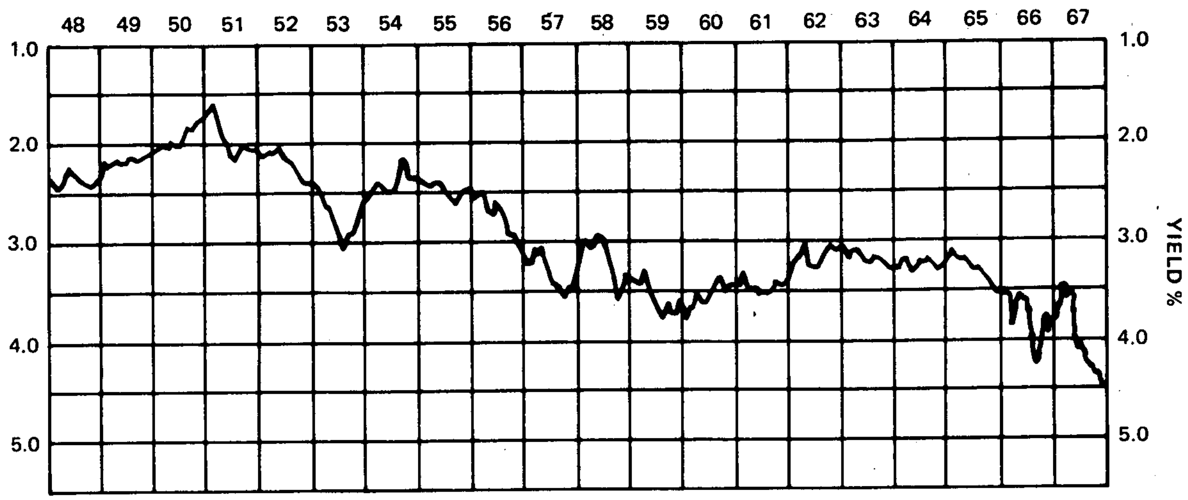

Figure 20 Trend of the Bond Market - 1948-1967

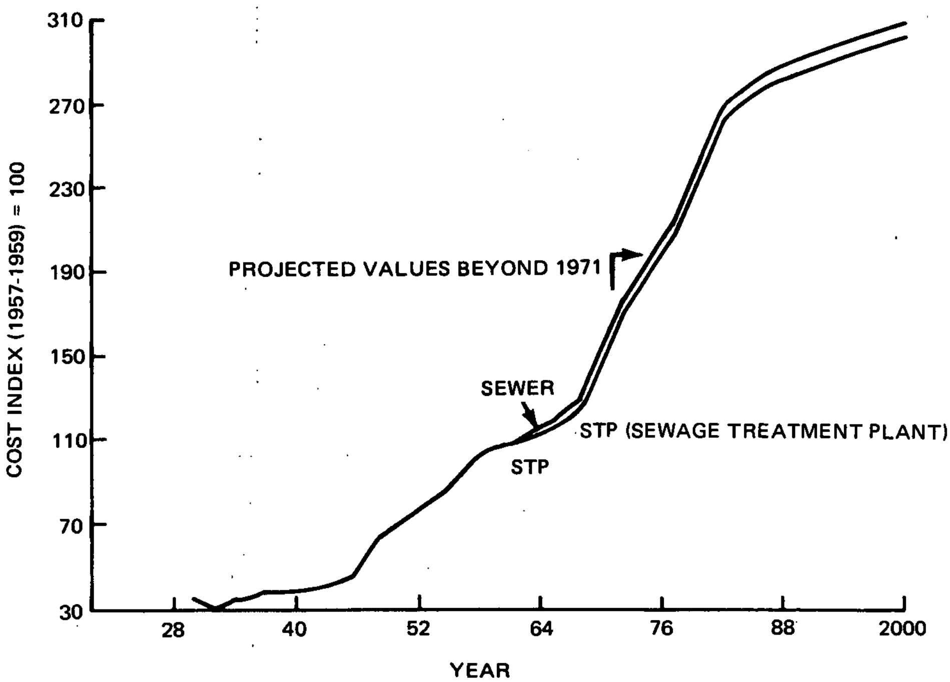

Figure 21 Cost Index for Sewers and Treatment Plants

WASTE WATER COLLECTION

Definitions

The standard collection sewers accept sewage from the house drainage plumbing and carry it to the interceptor. The names of the standard, gravity sewers, increasing in size in the direction of flow are (1) street or lateral, (2) branch, (3) sub-main, and (4) trunk. These sewers and their access provisions (manholes) comprise the sewage collection system. Its cost is related to population density and average daily flow per acre.

An interceptor is the large pipe (often only one) that transports the sewage from the collection system to the treatment plant. When the depth of gravity drained sewers becomes too great, a lift station pumps the sewage through a force main (pressurized pipe) to higher elevations. The force main, which is smaller in diameter, need not be sloped for draining. It discharges to the treatment plant or a gravity sewer. The length of a force main is dictated by economics of initial versus operating costs. The number of lift stations is prescribed by the local terrain. An outfall is the large pipe (gravity and/or pressure fed) which transports the treated sewage to the point of final discharge. The interceptor(s), outfall, lift station(s) and force main(s) costs are usually estimated as a percentage of the treatment plant costs.

Sewer Layout

The physical orientation of the source of waste water, its destination and the routing of lines between them, significantly affect the cost of sewers. In order to calculate sewer costs on an equivalent basis for each concept, a model of sewer runs was established. On the community site, the line routing is shown in Figure 17. The municipal sewer lines connecting the multiple communities in towns of 25,000 and 250,000 to the central processing are shown in Figures 18 and 19 respectively. The calculations of cost for reduced flow gravity sewers and vacuum collection systems are based on these models.

Gravity Collection Sewers for Standard Flows

The installed cost of collection sewers were analyzed by Michel[5] to be represented by equations for two ranges of population:

for 250 to 1250 people

$$\log(\text{installed cost}) = 6.9529 - \frac{5.0685}{\log(\text{population served})}$$

for 2500 to 25,000 people

$$\log(\text{installed cost}) = 7.6979 - \frac{7.0381}{\log(\text{population served})}$$

in terms of dollars. An arithmetic plot of the installed cost per capita is a strong reciprocal function of population in the low range; but the upper range appears to bottom out at about $45 per capita. Using the equation past the range for which it was derived, actually shows no lower limit. But it is obvious that this cannot be true. Since 25,000 people, at a density of 36 people per acre, represent an area of one square mile, it is reasonable to assume that populations well over 25,000 will be served by multiples of collection sewers priced at about the 25,000 level. Therefore, for this study, populations over 25,000 will be rated at $45/capita for collection sewers. Table 11 reflects this approach in presenting the annual amortization costs.

TABLE 11 ANNUAL AMORTIZATION COST PER CAPITA FOR COLLECTION SEWERS

Population Served	1968	1972	1977	1982	1986	2000
Cost Index Ratio	1.00	1.35	1.65	2.11	2.24	2.44
10,000	6.06	8.18	9.99	12.78	13.56	14.77
25,000	3.48	4.70	5.74	7.34	7.79	8.49
50,000	3.13	4.23	5.17	6.61	7.01	7.64
100,000	3.13	4.23	5.17	6.61	7.01	7.64
250,000	3.13	4.23	5.17	6.61	7.01	7.64

Interceptors for Standard Flows*

Interceptors are normally figured to cost some percentage of the treatment plant since both of them are sized by flow, with greater flow implying longer as well as bigger interceptors. On a regional basis, interceptor costs vary considerably more than treatment plant or sewer system cost. Table 12 shows the ratio of actual interceptor costs to actual treatment plant cost for various regions, in terms of 1968 dollars, derived from a statistical survey[5]. The location of these regions is shown in Figure 22.

In order to simplify handling of interceptor costs, which represent only part of sewage costs, the highest and lowest multipliers for each population are used. The resulting annual amortization costs are shown in Table 13, along with future projections of these costs. The multipliers were applied to per capita treatment plant costs shown in Table 14.

Operating Costs for Standard Flow Sewers

The major operating cost of sewers and interceptors is the cost of electricity for pumping stations. Since the number of lift stations and the pressure at which the pumps discharge is highly dependent on the specific installation, this cost can only be a accounted for by a general rule of thumb.

* Included in the cost category called "interceptors" are lift (pumping) stations, force mains and outfalls (the line carrying treated sewage to the point of discharge).

TABLE 12 INTERCEPTOR MULTIPLIERS

Population Served	Ratio To Plant Cost At Each Region 1	2	3	4	5	6	High	Low
10,000	1.18	0.68	0.88	0.63	1.23	0.60	1.23	0.60
25,000	1.85	1.00	1.15	0.87	1.91	1.12	1.91	0.87
50,000	2.20	1.19	1.54	1.09	2.35	1.50	2.35	1.09
100,000	2.20	1.25	1.58	1.13	2.53	1.50	2.53	1.13
250,000	2.85	1.82	2.40	1.46	2.85	1.50	2.85	1.46

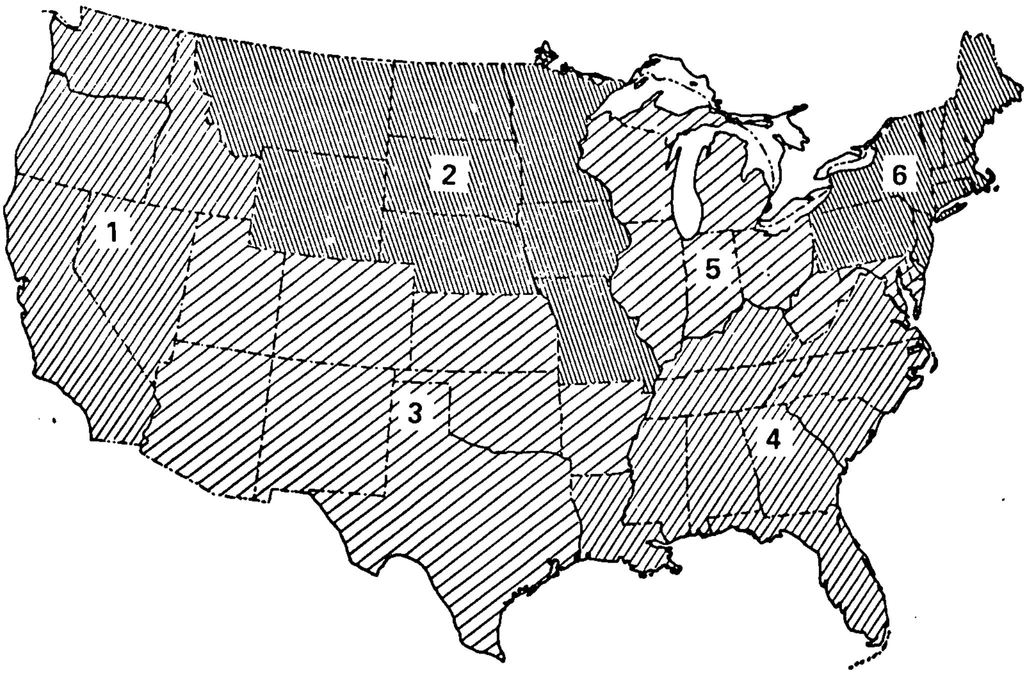

Figure 22 Inteceptor Regions

TABLE 13 ANNUAL AMORTIZATION COST PER CAPITA FOR INTERCEPTOR/OUTFALL

Population Served		1967	1972	1977	1982	1986	2000
Cost Index Ratio		1.0	1.40	1.70	2.16	2.28	2.48
10,000	High	3.70	5.18	6.29	8.00	8.45	9.18
	Low	1.81	2.53	3.07	3.90	4.12	4.48
25,000	High	5.52	7.74	9.40	11.93	12.59	13.70
	Low	2.52	3.52	4.28	5.43	5.74	6.24
50,000	High	6.01	8.42	10.22	12.98	13.71	14.91
	Low	2.79	3.90	4.74	6.02	6.36	6.92
100,000	High	6.04	8.45	10.26	13.04	13.76	14.97
	Low	2.70	3.77	4.58	5.83	6.15	6.68
250,000	High	6.16	8.62	10.47	13.30	14.04	15.27
	Low	3.15	4.42	5.36	6.81	7.19	7.83

Maintenance costs, also, are dependent on the specific installation with factors such as type and material of sewers, amounts of readily settleable industrial wastes, general populace habits with regard to what is disposed of into drains, grit infiltration, and corrosivity of the sewage.

As an overall rule of thumb, operating and maintenance (O&M) costs for sewers and interceptors will be assumed to be 20% of the O & M for the treatment plant.

Reduced Flow Gravity Sewers

Since the cost of a gravity sewer is greatly affected by the flow rate and sewers are a significant part of waste management, detailed cost estimates were made for sewers on the site of the apartment complex as well as street sewers for larger populations. The major factors in costing are: size, depth and material. Size is a function of peak flow which in turn is a function of population and average flow. Depth is a function of length and slope where slope is a function of peak flow. Large lines were specified as concrete and smaller buried lines as vitrified clay. Lines internal to a building were specified as cast iron as were pressure lines.

Line runs and points of connection were taken from Figures 17, 18 and 19. Line sizing and slopes followed the ASCE Manual No. 37 for the Design and Construction of Sanitary and Storm Sewers. Material and labor costs of buried reinforced concrete pipe were obtained from the 1972 Dodge Construction Pricing and Scheduling Manual. The effects of depth on buried pipe and a conversion from reinforced concrete to vitrified clay pipe were derived from cost data by Michel[5].

The conversion graphs can be expressed as:

$$R_1 = e^{a\,(I-5)} \qquad \text{Equation 1}$$

$$a = 0.318\, d^{-0.7962} \qquad \text{Equation 2}$$

$$R_2 = e^{0.05394\,(I-3.15)} \qquad \text{Equation 3}$$

where R_1, is the ratio of cost of pipe installed at depth I (in feet) to the cost of installation at a five foot invert, d is the nominal diameter of the pipe in inches. R_2 is the ratio of cost of vitrified clay pipe installed at depth to the cost of concrete pipe installed at the same depth.

Manholes were located according to the ASCE manual and priced by the Dodge manual. Lift stations were located at sewer invert elevations of 25 to 30 feet, consistent with minimum total pumping requirements. Installation, operating and maintenance costs were obtained from a Black and Veatch study report [6].

The results of these calculations are shown in Figure 23. The curve marked 2000 (the middle one) shows the annual cost to each family for a gravity sewerage system in the apartment complex. This curve is the basic one in the figure. For consideration of a single apartment complex, it is the only curve required. Annual cost is comprised of amortization, operating and maintenance costs.

When examining sewer costs in towns composed of multiples of these complexes, the total annual cost per family is the sum of costs for each complex plus that of municipal sewers. The municipal sewers connect each complex to the processing equipment in the center of the town. For these calculations, the towns are assumed to be comprised only of multiple, identical complexes. To simplify cost determinations for towns, the curves for municipal sewers have been graphically added to the curve for 2000 people, yielding the two upper curves in the figure.

The curve for 2000 people is nearly horizontal for flows up to 33,000 gpd since the lines are all at the minimum (four inches) and the slopes are all at the maximum (1/4 inch per foot). The slight increase is due to varying pumping capacity and electricity. As the flow increases, the slope of some lines decrease, the depth decreases and so does the cost. As the flow continues to increase, some sections of sewer become larger in diameter and account for the rise in cost. The cost of sewers with high hydraulic load, equal to a conventional system was obtained from the cost section on standard flow sewers.

The apparent anomoly of higher cost for street sewers in a town of 25,000 at flows under 20,000 gpd are due to the greater slopes required. This results in deeper sewers and relatively more lift stations than required for towns of 250,000.

The cost of a ten mile long outfall line was calculated in a similar manner for both 25,000 and 250,000 populations. The results are shown in Figure 24 in terms of annual cost to each family in the towns.

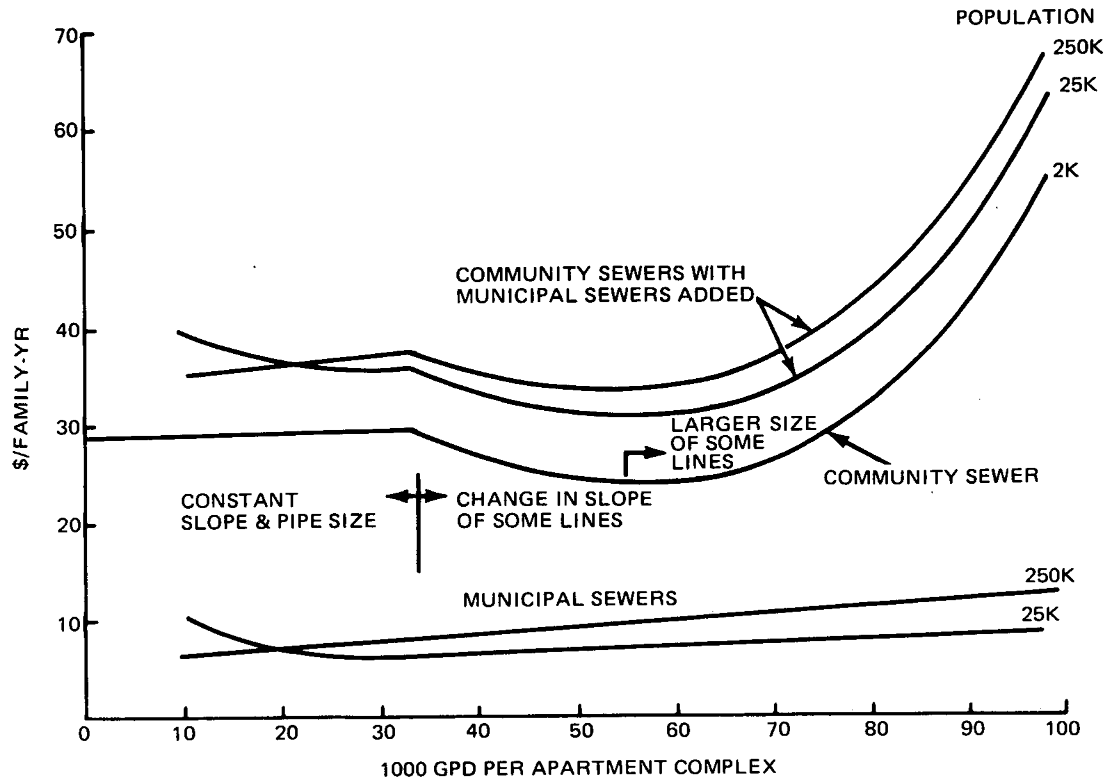

Figure 23 Cost of Gravity Sewers

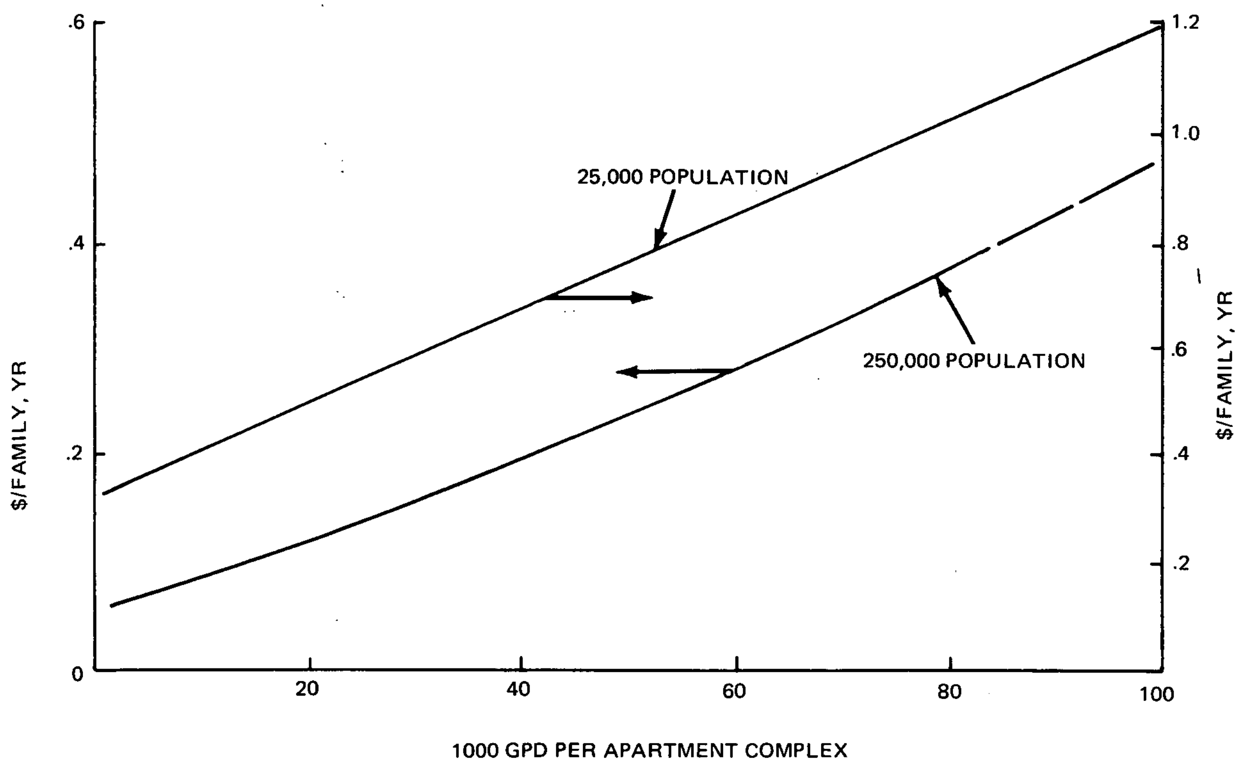

Figure 24 Cost of Outfalls

Vacuum Sewers

With the advent of a commercial vacuum toilet, vacuum sewers have become more prominent in recent years. Some of the concepts examined in this study utilize vacuum transport of black and/or gray water. Using the approach described for gravity sewers, costs for these systems were calculated for the model community and towns.

For a dual black and gray transport system in a community, the annual cost per family is \$20.10. The black water flow is constant in each concept and the variation of gray water flow does not affect the cost significantly. Transport of black water from each community to the central processing plant in model towns is accomplished by small diameter pressure sewers. For both town sizes, the annual cost per family is \$0.30.

In the concepts having vacuum collection of gray water only (gravity sewer for black water) the average annual cost per family is \$8.50. To this value is added the previously calculated municipal gravity sewer cost for the model towns.

Details of vacuum collection equipment are discussed in the Preliminary Design Section.

WASTE WATER PROCESSING COSTS

Biological Treatment

Since inventories of Municipal Waste Facilities in the United States were first started in 1940, the population served by primary treatment rose by 144% and those served by more than primary treatment rose by 314%[7]. The result, in 1968, was that of all the people served by treatment facilities, 66% had secondary treatment and 28% had primary treatment. The trend has definitely been towards a higher degree of treatment. With increasing emphasis on water pollution control, additional treatment (tertiary) will become more prevalent.

It is a reasonably safe assumption that biological treatment plants installed for new communities in the immediate future would have secondary treatment. Less safe but still reasonable is that new communities planned for construction toward the end of the century would contain tertiary treatment. The latter assumption may be altered by the possible change over to physical-chemical treatment of sewage. The inclusion of tertiary treatment will be assumed to follow a step curve. That is, starting five years hence, the percentage of completely new plants using tertiary processes will increase very rapidly over the next five years to perhaps 85% and gradually increase thereafter.

As shown in the 1968 Inventory the most common types of treatment plants are activated sludge and trickling filters (standard and high rate). The ratio of the population served by these plants vary according to the number of people served per system. While the capital costs of these systems are similar, the operating costs vary significantly. Therefore, factors representing percentage of population served by each of the two major systems versus population are shown in Table 14 and 16 in the columns marked: Factor.

Generalized costs for treatment plants versus population served are tabulated in Table 14. They are derived by weighing each of the two major secondary treatment process costs by applying the appropriate cost factors. Amortized and projected annual costs are given in Table 15.

Operating and maintenance (O & M) costs were obtained from Smith[8] in terms of cents per 1000 gallons for both activated sludge and trickling filter processes. Generalized O & M costs and per capita costs were calculated and are shown in Table 16. Projections of these costs in future years are presented in Table 17.

The largest single factor in the Operating and Maintenance (O & M) cost for biological sewage treatment is labor, representing 50 - 60% of the total. The trend in recent years towards higher labor costs is due in part to higher wage rates but also due to an increasing number of manhours expended[9]. Municipalities are recognizing that good operation requires more manpower. A large percentage of plants are presently understaffed.

A number of factors will continue to accelerate this trend in the future. The sustained emphasis on pollution control will provide the climate in which the public and the authorities will concede the need for more manpower and the social status of these jobs will rise. The status and wage rates will be enhanced by the current practice of inducing greater training and licensing of operators. The emphasis on pollution control will effect more sophisticated processing (tertiary treatment) requiring more and higher skilled labor. The trend towards greater instrumentation and automatic control of treatment plants may negate some increase in manhours required but will require skilled technicians at high labor rates. Projections of changing manpower requirements and their cost effects will not be made for this study.

With the increasing stress on waste water purification for reuse (directly or indirectly), the degree of treatment will definitely increase in the future. This added processing is called Advanced Waste Treatment (AWT). For the purposes of this study, the application of such additional costs will be taken in two parts: from 1972 to 1982 coagulation and sedimentation, ammonia stripping, granular carbon absorption and microstraining will be assumed included in a linear mode, i.e., 0% in 1972, 50% in 1977, and 100% in 1982; electrodialysis will be assumed to be 0% in 1977 and 100% in 1982. The linear rise in usage is a method of accounting for the fact that all plants constructed during these time periods will not include these processes but by the end of the period, they will. Presumptions as to the processes that will actually be used is not implied by the above mentioned processes. These processes are indicative of the types that will be used and were selected simply because cost data for these processes are available. The relative cost for electrodialysis is expected to decrease since the commercial development of this process is still in its early phases. Therefore, in view of the rising cost index the cost of this process projected into the future will be assumed constant.

Table 18 presents the annual per capita amortized cost of Advanced Waste Treatment projected to year 2000. The cost index multiplier used for 1977 is 50% of the expected multiplier since it is assumed that only 50% of the new plants will contain AWT. Table 19 presents the Operation and Maintenance costs for these processes.

TABLE 14 GENERALIZED COST OF TREATMENT PLANT CONSTRUCTION

Population Served	Process	Cost[12]	Factor		Generalized Cost*	Per Capita
10,000 (.85 MGD)	Activated Sludge	490,000	.18	88,200		
	Trickling Filter	420,000	.82	344,400	432,600	43.26
25,000 (2,5 MGD)	Activated Sludge	1,100,000	.39	429,000		
	Trickling Filter	1,000,000	.61	610,000	1,039,000	41.56
50,000 (5.2 MGD)	Activated Sludge	1,900,000	.59	1,121,000		
	Trickling Filter	1,750,000	.41	717,500	1,838,500	36.76
100,000 (11.2 MGD)	Activated Sludge	3,500,000	.69	2,415,000		
	Trickling Filter	3,300,000	.31	1,023,000	3,438,000	34.38
250,000 (31.5 MGD)	Activated Sludge	7,900,000	.72	5,688,000		
	Trickling Filter	7,400,000	.28	2,072,000	7,760,000	31.04

* Mid 1967 Dollars

TABLE 15

ANNUAL AMORTIZATION COST PER CAPITA FOR TREATMENT PLANTS

Population Served	1967	1972	1977	1982	1986	2000
Cost Index Ratio	1.0	1.40	1.70	2.16	2.28	2.48
10,000	3.01	4.22	5.11	6.50	6.86	7.47
25,000	2.89	4.05	4.92	6.25	6.59	7.17
50,000	2.56	3.58	4.35	5.52	5.83	6.34
100,000	2.39	3.35	4.07	5.17	5.45	5.93
250,000	2.16	3.02	3.67	4.67	4.93	5.36

TABLE 16 GENERALIZED OPERATING AND MAINTENANCE (O & M) COSTS OF SEWAGE TREATMENT PLANTS

Population Served	Process	$ Per 1000 gal.[12]	Cost Per Year	Factor	Generalized Cost*/Yr	$ Per Capita/Yr
10,000 (.85 MGD)	Activated Sludge Trickling Filter	0.09 0.063	27,922 19,546	.18 .82	21,054	2.11
25,000 (2.5 MGD)	Activated Sludge Trickling Filter	0.066 0.043	60,225 39,238	.39 .61	47,423	1.90
50,000 (5.2 MGD)	Activated Sludge Trickling Filter	0.056 0.033	106,288 62,634	.59 .41	88,390	1.77
100,000 (11.2 MGD)	Activated Sludge Trickling Filter	0.046 0.027	188,048 110,376	.69 .31	163,970	1.63
250,000 (31.5 MGD)	Activated Sludge Trickling Filter	0.035 0.0185	402,412 212,704	.72 .28	349,294	1.40

*Mid 1967 dollars

TABLE 17 ANNUAL OPERATING AND MAINTENANCE COSTS OF SEWAGE TREATMENT PLANTS PER CAPITA

Population Served	1972	1977	1982	1986	2000
Cost Index Ratio	1.40	1.70	2.16	2.28	2.48
10,000	2.95	3.59	4.56	4.81	5.23
25,000	2.66	3.23	4.10	4.33	4.71
50,000	2.48	3.01	3.82	4.04	4.39
100,000	2.28	2.77	3.52	3.72	4.04
250,000	1.96	2.38	3.02	3.19	3.47

TABLE 18 ANNUAL AMORTIZATION COST PER CAPITA OF ADVANCED WASTE TREATMENT

Population Served	Capital Cost (1967)	Per Capita Cost (1967)	Annual Amortization* (1967)	Annual Per Capita Cost 1977	1982	1986	2000
Cost Index Multiplier **				0.85	2.16	2.28	2.48
10,000	957,000	95.70	6.66	3.12	10.91	11.36	12.09
25,000	1,958,000	78.32	5.45	2.43	8.77	9.07	9.69
50,000	3,257,000	65.14	4.53	2.00	7.26	7.54	8.01
100,000	5,730,000	57.30	3.99	1.76	6.40	6.64	7.06
250,000	12,380,000	49.52	3.45	1.58	5.61	5.83	6.20

* Amortization Multiplier = 0.0696

** Cost Index Multiplier does not apply to electrodialysis which is assumed to have constant cost over the years. Multiplier for 1977 is 1.7 of which only 50% is applied to allow for average cost where all plants built in that year will not have AWT.

TABLE 19 ANNUAL OPERATING AND MAINTENANCE COST PER CAPITA FOR ADVANCED WASTE TREATMENT

Population Served	$ Per 1000 Gal.[12]	Flow in MGD	Annual Per Capita Cost 1977	1982	1986	2000
Cost Index Multiplier*			0.85	2.16	2.28	2.48
10,000	0.274	0.85	7.23	18.37	19.38	21.09
25,000	0.228	2.50	7.06	17.92	18.92	20.58
50,000	0.204	5.20	6.60	16.76	17.69	19.25
100,000	0.181	11.20	6.27	15.94	16.82	18.31
250,000	0.156	31.50	6.09	15.50	16.38	17.81

*Cost Index Multiplier for 1977 is 1.7 of which only 50% is applied to allow for average cost where all plants built in that year will not have AWT.

Physical-Chemical Processing

Black Water

The physical-chemical process cost model selected for black water contains a sequence of treatment steps. Chemical precipitation with hydrated lime is followed by sedimentation, absorption of soluble organics with powdered activated carbon (PAC) and filtration by dual media. The settled organics and lime together with spent carbon would be dewatered and burned in an incinerator with refuse.

In two reports by Shell and Burns [10, 11], cost data are given for three flow rates with granular activated carbon (GAC) systems and one flow rate with powdered carbon. Although the granular carbon systems are less expensive in the higher flow range shown in Figure 25, the authors imply that powdered carbon systems have greater potential for the low flow regimes. However, the slope of the line through the single cost point for PAC is drawn parallel to the GAC line, thereby conservatively penalizing PAC at the low flow end.

Gray Water

The phys-chem treatment process, selected for gray water is reverse osmosis. This technology is improving rapidly under the influence of substantial government funding and total costs of water reclaimed by this process are dropping. A cost curve, shown in Figure 26 was obtained for 30 mgd [12] and 440 gpd plants. The data for the large plant was adjusted to reflect a different salt concentration and revisions in preliminary processing. The data for the low flow was calculated, based upon a Grumman system currently operating with gray water. Two intermediate flow data points obtained from Dorr-Oliver [13] and Westinghouse [14] are also shown. With provisions for extending membrane life, these costs would show better agreement with the curve.

One technique that is applicable to the concepts evaluated in this study, is the use of a lower percentage yield with resulting larger flows of concentrate. This leads to less fouling of the membrane and longer membrane life. Since the cost of membranes and the labor involved in replacing them is a significant percentage of the operating cost, it is clear that the two intermediate data points can be lowered.

Distillation

The two types of distillation systems considered for reclaiming water from the gray waste water are thermal distillation and vapor compression distillation (VCD). Both systems are configured in the multiple step cascade design for the purposes of reclaiming the greatest amount of water from each unit of energy.

In the thermal distillation method using waste heat from other utilities systems, establishment of the optimum number of cascade steps would require extensive calculations. For this study, only two steps are assumed. The type of cascade is also assumed to be multiple effect since rejected heat can be further utilized for other purposes (i.e., heating, air conditioning). In the multi-stage flash cascade, the rejected heat would be at too low a temperature level for further use.

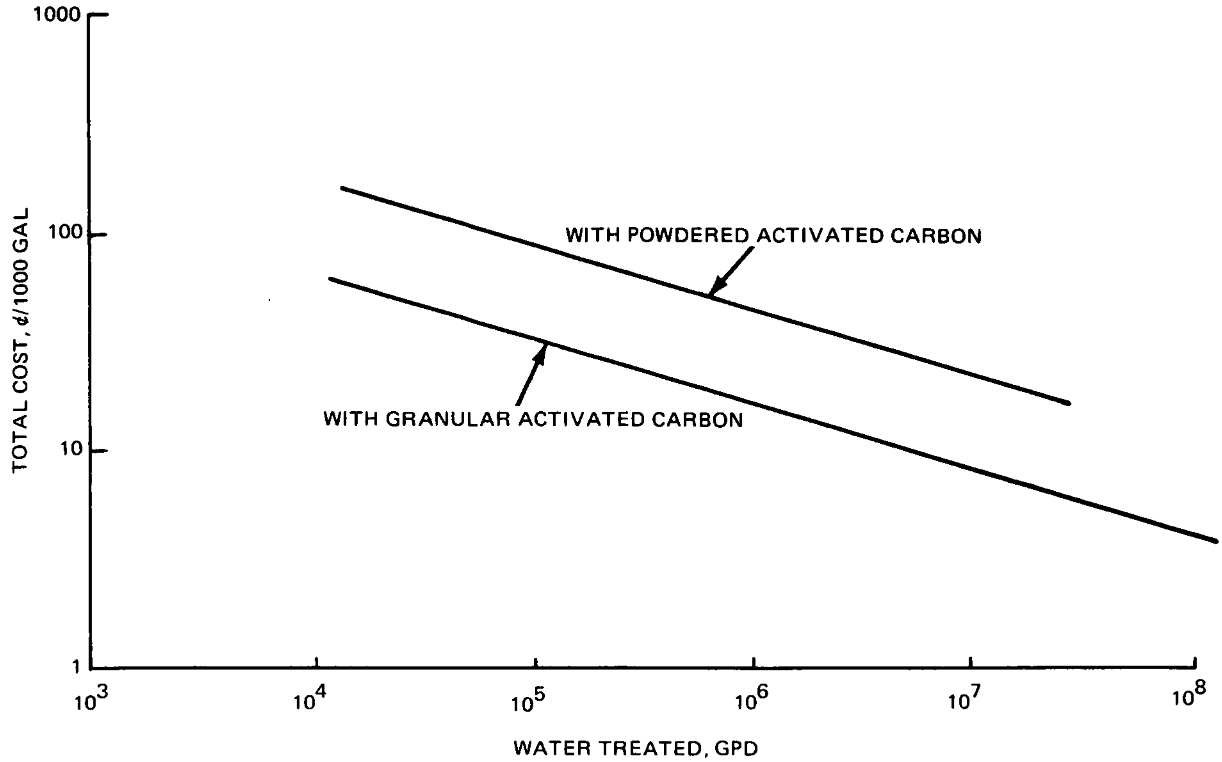

Figure 25 Costs for Phys-Chem Treatment of Black Water

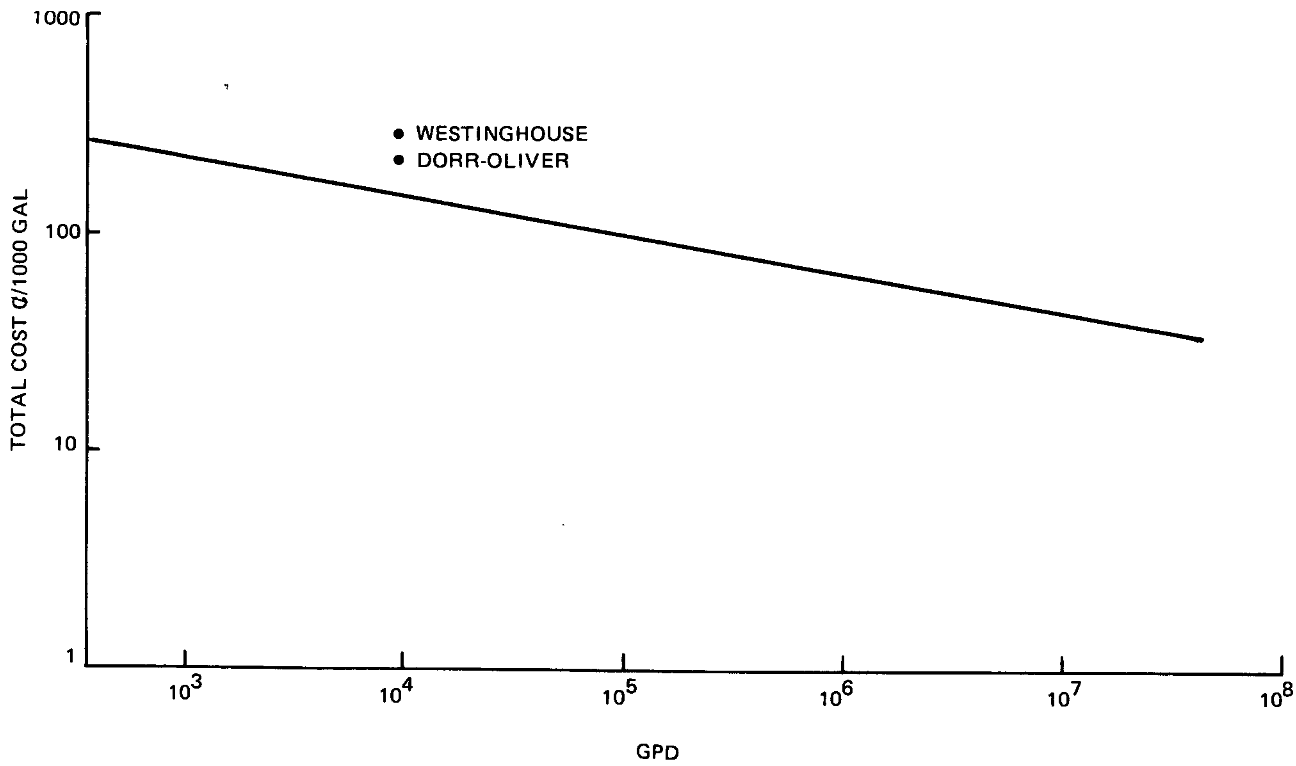

Figure 26 Reverse Osmosis Costs

Similar considerations for vapor compression distillation lead to the assumption of a single recompression stage. Furthermore, the VCD is penalized for its electrical power requirements whereas the thermal distillation is not penalized for its energy input since it uses waste heat.

With these assumptions, most of the available economic data for distillation is not directly applicable. Costs obtained for VCD at 0.1 mgd and 2.5 mgd [15] included energy costs, whereas the value at 50 mgd [16] did not. An estimated power cost was added to the latter value prior to preparing Figure 27. The thermal distillation line was generated by subtracting estimated power from the VCD line.

The fact that the VCD line is significantly higher than the thermal distillation line is the reason why vapor compression distillation is not considered for concept evaluation.

Effluent Disposal Costs

The most economical method of disposing of unusable gray water and/or treated black water effluent is to apply them to the soil near the source. This can be accommodated readily on the site of the apartment complex. But for larger populations, the volume to be disposed of emanates from the town's central processing system in the heart of town, and here soil disposal may not be practical. Excessive land area of high economic value may be required or the volume discharged may exceed the hydrological capacity of the ground in that vicinity. Alternate disposal methods, can discharge to the ground in neighboring areas, local streams, rivers, lakes or estuaries; or be used for farm irrigation. Transport of the treated effluent can be made by the storm water sewer and discharged wherever the storm water goes. For the model towns, gray water is disposed of at the community site. Effluents from the town's central processing system are transported by a ten mile long outfall line to an unspecified destination.

Two methods of infiltration/percolation are considered, a spreading basin and a tile leaching field. The spreading basin is used in conjunction with a storage pond which supplies used water for irrigation and/or acts as a pretreating clarifier to the spreading basin. Since the basin and pond are similar in form, they are priced together. Also included in the cost are pumps, electrical components and main distribution lines for the landscape irrigation equipment which draws water from the storage pond. The cost line for this entire package is labeled Storage Pond in Figure 28.

In similar fashion, an underground storage tank that precedes the tile field together with the pumps and main distribution lines for irrigation are priced as a unit. This cost labeled Tile Field is shown in Figure 28, for comparison.

The cost of excavating or bulldozing a pond or basin is very low, especially if this work is done during general excavation and grading for an apartment complex. The characteristic of the cost line is determined primarily by the pumping system. With the tile field package, the cost is governed mainly by the tile field itself. Since the size of the field is proportionate to flow, the cost per 1000 gal. is almost constant. Data for costing was gathered from the Dodge Construction Pricing Manual and pump manufacturers' quotations.

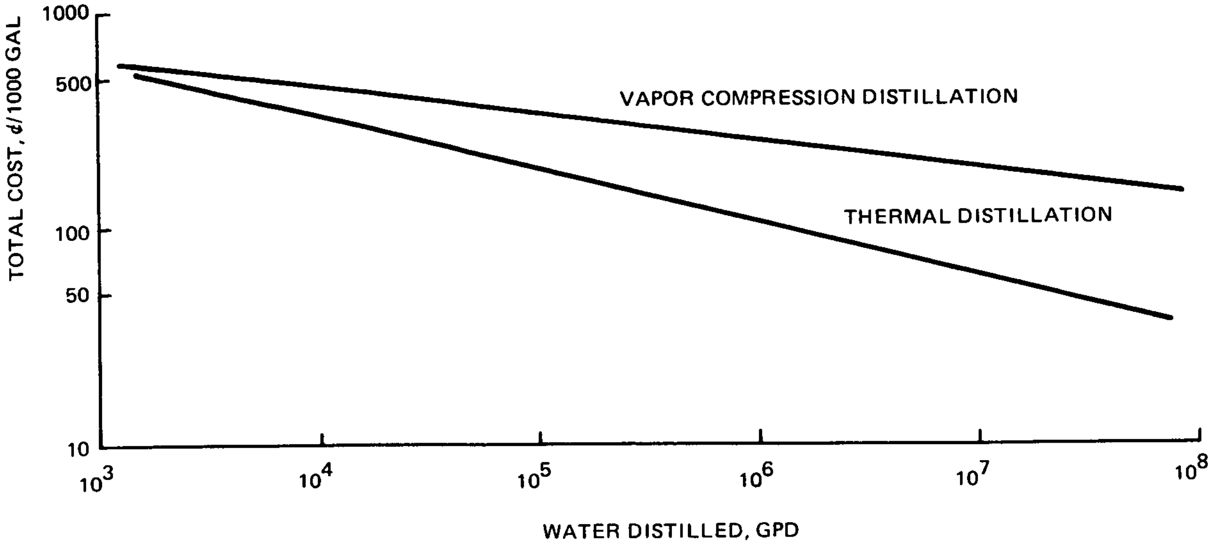

Figure 27 Distillation Costs

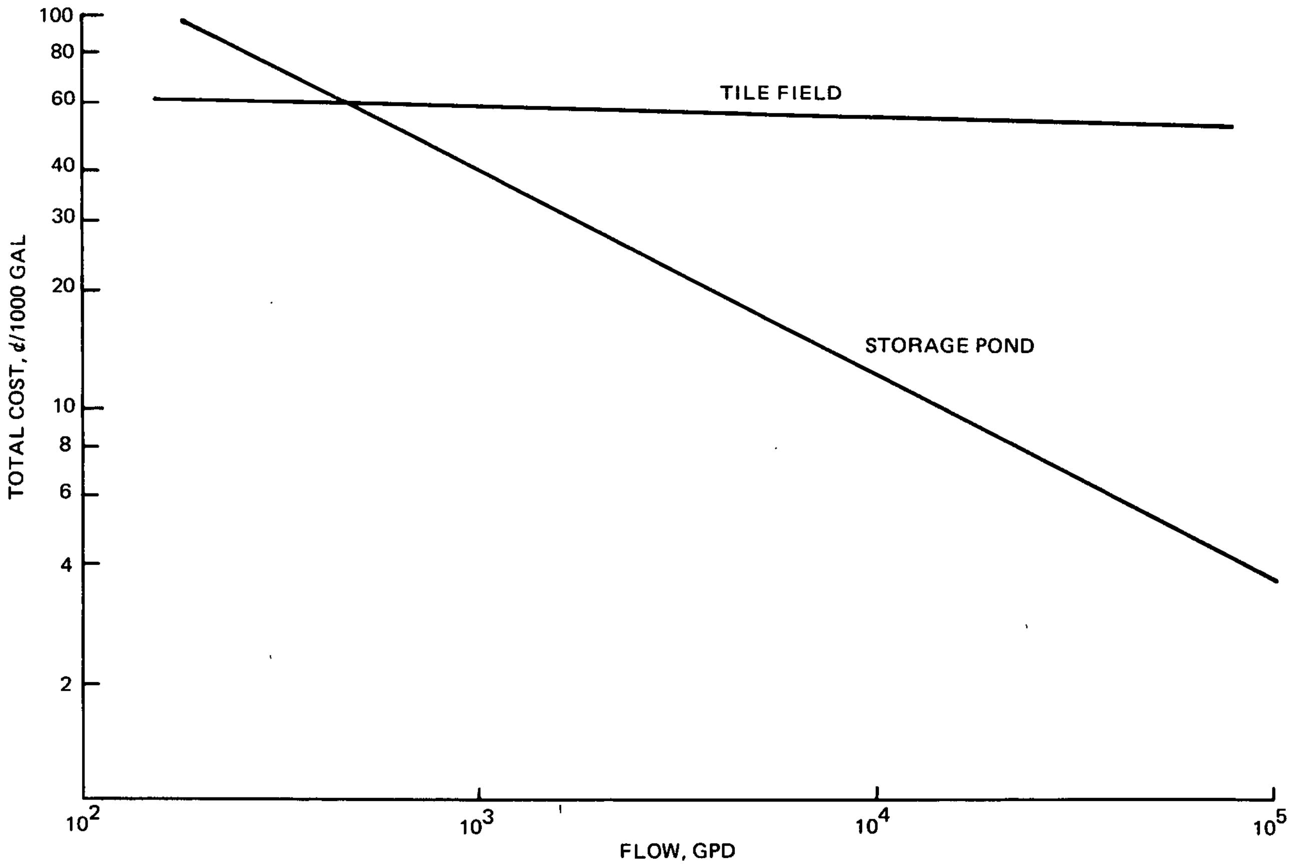

Figure 28 Tile Field and Storage Pond Costs

REFUSE COLLECTION COSTS

Estimates of the cost of refuse collection are based on a study of 20 municipalities in a metropolitan area in Ohio[17]. The equation representing their results is:

$$Y = 16.9 - 8.17X_6 + 5.85X_3 + 0.085X_1$$

where Y is the cost in dollars per family per year, X_6 is the nature of financing (0 = user is charged, 1 = general revenue), X_3 is the pickup location (0 = curb pickup, 1 = rear of dwelling pickup), and X_1 is the yearly collection frequency. Other variables such as X_5: the pickup density, X_4: crew size, X_2: combined or separate pickup have insignificant effects on cost. Assuming three collections per week at the rear of the dwelling and direct charge to the user, the annual unit cost is $35.95. Since the referenced study is based on one or two family residences, an adjustment to this cost was made to account for higher population density. Travel time from the point of collection to the central dumping point and return was estimated at 33%. The reduction in pickup time was estimated at 25% resulting in a total reduction of approximately 17%. The refuse collection cost used is thereby $35.95 x 0.83 = $30.

INCINERATION COSTS

The incinerator design used for concept evaluation is a water-wall (steam generating) type, capable of accepting wastewater sludge as well as refuse. Since directly applicable cost data was not available, an indirect valuation was made. Three averaged data points for an incinerator, burning concentrated sewage sludge (40% solids)[13] were used to develop a basic cost curve. To these points were applied a 1.25 multiplier to account for heat reclamation and a 1.31 multiplier to bring the costs up to date. The resultant data is shown in Figure 29. The cost of a modern, highly sophisticated refuse incinerator [18] having steam generation components, is shown in the figure after adding operating and maintenance cost from reference [13]. It falls on the calculated curve.

For comparison a curve for high pressure oxygen wet oxidation of sewage sludge (6% solids) is shown, revealing significantly higher costs per 1000 lbs.[20] than for incineration. The curve is based on specific operating installations. If refuse were to be included, additional equipment would be necessary to reduce the refuse particle size to acceptable values.

TOILET COSTS

It is assumed that there will be two toilets in each apartment unit in the model apartment complex. Based on manufacturer's information, the shallow-trap toilet costs $80 as opposed to $60 for a standard toilet of comparable quality. A dual flush mechanism which can fit into the tank of any toilet costs $14.

The partial recirculation toilet as developed by Sherwood Products, San Antonio, Texas costs $198 with approximately $30 for installation. The non-aqueous toilet separation system has a high operating cost, quoted as two cents per flush by the manufacturer. The capital cost appears to bottom out as costing about five dollars per capita year.

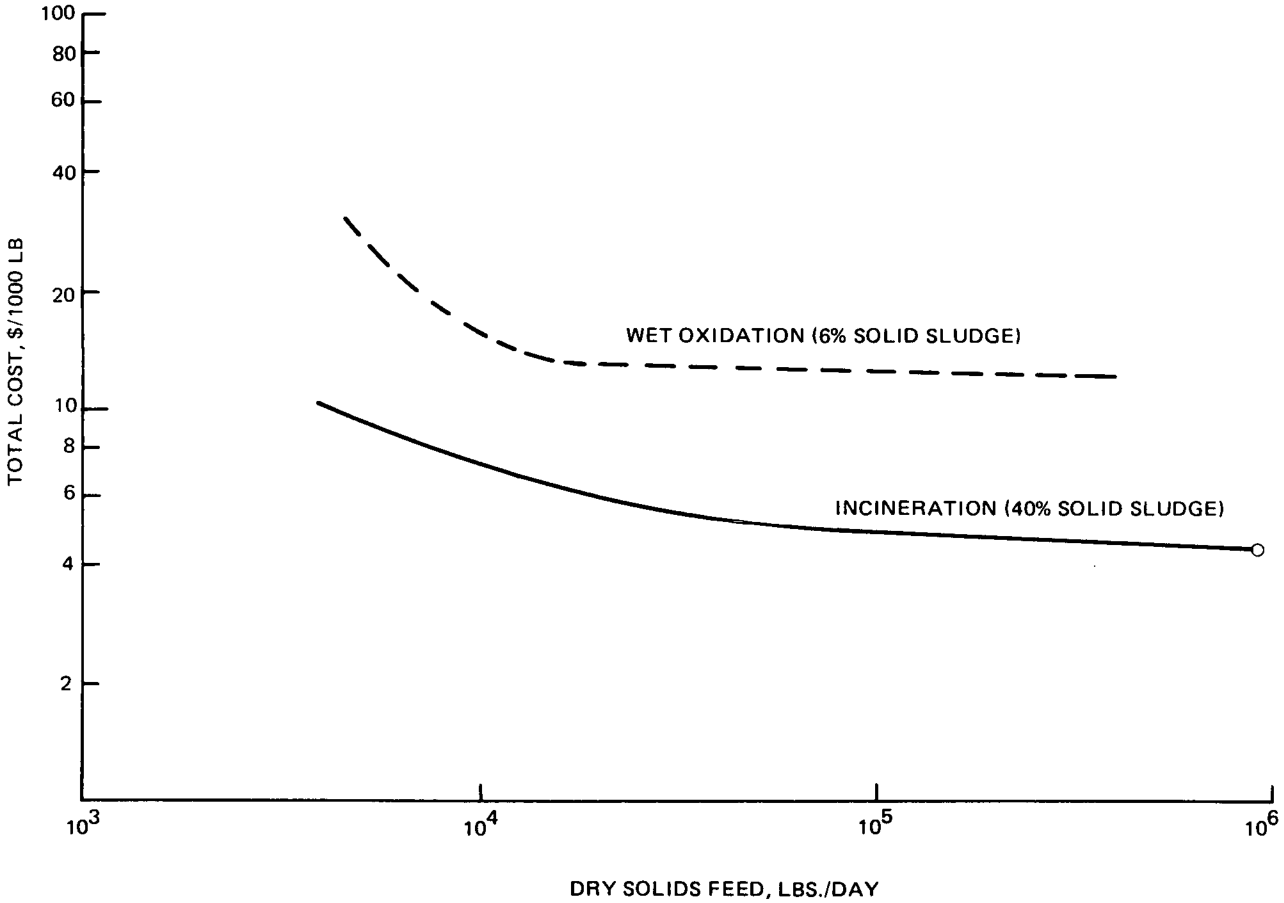

Figure 29 Incineration Costs

C^2

The resultant cost per family (of four) per year for each toilet is shown below.

Toilet	Annual Cost
Standard	$ 7.80
Shallow-trap dual-flush	12.20
Partial recirculation	25.80
Non-aqueous	34.20

While the non-aqueous system does not appear to cost much more than the partial recirculation toilet, the supply and drain lines will add to the cost. It is thereby not considered for subsequent evaluation. Oil supply and storage will increase the differential.

GREASE SEPARATION COSTS

Since many of the concepts examined utilize wastewater for irrigation with little or no processing, it is beneficial to remove kitchen fats and greases. As a result every building in the apartment complex is assumed to be equipped with a grease separator. The grease is diverted to black water collection equipment and is eventually incinerated.

The estimated cost for a separator installed in each building housing approximately 20 families is $250 with an operation and maintenance cost of $20 per year. This results in an annual cost for each family of $1.80. Minor variations in building population cause insignificant changes to this value which is used for every concept requiring a grease separator.

WASH WATER TOILET FLUSH UNIT COSTS

Certain system concepts reuse wash water from the bath and laundry to flush toilets. The water must be collected, pressurized or elevated and distributed. The assemblage of equipment and piping providing these functions is tabulated as Wash Water Toilet Flush Unit. It consists of a receiving tank, pump, controls, an overhead accumulator, chlorinator, piping from the pump to the accumulator and distribution pipes from the accumulator to the toilets. Since this unit is used only in concepts having shallow-trap dual-flush toilets, the size and cost is dependent only on population served. The cost of one unit servicing 20 apartments is estimated to be $6.70 per year per family. This value is comprised of amortization, operation and maintenance.

WASHING MACHINE COSTS

Washing machines are consider in two styles: Standard machines and those having a rinse reuse capability. The rinse reuse feature consists of a storage tank with its own pump, a diverter valve and additional control points in the machine timer. With one clothes washer in every building of 20 dwelling units, the machine is amortized over 10 years. The dishwasher located in each apartment is amortized over 15 years.

The annual family costs, including maintenance, are estimated as:

dishwasher with rinse reuse	- $32.20
dishwasher	- $27.00
clotheswasher with rinse reuse	- $ 3.50
clotheswasher	- $ 3.00

CLEANSING AGENTS COSTS

Very hard water doubles the cost of soaps and detergents.[20] The average cost of $58/year for all water related cleaners in the local area (soft water) was provided by the manager of a direct home sales organization. This is in very close agreement with estimates made by a California water district.[21]

WATER COSTS

The true cost of water to the consumer is seldom equal to the charges of his regular water bill. The investment in the water utility is commonly financed from general tax revenues; the operating costs are recovered in varying proportions by direct charge to the consumer and by general taxes. Water rates in larger communities are generally lower than the rates in the smaller community presumably because a a larger portion of the operating costs are covered by general tax revenues.

The most commonly used water pricing methods in practice today include:

Declining Block Rate: Provides a minimum base charge for the initial quantity followed by progressively smaller unit charges for additional quantities.

Constant Rate Schedule: Provides a constant unit price to all customers.

Flat Rate: A fixed charge regardless of the amount used.

Summer Differential Rate: Provides a higher rate for water used in lawn sprinkling.

Incremental Block Pricing: Unit price increases with water consumption.

In a survey conducted by the American Water Works Association (AWWA) in 1960[22] nearly all of the 807 responding water utilities used the declining block rate method. There did not appear to be any clear cut relationship between metered water rate and the geographic location. The spectrum of water rates for the first 1000 gallons per month is presented in Table 20.

In 1970, the San Antonio City Water Board compiled a list of water charges for the 54 largest cities in the U.S. Of this list 48 cities were directly comparable to the 1960 AWWA survey. For 1000 gallons per month, the average rate increased 27% during the intervening decade. For the purposes of this study a thirty percent per decade increase in the cost of water will be assumed.

TABLE 20 WATER COSTS

Monthly Charge For 1st 1000 Gallons ($)	No. Of Utilities	Percent
None or fixed amount	62	7.7
0.11 - 0.20	31	3.8
0.21 - 0.30	119	14.7
0.31 - 0.40	173	21.4
0.41 - 0.50	192	23.8
0.51 - 0.60	103	12.8
0.61 - 0.75	87	10.8
0.76 - 1.00	31	3.8
1.01 - 1.25	7	0.9
1.26 - 1.50	2	0.2
	807	99.9

If the full cost of water were to be paid by the consumer in his periodic water bill, the water rates would necessarily increase. Historically rate increases have resulted in decreased consumption for a period of a few years.[23] During this period, however, the consumption gradually increased to the previous level, but was actually less than what the consumption would have been, if there were no increase. On the other hand, if for some societal reason, general water usage declined, prices per unit volume would have to be raised to cover operating costs, which would not decrease in proportion to flow. Both of these situations tend to be self aggravating.

The cost of water has been increasing and will continue this trend over the years to due inflationary effects, the need to expand capacity and improvements in water quality. As noted in the section on water supply quality, 25% of the utilities failed to meet all the standards.

Whereas other utility industries have been successful in reducing their operating costs through technologic innovations, the same is not true for the water industry. One reason has been the inability to improve the load factor. This factor is a measure of the normal to peak demand. A poor factor requires a large system capacity which goes unused a good part of the time. The gas, electric and telephone industries have been able to effect improvements in load factors. Where the planned new community recycle system may have a real effect on water costs is in the improvement of these load factors. This effect will be highly dependent on the most economical distance between the consumer and the recycle equipment. If each consumer had his own recycle equipment, the load factor would be at the maximum of one; if the recycle equipment were located at the source for distribution of fresh water, the load factor would be unchanged.

Part of the problem with water is its use for fire protection. From six to twelve percent[24] of the fixed assets of a water supply system for larger populations is due to fire protection considerations. Below populations of 20,000 this percentage increases rapidly to an intercept of 35% for zero population. One philosophical approach considers fire protection as an incremental cost to a water supply system. Another approach is that water supply is an incremental cost to a fire protection system. With decreased consumption of fresh water in a recycle system, the latter philosophy may be more appropriate.

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VII INTEGRATED SYSTEM CONCEPTS

CONCEPT DEVELOPMENT

The overall objective of this task is to devise an integrated water and solid waste management system concept that would minimize water requirements and sewage and solid waste disposal, all within the constraint of economic practicality. Although consideration of total utilities systems (on-site electric power generation with waste heat utilization) is not within the scope of this program, semi-quantitative attention is given to their interactions with water and waste management system concepts.

The method used to establish the system concept for which a preliminary design is to be made is:

- identification a major water consuming operations
- identification of major treatment and disposal problems
- subjective selection of methods to minimize the above
- generation of combinations of these methods
- economic evaluations of the combinations
- selection of the most economic combination, compatible with minimum water consumption.

The ground rules that are used in developing system concepts are as follows:

- Portable drinking water is always available under pressure from an undefined municipal supply system.
- Waste water can be collected and treated in either of two approaches: all waters are collected and treated in a single process, or toilet wastes (black water) are collected and treated by one process and all other waste waters (gray water) are collected and treated by another process.
- Gray water can be reused for toilet flushing or irrigation without treatment except for disinfection.
- Water reclaimed (recycled) from gray water can be used for bathing or laundering but not for internal consumption, food preparation or glassware cleaning (kitchen functions)
- Water will not be reclaimed for household reuse from black water. The effluent of a black water treatment process however may be used for irrigation.
- Water will not be reclaimed for household reuse if there are community water needs that can be satisfied by wastewaters.
- Thermal reclamation systems will utilize waste heat only. Heat will not be generated for the specific purpose of water reclamation.

- Storm sewers and water for fire protection will not be included in concept development or cost evaluations. These considerations would be part of a community or town design regardless of the water and waste management system configuration.

Water Conservation

A prime purpose of this study is the reduction of water consumption in residences which will in turn effect a reduction in wastewater volume. Within the home, the major water users are the toilet, clotheswasher, shower/tub and dishwasher, with the lavatory and kitchen sink as minor users. A very simple, inexpensive method of reducing water consumption is the employment of flow limiting faucets and shower heads. All the concepts examined use these flow limiting devices with the exception of the conventional system that is included for comparison. Lawn irrigation is a suprisingly large user of water during the growing season. Requirements vary widely as a function of such factors as population density, community layout and climate.

The various approaches to water conservation are discussed in the following paragraphs.

Toilets

In a conventional home, the toilet is the largest single user of water, estimated as consuming 40 - 45% of the incoming water. Therefore, special attention was devoted to this fixture. Two toilet systems that do not use any water were examined and discarded. The incinerating toilet using gas, oil or electricity to vaporize water and oxidize urine and fecal residues was not included in any concepts because of poor odor control and very high cost of operation. Non-acceptance by the consumer is also anticipated because of its operational mode, especially with rapid repeated use. The non-aqueous toilet system, developed by the Chrysler Corporation employs recirculating mineral oil to flush a standard toilet. (See page III-5). The equipment that separates the waste from the oil and incinerates it is very expensive.

The two methods of restricting toilet water use that were selected for evaluation are: the partial recirculating toilet (see page III-9) in conjunction with a vacuum transport system, and the shallow trap, dual flush toilet. Although the former is not yet available commercially and requires demonstration for household use, it is a wet toilet that uses the very least amount of water. It is representative of the best that can be achieved in concentrating toilets. For the preliminary design phase of the study, a Liljendahl vacuum toilet is substituted for the partial recirculation unit in order to conservatively design related equipment. The Liljendahl unit uses about seven times as much water but this quantity is approximately one-fifteenth that used by a standard toilet.

Because so little water is used in the partial recirculation toilet, a vacuum transport system is required to move the solids through the line. This requires a separate transport line for black water (toilet flush) for at least some distance. Since the small quantity of water with the toilet wastes permits incineration as a practical treatment method, it is expedient to maintain a separate transport line for this type of toilet. A more detailed discussion of separate transport of black and gray water is contained in Section VIII. The second toilet selected for evaluation: the shallow-trap dual-flush unit, is discussed below.

Gray Water Toilet Flush

A simple expedient to minimize water consumption is the reuse of water in the household with little or no treatment. The flow requirement of the shallow-trap toilet (see page III-4) is slightly less than the gray water from the clothes washer and shower/bath. A set of concept combinations uses this approach with disinfection as the only treatment. Experimental household reuse of washwater for flushing toilets has been demonstrated to have relatively high user acceptance.

Rinse Water Reuse

Another method of reusing water that has been selected is the use of rinsewater from the clotheswasher in the wash cycle of a subsequent operation. The configurations using this method show a 50% reduction in water consumption for the washer, although temperature considerations may decrease the reduction. Even with a 50% reduced flow from the washer, there is sufficient effluent to supply flush water for the shallow trap toilet. Similar treatment for the dishwasher is considered. Since reduced water consumption will be accompanied by greater equipment expenses, two sets of configurations are evaluated, one with and one without rinse reuse.

Landscape Irrigation

A third method of reusing water, landscape irrigation, is considered for every configuration. Both gray water and treated disinfected black water are deemed suitable. Landscape irrigation is the preferred method for final disposal of excess water. It is presumed that the watering season is six months long, and an average of 3/4 inch of water per week is required. Since this water quantity is in excess of the waste water available, supplemental municipal water would be required. Therefore, during the warm weather, no water reclamation will be performed and all waste waters will be used for irrigation. The most appropriate method of application is subsurface irrigation, either by plastic tubing having protected perforations or by the use of a semi-permeable barrier several inches below the surface and subsurface distribution plenums. Subsurfaces irrigation equipment is described in detail in Section VIII.

The reservoir holding the gray water prior to processing or irrigation is in the form of an open or covered storage pond, located on the community site. For one category of concepts, black water effluent which had been treated to tertiary quality, is also fed to the pond. This would be an acceptable practice in view of similar operations at Lake Tahoe and Santee, California. The storage pond will be sized to hold waste water produced over a two or three day period and will act as a primary settler.

During the cold weather, the second choice for disposal of excess water is used: infiltration/percolation into the ground. In most geographical locations, a conservative rate of one gallon per day per square foot for infiltration should be acceptable. One exception is in areas of very high ground water levels. The spreading basin size will vary by the amount of excess water produced in each configuration, but will always be of reasonable size to fit into a model community layout. The main reason for using spreading basins is the avoidance of costly sewers.

Gray Water Recovery

Techniques for reclaiming potable water from gray waste water for the purpose of reducing water consumption and waste water flow, are considered. Although the techniques are capable of providing drinking water, the product water is used only for bathing and clotheswashing.

Of the techniques judged appropriate for the housing model assumed, reverse osmosis and thermal distillation are selected for inclusion in configurations that reclaim gray water. Vapor compression distillation is eliminated as a result of its being more costly, even though it has some definite advantages. Since VCD recovers its own heat of vaporization, it is subject to less restraint in scheduling its operation and setting its reclamation capacity. The selectable range of input and output temperatures is wider than for thermal distillation. However, a definitive configuration of a distillation process in heavily dependent on the community's power generation and energy management systems.

Black Water Treatment

The treatment methods for black water solids that are considered are incineration, precipitation-coagulation-sedimentation followed by carbon adsorption and biological treatment with AWT. Incineration is limited to the small flow from the partial recirculation toilet, the physical/chemical treatment is reserved for use with the shallow trap toilet where the gray water is collected separately, and the biological treatment is used for larger volume flows, which include combined black and gray water collection.

Waste Water Transport

Gravity, vacuum and pressure sewers are considered for the various configurations. The vacuum sewer is appropriate for highly concentrated black water (containing large solid particles). Large volumes of air, sweep slugs of water and solids through small, non-sloped lines. Eliminating slope greatly decreases sewer costs. For communities having a vacuum black water sewer, a vacuum gray water sewer is also appropriate. Although the water quantity is very much larger, the lack of significant solids eliminates the need for the air sweep. Thus, for a single vacuum pump providing motive power for both a black water and a gray water sewer (each with its own receiving tank), the load is mostly dictated by the black water. An occasional air sweep (once a week) of the gray water sewer should clear lines of sediment.

For towns (25,000 and 250,000 population) using the very low flow black water system, the black water sewer between communities is a pressure sewer. The smaller diameter and lack of slope minimizes cost.

Gravity sewers will be used for medium and higher flows of black, gray and combined (black and gray) waste lines both on the community site and between the communities and the town central processing system.

For the larger populations, treated effluent is assumed to be disposed of by pumping into a ten mile long gravity outfall sewer. Lift stations are installed where needed. For the purposes of this study, the destination of this water is considered indefinite. The presumption is made that there will be some natural place which will accept the flow located an average of ten miles away.

Refuse Disposal

Incineration is the only method considered for refuse. Landfill disposal, if available, is deemed a temporary situation, especially in an area that can justify the high density of apartment complexes. Composting requires significant land area and must be located near agricultural properties to be economical. Apartment buildings and farms are seldom found in close proximity. The heat from the incineration process is assumed to be used to help meet the thermal energy needs of the community.

Refuse collection for the populations considered is by standard transportation methods with a constant per capita cost. Total population does not seem to have a significant effect on cost. Vacuum collection of refuse is economical only with the high population densities produced by high-rise buildings according to equipment manufacturers.

CONCEPT DEFINITION

Nineteen system concepts are quantitatively examined and economically evaluated. These concepts do not represent a complete matrix of process and component selections, since some concepts are eliminated because of water balance limitations or obvious economic disadvantages when compared to other concepts being generated. The concepts are grouped by major process selections. The complete set of nineteen system concept schematics are contained in Appendix A. In order to give a visual understanding of the concept categories, four schematics that can be considered "typical" are included with the following descriptions.

Concept Category "A"

Systems in this category employ biological secondary treatment of sewage followed by tertiary treatment (referred to as AWT). Since the EPA expects to have AWT in all municipal treatment plants in the next decade, it is presumable that new biological plants will be designed with AWT at the outset.

Concept A-1 is the current "conventional" system with AWT. The toilet bowl is standard and there are no flow restricting devices of any kind. Refuse and biological sludge are burned in an incinerator. For a community of 2000 people (one model apartment complex) the treated waste water effluent goes to an on-site storage pond. This water is used for landscape irrigation during the growing season and is sent to a spreading basin for soil infiltration during the cold weather. In the model towns of 25,000 and 250,000 the effluent is transported out of town by an outfall line.

Concept A-2 achieves over thirty percent reduction in water requirements and wastewater effluent simply by employing more efficient household fixtures and appliances. Apartments are assumed to contain flow restricting shower heads, faucet aerators, front loading clotheswashers, and shallow trap toilets equipped with dual flush mechanisms (see Section III for equipment descriptions). Resultant water savings are the greatest that can be achieved by readily available, unmodified household equipment whose suitability for widespread household use has been thoroughly demonstrated. It may be considered a "Baseline Concept" against which the benefits of recycle, reuse and advanced household equipment can be measured. Figure 30 schematically describes this concept.

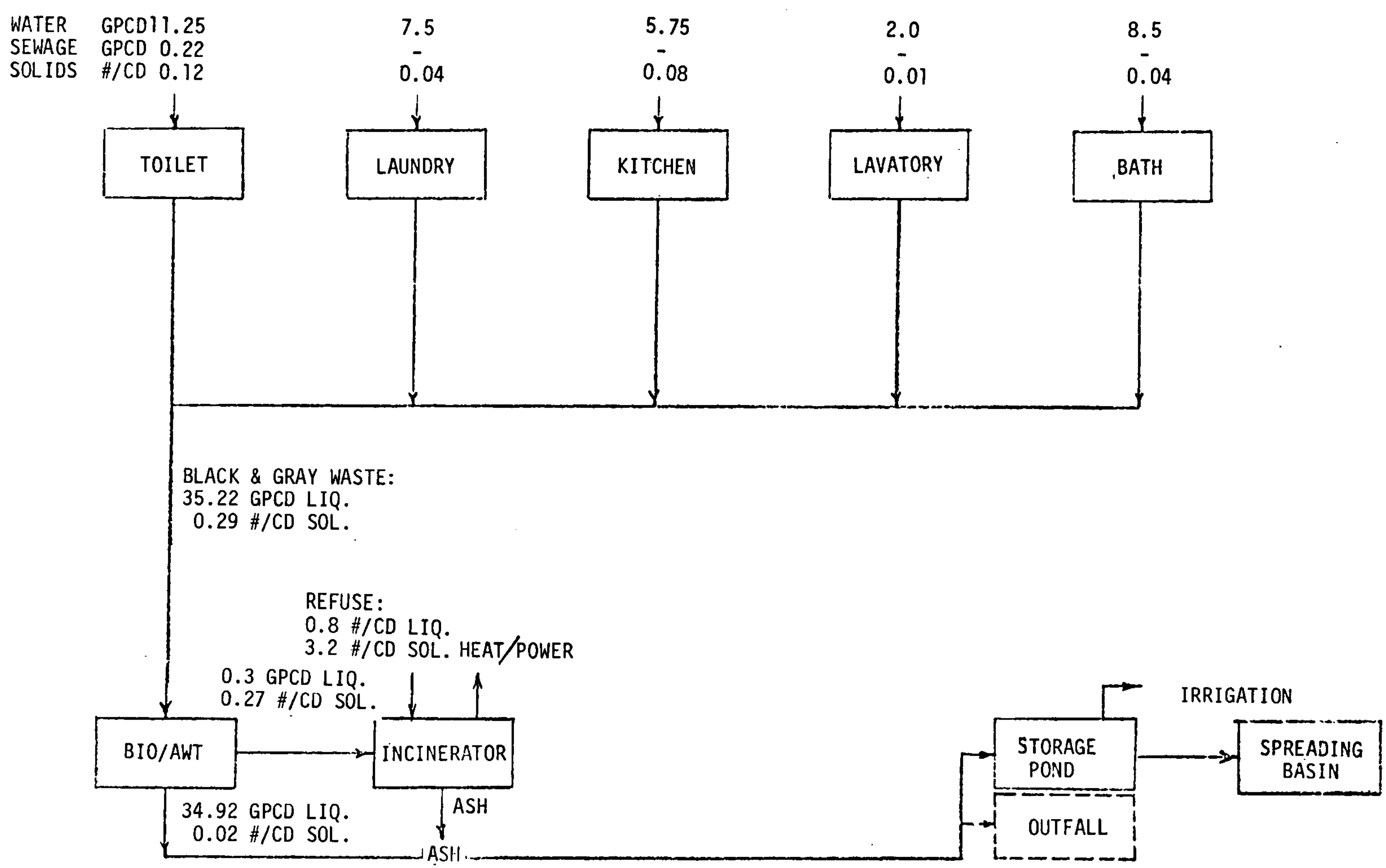


Figure 30 Baseline Concept (A-2)

Concept A-3 incorporates limited direct reuse. Dish and clothes washer reuse water is stored and reused in subsequent wash cycles prior to being collected for treatment.

Concept A-4 was created to determine the effect of separate gray water and black water collection on a biological treatment system. The resultant load on the biological treatment plant is roughly one-third of that of concept A-2. The gray water goes directly to the storage pond with disinfection as its only treatment. Fats and grease are removed from the kitchen sink drainline by a grease separator in order to eliminate fouling of the storage pond and spreading basin. The grease is sent with the black water to the biological treatment plant.

Concept Category "B"

Systems in this category employ a concentrating (partial recirculating) toilet with vacuum collection of the black water which is subsequently incinerated. Flow limiting devices are used on faucets and shower heads. Shown in Figure 31, concept B-1 is the simplest one in the category. Gray water is also collected by a vacuum transport sewer in the community and is sent to the storage pond/spreading basin for reuse or disposal. A grease separator protects the pond and basin from being coated. The addition of rinse reuse apparatus for the dishwasher and clothes washer creates concept B-2.

Concept B-3 builds upon B-1 by adding distillation of gray water to provide suitable water for the clothes washer. Concept B-4 has rinse reuse in addition to thermal distillation. Concepts B-5 and B-6 are respectively similar to B-3 and B-4 except that sufficient water is reclaimed to supply the shower/bath in addition to the clothes washer.

Concepts B-7 through B-10 are the same as B-3 through B-6 except that a phys-chem process (essentially reverse osmosis) is substituted for the thermal distillation process. Concept B-10, illustrated in Figure 32 is typical of this category.

Concept Category "C"

This concept category employs a shallow-trap dual-flush toilet that is supplied with used water from the clotheswasher and the shower/tub. A phys-chem process (chemical precipitation and carbon adsorption) is employed to treat black water. Chemical/biological sludge and spent carbon is incinerated with the refuse. This is shown in concept C-1 (see Figure 33). Concept C-2 is identical except for the addition of rinse reuse.

Concept C-3 is equivalent to C-1 with the addition of distillation of gray water to supply clotheswasher requirements. In Concept C-4, a reverse osmosis process is substituted for distillation.

Concept Category "D"

In the course of evaluating the concepts, the large effect of supply water hardness to overall cost became apparent. While none of the other concepts include municipal water tratement costs, Concept D was generated to determine the effect of a reverse osmosis system for softening the water. Since reverse osmosis works better at low percent recovery, the schematic provides for flushing shallow-trap

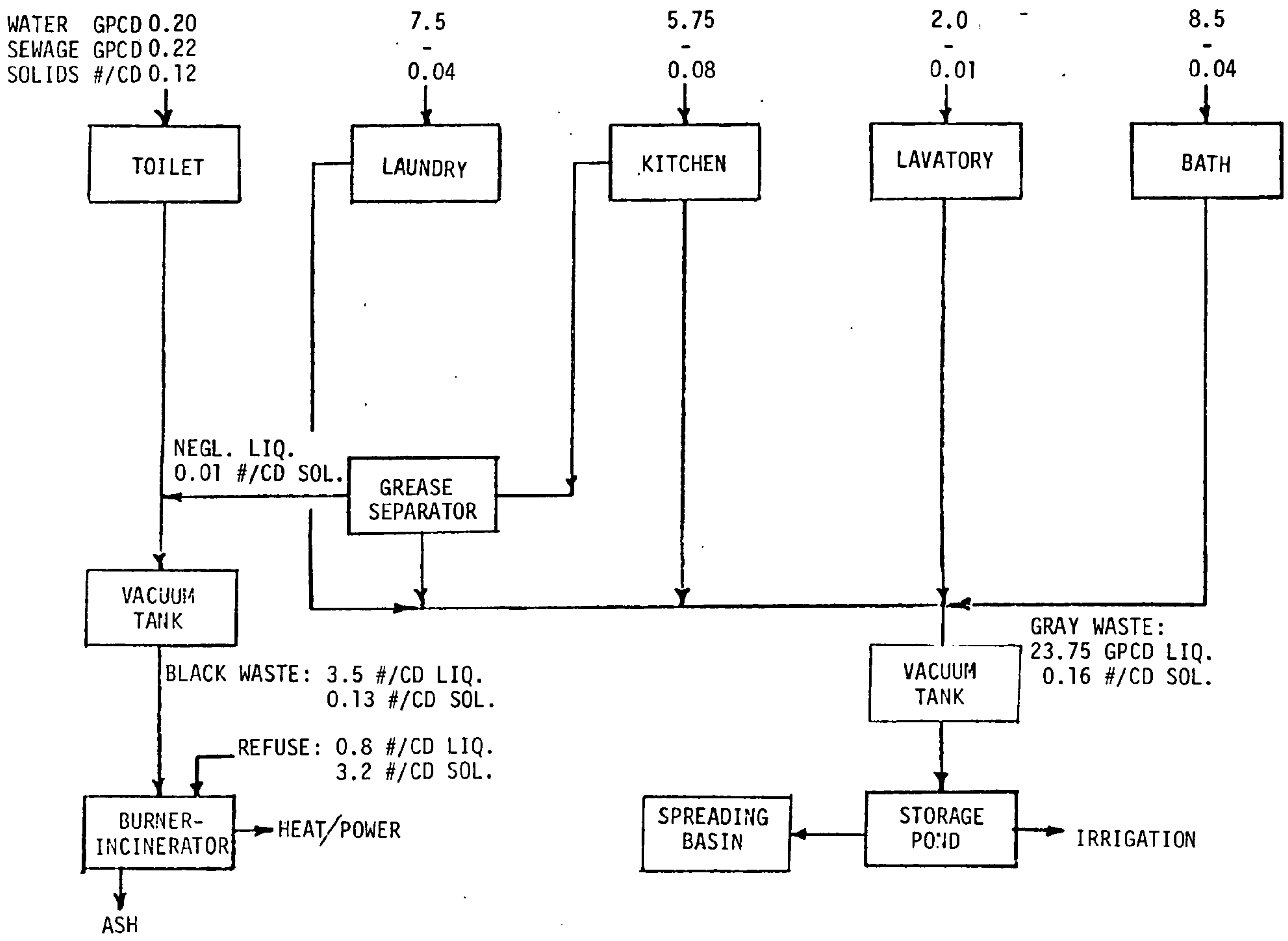


Figure 31 Typical Vacuum Collection Concept (B-1)

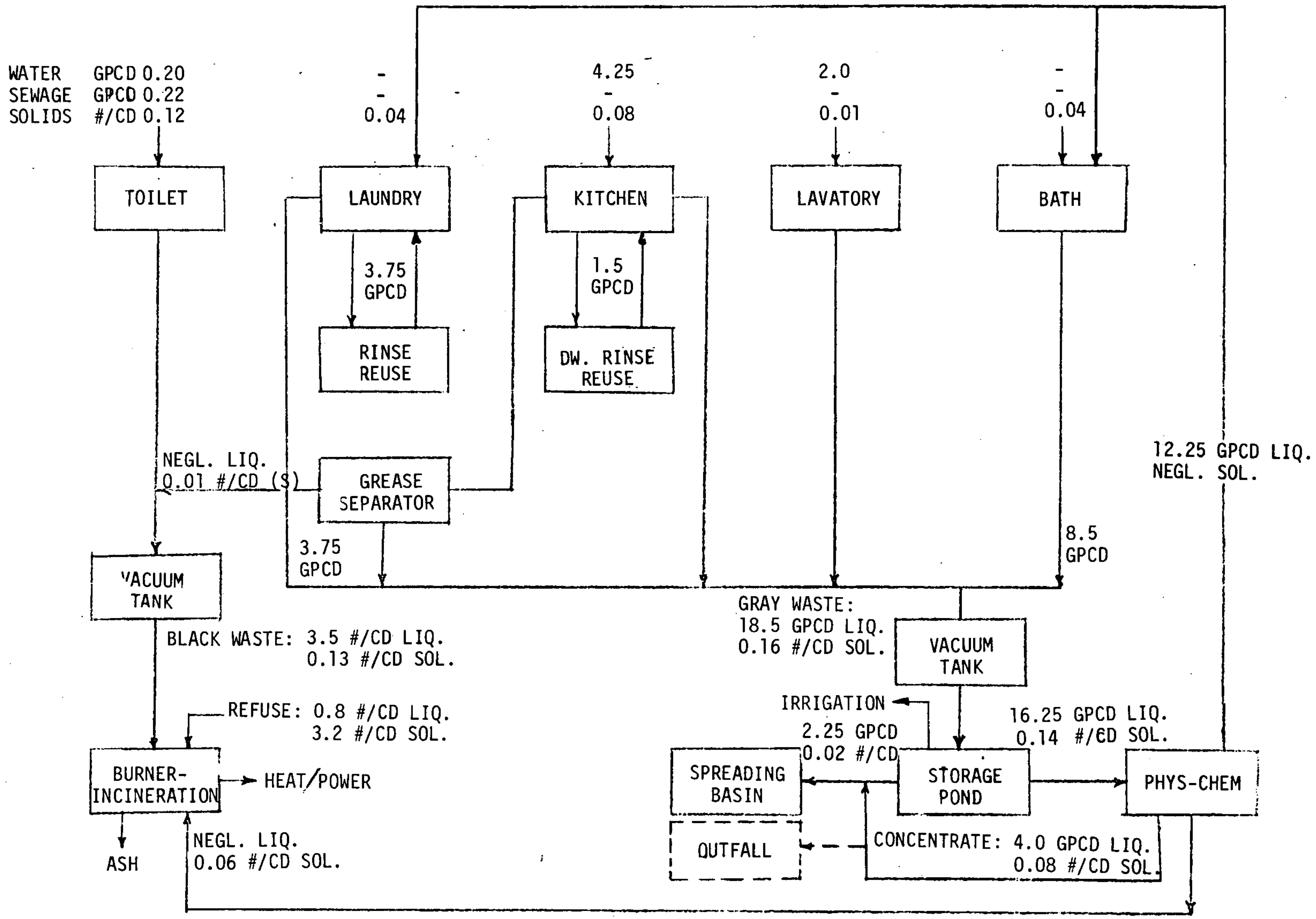


Figure 32 Typical Recycle Concept (B-10)

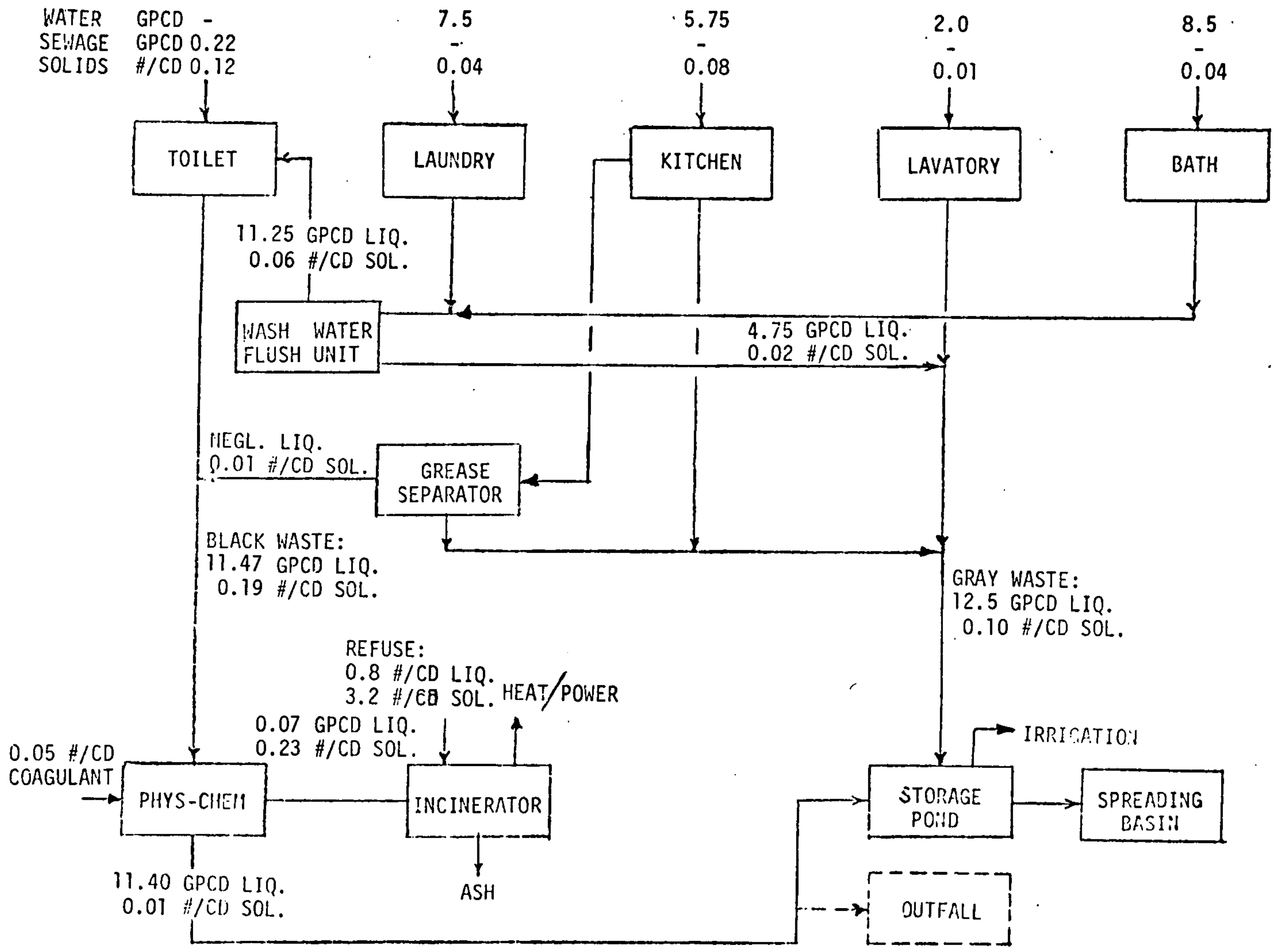


Figure 33 Typical Washwater Flush Concept (C-1)

toilets with reverse osmosis concentrate. The system would be operated to provide sufficient flush water with a small increase in solids concentration. A separate distribution network provides flush water.

CONCEPT EVALUATION AND SELECTION

Cost Summary

The nineteen concepts are evaluated by means of straightfoward cost comparison with some weight given to water consumption. A concept comparison cost summary was constructed and is presented as Table 21. Cost projections for the year 2000 are also made in order to grossly assess any shift in relative costs due to differing rates of cost increase in the various system components. The results are contained in Appendix A.

Table 21 is organized by consecutively numbered concepts. Within each concept, the costs are applied to one model community with a population of 2000 and to multiple communities with populations of 25,000 and 250,000. The costs are shown as the annual expense to each family. Capital costs are amortized at 5% interest for 30 years unless otherwise stated in the cost component descriptions below. Operating and maintenance costs complete each item total. Component cost percentages are presented relative to the total cost in a soft water area, except for concept D which is applicable only to hard water areas.

Description of Cost Components

1. Water Fixtures: The catalog prices for one bathtub with its fixtures and showerhead, one kitchen sink and faucet, two lavatory vanities, sinks and faucets are taken as $450. The price increase for these items is assumed to be 3% per year.

2. Toilet: Two toilets per dwelling unit are assumed. A standard toilet is used for concept A-1; the shallow trap dual flush toilet is used for concepts A-2 through A-4, C-1 through C-4 and D; the B concepts use the partial recirculation toilet. The rate of cost increase is again assumed to be 3% per year.

3. Wash Water Toilet Flush Unit: This unit, located in each apartment building, is described in Section VI. It is used for the C concepts only. Assumed rate of increase: 4% per year.

4. Clothes Washer: The washing machine is assumed to be a good quality, standard machine for concepts A-1, 2, 4; B-1, 3,5,7,9; C-1,3, 4 and D. The other concepts have machines with rinse reuse as described in Section VI. Assumed rate of increase: 3% per year for the washer and 4% per year for the rinse reuse equipment. Amortization period: 10 years.

5. Dishwasher: A standard machine in each apartment is used for concepts A-1, 2, 4; B-1, 3, 5, 7, 9; C-1, 3, 4 and D. The other concepts have machines with rinse reuse. Assumed rate of increase: same as item 4. Amortization period: 15 years.

6. Internal Building Piping: This piping is calculated by the number, size and line lengths for each concept, using a dimensioned building model. The yearly cost also includes maintenance. The cost per family is achieved by dividing the building piping cost by the number of apartments. Assumed rate of increase: 4 1/2% per year.

7. Renovated Water Return Lines: These lines carry reclaimed water from the source to the points of usage. For the single community of 2000 people, these lines go from the on-site reclamation system to the clothes washer in each building and in specific concepts, directly to the shower/bath. For the larger populations, these lines also run under the streets. Costs are calculated by number, size and length of pipes. Assumed rate of increase: 4% per year.

8. Vacuum Collection Sewer: This item includes all the pipes and equipment to collect black and gray water in a dual system on the community site. It is used for the B concepts only. Assumed rate of increase: 4 1/2% per year.

9. Black Water Sewer: The sewer priced in this item is a gravity sewer, starting at the building line and extending to the treatment plant, whether on-site or in the middle of a town. It is used for concepts A-4, C-1 through C-4 and D. Assumed rate of increase: 5% per year.

10. Gray Water Sewer: The gray water sewer is either an all gravity system or a combination of vacuum transport on the community site and gravity lines to the town central processing. An all gravity system is used for concepts A-4, C-1 through C-4 and D. In the B concepts, the gray water sewer in the community is vacuum operated. The cost for the system on the community site is included in Item 8. The cost of the municipal gravity lines is shown for the larger populations of concepts B-3 through B-10. There are no municipal lines for B-1 and B-2. Assumed rate of increase: 5% per year.

11. Combined Sewage Sewer: All waste waters in concepts A-1 through A-3 are collected in a single gravity line for transport to the waste treatment plant. The assumed rate of cost increase is 5% per year.

12. Refuse Collection: The cost of refuse collection is uniformly fixed for all concepts. A derivation of the applied value is given in Section VI. Assumed rate of increase: 4 1/2% per year.

13. Grease Separator: A grease separator is used in every building for all concepts except A-1 through A-3, since these concepts utilize combined sewers. Section VI contains the estimate basis. Assumed rate on increase: 3% per year.

14. Incinerator - Refuse and Sludge: For the purposes of evaluating concepts, the incinerator was assumed to be a refuse incinerator, modified to accept sludge, semi-solids or concentrated black water. Presumably, the water in the sludge or black water could be absorbed by the refuse or an evaporation/drying zone could be provided. It is expected that addition of wet waste would incrementally shift the cost along the incineration cost curve in Figure 29. All concepts evaluated include an incinerator. Assumed rate of increase: 4 1/2% per year.

15. Phys-Chem For Gray Water: The physico-chemical method of reclaiming water from gray water selected for evaluation is essentially reverse-osmosis. Concepts B-7 through B-10 and C-4 use this processing. Possible requirements for post-treatment by carbon adsorption for dissolved organics reduction is not considered in the pricing. Assumed rate of increase: 4 1/2% per year.

16. Phys-Chem for Black Water: The physico-chemical processing for treating black water is essentially chemical precipitation and sedimentation followed by powdered activated carbon adsorption and dual media filtration. Only the C concepts and the D concept use this processing of black water. Assumed rate of increase: 4 1/2% per year.

17. Bio-Treatment with AWT: The conventional methods of primary and secondary treatment of sewage followed by Advanced Waste Treatment (AWT) are designated for this item. It is used for concept group A. Assumed rate of increase: 5% per year.

18. Distillation: The apparatus used for the cost summary is assumed to use heat from the community's power generation equipment. It is employed in concepts B-3 through B-6 and C-3. Assumed rate of increase: 3% per year

19. Municipal Outfall Line: Outfall lines are considered for all the towns of 25,000 and 250,000 populations except in concepts B-1, B-2 and C-1. Assumed rate on increase: 5% per year.

20. Cleaning Agents: In the body of the cost summary are the costs of all cleaning agents that are used in or with water in a soft water area. The increase in cost of these agents in a hard water area is added to the subtotal at the bottom of each column except for concept D (see description of item 23). Assumed rate of increase: 3% per year

21. Water - Building, Internal: The municipal water used in each apartment plus that required for the clothes washer is considered in this item. A fixed rate of 40¢/1000 gal. is used. Assumed rates of increase: 2.6% per year.

22. Water - Irrigation: The cost of municipal water that supplements reused water for landscape irrigation is entered in this item. The charge and rate of increase is the same as for item 21 .

23. Municipal Water Softening: This item is considered only in concept D where the municipal drinking water source is hard enough to require treatment. The cost is a rough estimate for a nominal value of hardness. Treatment costs are normally a function of influent hardness and removal quantity. Note that column totals are not shown for soft water areas. This item is used in conjunction with item 24. The rate of cost increase assigned to this item is 3% per year.

24. R.O. Concentrate Distribution System: This item is comprised of separate municipal distribution lines in the streets of the town, on the community site and within each building, up to each toilet. It carries only R.O. concentrate. This item is used with item 23 only for concept D. Assumed rate of increase: 5% per year.

25. Storage Ponds: This cost entry includes the storage pond, the irrigation pumps, the main irrigation distribution lines and the spreading basin. In the larger populations for concepts A-1, A-2 and A-3, an outfall line replaces the pond and basin. Assumed rate of increase: 4 1/2% per year.

Concept Selection

The results of the cost summaries are presented visually by bar graphs with expanded scales in order to accentuate the cost differences between the concepts examined. Figures 34 and 35 show totals for soft and hard water areas respectively. Similar figures, contained in Appendix A roughly project concept costs to the year 2000. A water consumption comparison is presented in Figure 36.

Comparing the minimum costs and water consumption at a given population against the cost of A-1 (the "conventional" approach) at the same population gives the following results. For soft water areas concept B-1 is the least expensive concept at all populations, and uses 38% less water. Relative to A-1, it is 24, 25 and 21% less at the 2000, 25,000, and 250,000 levels, respectively. However, for hard water areas, concept B-8 is the least expensive at the 2000 level, being 28% less than A-1. Concept B-9 is 27% less than A-1 at the 25,000 population and B-10 is 26% less than A-1 at the 250,000 level. The water consumption is 47% less, 61% less and 63% less than A-1 for these three concepts respectively, at the population levels specified.

For the year 2000 (Appendix A) concept B-1 is again the least expensive at all populations in soft water areas. It is 34,33, and 29% less than A-1 as the population increases. But, for hard water areas, different concepts appear most economical. Concept B-4 is 34% less than A-1 for 2000 people and concept B-5 is 31% less than A-1 for 25,000 and 250,000 people. These concepts are 47% less and 61% less water than A-1 for their specified population levels. Water consumption rates for all concepts do not change for the year 2000.

The cost percentages are a function of the basis on which the concepts are compared. The cost for four line items in the tabulation are almost identical for all concepts. They are item (1) water fixtures, (2) refuse collection, (3) incineration, and (4) cleansing agents for soft water areas. These four items range from 42 to 59% of the total concept costs and have an average value of 50%. If these items are omitted, the absolute differences between concepts remain unchanged but the relative differences would double. The relative merits of the concepts could be observed more readily in this manner.

This form of reasoning also leads to the removal of the fixed portion of other line items, such as the cost of a standard dishwasher or clotheswasher from the same machines with rinse reuse features built in. This amounts to tabulating only the cost differentials. A further step would consider only differentials of sewers and treatment system costs. This leads to confusion and the loss of sight of what each concept actually costs. In order to avoid a subjective judgement of what fixed costs can rightfully be eliminated, the cost summary, graphs and comparisons are made on the basis of total system costs.

It should also be kept in mind that the bases of many of the costs contain assumptions that may not always apply in all situations. In addition, the estimates of costs have varying degrees of accuracy and reliability. Furthermore, the leading concept candidates have small differences between them in certain cases. As a result of these factors, the final selection of a particular concept is somewhat arbitrary and subjective. The cost summary analysis does provide some trend characteristics and eliminates some concepts but unfortunately, does not provide a distinct, absolute choice of a single concept.

The concept category A, which is characterized by biological treatment and relatively conventional equipment and the concept category C, characterized by flushing toilets with wash water, are both more costly than the concept category B. This applies to soft and hard water areas for 1972 as well as the year 2000. Concept D appears similar to the C concepts in cost.

Within the B category, the two leading contenders for selection are B-1 (no reclamation), and B-10 (phys-chem reclamation). The main characterisitc of category B is vacuum collection and incineration of very concentrated black water. In 1972, B-1 costs an average of 12% less than B-10 in a soft water area but costs an average of 7 1/2% more than B-10 for a hard water area. Furthermore, B-1 consumes an average of 29% more water than B-10.

Since the locale of a modular integrated utility system may be dictated by water availability coupled with the fact that water short areas tend to have greater hardness (e.g. the southwest), it is judged that B-10 is the better choice for further definition and evaluation.

TABLE 21 CONCEPT COST COMPARISONS

CONCEPT	A-1						A-2					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	7.9	29.2	8.4	29.2	8.9	29.2	9.1	29.2	9.6	29.2	10.2
2. Toilet	7.8	2.1	7.8	2.2	7.8	2.4	12.2	3.8	12.2	4.0	12.2	4.3
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-	
4. Clothes Washer	3.0	0.8	3.0	0.9	3.0	0.9	3.0	0.9	3.0	1.0	3.0	1.1
5. Dishwasher	27.0	7.3	27.0	7.7	27.0	8.3	27.0	8.4	27.0	8.8	27.0	9.5
6. Building Internal Piping	7.7	2.1	7.7	2.2	7.7	2.4	7.7	2.4	7.7	2.5	7.7	2.7
7. Renovated Water Return Lines	-		-		-		-		-		-	
8. Vacuum Collection Sewer	-		-		-		-		-		-	
9. Black Water Sewer	-		-		-		-		-		-	
10. Gray Water Sewer	-		-		-		-		-		-	
11. Combined Sewage Sewer	55.0	14.9	63.0	18.0	67.3	20.6	26.4	8.2	33.7	11.0	37.0	13.0
12. Refuse Collection	30.0	8.1	30.0	8.6	30.0	9.2	30.0	9.3	30.0	9.8	30.0	10.5
13. Grease Trap	-		-		-		-		-		-	
14. Incinerator (Refuse and Sludge)	49.0	13.2	31.0	8.9	26.2	8.0	49.0	15.3	31.0	10.2	26.2	9.2
15. Phys-Chem: For Gray Water	-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-	
17. Bio-Treatment with AWT	72.2	19.5	41.4	11.9	27.1	8.3	55.6	17.3	3[illegible].2	10.9	20.4	7.2
18. Distillation	-		-		-		-		-		-	
19. Municipal Outfall Line	-		11.7	3.4	4.6	1.4	-		9.3	3.0	3.2	1.1
20. Cleaning Agents (Soft Water Area)	58.0	15.7	58.0	16.6	58.0	17.7	58.0	18.1	58.0	19.0	58.0	20.4
21. Water: Building, Internal	28.6	7.7	28.6	8.2	28.6	8.7	20.4	6.3	20.4	6.7	20.4	7.2
22. Water: Lawn Irrigation	0	0	10.6	3.0	10.6	3.2	0.5	0.2	10.6	3.5	10.6	3.7
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-	
25. Storage Ponds	2.6	0.7	-		-		2.2	0.7	-		-	
TOTAL: SOFT WATER AREA	370.1	100.0	349.0	100.0	327.1	100.0	321.2	100.0	305.3	100.0	284.9	100.0
ADDITIONAL FOR HARD WATER AREA	58.0		58.0		58.0		58.0		53.0		58.0	
TOTAL: HARD WATER AREA	428.1		407.0		385.1		379.2		363.3		342.9	

CONCEPT	A-3						A-4					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	9.2	29.2	9.7	29.2	10.3	29.2	9.5	29.2	9.4	29.2	9.9
2. Toilet	12.2	3.8	12.2	4.1	12.2	4.3	12.2	3.9	12.2	3.9	12.2	4.1
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-	
4. Clothes Washer	3.5	1.1	3.5	1.2	3.5	1.2	3.0	1.0	3.0	1.0	3.0	1.0
5. Dishwasher	32.2	10.2	32.2	10.7	32.2	11.4	27.0	8.7	27.0	8.6	27.0	9.1
6. Building Internal Piping	7.7	2.4	7.7	2.6	7.7	2.8	15.9	5.2	15.9	5.1	15.9	5.4
7. Renovated Water Return Lines	-		-		-		-		-		-	
8. Vacuum Collection Sewer	-		-		-		-		-		-	
9. Black Water Sewer	-		-		-		29.4	9.5	35.9	11.5	36.6	12.4
10. Gray Water Sewer	-		-		-		8.5	2.8	15.0	4.8	15.7	5.3
11. Combined Sewage Sewer	24.3	7.7	30.9	10.3	33.5	11.9	-		-		-	
12. Refuse Collection	30.0	9.5	30.0	10.0	30.0	10.6	30.0	9.7	30.0	9.6	30.0	10.1
13. Grease Trap	-		-		-		1.8	0.6	1.8	0.6	1.8	0.6
14. Incinerator (Refuse and Sludge)	49.0	15.5	31.0	10.3	26.2	9.3	48.0	15.5	30.4	9.7	25.6	8.7
15. Phys-Chem: For Gray Water	-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-	
17. Bio-Treatment with AWT	49.0	15.5	29.2	9.7	18.7	6.6	22.8	7.4	13.7	4.4	6.0	2.0
18. Distillation	-		-		-		-		-		-	
19. Municipal Outfall Line	-		8.4	2.8	2.8	1.0	-		7.3	2.3	2.2	0.7
20. Cleaning Agents (Soft Water Area)	58.0	18.3	58.0	19.3	58.0	20.6	58.0	18.8	58.0	18.6	58.0	19.6
21. Water: Building, Internal	17.4	5.5	17.4	5.8	17.4	6.2	20.4	6.6	20.4	6.5	20.4	6.9
22. Water: Lawn Irrigation	2.0	0.6	10.6	3.5	10.6	3.8	0.4	0.1	10.6	3.4	10.6	3.6
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-	
25. Storage Ponds	2.1	0.7	-		-		2.2	0.7	1.8	0.6	1.8	0.6
TOTAL: SOFT WATER AREA	316.6	100.0	300.3	100.0	282.0	100.0	308.8	100.0	312.2	100.0	296.0	100.0
ADDITIONAL FOR HARD WATER AREA	58.0		58.0		58.0		58.0		58.0		58.0	
TOTAL: HARD WATER AREA	374.6		358.3		340.0		366.8		370.2		354.0	

TABLE 21 CONCEPT COST COMPARISONS (Continued)

CONCEPT	B-1						B-2						B-3						B-4					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	10.5	29.2	11.2	29.2	11.4	29.2	10.3	29.2	11.0	29.2	11.2	29.2	9.4	29.2	9.8	29.2	10.5	29.2	9.6	29.2	9.8	29.2	10.5
2. Toilet	25.8	9.2	25.8	9.8	25.8	10.0	25.8	9.0	25.8	9.7	25.8	9.2	25.8	8.3	25.8	8.7	25.8	9.3	25.8	8.6	25.8	8.7	25.8	9.3
3. Wash Water Toilet Flush Unit	--		--		--		--		--		--		--		--		--		--		--		--	
4. Clothes Washer	3.0	1.1	3.0	1.2	3.0	1.2	3.5	1.3	3.5	1.3	3.5	1.3	3.0	0.9	3.0	1.0	3.0	1.1	3.5	1.2	3.5	1.2	3.5	1.3
5. Dishwasher	27.0	9.7	27.0	10.3	27.0	10.5	32.2	11.4	32.2	12.2	32.2	12.3	27.0	8.7	27.0	9.1	27.0	9.7	32.2	10.7	32.2	10.8	32.2	11.6
6. Building Internal Piping	16.6	5.8	16.6	6.1	16.6	6.3	16.6	5.9	16.6	6.2	16.6	6.4	14.1	4.5	14.1	4.8	14.1	5.1	14.1	4.6	14.1	4.8	14.1	5.1
7. Renovated Water Return Lines	--		--		--		--		--		--		1.8	0.6	1.5	0.5	2.0	0.7	1.8	0.6	1.5	0.5	2.0	0.7
8. Vacuum Collection Sewer	20.1	7.2	20.4	7.8	20.4	7.9	20.1	7.1	20.4	7.6	20.4	7.8	20.1	6.4	20.4	6.9	20.4	7.3	20.1	6.7	20.4	6.9	20.4	7.3
9. Black Water Sewer	--		--		--		--		--		--		--		--		--		--		--		--	
10. Gray Water Sewer	--		--		--		--		--		--		--		7.9	2.7	6.7	2.4	--		11.9	4.0	6.1	2.2
11. Combined Sewage Sewer	--		--		--		--		--		--		--		--		--		--		--		--	
12. Refuse Collection	30.0	10.7	30.0	11.5	30.0	11.7	30.0	10.6	30.0	11.3	30.0	11.5	30.0	9.6	30.0	10.1	30.0	10.8	30.0	9.9	30.0	10.1	30.0	10.8
13. Grease Trap	1.8	0.6	1.8	0.7	1.8	0.7	1.8	0.6	1.8	0.7	1.8	0.7	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6
14. Incinerator (Refuse and Sludge)	48.6	17.4	30.7	11.7	25.9	10.1	48.6	17.1	30.7	11.5	25.9	9.9	49.5	15.9	31.4	10.6	26.4	9.5	49.2	16.3	31.2	10.5	26.3	9.5
15. Phys-Chem: For Gray Water	--		--		--		--		--		--		--		--		--		--		--		--	
16. Phys-Chem: For Black Water	--		--		--		--		--		--		--		--		--		--		--		--	
17. Bio-Treatment with AWT	--		--		--		--		--		--		--		--		--		--		--		--	
18. Distillation	--		--		--		--		--		--		34.0	10.9	18.5	6.2	10.4	3.7	19.5	6.5	10.6	3.6	6.2	2.2
19. Municipal Outfall Line	--		--		--		--		--		--		--		6.0	2.0	1.6	0.6	--		5.7	1.9	1.5	0.5
20. Cleaning Agents (Soft Water Area)	58.0	20.7	58.0	22.1	58.0	22.6	58.0	20.5	58.0	21.8	58.0	22.2	58.0	18.6	58.0	19.6	58.0	20.8	58.0	19.2	58.0	19.5	58.0	20.9
21. Water: Building, Internal	14.0	5.0	14.0	5.3	14.0	5.4	10.9	3.8	10.9	4.1	10.9	4.2	9.6	3.1	9.6	3.2	9.6	3.5	8.7	2.9	8.7	3.0	8.7	3.1
22. Water: Lawn Irrigation	3.7	1.3	3.7	1.4	3.7	1.4	5.2	1.9	5.2	2.0	5.2	2.0	6.0	1.9	10.6	3.6	10.6	3.8	6.3	2.1	10.6	3.6	10.6	3.8
23. Municipal Water Softening (R.O.)	--		--		--		--		--		--		--		--		--		--		--		--	
24. R. O. Concentrate Distribution System	--		--		--		--		--		--		--		--		--		--		--		--	
25. Storage Ponds	1.8	0.6	1.8	0.7	1.8	0.7	1.6	0.5	1.6	0.6	1.6	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.6	0.5	1.6	0.5	1.6	0.6
TOTAL: SOFT WATER AREA	279.6	100.0	262.0	100.0	257.2	100.0	283.5	100.0	265.9	100.0	261.1	100.0	311.7	100.0	296.6	100.0	278.4	100.0	301.8	100.0	296.8	100.0	278.1	100.0
ADDITIONAL FOR HARD WATER AREA	58.0		58.0		58.0		58.0		58.0	--	58.0	--	10.0		10.0		10.0		10.0	--	10.0	--	10.0	
TOTAL: HARD WATER AREA	337.6		320.0		315.2		341.5		323.9		319.1	--	321.7		306.6		288.4		311.8	--	306.8	--	288.1	

TABLE 21 CONCEPT COST COMPARISONS (Continued)

CONCEPT	B-5						B-6						B-7						B-8					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	8.6	29.2	9.6	29.2	10.3	29.2	8.7	29.2	9.6	29.2	10.2	29.2	9.6	29.2	10.0	29.2	10.6	29.2	9.8	29.2	10.0	29.2	10.5
2. Toilet	25.8	7.6	25.8	8.5	25.8	9.1	25.8	7.7	25.8	8.5	25.8	9.0	25.8	8.5	25.8	8.9	25.8	9.3	25.8	8.6	25.8	8.8	25.8	9.3
3. Wash Water Toilet Flush Unit	--		--		--		--		--		--		--		--		--		--		--		--	
4. Clothes Washer	3.0	0.9	3.0	1.0	3.0	1.1	3.5	1.0	3.5	1.2	3.5	1.3	3.0	1.0	3.0	1.0	3.0	1.1	3.5	1.2	3.5	1.2	3.5	1.3
5. Dishwasher	27.0	8.0	27.0	8.9	27.0	9.5	32.2	9.6	32.2	10.6	32.2	11.3	27.0	8.9	27.0	9.3	27.0	9.8	32.2	10.8	32.2	11.0	32.2	11.6
6. Building Internal Piping	15.6	4.6	15.6	5.1	15.6	5.5	15.6	4.7	15.6	5.1	15.6	5.5	14.1	4.7	14.1	4.8	14.1	5.1	14.1	4.8	14.1	4.8	14.1	5.1
7. Renovated Water Return Lines	3.4	1.0	2.8	0.9	2.9	1.0	3.4	1.0	2.8	0.9	2.9	1.0	1.8	0.6	1.5	0.5	2.0	0.7	1.8	0.6	1.5	0.5	2.0	0.7
8. Vacuum Collection Sewer	20.1	5.9	20.4	6.7	20.4	7.2	20.1	6.0	20.4	6.7	20.4	7.2	20.1	6.6	20.4	7.0	20.4	7.4	20.1	6.7	20.4	6.9	20.4	7.4
9. Black Water Sewer	--		--		--		--		--		--		--		--		--		--		--		--	
10. Gray Water Sewer	--		6.2	2.0	8.0	2.8	--		6.2	2.1	7.5	2.6	--		7.0	2.4	7.0	2.5	--		10.5	3.6	6.3	2.3
11. Combined Sewage Sewer	--		--		--		--		--		--		--		--		--		--		--		--	
12. Refuse Collection	30.0	8.9	30.0	9.9	30.0	10.5	30.0	8.9	30.0	9.9	30.0	10.5	30.0	9.9	30.0	10.3	30.0	10.8	30.0	10.0	30.0	10.2	30.0	10.8
13. Grease Trap	1.8	0.5	1.8	0.6	1.8	0.6	1.8	0.5	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.7
14. Incinerator (Refuse and Sludge)	50.2	14.8	31.8	10.5	26.8	9.4	50.1	14.9	31.8	10.5	26.8	9.4	49.0	16.2	31.0	10.7	26.2	9.5	49.0	16.4	31.0	10.6	26.2	9.5
15. Phys-Chem: For Gray Water	--		--		--		--		--		--		25.4	8.4	14.5	5.0	8.7	3.1	16.6	5.6	8.4	2.9	5.2	1.9
16. Phys-Chem: For Black Water	--		--		--		--		--		--		--		--		--		--		--		--	
17. Bio-Treatment with AWT	--		--		--		--		--		--		--		--		--		--		--		--	
18. Distillation	59.6	17.6	31.0	10.2	18.0	6.3	51.5	15.4	25.6	8.5	14.6	5.1	--		--		--		--		--		--	
19. Municipal Outfall Line	--		4.4	1.4	1.0	0.4	--		4.2	1.4	0.9	0.3	--		6.0	2.1	1.6	0.6	--		5.8	2.0	1.5	0.5
20. Cleaning Agents (Soft Water Area)	58.0	17.1	58.0	19.1	58.0	20.4	58.0	17.3	58.0	19.1	58.0	20.3	58.0	19.2	58.0	19.9	58.0	21.0	58.0	19.4	58.0	19.8	58.0	20.9
21. Water: Building, Internal	4.6	1.4	4.6	1.5	4.6	1.6	3.8	1.1	3.8	1.3	3.8	1.3	9.6	3.2	9.6	3.3	9.6	3.5	8.7	2.9	8.7	3.0	8.7	3.1
22. Water: Lawn Irrigation	8.6	2.6	10.6	3.5	10.6	3.7	8.9	2.7	10.6	3.5	10.6	3.8	5.9	2.0	10.6	3.6	10.6	3.8	6.3	2.1	10.6	3.6	10.6	3.8
23. Municipal Water Softening (R.O.)	--		--		--		--		--		--		--		--		--		--		--		--	
24. R. O. Concentrate Distribution System	--		--		--		--		--		--		--		--		--		--		--		--	
25. Storage Ponds	1.8	0.5	1.8	0.6	1.8	0.6	1.6	0.5	1.6	0.5	1.6	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.6	0.5	1.6	0.5	1.6	0.6
TOTAL: SOFT WATER AREA	338.7	100.0	304.0	100.0	284.5	100.0	335.5	100.0	303.1	100.0	285.2	100.0	302.5	100.0	291.3	100.0	276.8	100.0	298.7	100.0	293.1	100.0	277.1	100.0
ADDITIONAL FOR HARD WATER AREA	--		--		--		--	--	--		--		10.0		10.0		10.0		10.0		10.0		10.0	
TOTAL: HARD WATER AREA	338.7		304.0		284.5		335.5		303.1		285.2		312.5		301.3		286.8		308.7		303.1		287.1	

TABLE 21 CONCEPT COST COMPARISONS (Continued)

CONCEPT	B-9						B-10						C-I						C-2					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	8.9	29.2	9.8	29.2	10.3	29.2	9.1	29.2	9.6	29.2	10.3	29.2	9.3	29.2	9.7	29.2	10.0	29.2	9.0	29.2	9.3	29.2	9.7
2. Toilet	25.8	7.9	25.8	8.6	25.8	9.1	25.8	8.0	25.8	8.5	25.8	9.1	12.2	3.9	12.2	4.1	12.2	4.2	12.2	3.8	12.2	3.9	12.2	4.0
3. Wash Water Toilet Flush Unit	--	--	--		--		--		--		--		6.7	2.1	6.7	2.2	6.7	2.3	6.7	2.1	6.7	2.1	6.7	2.2
4. Clothes Washer	3.0	0.9	3.0	1.0	3.0	1.1	3.5	1.1	3.5	1.2	3.5	1.2	3.0	1.0	3.0	1.0	3.5	1.0	3.5	1.1	3.5	1.1	3.5	1.2
5. Dishwasher	27.0	8.2	27.0	9.0	27.0	9.5	32.2	10.0	32.2	10.6	32.2	11.4	27.0	8.6	27.0	9.0	27.0	9.2	32.2	9.9	32.2	10.3	32.2	10.7
6. Building Internal Piping	15.6	4.7	15.6	5.3	15.6	5.6	15.6	5.1	15.6	5.4	15.6	5.6	18.2	5.8	18.2	6.1	18.2	6.2	18.2	5.6	18.2	5.8	18.2	6.0
7. Renovated Water Return Lines	3.4	1.0	2.8	0.9	2.9	1.0	3.4	1.1	2.8	0.9	2.9	1.0	--		--		--		1.8	0.5	1.5	0.5	2.0	0.7
8. Vacuum Collection Sewer	20.1	6.1	20.4	6.8	20.4	7.2	20.1	6.3	20.4	6.7	20.4	7.2	--		--		--		--		--		--	
9. Black Water Sewer	--		--		--		--		--		--		29.4	9.3	35.9	11.9	36.6	12.5	29.4	9.1	35.9	11.5	36.6	12.1
10. Gray Water Sewer	--		6.5	2.2	8.6	3.0	--		6.2	2.1	8.0	2.8	8.5	2.7	15.0	5.0	15.7	5.4	8.5	2.6	15.0	4.8	15.7	5.2
11. Combined Sewage Sewer	--		--		--		--		--		--		--		--		--		--		--		--	
12. Refuse Collection	30.0	9.2	30.0	10.0	30.0	10.6	30.0	9.4	30.0	9.9	30.0	10.6	30.0	9.5	30.0	10.0	30.0	10.3	30.0	9.3	30.0	9.6	30.0	9.9
13. Grease Trap	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.6	1.8	0.5	1.8	0.6	1.8	0.6
14. Incinerator (Refuse and Sludge)	49.0	14.9	31.0	10.4	26.2	9.3	49.0	15.3	31.0	10.2	26.2	9.2	48.6	15.5	30.7	10.2	25.9	8.9	49.5	15.3	31.4	10.0	26.4	8.7
15. Phys-Chem: For Gray Water	50.6	15.4	26.2	8.8	16.5	5.8	37.6	11.7	26.0	8.6	13.1	4.6	--		--		--		--		--		--	
16. Phys-Chem: For Black Water	--		--		--		--		--		--		22.4	7.1	10.4	3.5	5.2	1.8	22.4	6.9	10.4	3.3	5.2	1.7
17. Bio-Treatment with AWT	--		--		--		--		--		--		--		--		--		--		--		--	
18. Distillation	--		--		--		--		--		--		--		--		--		--		--		--	
19. Municipal Outfall Line	--		4.5	1.5	1.0	0.4	--		4.3	1.4	0.9	0.3	--		--		--		--		4.0	1.3	0.8	0.3
20. Cleaning Agents (Soft Water Area)	58.0	17.7	58.0	19.4	58.0	20.5	58.0	18.1	58.0	19.2	58.0	20.5	58.0	18.4	58.0	19.3	58.0	19.9	58.0	17.9	58.0	18.5	58.0	19.2
21. Water: Building, Internal	4.6	1.4	4.6	1.5	4.6	1.6	3.8	1.2	3.8	1.3	3.8	1.4	13.9	4.4	13.9	4.6	13.9	4.8	13.9	4.3	13.9	4.4	13.9	4.6
22. Water: Lawn Irrigation	8.8	2.5	10.6	3.6	10.6	3.8	8.8	2.7	10.6	3.5	10.6	3.7	3.7	1.2	7.0	2.3	7.0	2.4	5.1	1.6	8.5	2.7	8.5	2.8
23. Municipal Water Softening (R.O.)	--		--		--		--		--		--		--		--		--		--		--		--	
24. R. O. Concentrate Distribution System	--		--		--		--		--		--		--		--		--		--		--		--	
25. Storage Ponds	1.8	0.6	1.8	0.6	1.8	0.6	1.6	0.5	1.6	0.5	1.6	0.6	1.8	0.6	1.4	0.5	1.4	0.5	1.6	0.5	1.1	0.3	1.1	0.4
TOTAL: SOFT WATER AREA	328.2	100.0	298.8	100.0	283.0	100.0	320.4	100.0	302.8	100.0	283.6	100.0	314.4	100.0	300.4	100.0	291.8	100.0	324.0	100.0	313.5	100.0	302.0	100.0
ADDITIONAL FOR HARD WATER AREA	--		--		--		--		--		--		58.0		58.0		58.0		58.0		58.0		58.0	
TOTAL: HARD WATER AREA	328.2		298.8		283.0		320.4		302.8		283.6		372.4		358.4		349.8		382.0		371.5		360.0	

TABLE 21 CONCEPT COST COMPARISONS (Continued)

CONCEPT	C-3						C-4						D											
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	29.2	8.4	29.2	9.1	29.2	9.7	29.2	8.7	29.2	9.2	29.2	9.8	29.2	8.1	29.2	8.9	29.2	9.6						
2. Toilet	12.2	3.5	12.2	3.8	12.2	4.0	12.2	3.6	12.2	3.8	12.2	4.1	12.2	3.4	12.2	3.7	12.2	4.0						
3. Wash Water Toilet Flush Unit	6.7	1.9	6.7	2.1	6.7	2.2	6.7	2.0	6.7	2.1	6.7	2.2	-		-		-							
4. Clothes Washer	3.0	0.9	3.0	0.9	3.0	1.0	3.0	0.9	3.0	0.9	3.0	1.0	3.0	0.8	3.0	0.9	3.0	1.0						
5. Dishwasher	27.0	7.8	27.0	8.4	27.0	9.0	27.0	8.0	27.0	8.5	27.0	9.0	27.0	7.5	27.0	8.2	27.0	8.8						
6. Building Internal Piping	15.7	4.6	15.7	4.9	15.7	5.2	15.7	4.7	15.7	4.9	15.7	5.2	18.2	5.0	18.2	5.5	18.2	6.0						
7. Renovated Water Return Lines	1.8	0.5	1.5	0.5	2.0	0.7	1.8	0.5	1.5	0.5	2.0	0.7	-		-		-							
8. Vacuum Collection Sewer	-		-		-		-		-		-		-		-		-							
9. Black Water Sewer	29.4	8.5	35.9	11.2	36.6	12.2	29.4	8.7	35.9	11.3	36.6	12.2	29.4	8.1	35.9	10.9	36.6	12.0						
10. Gray Water Sewer	8.5	2.5	15.0	4.7	15.7	5.2	8.5	2.5	15.5	4.9	15.5	5.1	8.5	2.4	15.0	4.6	15.7	5.1						
11. Combined Sewage Sewer	-		-		-		-		-		-		-		-		-							
12. Refuse Collection	30.0	8.7	30.0	9.4	30.0	10.0	30.0	8.9	30.0	9.5	30.0	10.0	30.0	8.3	30.0	9.1	30.0	9.8						
13. Grease Trap	1.8	0.5	1.8	0.6	1.8	0.6	1.8	0.5	1.8	0.6	1.8	0.6	1.8	0.5	1.8	0.5	1.8	0.6						
14. Incinerator (Refuse and Sludge)	49.5	14.3	31.4	9.8	26.4	8.8	49.0	14.5	31.0	9.8	26.2	8.8	48.6	13.5	30.7	9.3	25.9	8.5						
15. Phys-Chem: For Gray Water	-		-		-		25.6	7.6	14.5	4.6	8.6	2.9	-		-		-							
16. Phys-Chem: For Black Water	22.4	6.5	10.4	3.2	5.2	1.7	22.4	6.7	10.4	3.3	5.2	1.7	22.4	6.2	10.4	3.2	5.2	1.7						
17. Bio-Treatment with AWT	-		-		-		-		-		-		-		-		-							
18. Distillation	34.0	9.8	18.5	5.8	10.4	3.4	-		-		-		-		-		-							
19. Municipal Outfall Line	-		4.0	1.2	0.8	0.3	-		4.0	1.3	0.8	0.3	-		5.1	1.6	1.3	0.4						
20. Cleaning Agents (Soft Water Area)	58.0	16.7	58.0	18.1	58.0	19.3	58.0	17.2	58.0	18.3	58.0	19.4	58.0	16.1	58.0	17.6	58.0	19.0						
21. Water: Building, Internal	9.5	2.7	9.5	3.0	9.5	3.1	9.5	2.8	9.5	3.0	9.5	3.2	13.9	3.8	13.9	4.2	13.9	4.5						
22. Water: Lawn Irrigation	5.9	1.7	9.3	2.9	9.3	3.1	5.7	1.7	9.9	3.1	9.9	3.3	0.5	0.1	0.5	0.2	0.5	0.2						
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-		53.6	14.8	33.7	10.3	22.5	7.4						
24. R. O. Concentrate Distribution System	-		-										3.0	0.8	2.5	0.8	2.5	0.8						
25. Storage Ponds	1.8	0.5	1.4	0.4	1.4	0.5	1.8	0.5	1.4	0.4	1.4	0.5	2.2	0.6	1.8	0.5	1.8	0.6						
TOTAL: SOFT WATER AREA	346.4	100.0	320.5	100.0	300.9	100.0	337.3	100.0	317.2	100.0	299.3	100.0												
ADDITIONAL FOR HARD WATER AREA	10.0		10.0		10.0		10.0		10.0		10.0													
TOTAL: HARD WATER AREA	356.4		330.5		310.9		347.3		327.2		309.3		361.5	100.0	328.9	100.0	305.3	100.0						

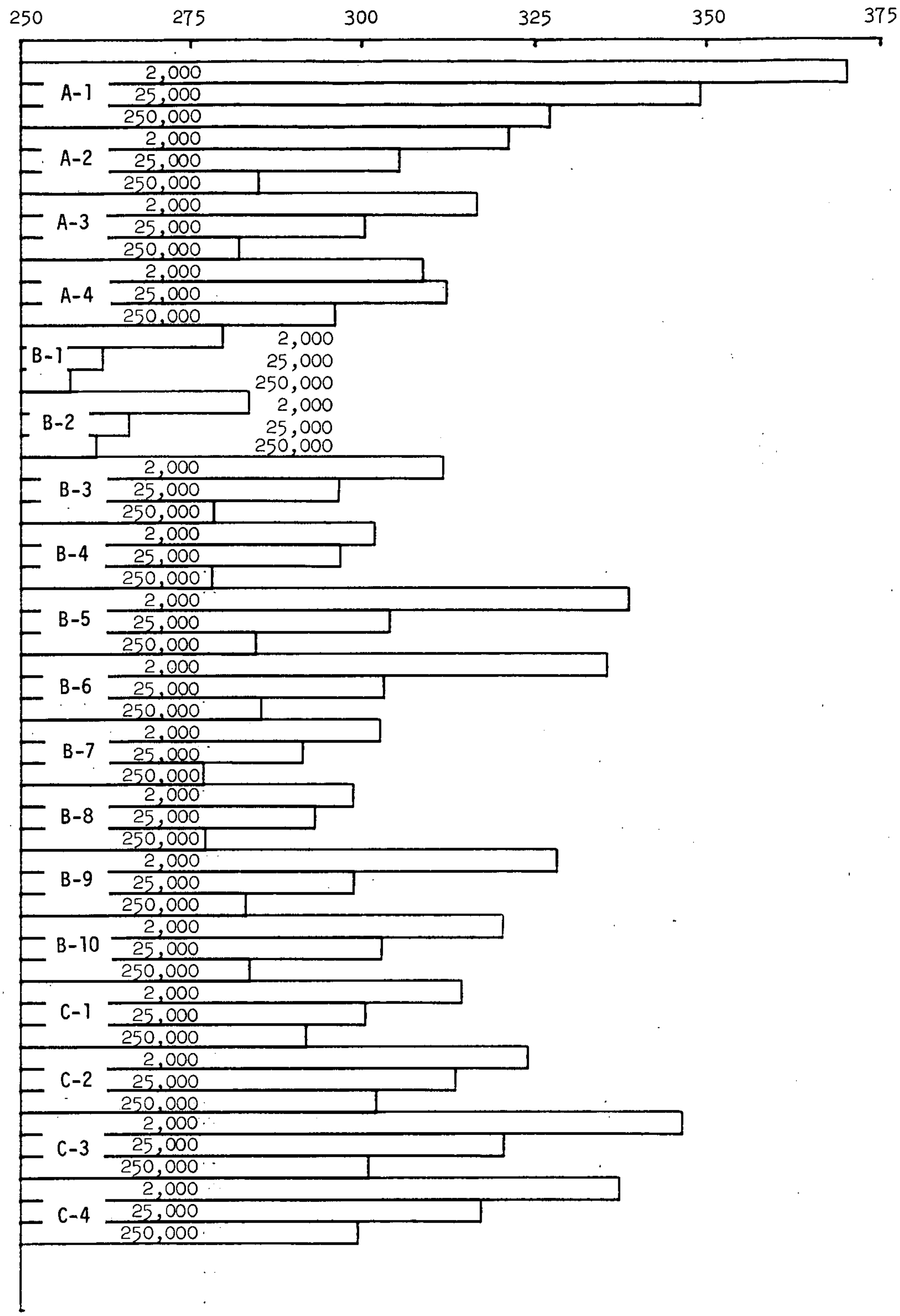


Figure 34 Total Cost ($/Family-Year), Soft Water Area

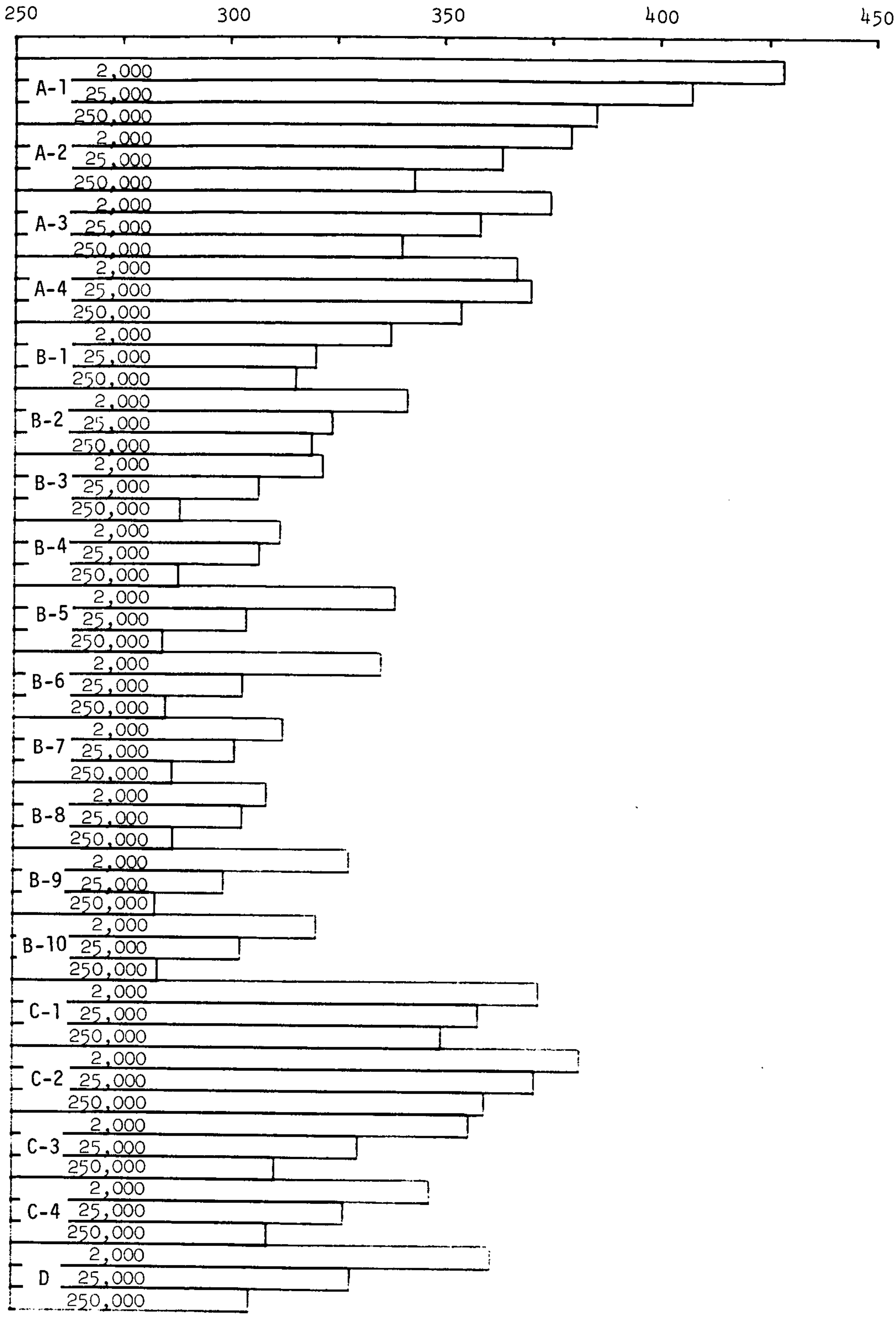


Figure 35 Total Cost ($/Family-Year) Hard Water Area

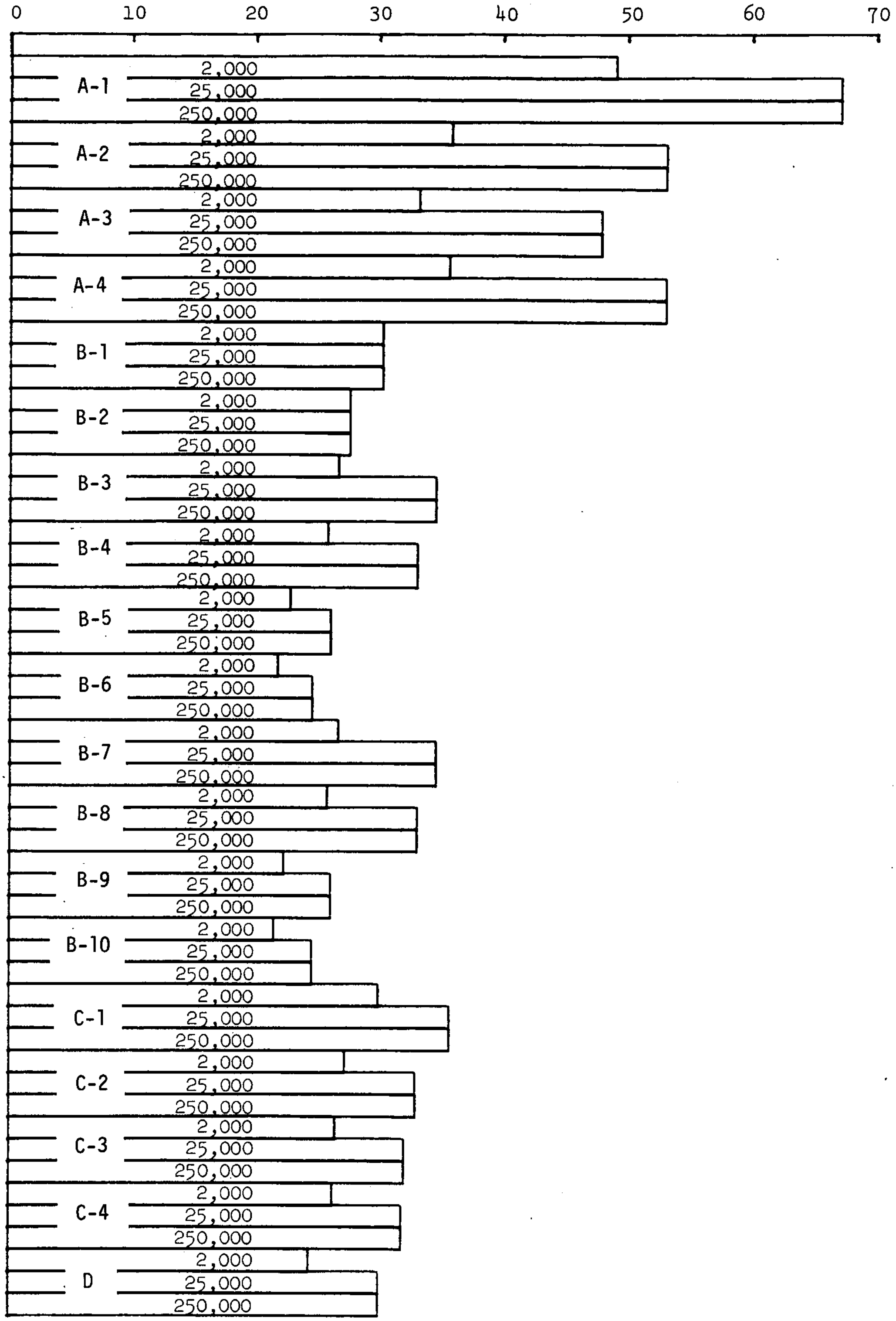


Figure 36 Water Consumption (GPCD)

VIII PRELIMINARY DESIGN

This section describes a preliminary design of the selected water recovery and solid waste processing system concept. It contains: an overall system description, a detailed description of each functional portion of the system and tabulations of the design and performance characteristics of major components and assemblies. A discussion of the manner in which the system might interface with other utility systems in the model apartment complex (power generation, heating and air conditioning) is also included.

As discussed in the previous section, the selected system concept contains the following:

- Water conservation: vacuum toilet, flow limiting devices, and front loading clothes washing machines.
- Direct reuse: dish and clothes rinse water reused for subsequent wash cycles.
- Waste water collection and transport: separate vacuum collection and transport of gray and black water - common vacuum source.
- Waste water processing:
  - Separate incineration of concentrated black water and refuse with heat recovery for power generation.
  - Subsurface gray water irrigation in growing seasons - treatment to potable quality for limited household reuse during the remainder of the year.

Water recovery requirements are minimized by reducing household use and by recycling only when there is no need for water of less than potable quality.

GENERAL DESCRIPTION

Figures 37 and 38 contain seasonal mass balances for the selected system. They are identical to Concept B-10 except that a greater quantity of water is used for toilet flushing. While the partial recirculating toilet used in Concept B-10 appears to be a practical means of reducing water use to an absolute minimum, its use with vacuum collection equipment has not been demonstrated. As a result, the more conservative flows recommended by the vacuum system manufacturer are used in the preliminary design.

Figure 39 illustrates the interrelationships between the major functional elements of the system. Black water is concentrated in vacuum toilets, transported directly to vacuum receivers located in the center of the community, and incinerated on a more or less continuous basis. Gray water is accumulated in each apartment building and periodically transported to separate central vacuum receivers. Each

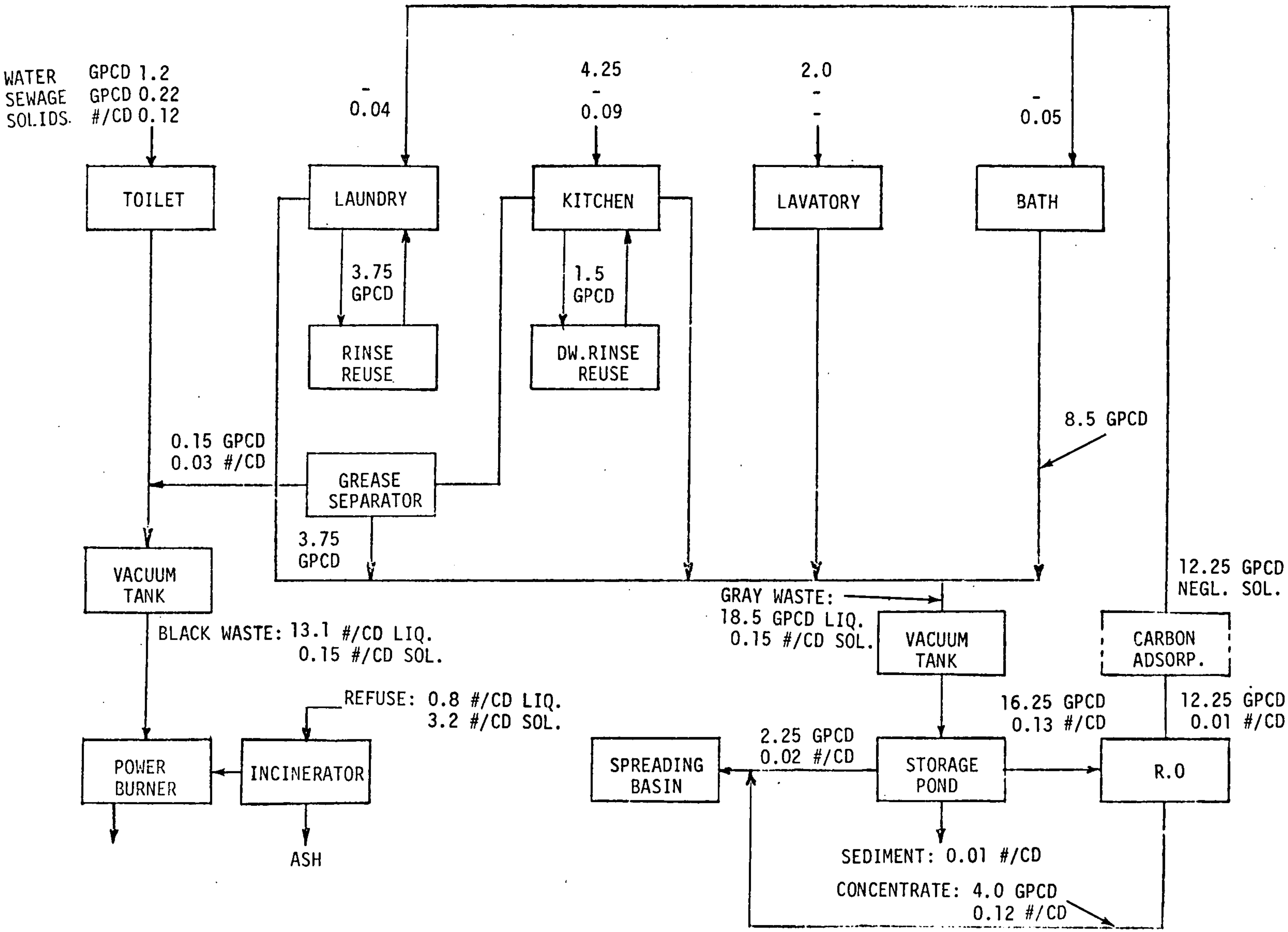


Figure 37 Preliminary Design Mass Balance Winter Operation

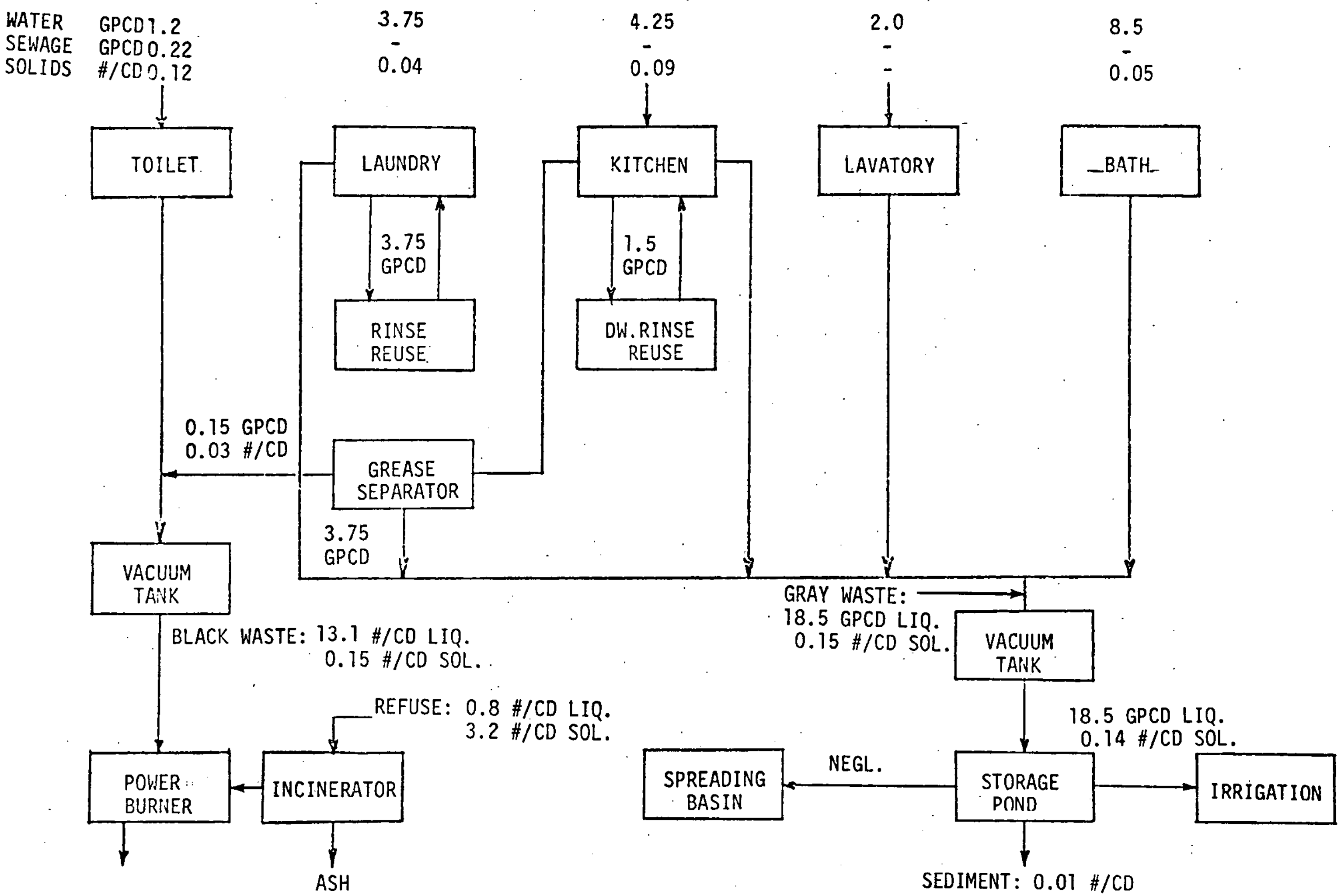


Figure 38 Preliminary Design Mass Balance Summer Operation

apartment is also equipped with a tube settler designed to separate solids and grease and periodically discharge them to black water vacuum lines. Gray water is then pumped to a small storage pond or tank. A spreading basin is also provided to accommodate periods when the gray water supply exceeds the demand.

During growing seasons, landscape irrigation requires a greater quantity of water than the community consumes. As a result, gray water is directed during these periods to a subsurface irrigation network. During periods when irrigation is not required, gray water is directed to reclamation equipment where it is treated to potable quality and reused for clothes washing and bathing. Reclamation is accomplished by a treatment process that features reverse osmosis membranes.

DETAILED DESCRIPTION

The following paragraphs describe the detailed system configuration illustrated in Figure 39. Descriptions are subdivided in accordance with the major functional groups of equipment.

Direct Household Reuse

Direct household reuse is limited to utilizing laundry and dishwashing machine rinse water for subsequent wash cycles. This results in a significant reduction in water demand (as high as 50%). Standard machines are modified by adding: a storage tank to hold the machine's rinse water, a diverter valve which directs rinse water to the tank, a pump which returns water to the machine on the next wash cycle, and provisions for overflow. The machine's controller is modified slightly to provide for operation of the additional pump and solenoid valve. The configurations for laundry and dishwash are illustrated in Figure 40.

Operation of the laundry machine for a cold wash is accomplished by using the stored rinse water only. The wash water is drained to gray water collection tanks. Rinse water is taken from the municipal water supply in the summer and from the reclaimed water supply in the winter. Hot washes are similar except that hot water for the wash cycle comes from the municipal hot water supply in the summer and from the reclaimed hot water supply in the winter. The mass balances in Figure 37 and 38 reflect a cold wash condition.

Dishwasher operation is similar except that heating of the reused rinse water is accomplished by the conventional heating coil in the dishwasher. Rinse water is taken from the municipal hot water supply.

The quality of rinse water from the clothes washer is considered high enough for the wash cycle. Should there be a problem of interfamily acceptance, a laundry machine can be provided for each apartment. Rinse water storage can be below both the laundry and dishwasher machines without increasing floor space. Due to the use of front loaders, access to the clothes and dishes is improved with this arrangement.

Apartment Building Collection

Black and gray waste waters are separately transported by vacuum collection equipment to separate, central processing and disposal sections of the system. A

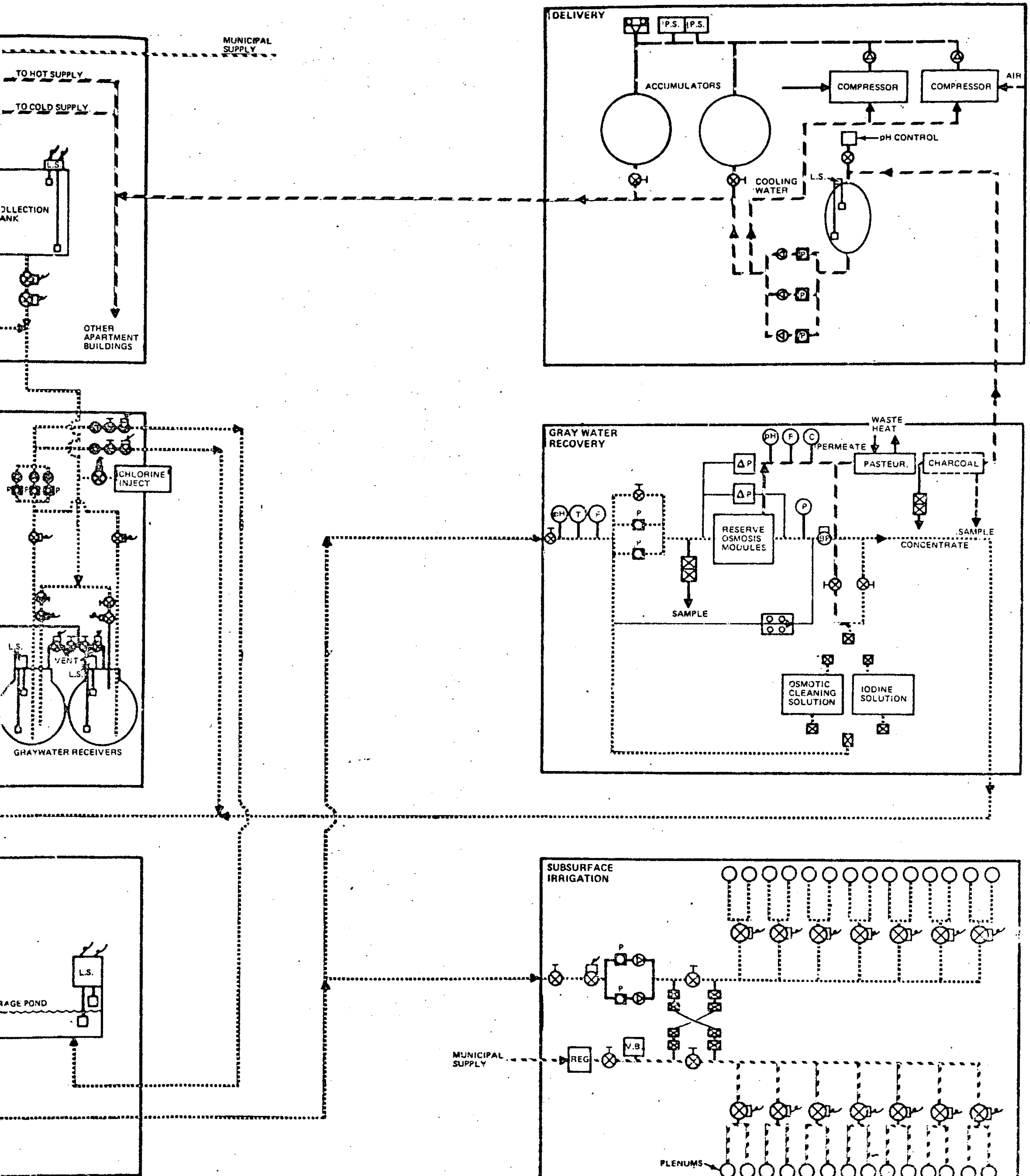
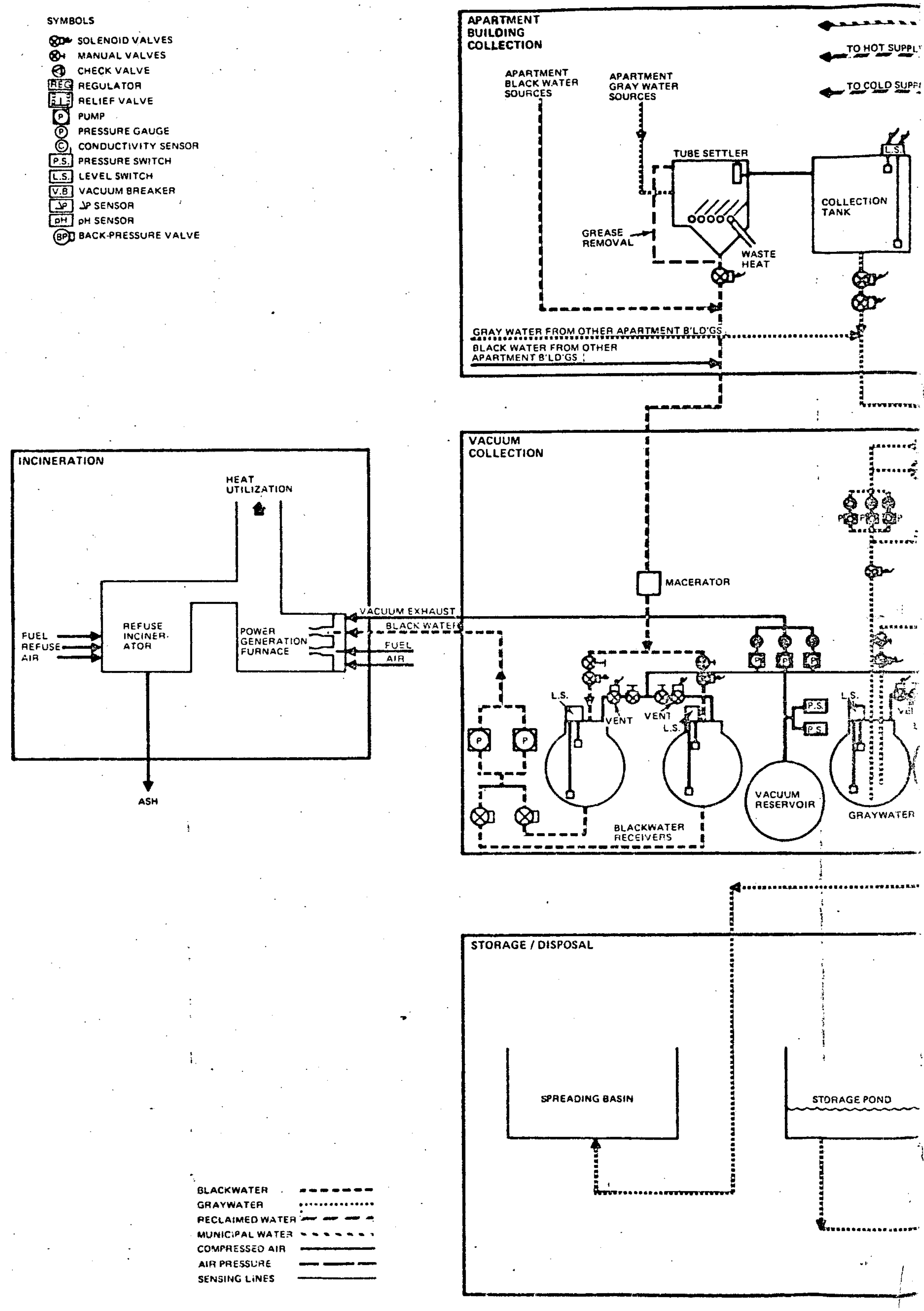


Figure 39 Water Recovery and Solid Waste Processing System Schematic

FOLDOUT FRAME



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FOLDOUT FRAME

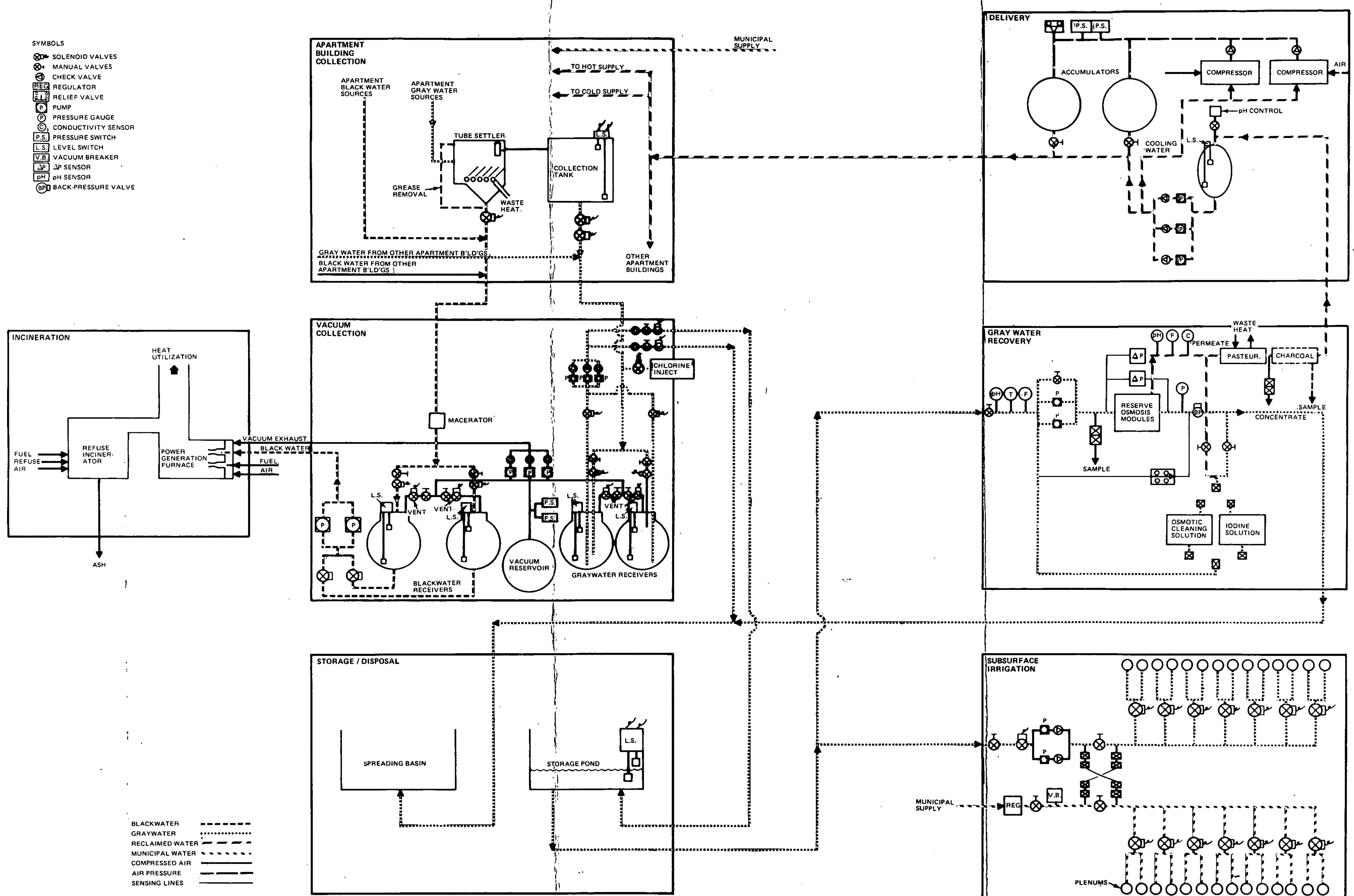


Figure 39 Water Recovery and Solid Waste Processing System Schematic

A

B

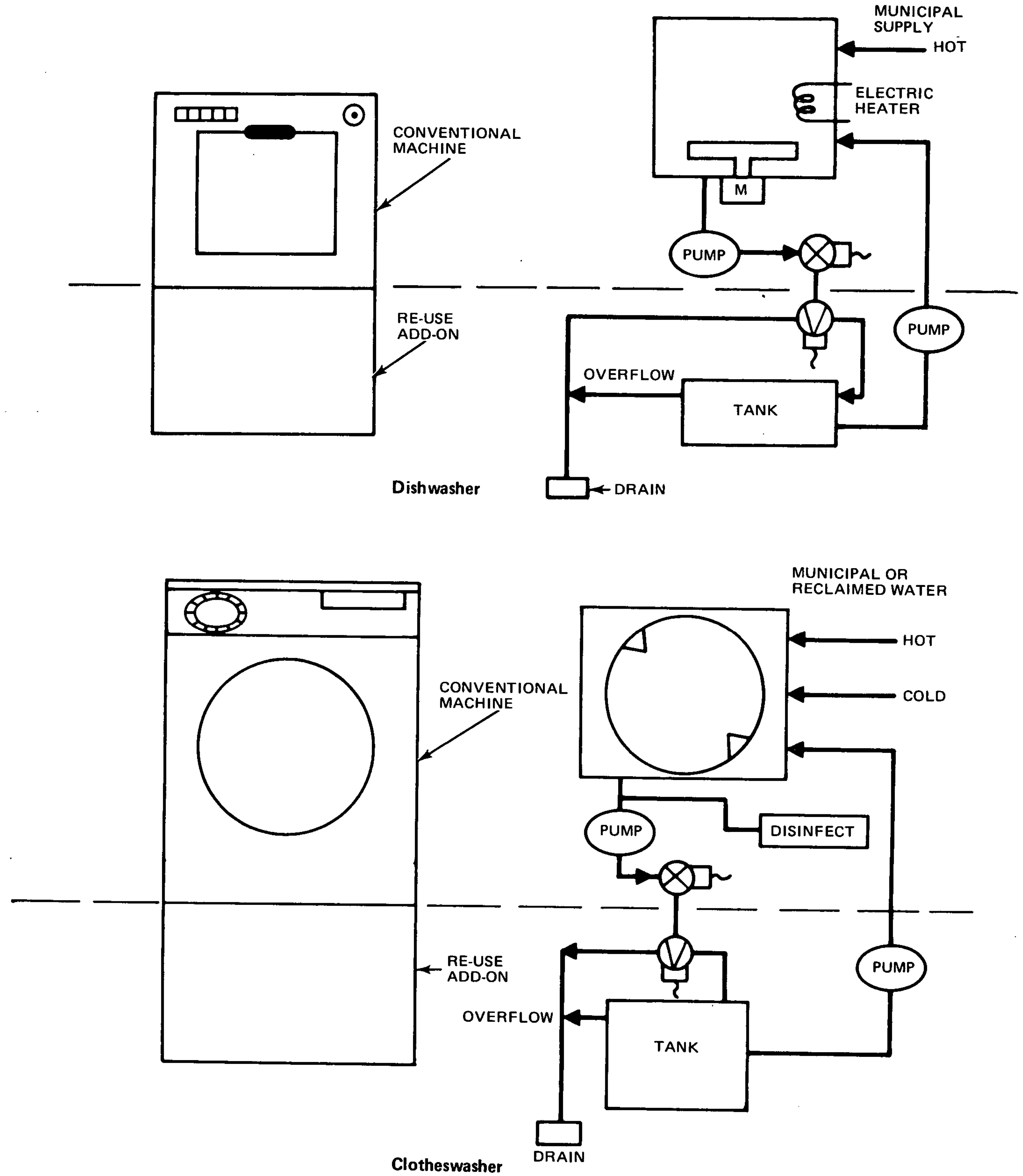
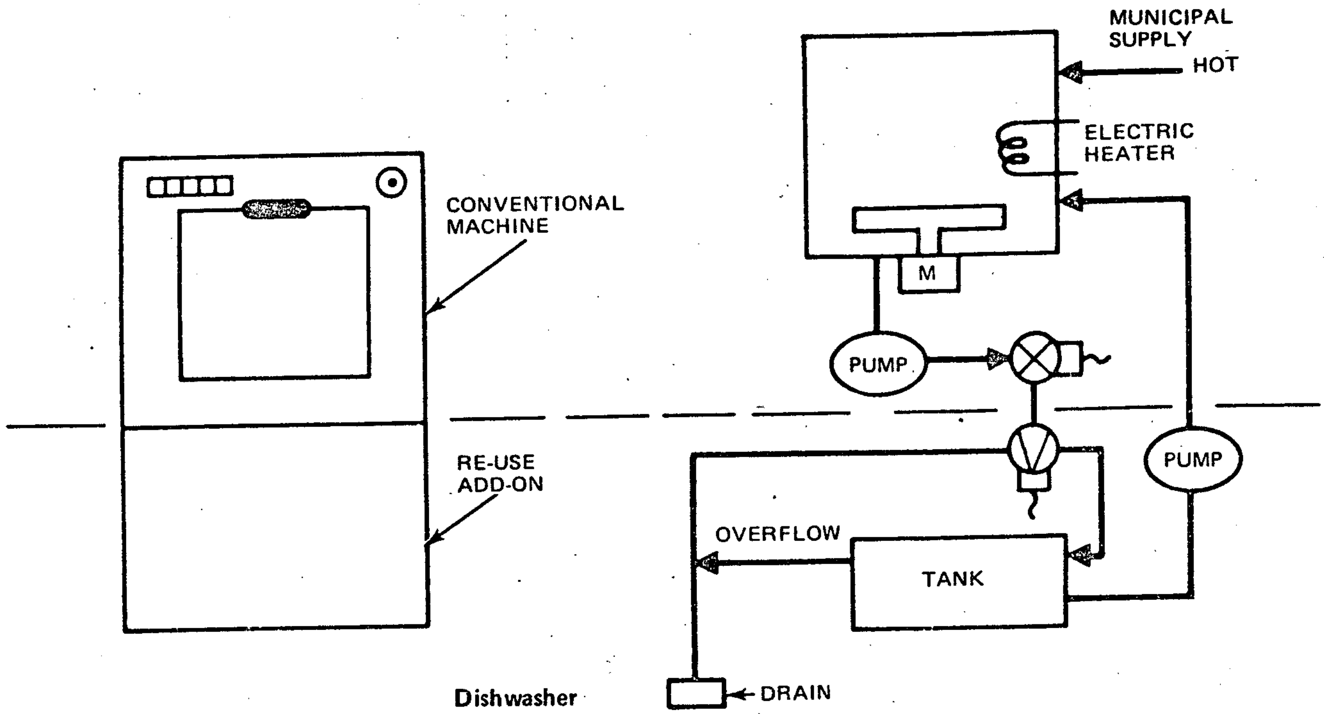


Figure 40 Rinse Re-use



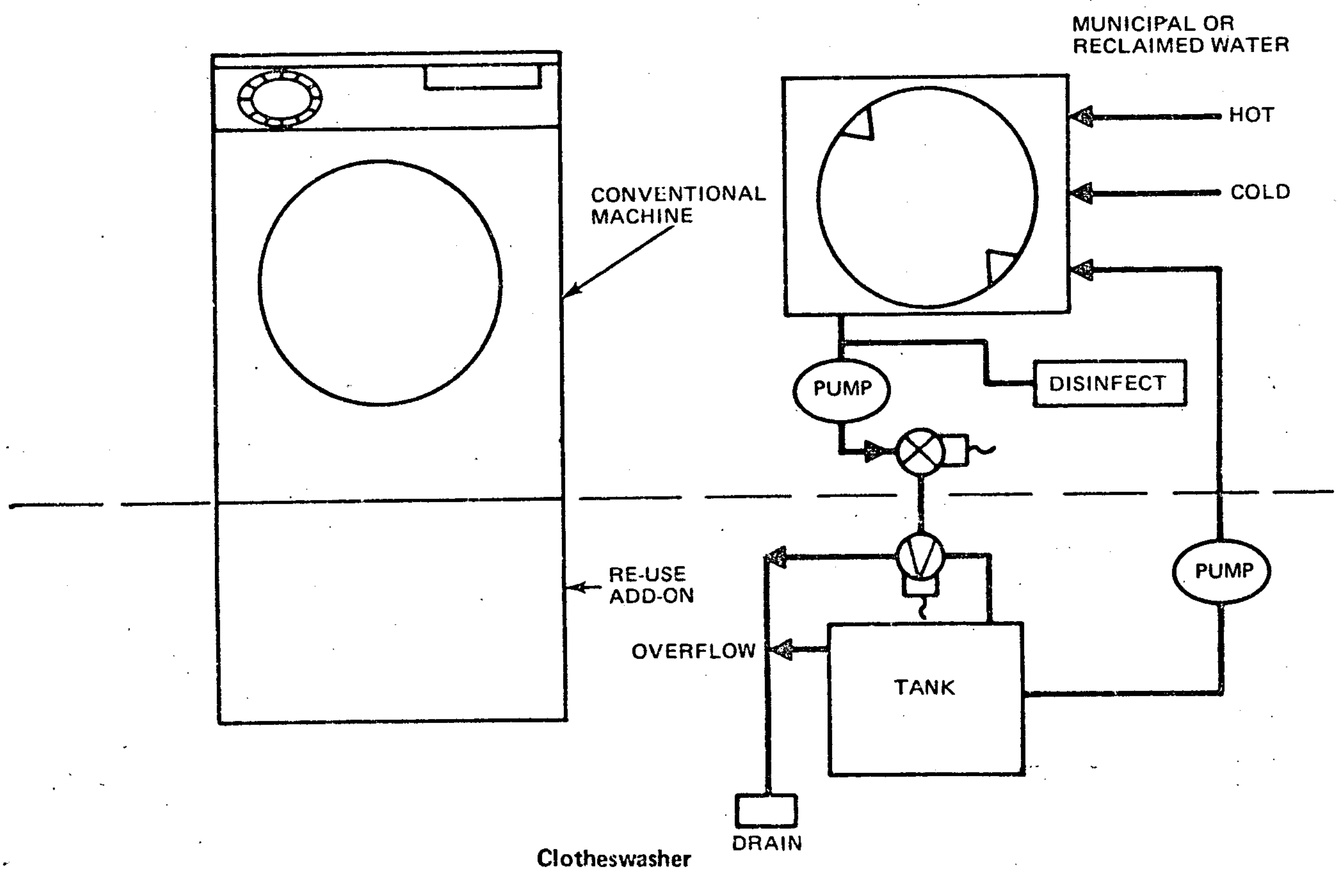


Figure 40 Rinse Re-use

common vacuum reservoir is employed to convey the waste water streams to their respective holding tanks.

Concentrated black water is produced by low water use vacuum toilets. Two are installed in each apartment unit. Described in detail on page III-6, the toilet has a vitreous china bowl with a 1-9/16 inch inside diameter exit, a discharge valve separating vacuum piping from the bowl contents, and a flushing mechanism. A push button initiates a flush cycle, which opens the discharge valve and permits three and one-half cubic feet of atmospheric air to flush the contents of the bowl. This volume is converted to seven cubic feet at one-half atmosphere as it transports the waste material. This assures solids transport without clogging. The waste liquid and solids are transported through a line which contains pockets to facilitate vacuum transport, directly to a central receiving tank. A fine spray of water washes the bowl during the cycle and 0.2 gallons remain in the bowl at the end of the cycle. The total flush cycle is seven seconds long and consumes one-third of a gallon of water. A vacuum breaker prevents back siphonage.

Gray water from the building plumbing is first gravity collected at each apartment building in a receiver consisting of a tube settler and collection tank. Grease will tend to accumulate on the surface of the primary separation stage of the tube settler. Food scraps and settleable solids from the kitchen, laundry and bath will collect at the bottom of the settling tank. The use of tubes will increase the solid settling efficiency, but greases can be expected to cling to the upper tube surfaces as well as form a film at the upper water level. Once a week, during a period of low building heat demand, the tank is heated to 160^{o} by waste heat from the central heating system. After a time delay, a top layer of liquid water and grease is vacuum collected to the black water collection system. Solid sediment and grease are vacuum collected simultaneously. Weekday periods of low building heat demand are likely to be periods of low black water production. An increase in vacuum pumping capacity is thereby not required to collect gray water solids and grease.

The settled gray water is stored in the collection tank, which contains level controls as part of the integrated vacuum collection control.

Gray water collection is accomplished by automatically scanning each apartment house every twenty minutes for waste water quantity. If the level is lower than the selected control level, it is by-passed to the next apartment building. If the level is at or above the selected level, a valve is actuated and the central vacuum collects the water. A high level will override the normal selection process and cause the vacuum collection to occur out of rotation.

Central Vacuum Collection

As shown in Figure 39 separate pairs of black and gray water receivers are serviced by a single vacuum reservoir. A central vacuum controller is provided to schedule gray water collection from apartment houses, provide adequate reserve vacuum, and assure that central black and gray water reveicer tanks are pumped out in response to household effluent rates. The vacuum reservoir tank is sized to permit black and gray waste collection tanks to receive maximum flow rates for three minutes without outflow pumps operating. The 855 cubic foot tank normally operates in the range of 13 to 18 inches of mercury absolute. The selected tank is carbon steel, 10 foot diameter by 12 feet long, with dished heads. An internal and external epoxy tar coating is compatible with the operating conditions and provides good corrosion protection. Three water sealed vacuum pumps are provided, two of which will supply the maximum required flow. Normally each pump will alternately be selected for operation. Under average demand a pump will operate three minutes followed by approximately three minutes off. At 13 inches of mercury absolute, all pumps go off. At 18 inches, one pump goes on and at 20 inches, two pumps go on and remain on until 13 inches is reached. Water make-up for the water seal pumps comes from the gray water storage tank. The colloidal material remaining in the wash water is not expected to create a problem. Check valves are provided to prevent atmospheric leakback.

The black water tanks receive black water from all apartment houses in the community. Two tanks are each sized to hold the maximum anticipated waste supply rate while providing a steady flow rate to the incinerator. The maximum rate is expected to occur between 6 and 8 A.M. on weekdays. While one tank is receiving waste, the other is being pumped out to the incinerator. When the tank is empty, the low level control shuts off the pump. When a tank is full the high level control initiates flow to the other tank and pumps out the full tank. This occurs even if the second tank is not empty. Vacuum is relieved, prior to pump out, through a three way valve in each supply line, while the vacuum source is isolated by another solenoid valve. The minimum time required to fill one tank is 50 minutes.

The collected black water is transferred by redundant progressing cavity positive displacement pumps. Rated pump flow is approximately 50 percent higher than the average flow rate. As a result, the tank accepts peak flow and allows for essentially steady flow to the incinerator. The pump is shut off momentarily by the low level sensor for switch over. The redundant pump is alternately selected. Failure of one pump to operate will result in an alarm at the central station, while a redundant pump is operating. Teflon or mechanical packing is used with water cooling to minimize maintenance.

A waste macerator is installed in the line upstream of the tanks to reduce debris to approximately 0.25 inch diameter particles. The largest dimension that can pass through the toilet is approximately two inches in diameter. They may vary from soft objects such as rags to flexible and hard objects such as toys. A disk made by casting abrasives in plastic, grinds the material until it is small enough to fit through holes in the disk. The macerator permits the use of smaller, less expensive transfer pumps.

Two central gray water collection tanks receive gray water from all the apartment houses in the community. It is received by vacuum collection equipment which uses a vacuum reservoir and a central automatic controller to alternately select each apartment house's collected water. The tanks have each been sized to receive the maximum community demand that can be expected in three minutes. An epoxy tar coating protects the tank from interior or exterior corrosion.

Each tank contains level controls, which provide signals for the central controller to switch from a full tank to the second tank, so as to maintain uninterrupted collection. The full tank's vacuum is relieved to facilitate pumping via a three way valve in each supply line, while the vacuum source is isolated by another solenoid valve. A low level control provides a signal for shutting off the pumps.

The collected gray water is pumped to a storage pond for use in irrigation or reclamation. The water is pumped to a spreading basin if the pond is full. Three pumps are provided with two sized to handle the maximum required flow. Normally one pump will be turned on by a signal initiated by the high level control via the control system. If the second tank is filled and switched over before the pump-out operation is complete, two pumps will pump out the full tank. The third pump will be alternately selected to share operating time. Failure of one pump to operate will result in an alarm at the central station, while redundant pump(s) operate. Check valves are included with each pump to prevent back flow.

Chlorine is injected into the tank supply line each time another tank is selected to be filled. The quantity injected will be sufficient to destroy all bacteria while exposed to the worst expected organic load. The pH in the tank is normally between 6 and 8 even with the presence of laundry water. This coupled with a minimum residence time in the tank will insure that no pathagenic organisms are introduced into the storage pond.

The vacuum collection plumbing will be in accordance with the recommendations of the developing manufacturer and National Plumbing Codes. Ten feet of water is allowed for line pressure and elevation losses and seven feet for toilet and valving. As a result of the high air flow in the black water lines, the average pipe size is five inches in diameter. Shallow trap pockets are installed at intervals equal to 1500 times the pipe diameter, to provide liquid plugs for effective vacuum transport. The gray water lines average four inches in diameter which allows for high purge flows during low demand periods. Extra heavy cast iron soil pipe or PVC piping may be used depending on the overall cost at the site location. Cleanout plugs are provided at each change in pipe direction. Piping installation costs are minimized by following the National Plumbing Code recommendation of burying waste drainage lines twelve inches below potable water lines. Excavation costs for the drainage pipes may then be considered to be the difference between excavating the two required depths.

Gray Water Storage and Disposal

In order to accommodate variations in gray water production and demand, an accumulator in the form of a small open pond or closed tank of equivalent volume is required. As a result of economical considerations an open pond, excavated during community construction, is preferred. Chlorination prior to pond entry insures contact quality from a bacterial standpoint. If necessary, small quantities of blue-green dye could be added to offset any objectionable cloudy appearance. Properly landscaped, the pond should enhance the appearance of the community. A small "spreading basin" is also necessary to dispose of the small quantities of excess gray water produced during winter months. In most site locations a much larger basin is required to handle stormwater run off from the community grounds. Where this is the case, the stormwater basin would also handle excess graywater.

The pond is sized to hold three days of average gray water flow. This permits variations in gray water production without unnecessary overflow to the spreading basin. Figure 41 can be used to calculate pond areas resulting from various inflows, depths and days of storage. In areas having clay and other impervious materials, no bottom preparation is required. In other areas a clay spray or asphalt can be applied to the bottom. In the event that excessive sediment buildup should occur, the bottom can be "vacuum cleaned" every few years when the pond level is low.

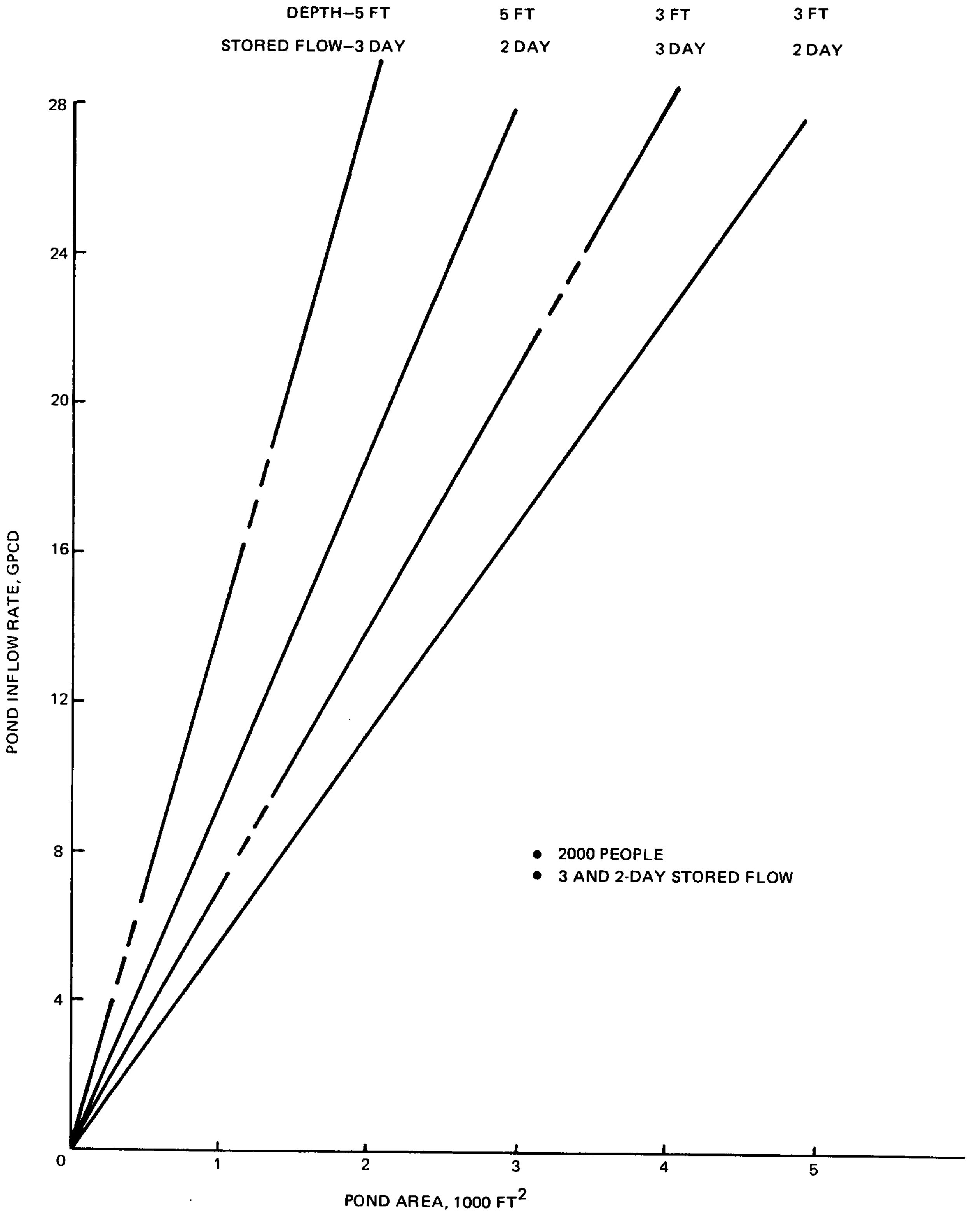


Figure 41 Storage Pond Inflow vs Area

Level sensing is incorporated to provide for control when the level is high or low. A low level sensor causes cut-out of the irrigation pump or the reclamation equipment. When the level is too high, wash water supply is diverted to the spreading basin. The spreading basin should never go septic even if a batch of water does not drain readily. This is because the influent is disinfected and the shallowness of the basin permits natural oxygenation as in a sewage effluent lagoon. With reasonable infiltration rates, the basin will be periodically dry and the sediment will be aerobically digested. The operation of the many recharge basins on Long Island, New York demonstrate that septicity will not be a problem.

The storage pond water is delivered to subsurface irrigation equipment by pumps, plastic tubing and solenoid valves, all of which are controlled by the central control unit. It is delivered to the reclamation unit by redundant pumps sized to flow the average gray water supply over a 24 hour period. A storage pond low level will result in a signal to shut off the pump. Shutoff or failure of one pump automatically results in selection of the second pump upon additional demand.

The spreading basin is considered to be similar to those commonly used for storm drainage. Its size is based on the assumption that it will be used only to percolate excess water not reused for irrigation or reclaimed for household reuse. The requirement for storage pond over flow provisions is dictated by the groundrule that only municipal water is used for kitchen functions. The use of recycled water in dish washers would balance gray water production and recycled water demand. While this would eliminate gray water over flow, a basin is nevertheless required to accommodate stormwater runoff.

An alternate to the pond, that would eliminate the need for tube settlers in each apartment building, is a clarifier of equal area and depth. Illustrated in Figure 42 the clarifier would be lined with concrete. As shown, it could be of the upflow type equipped with a coagulator, sediment recirculator, rotating scraper and a sediment thickener.

This approach would result in much higher suspended solids and grease levels in the centrally located pond and would increase the solids loading on the gray water vacuum collection equipment. On the other hand it would provide a greater solids removal capability which would prolong the life of reclamation and irrigation equipment.

Subsurface Irrigation

All gray water is used to irrigate the community's twenty-five acres of lawn during the growing season. An average irrigation period of 6 months has been assumed with a required weekly application rate of 3/4 of an inch. This value is approximately twice as high as the average gray water effluent from the apartment complex. Considering that tests have shown that most soils and vegetation have an avarage capacity for 2 inches per week, there is sufficient margin for normal rain and fluctuations in gray water production.

Subsurface irrigation equipment design is strongly influenced by soil and landscape conditions, soil microbiology, type of vegetation, and waste composition and

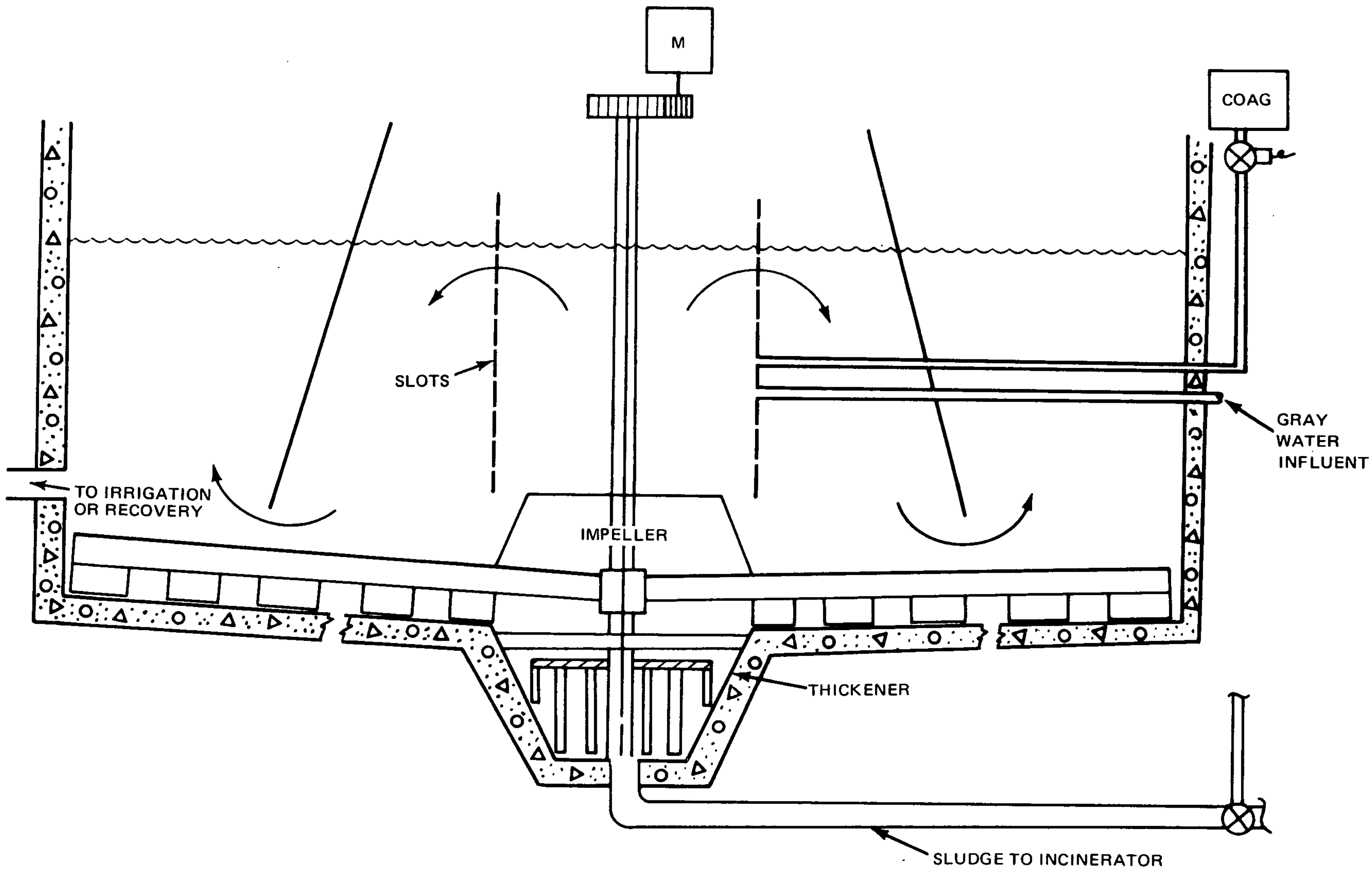


Figure 42 Gray-Water Clarifier Pond

flow rate. Trickle and Moisture Barrier approaches are the basic alternatives. Both are relatively recent developments although a significant number of installations have been and are being evaluated. Their effectiveness in improving crops has already been proven. Additional data is, however, required on life and operational characteristics.

Trickle irrigation is accomplished by supplying water to subsurface perforated plastic tubing. Efficient plant water utilization is achieved by using very low feed rates to permit water to move horizontally by capillary action and uniformly maintain moist roots. For lawn irrigation, tubes are typically one half inch in diameter, and are buried about six inches deep and thirty inches apart. Perforations are nominally 0.02 inches in diameter. A variety of tubing configurations have been developed in an attempt to minimize clogging. Some employ nozzle inserts while others use double walls. The tubing is buried by either a vibrating machine which pulls it through the ground or a power chisel which lays it into a narrow trench. A 150 mesh wire back flushable filter is normally employed to prevent clogging.

As shown in Figures 43 and 44 the Moisture Barrier consists of a 1/8 inch layer of asphalt sprayed as deep as 30 inches, while a tractor mounted wedge lifts the soil. Water is fed by flooding methods and ultimately gets to plant roots by capillary action. Recommended barrier depths are 18 inches for coarse sand and 30 inches for fine sand. Clay soils form a natural barrier. The barrier is formed by laying 32 inch wide, overlapping channel shaped asphalt troughs. A crawler tractor can lay an effective width of 24" at the rate of three miles per hour on farm land. 1000 gallons of asphalt are expended per acre. This results in 90% water retention in a properly designed system. The 10% leakage will permit purging of salts, which are likely to be in waste water. Strategically located penetrations are provided to accommodate storm water.

Waste water feed methods will depend on landscaping and soil composition. Main feeder lines can deliver water to irrigation zones. Distribution within zones can be accomplished by a simple plenum for course sands, either central or at the top of a slope. Fine sand requires the use of distribution devices with large holes such as drain tiles or pre-cast concrete channels. Tight clay soils require a more intricate distribution system. This approach is not very sensitive to waste water composition, especially when settleable and some precipitated solids have already been removed. As a result, it has been selected for the preliminary design configuration.

As mentioned previously, the average flow available is normally about half of that required by the lawn acreage in the model community. Therefore, when there is no rain, half the community will be irrigated by gray water and half will be irrigated by municipal water. As shown in Figure 39, this is accomplished by establishing approximately fourteen irrigation zones and alternating gray and municipal water to each zone on a daily basis. Each zone has at least two branches for feeding irrigation plenums. A controller selects the zones as is done presently in automated sprinkler systems. Redundant irrigation pumps are used to maintain gray water pressure. Figure 45 can be used to determine the depth and pump rate for various irrigation rates for the 25 acres.

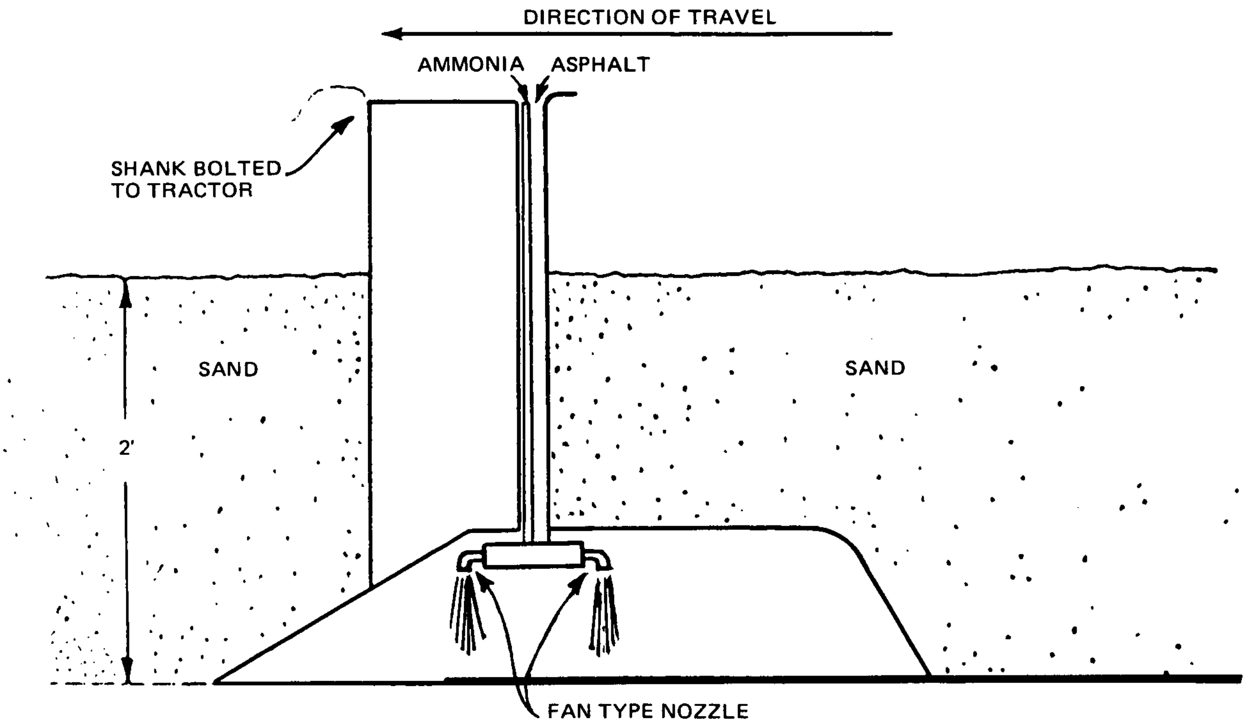


Figure 43 Asphalt Moisture Barrier Applicator

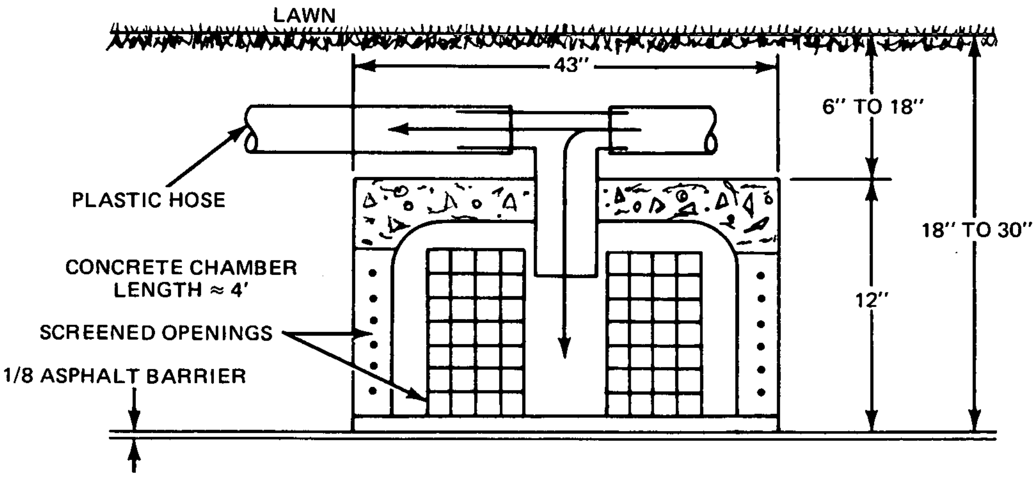


Figure 44 Typical Subsurface Irrigation Plenum

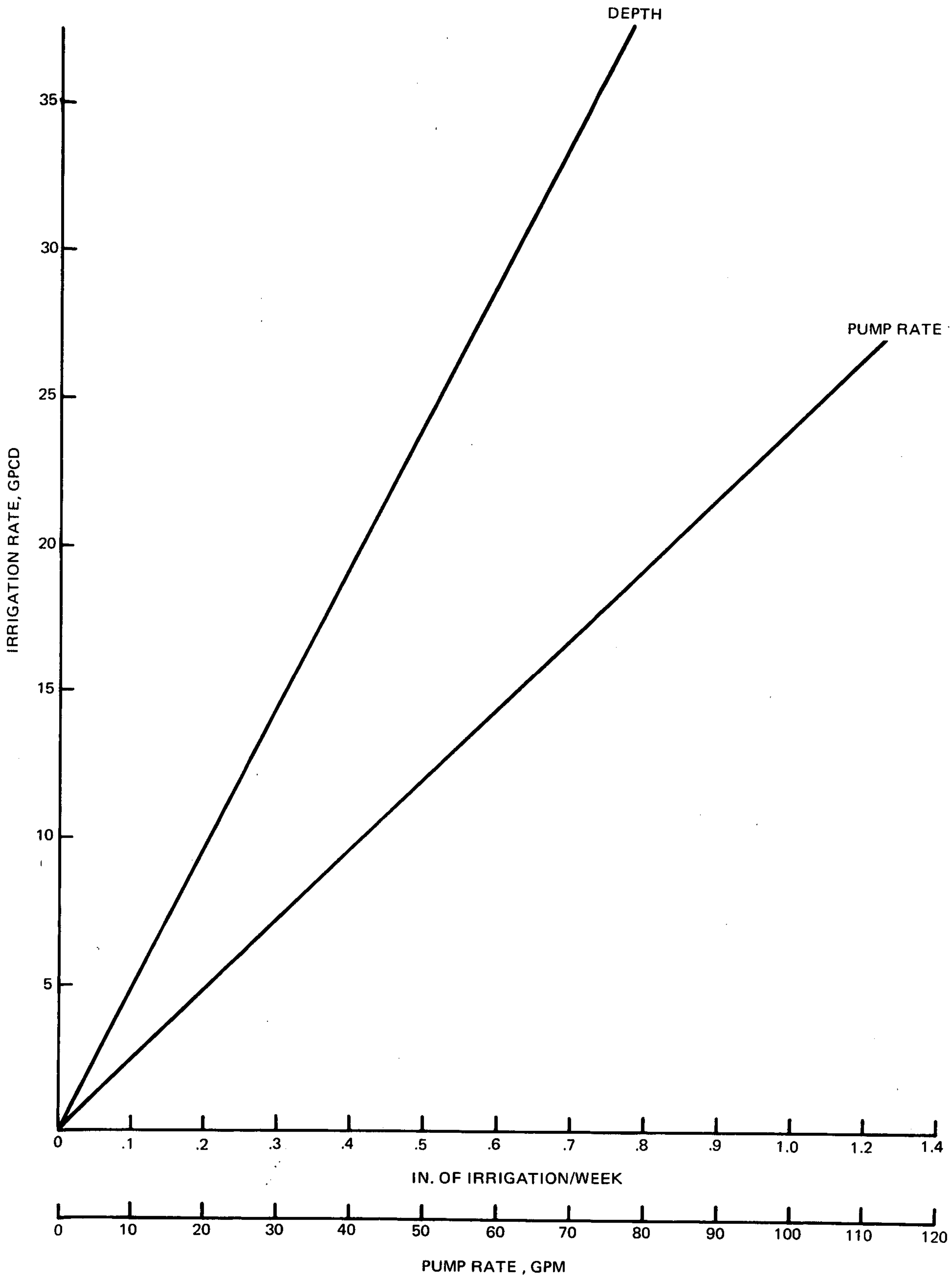


Figure 45 Irrigation and Pump Rates for 25 Acres of Vegetation

Gray Water Recovery

A gray water treatment process, featuring reverse osmosis membranes, reclaims water for limited household reuse during the approximately six months yearly that irrigation is not required. A tubular design concept was selected with the membrane "drop-casted" in a resin-bonded sand core. A cross section of the membrane configuration is shown in Figure 46. This design minimizes clogging problems by providing for good surface velocity distribution and a unique back-flush capability. The tube ends are chemically sealed to prevent leakage. Six inch by six foot modules containing thirty six half inch tubes are arranged in a parallel/series tapered flow arrangement, which attempts to approach a constant surface velocity. The membrane modules are installed horizontally in racks two deep to facilitate access.

Pre-treatment has not been included at this point due to the chosen membrane configuration. The manufacturer (Westinghouse) has used these modules with gray water of similar quality. In addition, the modules will only be operated approximately six months a year which will double the membrane replacement interval.

Normal operation includes a four minute shut off cycle every four hours. During this period normal osmosis occurs, with the water in the sand portion of module penetrating the membrane, so as to loosen material from the wash water side. This can then be flushed out with the concentrated wash water flowing through the inside of the tubes. The unit operates in this fashion 24 hours a day so as to limit its size.

Approximately once per month the membranes are rejuvenated by flushing the unit with an "Osmotic" cleaning solution (proprietary to Westinghouse). This is done with the unit off line. The solution is circulated through the entire unit for 30 minutes. The reverse osmosis pump can be used up to its operating pressure and recirculated. The solution contains a chemical compound which will penetrate the membrane. The pump is turned off for 10 minutes and the solution back-flushes the membrane. The unit is then flushed with wash water for twenty minutes. The overall result is that both the membrane and inside of the tubes are cleaned. The membrane construction will also permit 50 psi back-flushing if required.

The membrane life decay will show itself in the form of decreasing flux (GPM per square foot of membrane surface). In operation, the flux is maintained constant by increasing the back-pressure from the 325 psi initial pressure to 450 psi final pressure. Differential pressure sensors provide a means of checking for failures across the membranes and proper flow through the membranes. Membrane modules can be replaced such that the module housing can be reused.

In order to prevent micro-organism build-up in the membranes, a solution with 5 PPM titratable Iodine is periodically flushed through the unit for 15 minutes. The residual Iodine can be flushed to the spreading basin or permitted to flow with the reclaimed water. The entire operation can easily be automated. Membranes are presently being developed which will be able to withstand temperatures in the pasteurization range. This would permit pasteurization upstream of the membranes and thereby eliminate periodic Iodine treatment.

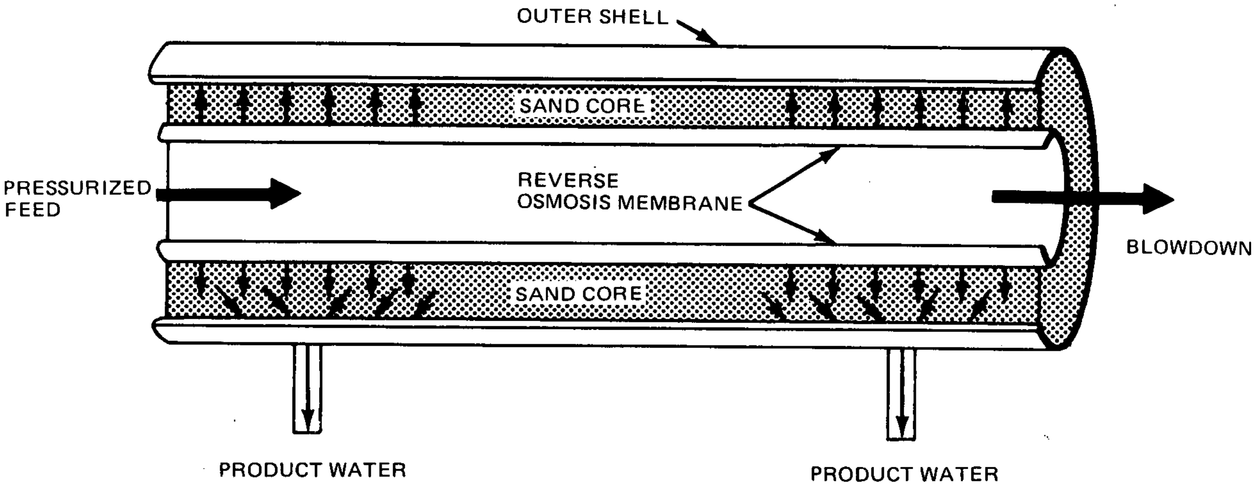


Figure 46 Membrane Module Configuration

A limited amount of instrumentation is required to monitor the unit's performance. Of greatest significance is the pumping pressure and permeate flow. Chemical quality monitoring can be similar to that of municipal drinking water systems, where one or more samples a week are examined for turbidity, color, odor and taste. More comprehensive analyses are made less frequently. Conductivity and ΔP measurements are made to detect malfunctions. pH is also monitored and adjusted as required, prior to reuse. The reverse osmosis equipment should be capable of producing chemically potable water. In the event that actual washwaters have undesirable COD components that are small enough to penetrate the membranes, carbon adsorption beds can be installed downstream of the pasteurization equipment. This location would prevent bacteria growth in the bed and generally improve performance. Based on results obtained by processing concentrated laundry water through a nylon membrane, approximately 120 pounds of carbon a day would be required to remove 20 pounds of COD per million pounds of water. If carbon can be regenerated locally, the regeneration cost would be approximately $0.09 per pound or $7.50 per family year.

Reclaimed Water Delivery

As shown in Figure 39 reclaimed water is stored and pressurized for reuse by pumps, accumulators and compressors. The pump delivers reclaimed water at the average rate that it is produced. A receiver accommodates differences in process and pump flow rates. A heating coil is located upstream of the receiver. It utilizes power generation system waste heat for pasteurization. The reclaimed water will normally be free of pathogenic micro-organisms. However any organisms that may enter the system due to maintenance or malfunction will be destroyed after thirty seconds at the 160°F temperature level. Downstream plumbing will receive initial chemical sterilization in the same manner as existing water supply systems.

Compressor cooling water is provided by the reclaimed water delivery pump and is discharged into the accumulator with the compressed air.

The pump sizing results in an operating cycle of two minutes on and three to four minutes off. Water is delivered to an accumulator against a back pressure from which it is piped to apartment buildings. Any abnormally high demand is satisfied by municipal water.

The hydro-pneumatic tank is used to avoid the need for an elevated tank. It is sized to hold two thirds water and one third air. The air quantity is determined by the combined action of a level sensor and pressure switch. The level sensor limits operation of the air compressors unless the water level is at the two third point or the pressure is less than 50 psig. As the pressure becomes higher than 50 psig, the compressor will cut out unless the water level is high enough. Normally, one compressor will go on at 60 psig and go off at 75 psig. During high demand two compressors will go on at 50 psig and cut out at 75 psig. Inlet silencers are included to lower the noise to acceptable levels.

The supply lines to the apartment buildings are sized such that the pressure available at the apartment house will be a minimum of 30 psi under maximum flow conditions. They will be insulated in the same manner as the central heating supply lines, to conserve the pasteurization heat. However, the cold water line will be tapped off in the street and uninsulated so as to lose heat to the ground.

Estimated Quality of Recovered Water

The quality of recovered water at various stages of processing is estimated in Table 22. Initial gray water quality was established by combining the kitchen, lavatory, bath and laundry water borne waste generation data contained in Table 6 and applying it to the average flow rate of 18.5 gallons per capita day. Some precipitation and settling will occur in the gray water collection equipment located in each apartment building. This is estimated to result in the storage pond water quality tabulated. The water quality subsequent to reverse osmosis treatment is based on estimates made by the membrane manufacturer which, in turn are based on tests with gray water inputs of similar makeup. Once pasteurized, the reverse osmosis permeate is expected to be potable. As discussed previously, in the event that particular constituents in the permeate are found to be objectionable, carbon post treatment can be incorporated. Table 22 also contains an estimate of water quality subsequent to such treatment. It is better than most existing municipal supplies.

Blackwater Burner and Refuse Incinerator

Blackwater burning and refuse incineration equipment design is heavily influenced by the power generation and energy management systems that presumably service the community or town. Only a cursory investigation of these systems was made for the purpose of understanding potential thermal interfaces (see Appendix B). As a result, the equipment described must be considered representative of what would be expected in a total utilities installation.

Blackwater Burner

Black water is disposed of by incineration in a commercial burner that is capable of firing any combination of oil and gas. This burner is used to generate the heat required for power generation. The black water is injected into the combustion zone through the fuel oil nozzle. If oil were to be the specified fuel, some modification of the burner system would be required.

The burner is rated primarily by the thermal requirements of power generation. Only a moderate increase in capacity is required for the black water at the design flow of 3 GPM. The output of the burner is variable to 20% of its maximum, capable of satisfying minimum power demands. The heat of combustion of the black water organics and the sensible heat of the water vapor are utilized in the power cycle. The latent heat of vaporization of the water as well as the water itself are presumably recovered in the scrubber.

Incinerator

The packaged incinerator for on-site combustion of refuse is located adjacent to the power generation furnace. The fuel gas is directed into the furnace where its heat content offsets some of the fuel requirement for power generation. It has a semi-automatic loader which can charge refuse during the burning operation.

The incinerator is of the starved combustion type, having an overfire burner and temperature controlled underfire and overfire air supplies. The combustion chamber temperature is regulated by the air supplies and the overfire burner at 1400-1500°F. An afterburner ensures complete combustion of volatiles and smoke.

TABLE 22 ESTIMATED WATER QUALITY

Water Composition * (PPM except for pH & Micro)	Apartment	Storage Pond	Reclaimed	Charcoal Treated
COD	700	600	40	< 10
BOD	357	300	20	< 10
Total Solids	1,100	980	150	100
Total Volatile Solids	628	---	---	---
Total Fixed Solids	471	---	---	---
Total Suspended Solids	286	173	0	Neg.
Volatile Suspended Solids	228	---	---	---
Fixed Suspended Solids	57	---	---	---
Total Phosphate	57	50	3	1
Detergent	14	14	2	Neg.
pH	6 to 9	6 to 8	6 to 8	6 to 8
Microbiology (organisms/ml)	1×10^6	1×10^5	Neg.**	Neg.**

* Based on average flow rate of 18.5 GPCD.

** No pathogenic organisms (by reason of pasteurization).

Since the incinerator is cold at the start of a shift, the large door can be opened, ash removed and any large items, such as furniture, placed in the chamber. The door is closed and additional refuse is charged by a hydraulic loader.

With the blower on, providing air underneath the charge, the overfire burner is started. This combustion dries and ignites the top layer of refuse while helping to raise the chamber temperature to about 1500°F. In a few minutes, the temperature is up and the overfire burner cuts out. Should the temperature fall due to charging, drying of a zone of very moist refuse, or near completion of refuse combustion, the overfire burner will re-ignite. For most of the burn time, the overfire burner does not operate.

At the beginning of the incineration process, the afterburner is ignited and stays on until the afterburner chamber is brought to about 1700°F. Additional combustion air is fed to this chamber so hot organic vapors and smoke emanating from the main chamber can burn. This secondary combustion is not sufficient to maintain temperature continuously with Type 2 (household) refuse, so the afterburner cycles on and off, firing about 60-70% of the time.

The incinerator operator fills the hydraulic loader and charges the incinerator at regular intervals by actuating the hydraulic mechanism. After the last charge of the day, the operator can set a timer to permit the afterburner and overfire burner to operate as needed for several hours to insure complete incineration. The combustion air blower is allowed to operate overnight to help cool the incinerator for cleanout the following day. During cleanout, the blower is shut off.

Typical Power and Energy Utilization Plant

The Power and Energy Utilization Plant, located with other central processing equipment could be comprised of: a furnace and burner, Brayton cycle and organic Rankine cycle turbines, generator and air compressor, heat exchangers for energy input to the turbine fluids, heat exchangers for cooling the Rankine fluid and combustion air, and a scrubber. The cooling exchangers transfer energy to other functions that utilize what would ordinarily be waste heat. Figure 47 indicates some of these functions such as building heating, pasteurization and refrigeration for air conditioning. Other functions such as hot water heating and thermal degreasing of gray water collection tanks are derived from the heating system.

A brief discussion of candidate thermodynamic cycles and of temperature considerations are given in Appendix B, which is a more general review of total energy systems.

The flooded bed scrubber uses gray water from the storage pond to remove fly ash from the combustion exhaust gas. Since this high efficiency scrubber uses relatively little water, the temperature of the water exiting will be high, but still low enough to condense the water vapor in the combustion gas. The hot gray water leaving the scrubber is passed through a clarifier, directed to appropriate heat exchangers for transfer of energy for other community functions, and returned to the pond.

The heat sink for the Rankine cycle and the absorption refrigeration is left indefinite. The choice of sink will be strongly influenced by the availability of natural heat sinks at the particular installation site. The storage pond water might be adequate if the temperatures are compatible.

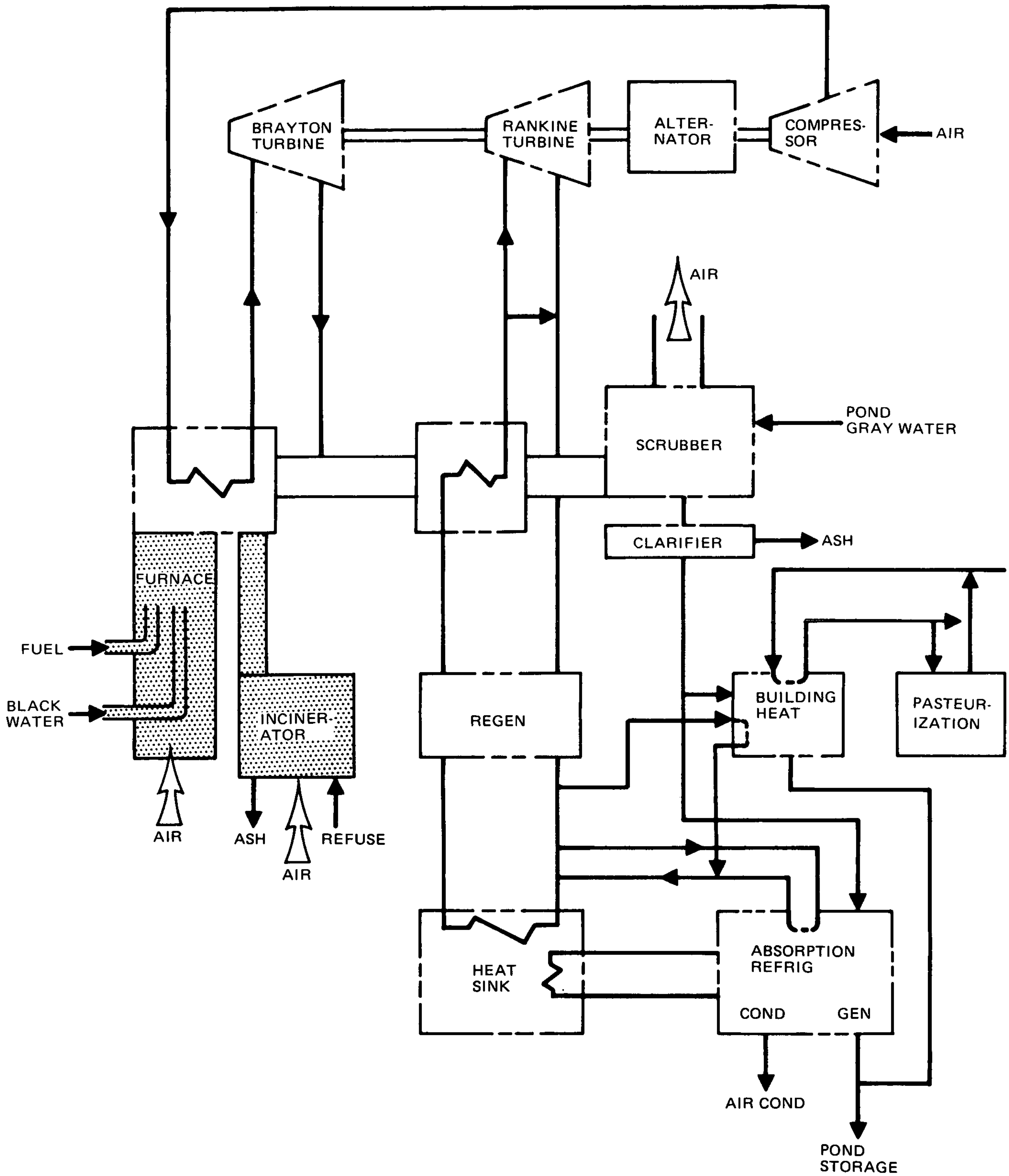


Figure 47 Total Energy System Interfaces

EQUIPMENT DESIGN AND PERFORMANCE CHARACTERISTICS

The design and performance characteristics of major system components and assemblies are tabulated on the following data sheets. The information is approximate and is intended to provide a physical appreciation for the principle elements of the system. Much of the data was obtained from equipment manufacturers in the form of proposals, descriptive literature and verbal communications. It provides a basis for proceeding to higher levels of design definition. Where appropriate, equipment has been sized in accordance with the National Plumbing Code. The Code estimates water demand in terms of the number of "fixture units" being serviced (see Figure 48). In order to use the Code, the "fixture unit" equivalencies shown in Table 23 were developed to correct for low water consuming devices and appliances.

TABLE 23 APARTMENT HOUSE FIXTURE UNITS

Fixture Type	Fixture Units (per family)	
	Conventional	Selected Concept Equivalent
Gray water		
Kitchen	2	1/2 (rinse re-use)
Lavatory	1	1
Shower	2	1 1/2
Laundry	3	1 1/2
Black water		
Water Closet	3	(Not applicable)

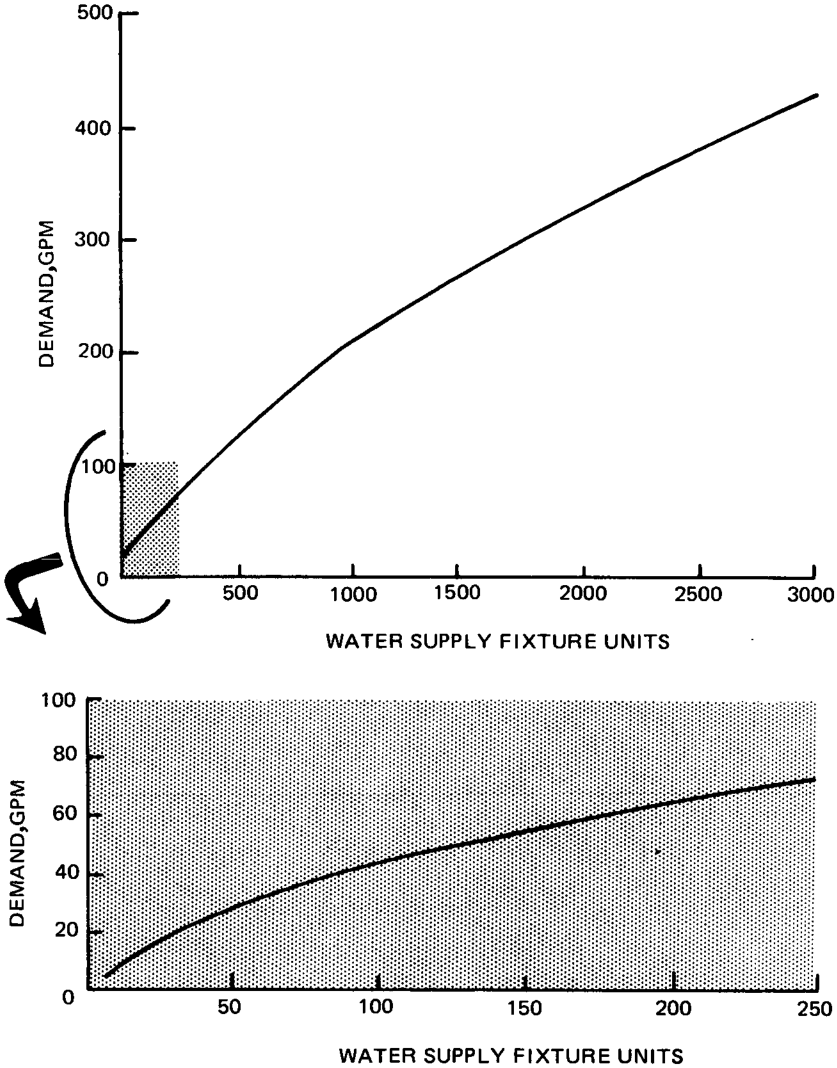


Figure 48 Curves for Estimating Demand Load

Title: Clothes Washer, Rinse Reuse

Description: A clothes wash machine of the front loading type includes the capability for storing and reusing rinse water. The rinse water storage is underneath the machine, thereby allowing easier front loading access.

Performance and Design Definition:

Water Requirement, wash plus flush rinse	16.5 gallons
Water Requirement, deep rinse	16.5 gallons
Laundry load	12 pounds
Water Supply Pressure	30 to 100 psi
Supply Flow GPM	4 to 6
Discharge Flow GPM	12 to 20
Supply Temperature (Cold to Hot)	50^{o}F to 160^{o}F
Cycle Time to Fill (Min)	8
Cycle Time to Drain (Min)	2
Total Cycle Time (Min)	40
Maximum Drain Pumping Head	8 to 12 feet
Power	1/2 H.P.
Use Rate	0 to 3 times per day
Noise	Same as conventional units
Volume	19 cubic feet
Floor Space	4.7 square feet (27" wide x 25" deep)
Weight	350 pounds
Interfaces	
Power	120 V.A.C., 60 cycle, 15 Amp
Supply Connections	3/4" garden hose
Drain Connection	1" hose
Materials (Exposed to Water)	Porcelain, polypropylene
Filtration	Perforated tray, Nylon fingers Back wash filter
Waste Composition	See Table 6

Title: Dishwasher, Rinse Reuse

Description: A dishwash machine includes the capability for storing and re-using rinse water. The rinse water storage is underneath the machine, resulting in better access for the dishes.

Performance and Design Definition:

Water Requirement wash cycle	9 gallons
Water Requirement rinse cycle	6 gallons
Water Supply Pressure	15 PSI
Temperature	140 to 160°F
Supply Flow GPM	1.6 to 2.5
Discharge Flow GPM	4.5 to 7.5
Supply Temperature °F	140 to 160°F
Cycle Time to Fill	1.5 Minutes
Cycle Time to Drain	1.5 Minutes
Cycle Time	Approx. 60 minutes normal
Maximum Drain Pumping Head	15 feet
Noise	Same as conventional units
Volume	14 cubic feet
Floor Space	4.2 square foot (24" x 25")
Interfaces	
Power	120 V.A.C., 12.6 AMP., 60 cycle
Supply connections	3/8"
Drain connections	5/8"
Materials (Exposed to Water)	Porcelain
Filtration	Perforated Plate (Back Wash)
Constraints	Cycle time impacted by water supply temperature
Waste Composition	See Table 6

Title: Apartment Gray Water Receiver

Description: The gray water receiver provides for solids separation and storage of gray water at each apartment building, prior to vacuum collection. It is sized for the maximum demand of 100 "fixture units". Collection frequency, determined by a central control, is approximately 20 minutes. Level controls prohibit vacuum collection at low tank levels and assure collection at high tank levels.

Once a week the tank is heated by hot water heating tubes to cause all grease to go to the separator surface. A grease/water layer and settled solids are vacuum collected after a time delay. Details are shown in Figure 49.

Performance and Design Definition:

Solids Settling Tank	
Volumetric capacity	48 ft.^{3}
Detention Time	5.6 min.
Tube Flow Area	11.5 ft^2
Tube angle with horizontal	60^o
Solids removal frequency	once per week
Temperature range	70 to 160^{o}F
Dimensions	5.5' wide x 6' deep x 3' high
Quantity per building	1
Weight	650 lbs
Materials	
Tank	Epoxy coated carbon steel
Settling Tubes	stainless steel
Hot Water Coil	Copper
Collection Tank	
Capacity required	880 gallons
Ullage	70 gallons
Total Tank Size	950 gallons
Dimensions	5' diameter x 8' long
Quantity per building	1
Weight	1200 pounds

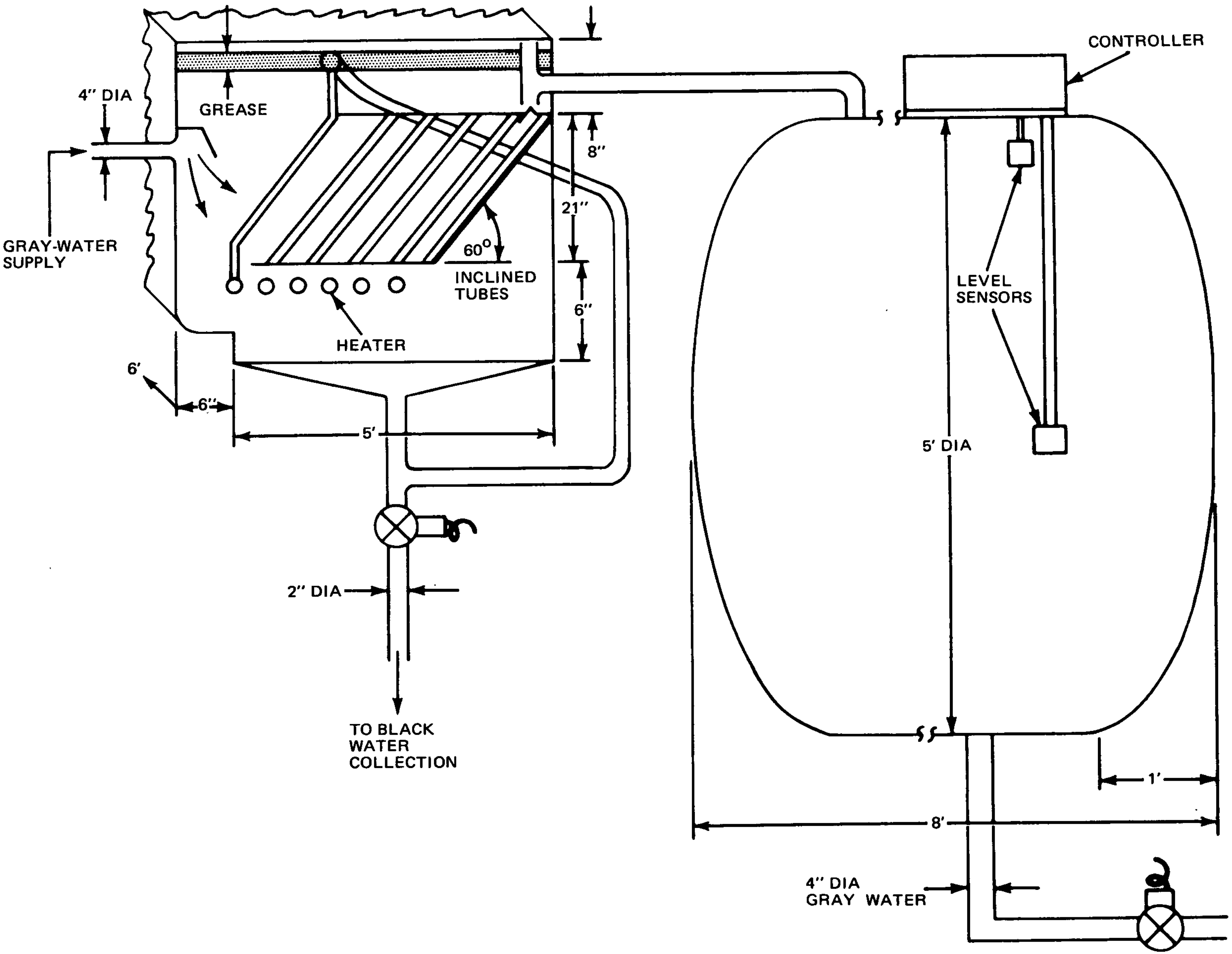


Figure 49 Gray-Water Receiver

Title: Vacuum Reservoir

Description: The vacuum reservoir tank is sized to permit the waste collection tanks to receive black and gray waste for 3 minutes at a maximum demand rate without outflow pumps operating.

Performance and Design Definition:

Capacity	855 ft^3 (6,400 gal)
Maximum Vacuum	13" Hga
Diameter	10'
Length (including heads)	12'
Quantity	1
Weight (each)	6,170 pounds
Interfaces	
Manhole	11" x 15"
Instrument Holes	6"
Materials	
Tank	Carbon Steel
Coating	0.03" epoxy tar
Tank Life	30 years minimum
Plumbing Interfaces	
Gray water supply	4" dia.
Gray water discharge	4" dia.
Black water connection	2" dia.
Hot Water (in and out)	3/8" dia.

Title: Waste Water Collection Vacuum Pumps

Description: The water ring seal vacuum pumps are used to create a vacuum reservoir for the gray and black water vacuum collection tanks. Three pumps are used with two sized to handle the maximum required flow. Normally each pump will be selected alternately. Under average demand a pump will operate 3 minutes followed by a 3 minute period with all pumps off. Each pump will have a check valve to prevent atmospheric backflow.

Performance and Design Definition:

Flow (at vacuum)	200 cfm @ 7.35 psia
Vacuum Range	13 to 20 inches Hga
RPM	1200
Power	15 H.P., 230/460 V, 60 cycle, 3 phase, 1200 RPM
Cooling water rate	6 GPM
Quantity	3
Dimensions, overall (3)	30" x 37" x 144"
Weight	Less than 1,000 lbs
Interface	
Suction Connections	3"
Discharge Connections	2"
Noise	80 DBA
Materials	Cast Iron
Operation Points	
20" Hga	Second pump goes on
18" Hga	First pump goes on
13" Hga	All pumps off

Title: Waste Macerator

Description: The waste macerator operates in the vacuum line to black waste collection tanks. The design lends itself to quick interchange of parts or units for maintenance. A window is provided for easy inspection of the macerator disk.

Performance and Design Definition:

Flow Required	7.1 GPM
Flow Capacity	100 GPM
Outlet particle size	0.25" dia. max.
Power	1/2 H.P.
Type	Abrasive grinding disks
Dimensions	15" wide x 10" lg x 22" high
Quantity	1
Weight	100 pounds
Interfaces	~ 11" O.D. flanges

Title: Black Water Receivers

Description: The black water receivers accept black water from all apartment houses of the community. It is collected by the vacuum provided by the Vacuum Reservoir. Two tanks have each been sized to satisfy the maximum anticipated rate and provides for a more or less steady flow to the incinerator.

Performance and Design Definition:

Capacity	200 gallons
Maximum Vacuum	13" Hga
Diameter	3 feet
Length, including heads	4.5 feet
Quantity	2
Weight (each)	475 pounds
Interfaces	
Instrument Holes	6" diameter
Materials	
Tank	Carbon steel
Coating	0.03" epoxy tar
Level Control	Stainless steel
Tank Life	30 years minimum

Title: Gray Water Receivers

Description: The gray water receivers accept gray water from all the community apartment houses. They utilize a vacuum controlled by the central controller in conjunction with the tank level controls. Two tanks have each been sized to receive maximum community demand, based on 2500 fixture units, in 3 minutes.

Performance and Design Definition:

Capacity Required	1210 gallons
Ullage	70 gallons
Total Volume	1280 gallons
Pressure	13 to 30 Hga
Diameter	6'
Length	6.5'
Quantity	2
Weight (each)	2,100 pounds
Interfaces	
Instrument Hole	6" dia.
Misc. Equipment	Level controls
	Chlorination
Materials	
Tank	Carbon steel (or fiberglass)
Coating	0.03" epoxy tar (for carbon steel)
Level Controls	Stainless steel
Tank Life	30 years minimum

Title: Collected Black Water Transfer Pump

Description: This pump transfers black water from the black water collection tanks to the black water incinerator. Redundant variable speed pumps each provide sufficient flow, in conjunction with the collection tank capacity, to handle maximum waste generation rates while delivering a steady flow to the incinerator. Pumps are alternately selected for operation.

Performance and Design Definition:

Flow	3 GPM
Positive Pressure	40 psi
Suction Pressure	None
Power	1/2 H.P. 220/440 Volt, 3 phase, 60 cycle, 200 RPM
Type	Progressing cavity, positive displacement
Dimensions (each)	7" wide x 38" long x 10" high
Quantity	2
Weight (each)	14 pounds
Suction Connection	6" O. D. flange
Discharge Connection	10" O.D. flange
Maximum Particle Diameter	0.6"

Title: Collected Gray Water Transfer Pump

Description: This pump unit lifts gray water from the vacuum collection tanks and transfers it to the storage pond or spreading basin. Three pumps are provided with two sized to handle maximum required flow. They operate in response to the control system to satisfy high and low pump out demands and are cut out at low tank levels.

Check valves are included for each pump to prevent back-flow.

Performance and Design Definition:

Flow (each)	190 GPM
Positive Head	30 psi
Suction Head	3 psi
Power (each)	7 1/2 H.P., 220/440 V, 60 cycle, 3 phase, 1750 RPM
Type	Centrifugal
Dimensions (each)	10 1/2" wide x 24" long x 13" high
Quantity	3
Weight (each)	200 pounds
Suction Connections	2" NPT
Discharge Connections	1 1/2" NPT

Title: Storage Pond

Description: The storage pond is designed to store gray water for irrigation and reclamation. The size is large enough to hold a minimum of three days of average gray water flow.

Sensors are installed in the tank to permit control of associated equipment when the level is high or low.

Performance and Design Definition:

Capacity	50, 500 gallons
Ullage	60 gallons
Surface area	1,350 ft^2
Average Diameter	41.5'
Depth (max)	5.5'
Side Slope	60°
Percolation rate	Negligible

Title: Spreading Basin

Discussion: The spreading basin is designed to accept excess gray water not required for irrigation or reclamation and reuse.

Performance and Design Definition:

Capacity	100,000 gal. (13,500 ft^3)
Average Diameter	76 feet
Depth	3'
Side Slope (from vertical)	60^o
Percolation rate	1 gal/ft^2-day

Title: Pond Gray Water Delivery Pumps

Description: This unit consists of supply pumps and valves required to deliver pond water to community lawn irrigation or to the reclamation equipment. In both cases redundant pumps are sized to handle the average daily community gray water flow rate. The irrigation pumps are sized to flow the average daily quantity over an 8 hour period. The reclamation flow rate is on a 24 hour basis.

Performance and Design Definition:

Reclamation Supply Pump	
Flow	25.7 GPM
Positive Head	5 psi
Suction Head	Negligible
Power	0.5 H.P., 115/230 V, 60 cycle, 1 phase, 3450 RPM
Type	Centrifugal
Quantity	2
Suction connections	2" NPT
Discharge connections	1" NPT
Material (wet)	Bronze & Stainless Steel
Irrigation Pump	
Flow	77 GPM
Positive Head	25 psi
Suction Head	Negligible
Power	2 H.P., 220/440 V, 60 cycle, 3 phase, 2900 RPM
Type	Centrifugal
Quantity	2
Suction Connections	2" NPT
Discharge Connections	1" NPT
Material (wet)	Bronze & Stainless Steel
Overall Unit Design	
Dimensions	20" wide x 24" long x 24 high
Weight	300 pounds

Title: Gray Water Reclamation Equipment

Description: The reverse osmosis equipment is designed to reclaim gray water for household reuse. It consists of membrane modules installed in a parallel/series tapered flow arrangement, redundant pumps and instrumentation for physical parameters.

Performance and Design Definition:

Total Wastewater flow	32,500 GPD
Permeate Flow	25,000 GPD
Membrane type	Tube, cast in resin-bonded and sand
Membrane material	Modified cellulose acetate
Module quantity	90
Module size	6" dia. x 6' long
Tube size	1/2"
Tubes/Module	36
Temperature limitation	105^{o}F
pH allowable range	3 to 8
Max allowable suspended solids	500 PPM
Overall unit size (each rack)	4 racks, 2 1/2' wide x 14' long x 7' high
Floor Area (including aisles)	22' x 27'
R.O. Pump Design	Multistage Centrifugal
R.O. Pump Pressure	325 to 450 psi
R.O. Pump Power	100 H.P.
Pump quantity	2

Title: Reclaimed Water Delivery Pump Unit

Description: This unit receives potable water from the gray water reclamation equipment and delivers it to apartment buildings for reuse. It includes redundant pumps and small receiving tank to eliminate mismatchs between process supply-pump rates.

Performance and Design Definition:

Tank	
Capacity	56 gallons
Ullage	4 gallons
Pressure	5 psi
Temperature (max)	165°F
Diameter	20"
Length	50"
Weight	150 pounds
Quantity	1
Material	Epoxy coated carbon steel
Pump	
Flow	45 GPM
Positive Head (normal)	60 psig
Positive Head (max)	75 psig
Suction Head	Negligible
Temperature	165°F
Power	5 H.P., 220/440V, 60 cycle 3 phase, 3500 RPM
Pump Type	Centrifugal
Dimensions	9" wide x 23" long x 10" high
Weight	80 pounds
Quantity	2
Interfaces	
Suction Connections	2" NPT
Discharge connections	1" NPT
Hot water coil connections	1/2" NPT
Materials	Bronze and Stainless Steel
Overall Unit Operation	
Pump on	2.0 minutes
Pump off	3.3 minutes

Title: Reclaimed Water Accumulator

Description: This unit accumulates water to satisfy peak household demands. Redundant pressure switches are installed on the tank to actuate air compressors to provide required delivery rates. A fail open relief valve is also installed to protect the tanks.

Performance and Design Definition:

Capacity Required (each)	16,000 gallons
Ullage (each)	5,550 gallons
Total Volume (each)	22,150 gallons
Pressure (operating)	50 to 75 psi
Relief Pressure	80 psi max
Diameter	10 feet
Length	39 feet
Quantity	2
Weight (each)	33,630
Interfaces	
Manhole	11" x 17"
Gauge and Instrument Openings	1/2"
Compressed air connections	6"
Water connection	6"
Misc. Installed Equipment	
	Level controls
	Pressure switch
Materials	
Tank	Carbon steel
Coating	0.03" epoxy
Operation of Pressure Switch	
50 psig	signal for 2 compressors
60 psig	signal for 1 compressor on
75 psig	signal for all compressors off

Title: Accumulator Compressor Assembly

Description: These compressors are designed to provide air at a flow and pressure sufficient to provide an expulsion force in response to peak reclaimed water demand. Three compressors are provided with two sized to satisfy anticipated peak demand. Normally, they will be selected alternately for operation. Cooling water is obtained from the recovered water delivery pump and delivered to the accumulator with the compressed air.

Performance and Design Description:

Each Compressor	
Type	Water sealed
Flow (approx. constant at all pressure)	74 scfm @ 60 psig
Pressure	50 to 75 psig
Power, overall	22 H.P. 220/440 V, 60 cycle, 3 phase, 1750 RPM
Cooling water flow	7 GPM
Quantity	3
Dimensions (3 units)	150" wide x 77" long x 48" high
Weight (each)	580 pounds
Interfaces	
Inlet Connection	2" Flange
Outlet Connection	1 1/2 flange
Cooling water	3/4" NPT
Noise	80 DBA
Material (Wet)	Cast Iron
Operation points	
50 psig	Second pump goes on
60 psig	First pump goes on
75 psig	All pumps off

Title: Power and Black Water Burner

Description: The Power and Black Water Burner Unit includes fuel and black water nozzles, a vortex burner, blower and controls.

Performance and Design Definition:

Black Water Capacity	940 pounds per hour
Fuel Capacity	24 million BTU per hour
Combustion Chamber Temperature	1800°F
Blower flow	4500 cfm @ 18" W.C.
Blower Power	30 H.P. @ 230/460 V, 60 cycle 3 phase

Title: Refuse Incinerator

Description: The Refuse Incinerator is a starved combustion type with integral afterburner and semi-automatic loader. It will accept large objects such as pieces of furniture through the end door.

Performance and Design Definition:

Refuse Capacity	1750 lbs/hr of Type 2 refuse using the semi-automatic loader
Chamber Volume	10.6 cu. yds.
Loader Volume	1.5 cu. yds.
Overfire burner rating	700,00 BTU/hr
Afterburner rating	700,000 BTU/hr
Blower motor	3 HP @ 115 V, 60 cycle, single phase
Loader hydraulic motor	5 HP @ 230/460 V, 60 cycle, 3 phase

PRELIMINARY DESIGN DATA SOURCES

Information was received from a number of manufacturers. More commonly used sources are identified below. It is not intended that they be considered as the only or preferred sources for this design application.

Vacuum Collection Systems, AIR VAC/DIV. National Homes Construction Corporation, Rochester, Indiana

Vacuum Pumps and Compressors, The Nash Engineering Company, South Norwalk, Connecticut

Tanks, Buffalo Tank, Dunellen, New Jersey, Wood Industrial Products, Conshohoken, Pennsylvania, Ravens Industries, South Dakota

Pumps, Peerless Pump, Indianapolis, Indiana, Moyno Pump, Springfield, Ohio

Pond Construction, Staff Industries, Upper Montclair, New Jersey

Clarifiers, Graver Water Conditioning Company, Union, New Jersey, Neptune Micro-floc, Corvallis, Oregon, Gulf Degremont, Inc., Liberty Corner, New Jersey, PER Corporation, Orange, New Jersey, Vacumites Inc., Camp Hill, Pennsylvania

Waste Macerator, BIF Sanitrol, Largo, Florida

Sub-surface Barrier Irrigation, Michigan State University, East Lansing, Michigan, Amoco Moisture Barrier Company, Chicago, Illinois

Sub-surface Trickle Irrigation, Texas A & M University Agricultural Research, Lubbock, Texas, Anjac Plastics, Inc., El Monte, California, Submatic, Inc., Lubbock, Texas

Reverse Osmosis, Westinghouse Electric Corporation, Philadelphia, Pennsylvania, Grumman, Bethpage, New York, Report ADR-04-03-72.1 April 1972

Carbon Treatment, Imperial Chemicals LTD, Wilmington, Deleware, Barneby Cheney, Columbus, Ohio, Burns, D.E. and Shell, G.L. Physical-Chemical Treatment of a Municipal Wastewater Using Powdered Activated Carbon

Incineration, Thermal Research and Engineering, Conshohocken, Pennsylvania, The Air Preheater Company, Wellsville, New York

Plumbing System, National and New York State Plumbing Codes

APPENDICES

APPENDIX A - CONCEPT SCHEMATICS AND COST PROJECTIONS

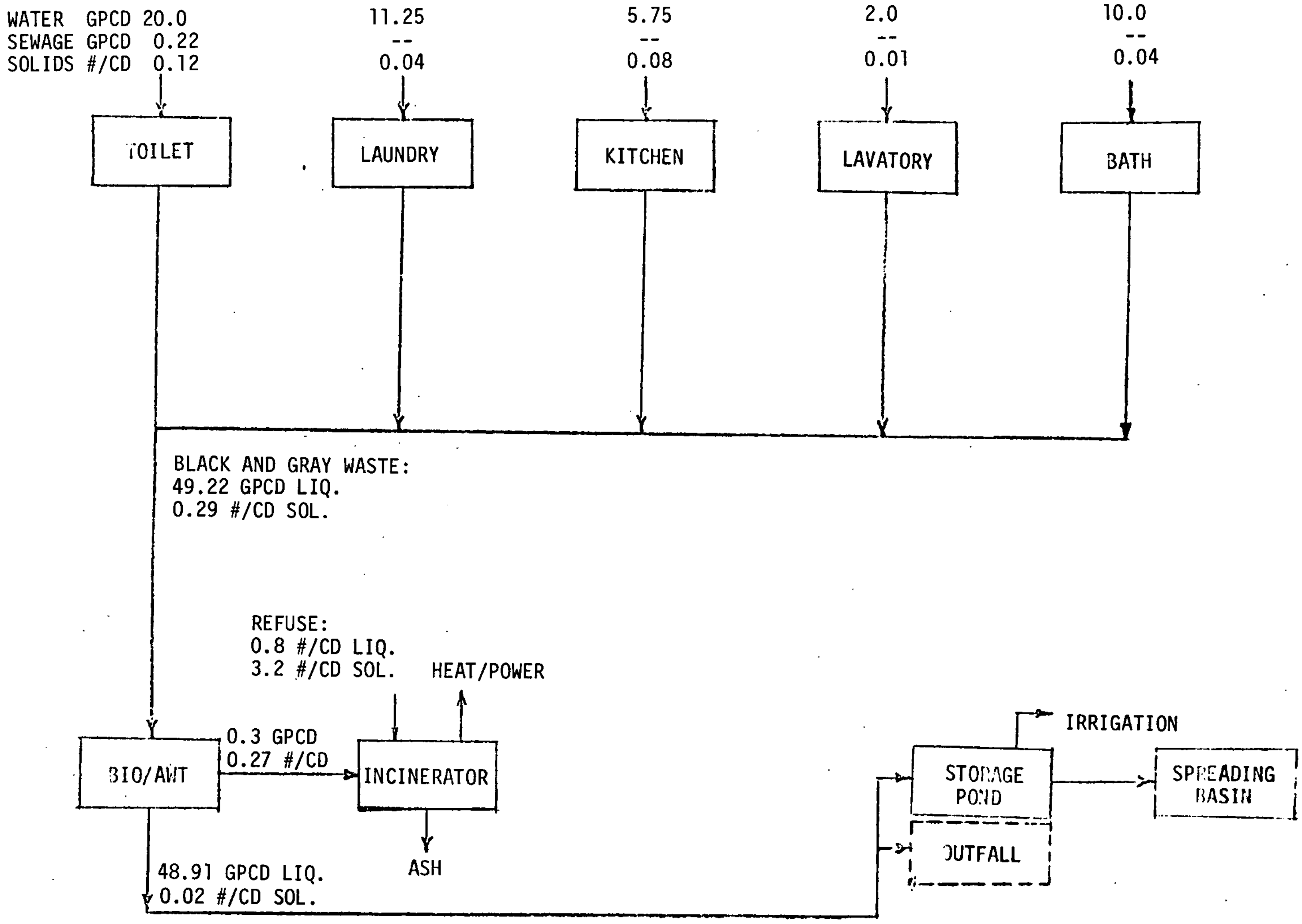
APPENDIX B - POWER GENERATION SYSTEMS

APPENDIX C - POWER USE AND COSTS

APPENDIX A

CONCEPT SCHEMATICS AND COST PROJECTIONS

This Appendix contains; (1) a complete set of mass balance schematics for the system concepts studied, (2) tabulations of projected costs for each concept and (3) expanded bar graphs of the projected costs. Current cost comparison tabulations are contained in the body of the report.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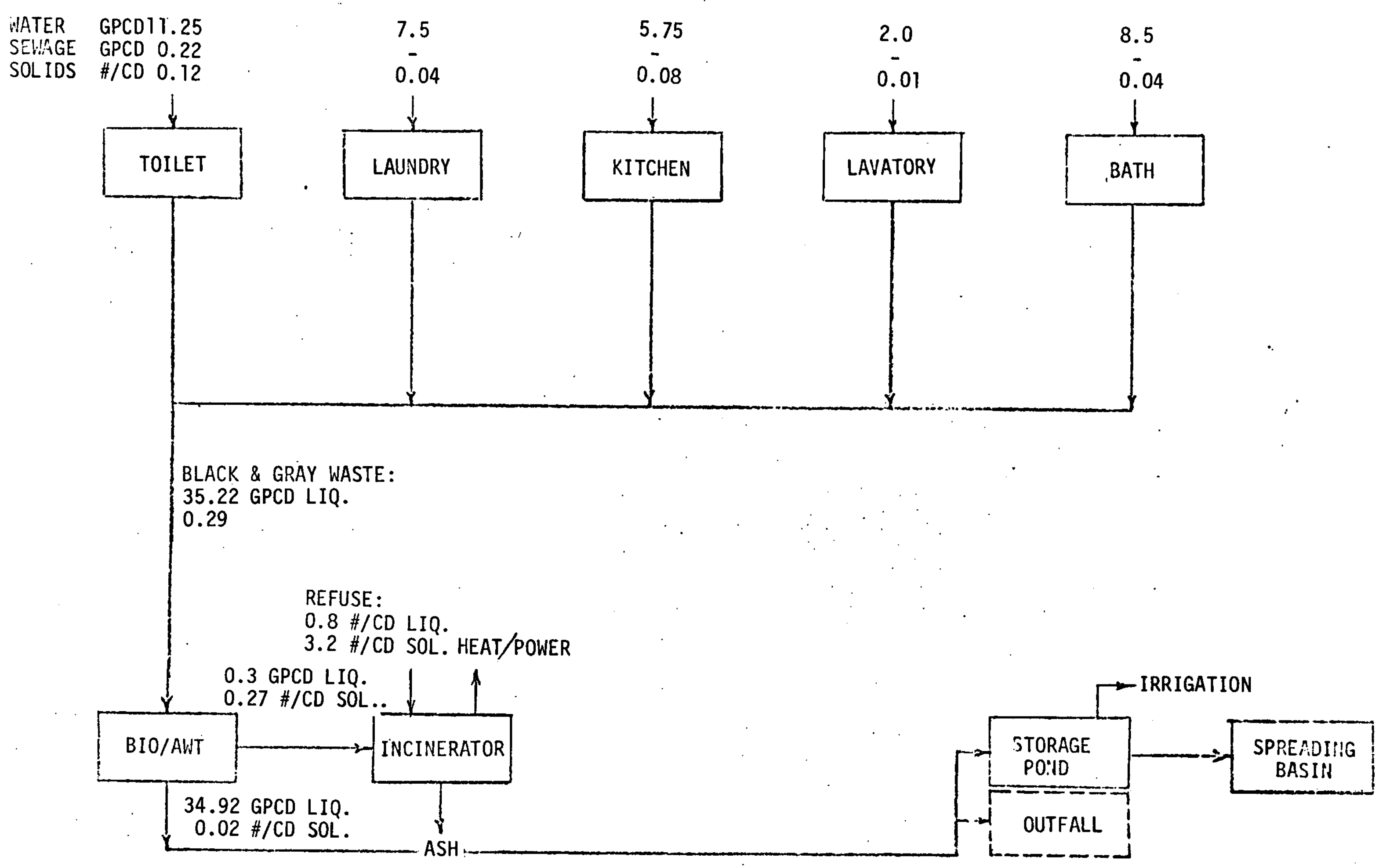
11.25
--
0.04
5.75
--
0.08
2.0
--
0.01
10.0
--
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
BLACK AND GRAY WASTE:
49.22 GPCD LIQ.
0.29 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
0.3 GPCD
0.27 #/CD
BIO/AWT
INCINERATOR
ASH
48.91 GPCD LIQ.
0.02 #/CD SOL.
IRRIGATION
STORAGE POND
OUTFALL
SPREADING BASIN

CONCEPT A-1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SOLIDS #/CD 0.12
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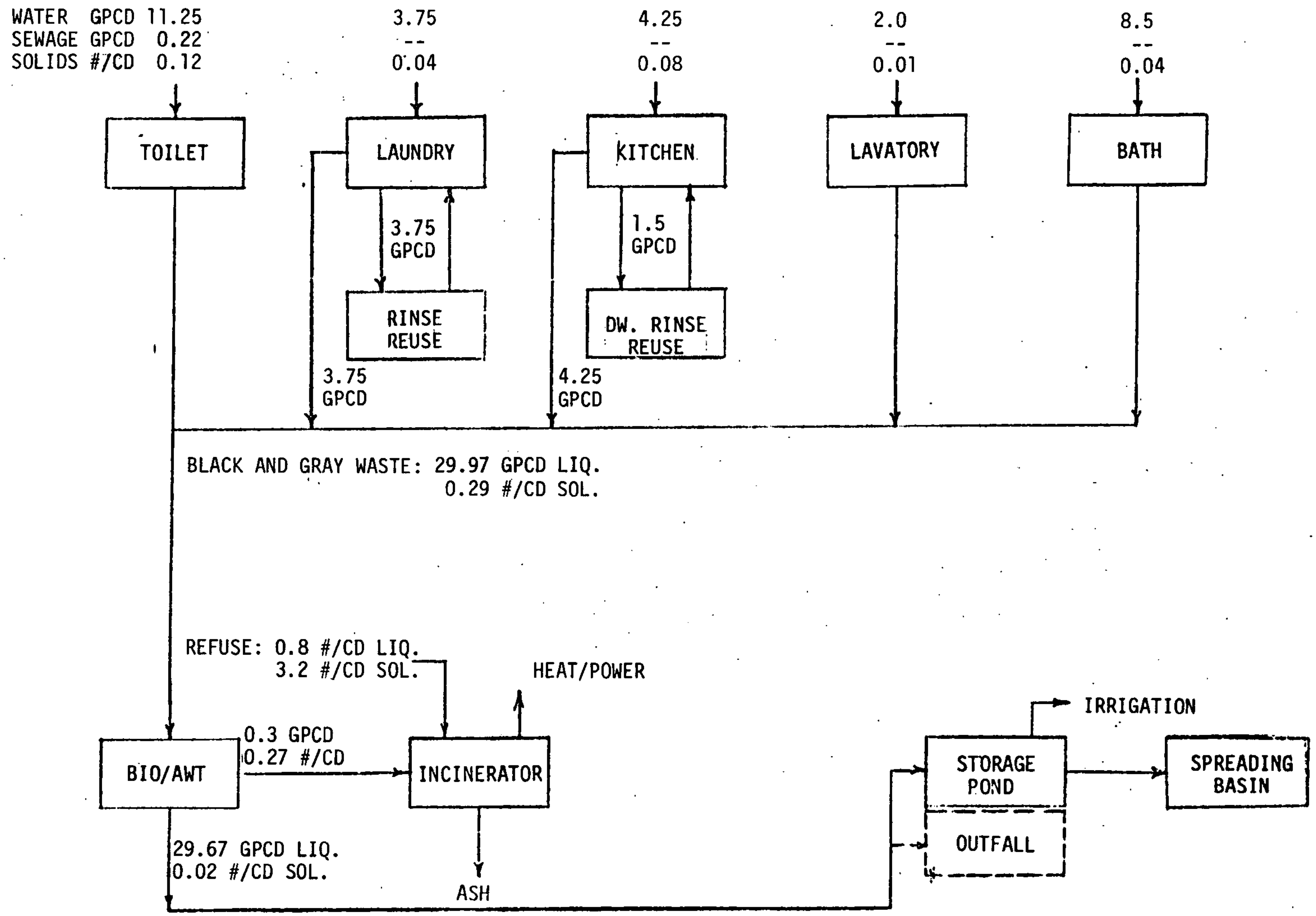
0.04
5.75
-
0.08
2.0
-
0.01
8.5
-
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
BLACK & GRAY WASTE:
35.22 GPCD LIQ.
0.29
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
0.3 GPCD LIQ.
0.27 #/CD SOL.
BIO/AWT
INCINERATOR
34.92 GPCD LIQ.
0.02 #/CD SOL.
ASH
IRRIGATION
STORAGE POND
OUTFALL
SPREADING BASIN

CONCEPT A-2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0.04
4.25
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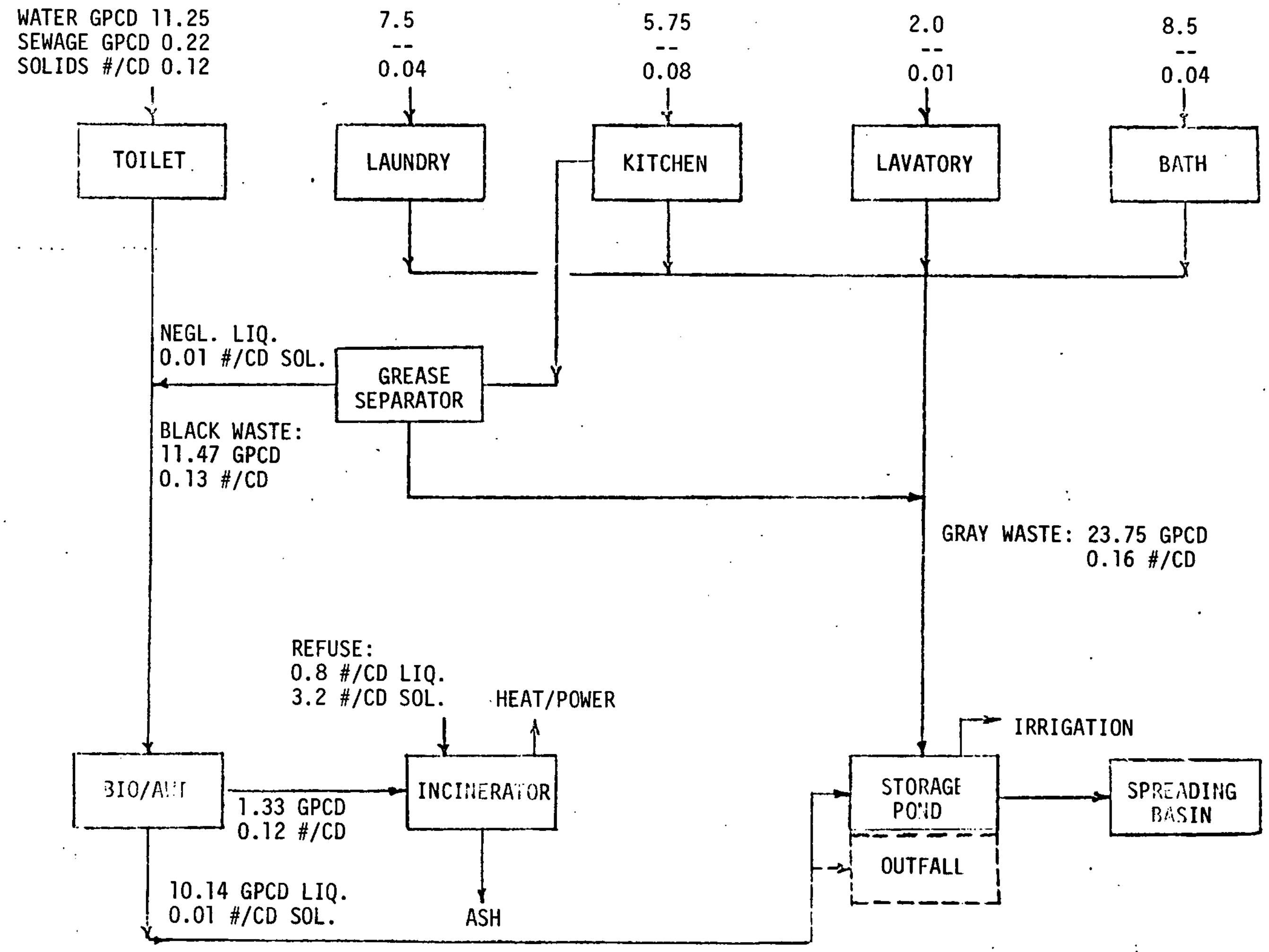
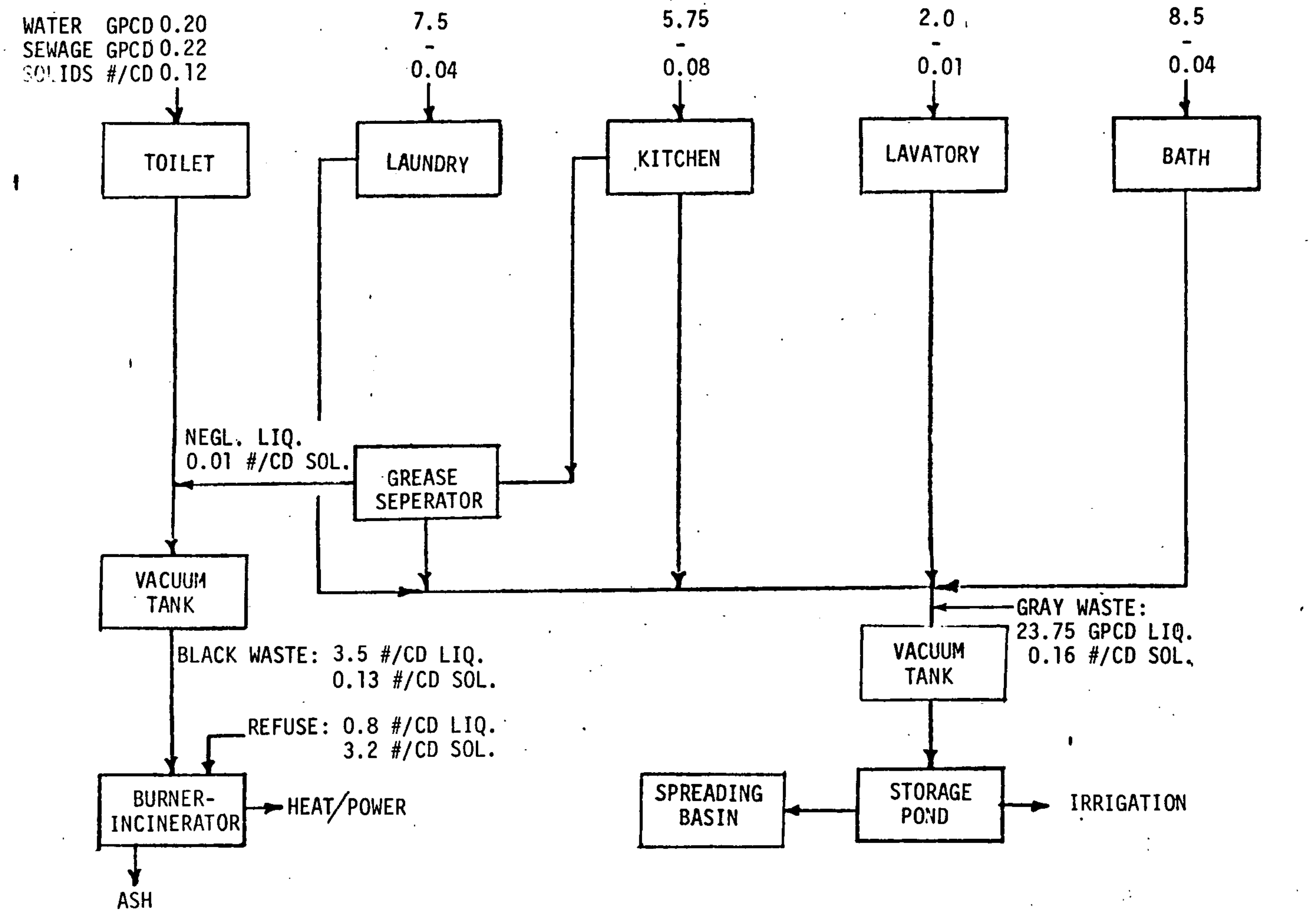
0.08
2.0
--
0.01
8.5
--
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
3.75
GPCD
RINSE
REUSE
1.5
GPCD
DW. RINSE
REUSE
3.75
GPCD
4.25
GPCD
BLACK AND GRAY WASTE: 29.97 GPCD LIQ.
0.29 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
IRRIGATION
0.3 GPCD
0.27 #/CD
BIO/AWT
INCINERATOR
STORAGE
POND
SPREADING
BASIN
OUTFALL
29.67 GPCD LIQ.
0.02 #/CD SOL.
ASH

CONCEPT A-3



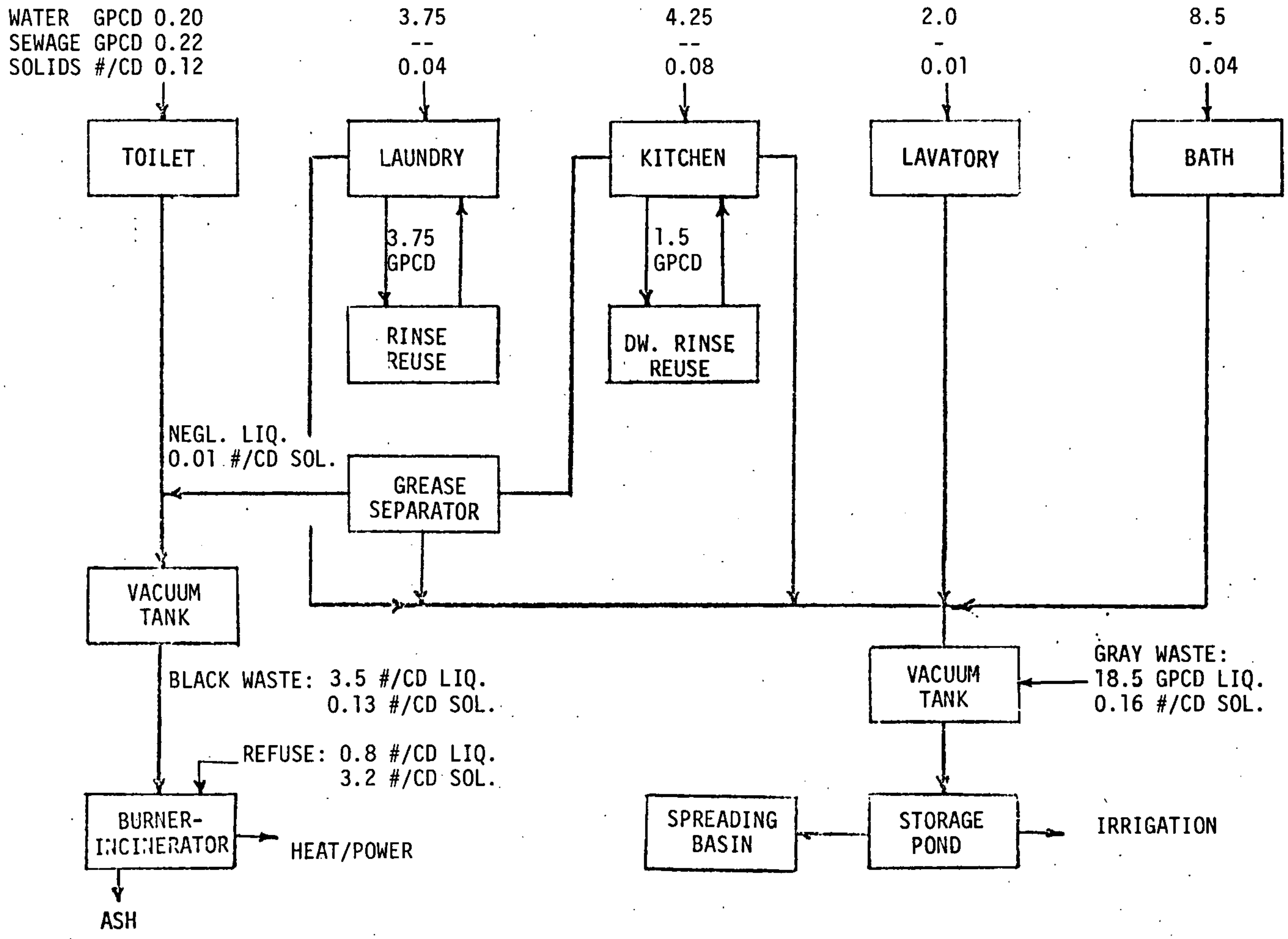
WATER GPCD 11.25
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
7.5
--
0.04
5.75
--
0.08
2.0
--
0.01
8.5
--
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
NEGL. LIQ.
0.01 #/CD SOL.
GREASE SEPARATOR
BLACK WASTE:
11.47 GPCD
0.13 #/CD
GRAY WASTE: 23.75 GPCD
0.16 #/CD
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
IRRIGATION
BIO/AUT
1.33 GPCD
0.12 #/CD
INCINERATOR
STORAGE POND
OUTFALL
SPREADING BASIN
10.14 GPCD LIQ.
0.01 #/CD SOL.
ASH

CONCEPT A-4



WATER GPCD 0.20
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
7.5
-
0.04
5.75
-
0.08
2.0
-
0.01
8.5
-
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
NEGL. LIQ.
0.01 #/CD SOL.
GREASE SEPERATOR
VACUUM TANK
GRAY WASTE:
23.75 GPCD LIQ.
0.16 #/CD SOL.
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATOR
HEAT/POWER
ASH
SPREADING BASIN
STORAGE POND
IRRIGATION

CONCEPT B-1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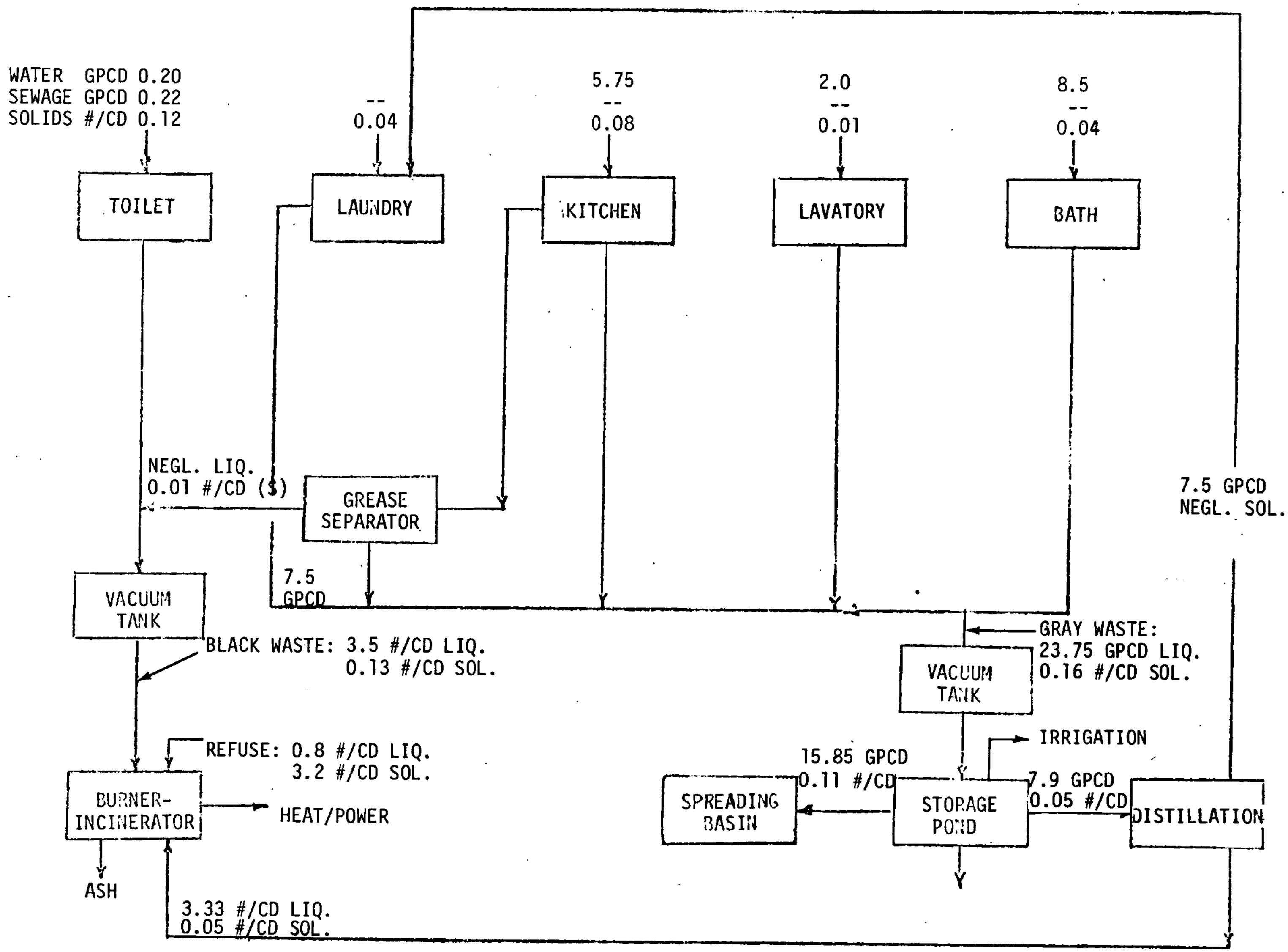
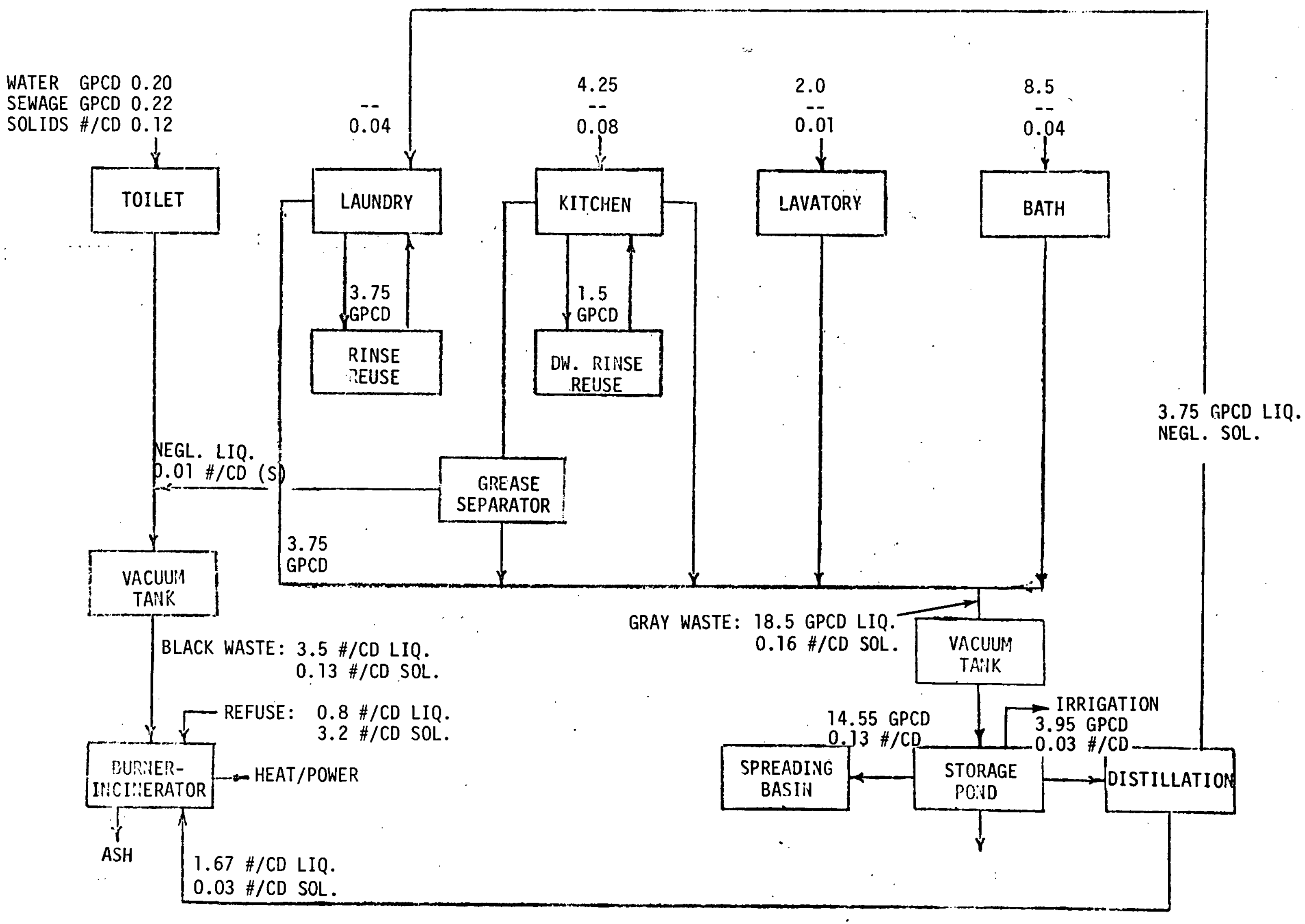
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
3.75
--
0.04
4.25
--
0.08
2.0
-
0.01
8.5
-
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
3.75
GPCD
1.5
GPCD
RINSE
REUSE
DW. RINSE
REUSE
NEGL. LIQ.
0.01 #/CD SOL.
GREASE
SEPARATOR
VACUUM
TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-
INCINERATOR
HEAT/POWER
ASH
VACUUM
TANK
GRAY WASTE:
18.5 GPCD LIQ.
0.16 #/CD SOL.
SPREADING
BASIN
STORAGE
POND
IRRIGATION

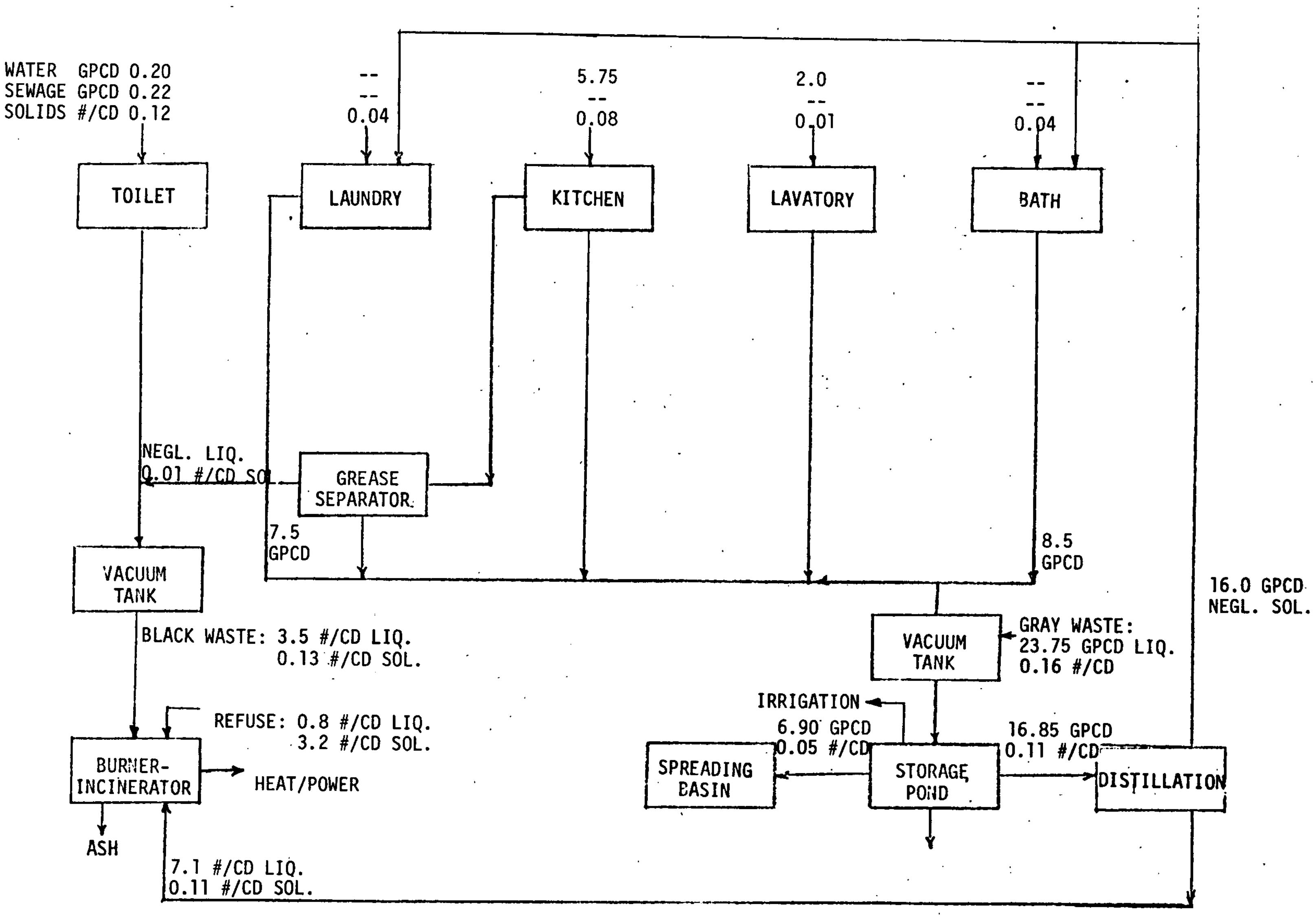
CONCEPT B-2


WATER GPCD 0.20
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
0.04
LAUNDRY
5.75
--
0.08
KITCHEN
2.0
--
0.01
LAVATORY
8.5
--
0.04
BATH
NEGL. LIQ.
0.01 #/CD (S)
GREASE SEPARATOR
7.5 GPCD
7.5 GPCD
NEGL. SOL.
VACUUM TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
GRAY WASTE:
23.75 GPCD LIQ.
0.16 #/CD SOL.
VACUUM TANK
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATOR
HEAT/POWER
ASH
IRRIGATION
15.85 GPCD
0.11 #/CD
SPREADING BASIN
STORAGE POND
7.9 GPCD
0.05 #/CD
DISTILLATION
3.33 #/CD LIQ.
0.05 #/CD SOL.

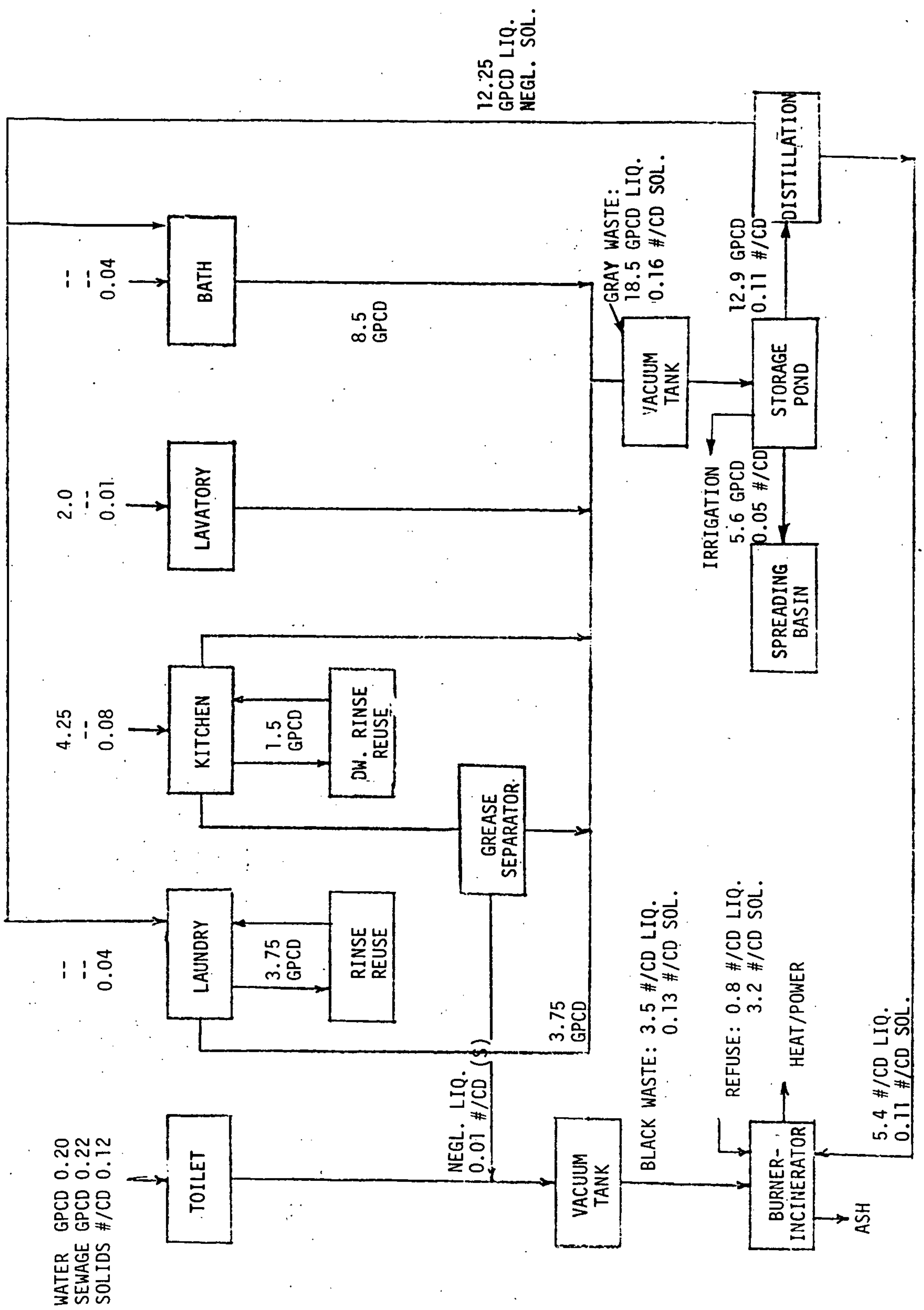
CONCEPT B-3


WATER GPCD 0.20
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
0.04
LAUNDRY
3.75
GPCD
RINSE
REUSE
4.25
--
0.08
KITCHEN
1.5
GPCD
DW. RINSE
REUSE
2.0
--
0.01
LAVATORY
8.5
--
0.04
BATH
3.75 GPCD LIQ.
NEGL. SOL.
NEGL. LIQ.
0.01 #/CD (S)
GREASE
SEPARATOR
3.75
GPCD
VACUUM
TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-
INCINERATOR
HEAT/POWER
ASH
1.67 #/CD LIQ.
0.03 #/CD SOL.
GRAY WASTE: 18.5 GPCD LIQ.
0.16 #/CD SOL.
VACUUM
TANK
IRRIGATION
3.95 GPCD
0.03 #/CD
14.55 GPCD
0.13 #/CD
SPREADING
BASIN
STORAGE
POND
DISTILLATION

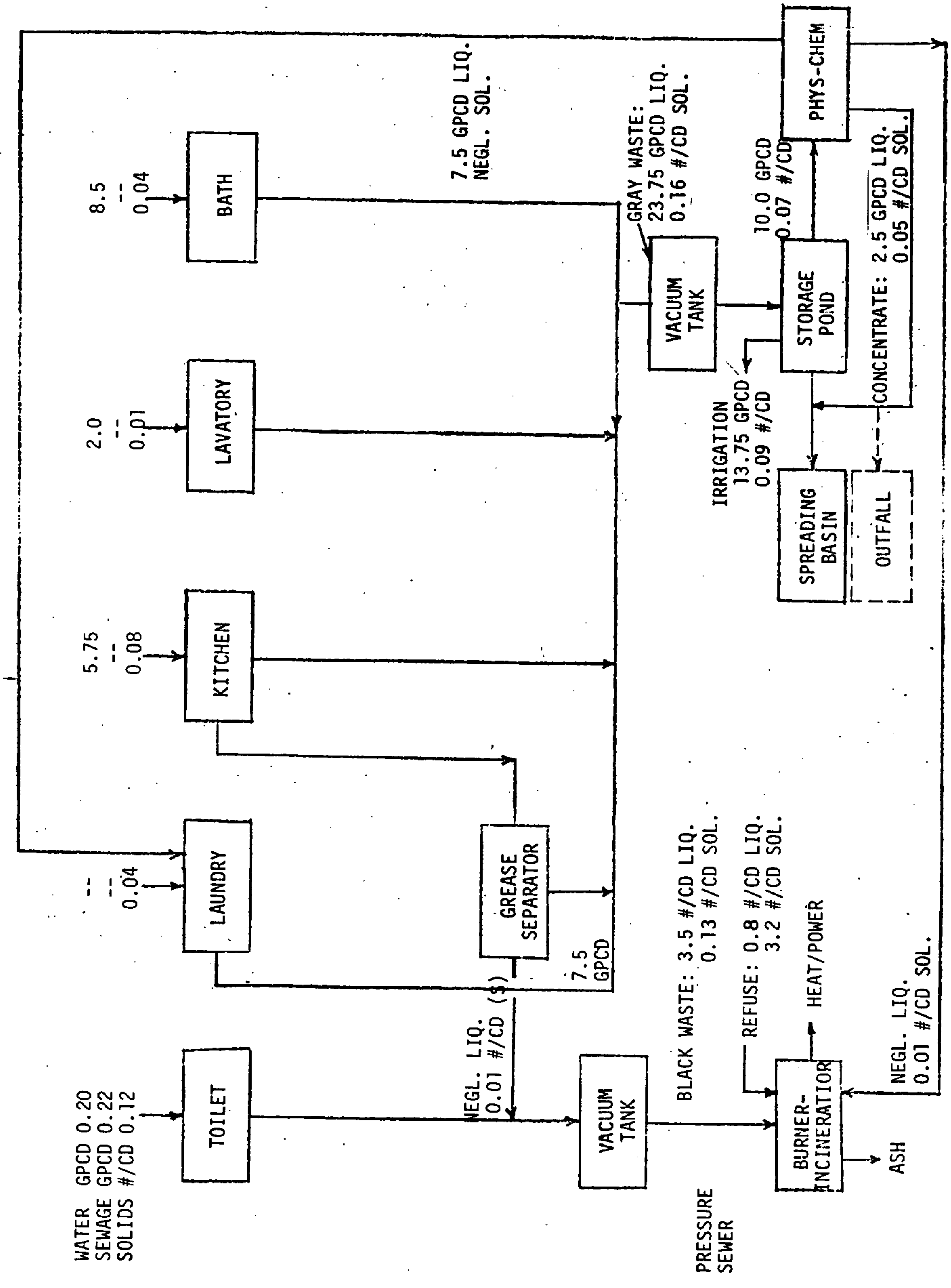
CONCEPT B-4


WATER GPCD 0.20
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
--
0.04
LAUNDRY
5.75
--
0.08
KITCHEN
2.0
--
0.01
LAVATORY
--
--
0.04
BATH
NEGL. LIQ.
0.01 #/CD SOL.
GREASE SEPARATOR
7.5 GPCD
8.5 GPCD
VACUUM TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
VACUUM TANK
GRAY WASTE:
23.75 GPCD LIQ.
0.16 #/CD
16.0 GPCD
NEGL. SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATOR
HEAT/POWER
ASH
IRRIGATION
6.90 GPCD
0.05 #/CD
SPREADING BASIN
STORAGE POND
16.85 GPCD
0.11 #/CD
DISTILLATION
7.1 #/CD LIQ.
0.11 #/CD SOL.

CONCEPT B-5


WATER GPCD 0.20
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
-- -- 0.04
4.25 -- 0.08
2.0 -- 0.01
-- -- 0.04
3.75 GPCD
RINSE REUSE
1.5 GPCD
DW. RINSE REUSE
GREASE SEPARATOR
8.5 GPCD
3.75 GPCD
NEGL. LIQ. 0.01 #/CD (S)
VACUUM TANK
BLACK WASTE: 3.5 #/CD LIQ. 0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ. 3.2 #/CD SOL.
HEAT/POWER
BURNER-INCINERATOR
ASH
5.4 #/CD LIQ. 0.11 #/CD SOL.
GRAY WASTE: 18.5 GPCD LIQ. 0.16 #/CD SOL.
VACUUM TANK
STORAGE POND
IRRIGATION 5.6 GPCD 0.05 #/CD
SPREADING BASIN
12.9 GPCD 0.11 #/CD
DISTILLATION
12.25 GPCD LIQ. NEGL. SOL.

CONCEPT B-6



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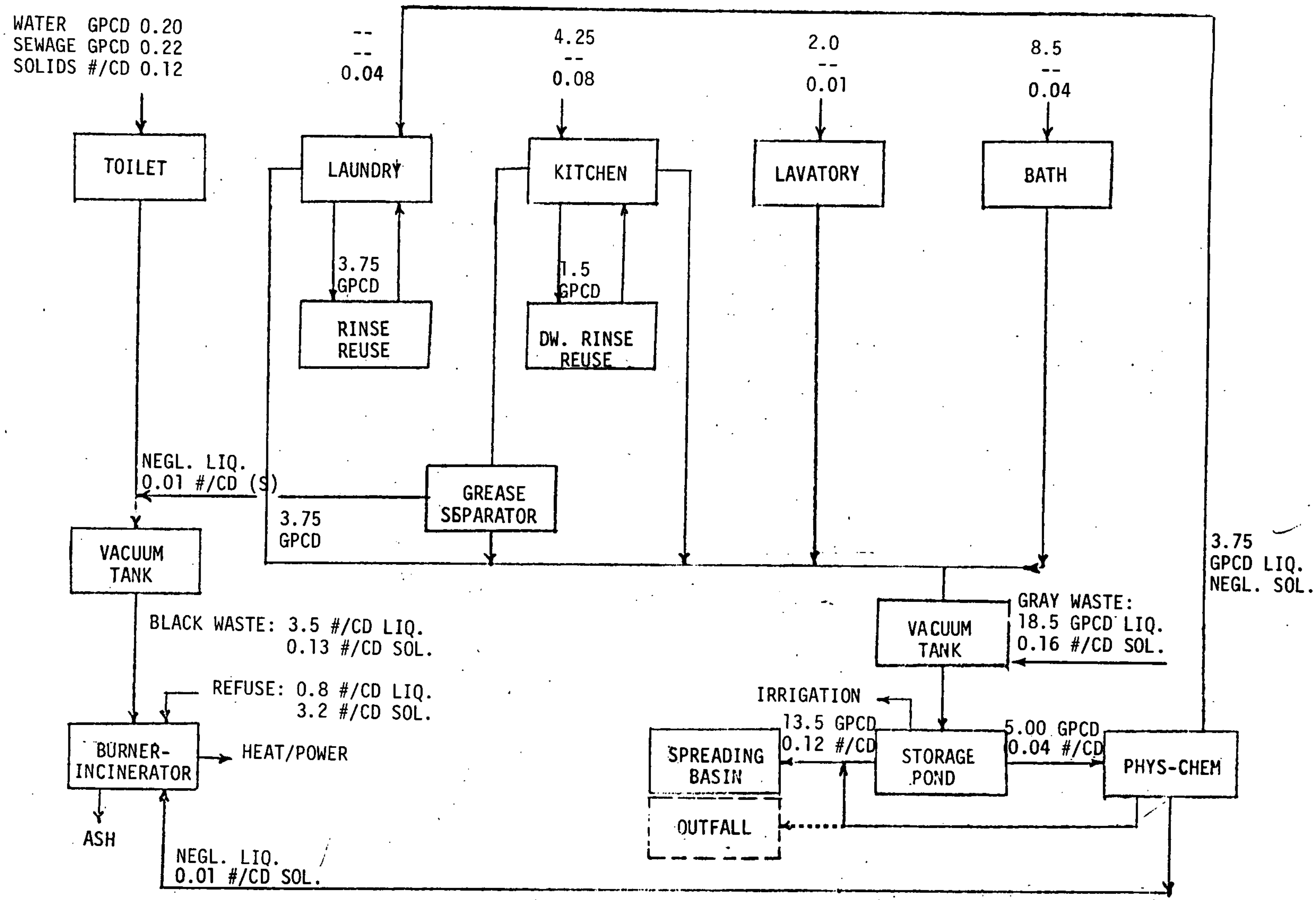
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
LAUNDRY
0.04
KITCHEN
5.75
0.08
LAVATORY
2.0
0.01
BATH
8.5
0.04
GREASE SEPARATOR
7.5 GPCD
NEGL. LIQ.
0.01 #/CD ($)
VACUUM TANK
PRESSURE SEWER
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
BURNER-INCINERATOR
ASH
NEGL. LIQ.
0.01 #/CD SOL.
7.5 GPCD LIQ.
NEGL. SOL.
GRAY WASTE:
23.75 GPCD LIQ.
0.16 #/CD SOL.
VACUUM TANK
STORAGE POND
10.0 GPCD
0.07 #/CD
PHYS-CHEM
CONCENTRATE: 2.5 GPCD LIQ.
0.05 #/CD SOL.
IRRIGATION
13.75 GPCD
0.09 #/CD
SPREADING BASIN
OUTFALL

CONCEPT B-7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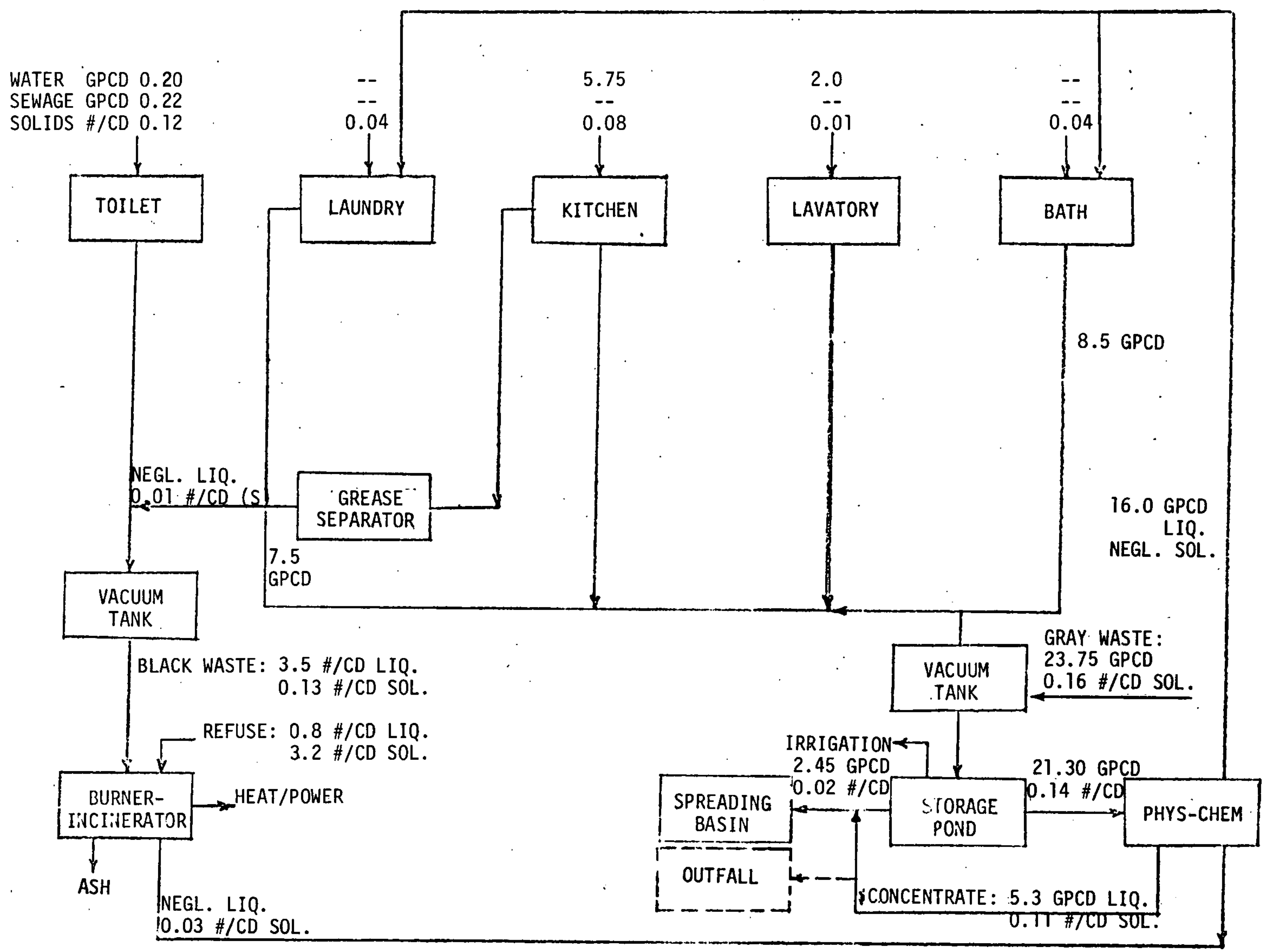
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
--
0.04
LAUNDRY
3.75
GPCD
RINSE REUSE
4.25
--
0.08
KITCHEN
1.5
GPCD
DW. RINSE REUSE
2.0
--
0.01
LAVATORY
8.5
--
0.04
BATH
NEGL. LIQ.
0.01 #/CD (S)
GREASE SEPARATOR
3.75
GPCD
VACUUM TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATOR
HEAT/POWER
ASH
NEGL. LIQ.
0.01 #/CD SOL.
3.75
GPCD LIQ.
NEGL. SOL.
VACUUM TANK
GRAY WASTE:
18.5 GPCD LIQ.
0.16 #/CD SOL.
IRRIGATION
13.5 GPCD
0.12 #/CD
SPREADING BASIN
OUTFALL
STORAGE POND
5.00 GPCD
0.04 #/CD
PHYS-CHEM

CONCEPT B-8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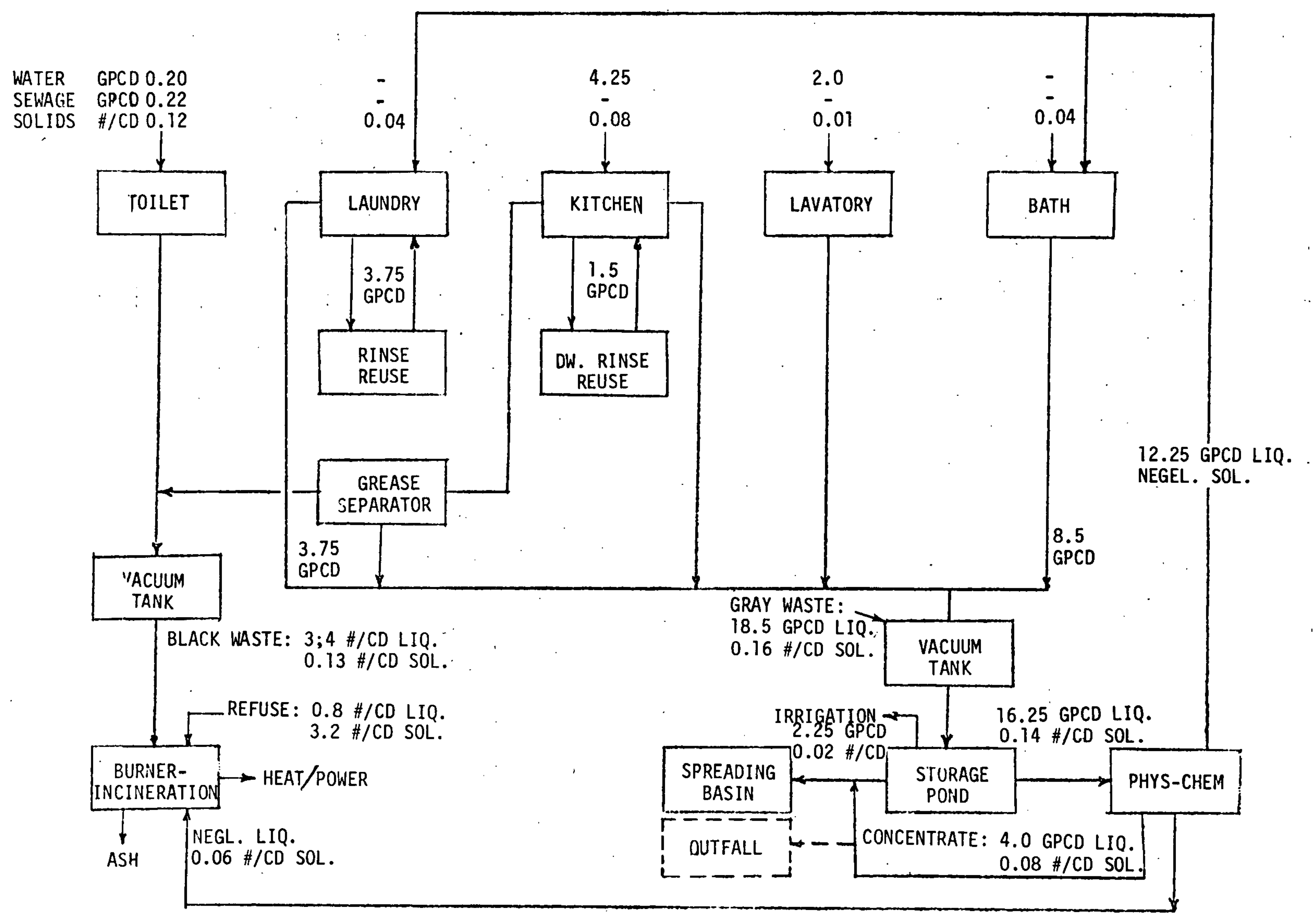
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
--
0.04
LAUNDRY
5.75
--
0.08
KITCHEN
2.0
--
0.01
LAVATORY
--
--
0.04
BATH
8.5 GPCD
NEGL. LIQ.
0.01 #/CD (S)
GREASE SEPARATOR
7.5 GPCD
16.0 GPCD LIQ.
NEGL. SOL.
VACUUM TANK
BLACK WASTE: 3.5 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATOR
HEAT/POWER
ASH
NEGL. LIQ.
0.03 #/CD SOL.
VACUUM TANK
GRAY WASTE:
23.75 GPCD
0.16 #/CD SOL.
IRRIGATION
2.45 GPCD
0.02 #/CD
SPREADING BASIN
OUTFALL
STORAGE POND
21.30 GPCD
0.14 #/CD
PHYS-CHEM
CONCENTRATE: 5.3 GPCD LIQ.
0.11 #/CD SOL.

CONCEPT B-9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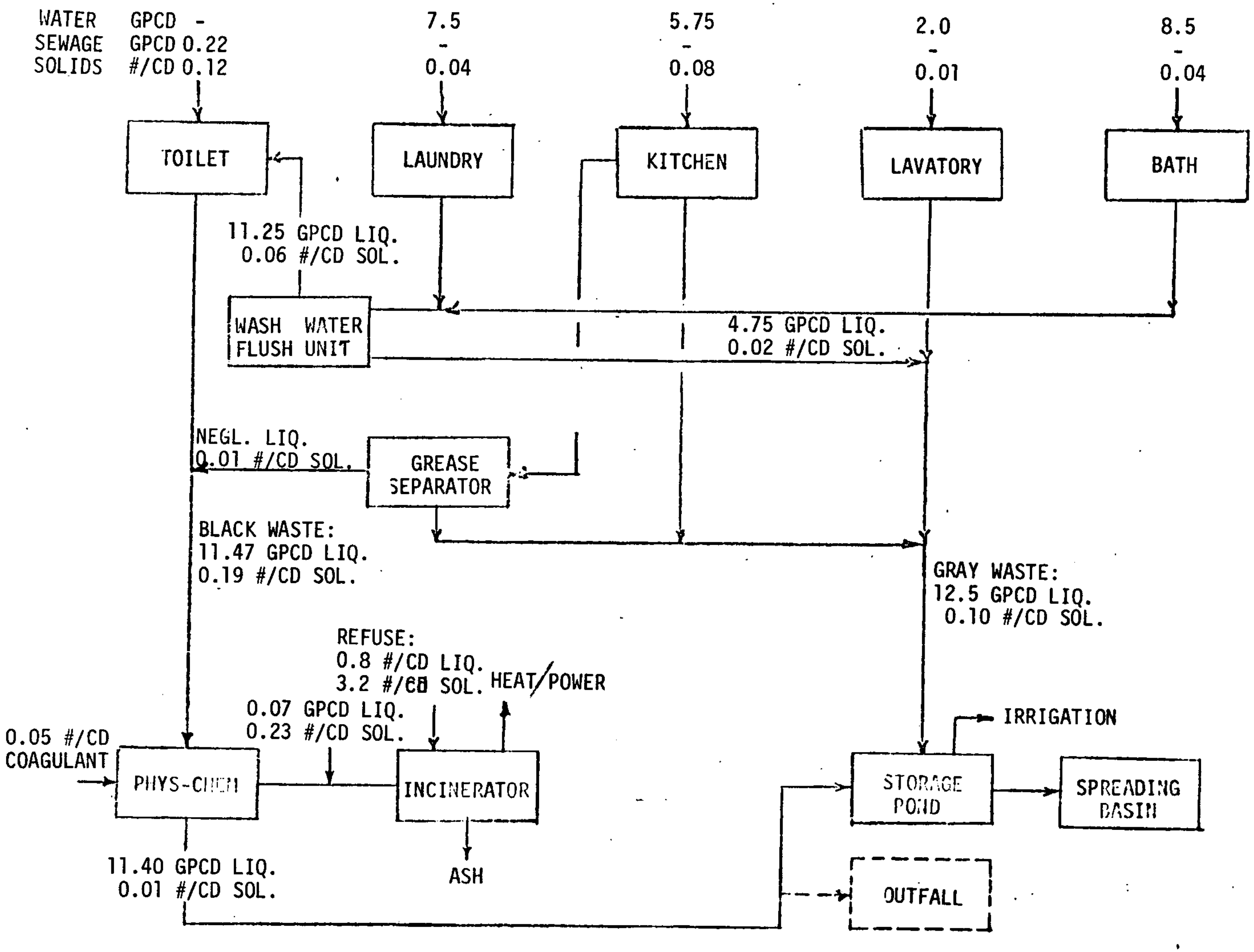
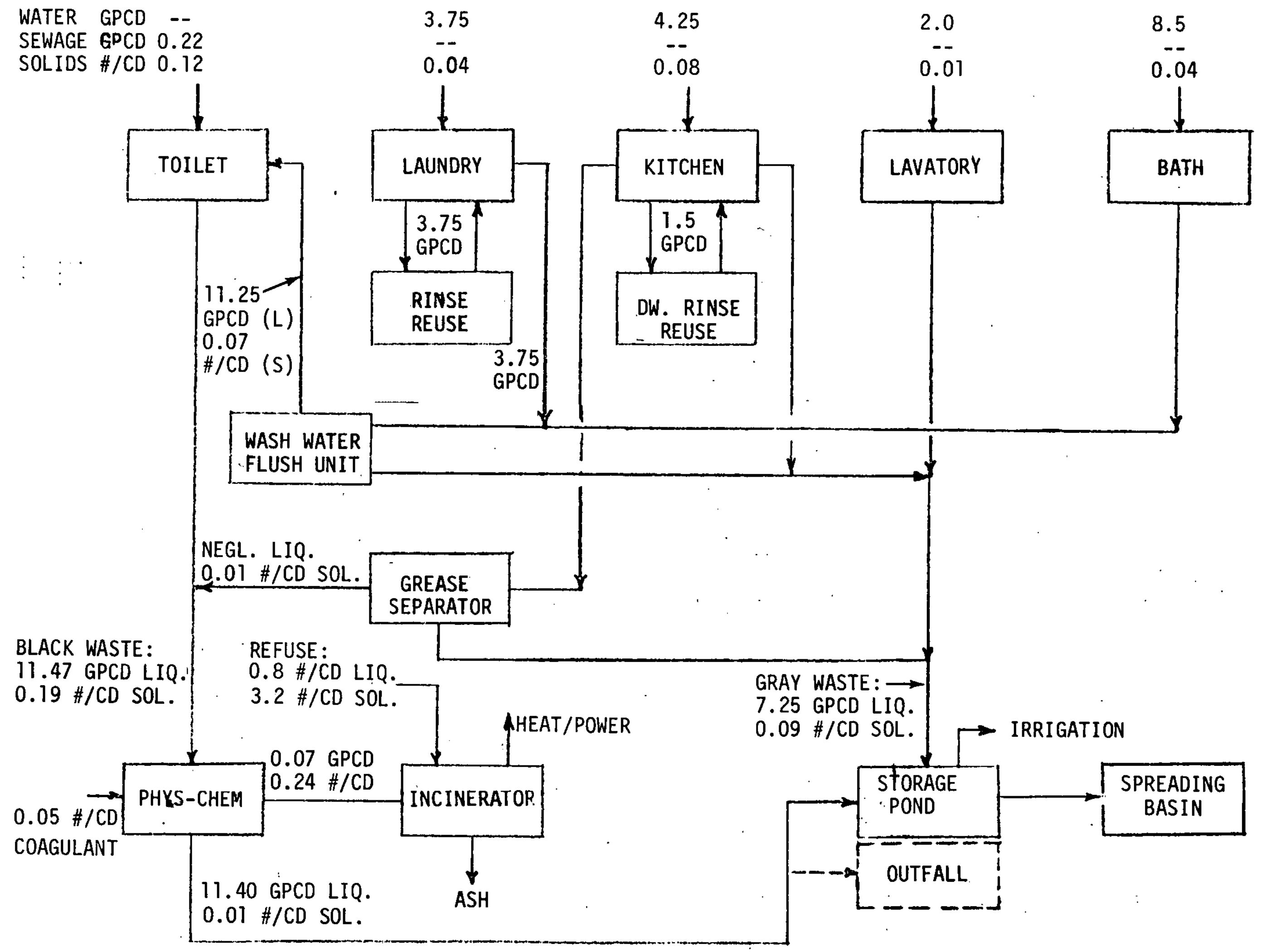
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
VACUUM TANK
BLACK WASTE: 3;4 #/CD LIQ.
0.13 #/CD SOL.
REFUSE: 0.8 #/CD LIQ.
3.2 #/CD SOL.
BURNER-INCINERATION
HEAT/POWER
ASH
NEGL. LIQ.
0.06 #/CD SOL.
-
-
0.04
LAUNDRY
3.75
GPCD
RINSE REUSE
GREASE SEPARATOR
3.75
GPCD
4.25
-
0.08
KITCHEN
1.5
GPCD
DW. RINSE REUSE
2.0
-
0.01
LAVATORY
-
-
0.04
BATH
8.5
GPCD
12.25 GPCD LIQ.
NEGEL. SOL.
GRAY WASTE:
18.5 GPCD LIQ.
0.16 #/CD SOL.
VACUUM TANK
16.25 GPCD LIQ.
0.14 #/CD SOL.
IRRIGATION
2.25 GPCD
0.02 #/CD
SPREADING BASIN
STORAGE POND
PHYS-CHEM
OUTFALL
CONCENTRATE: 4.0 GPCD LIQ.
0.08 #/CD SOL.

CONCEPT B-10

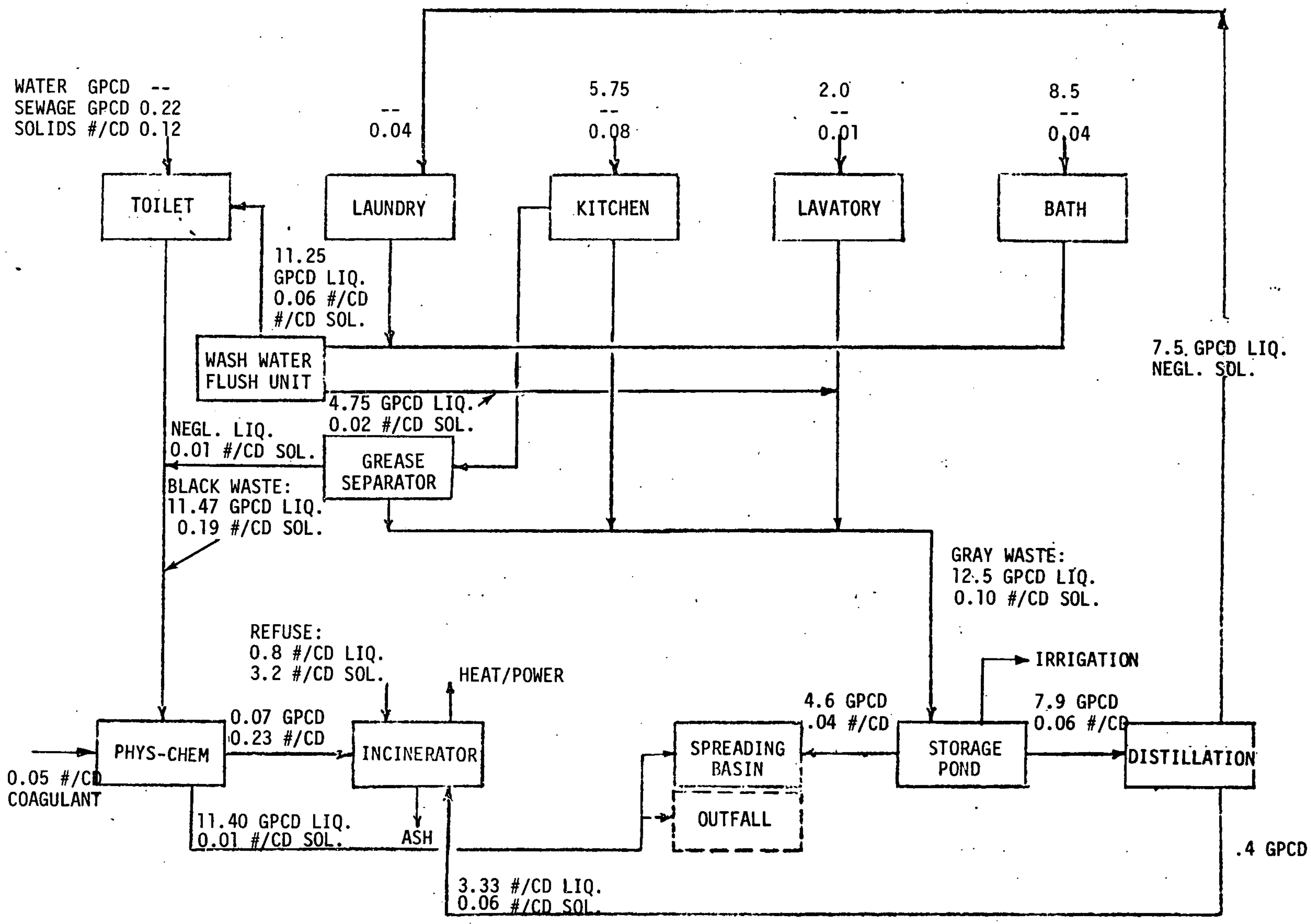

WATER GPCD -
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
7.5
-
0.04
5.75
-
0.08
2.0
-
0.01
8.5
-
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
11.25 GPCD LIQ.
0.06 #/CD SOL.
WASH WATER
FLUSH UNIT
4.75 GPCD LIQ.
0.02 #/CD SOL.
NEGL. LIQ.
0.01 #/CD SOL.
GREASE
SEPARATOR
BLACK WASTE:
11.47 GPCD LIQ.
0.19 #/CD SOL.
GRAY WASTE:
12.5 GPCD LIQ.
0.10 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
0.07 GPCD LIQ.
0.23 #/CD SOL.
0.05 #/CD
COAGULANT
PHYS-CHEM
INCINERATOR
ASH
11.40 GPCD LIQ.
0.01 #/CD SOL.
IRRIGATION
STORAGE
POND
SPREADING
BASIN
OUTFALL

CONCEPT C-1



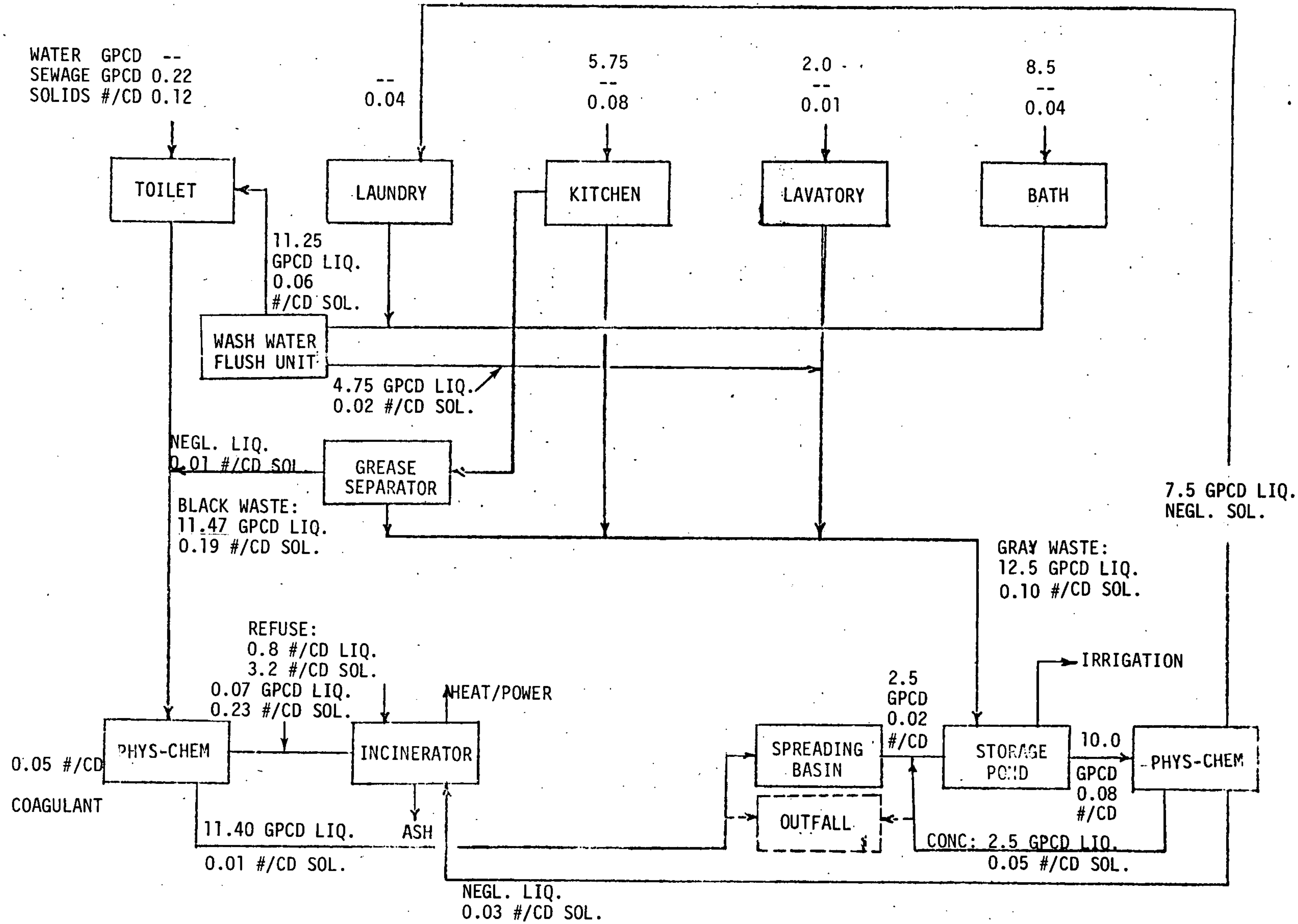
WATER GPCD --
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
3.75
--
0.04
4.25
--
0.08
2.0
--
0.01
8.5
--
0.04
TOILET
LAUNDRY
KITCHEN
LAVATORY
BATH
3.75
GPCD
1.5
GPCD
RINSE
REUSE
DW. RINSE
REUSE
11.25
GPCD (L)
0.07
#/CD (S)
3.75
GPCD
WASH WATER
FLUSH UNIT
NEGL. LIQ.
0.01 #/CD SOL.
GREASE
SEPARATOR
BLACK WASTE:
11.47 GPCD LIQ.
0.19 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
GRAY WASTE:
7.25 GPCD LIQ.
0.09 #/CD SOL.
IRRIGATION
0.07 GPCD
0.24 #/CD
PHYS-CHEM
INCINERATOR
STORAGE
POND
SPREADING
BASIN
0.05 #/CD
COAGULANT
OUTFALL
11.40 GPCD LIQ.
0.01 #/CD SOL.
ASH

CONCEPT C-2



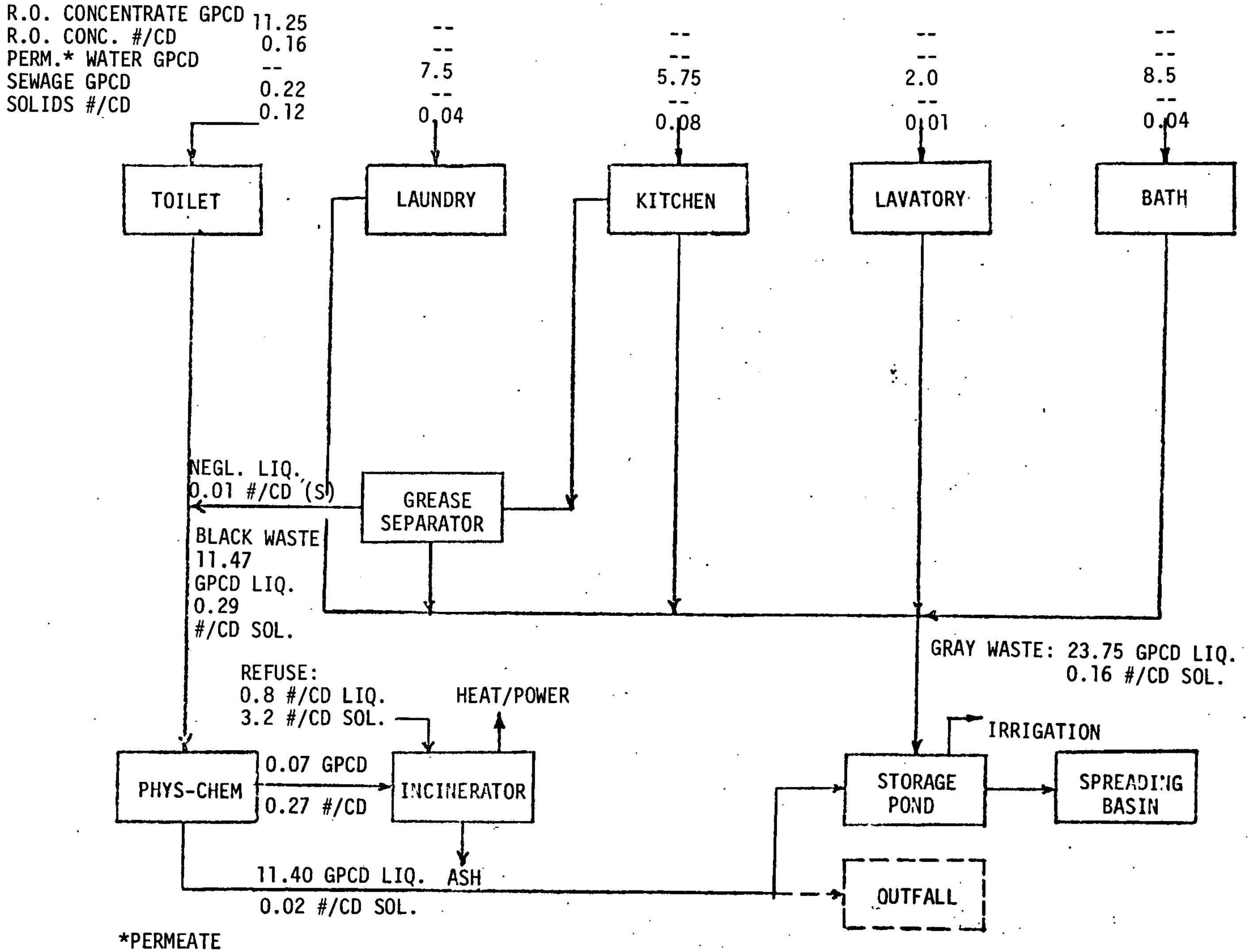
WATER GPCD --
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
0.04
LAUNDRY
5.75
--
0.08
KITCHEN
2.0
--
0.01
LAVATORY
8.5
--
0.04
BATH
11.25
GPCD LIQ.
0.06 #/CD
#/CD SOL.
WASH WATER
FLUSH UNIT
4.75 GPCD LIQ.
0.02 #/CD SOL.
NEGL. LIQ.
0.01 #/CD SOL.
GREASE
SEPARATOR
BLACK WASTE:
11.47 GPCD LIQ.
0.19 #/CD SOL.
7.5 GPCD LIQ.
NEGL. SOL.
GRAY WASTE:
12.5 GPCD LIQ.
0.10 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
IRRIGATION
0.07 GPCD
0.23 #/CD
PHYS-CHEM
INCINERATOR
0.05 #/CD
COAGULANT
11.40 GPCD LIQ.
0.01 #/CD SOL.
ASH
4.6 GPCD
.04 #/CD
SPREADING
BASIN
OUTFALL
STORAGE
POND
7.9 GPCD
0.06 #/CD
DISTILLATION
.4 GPCD
3.33 #/CD LIQ.
0.06 #/CD SOL.

CONCEPT C-3



WATER GPCD --
SEWAGE GPCD 0.22
SOLIDS #/CD 0.12
TOILET
--
0.04
LAUNDRY
5.75
--
0.08
KITCHEN
2.0
--
0.01
LAVATORY
8.5
--
0.04
BATH
11.25
GPCD LIQ.
0.06
#/CD SOL.
WASH WATER
FLUSH UNIT
4.75 GPCD LIQ.
0.02 #/CD SOL.
NEGL. LIQ.
0.01 #/CD SOL.
GREASE
SEPARATOR
BLACK WASTE:
11.47 GPCD LIQ.
0.19 #/CD SOL.
7.5 GPCD LIQ.
NEGL. SOL.
GRAY WASTE:
12.5 GPCD LIQ.
0.10 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
0.07 GPCD LIQ.
0.23 #/CD SOL.
HEAT/POWER
IRRIGATION
2.5
GPCD
0.02
#/CD
0.05 #/CD
COAGULANT
PHYS-CHEM
INCINERATOR
SPREADING
BASIN
STORAGE
POND
10.0
GPCD
0.08
#/CD
PHYS-CHEM
OUTFALL
11.40 GPCD LIQ.
0.01 #/CD SOL.
ASH
CONC: 2.5 GPCD LIQ.
0.05 #/CD SOL.
NEGL. LIQ.
0.03 #/CD SOL.

CONCEPT C-4


R.O. CONCENTRATE GPCD
R.O. CONC. #/CD
PERM.* WATER GPCD
SEWAGE GPCD
SOLIDS #/CD
11.25
0.16
--
0.22
0.12
TOILET
--
--
7.5
--
0.04
LAUNDRY
--
--
5.75
--
0.08
KITCHEN
--
--
2.0
--
0.01
LAVATORY
--
--
8.5
--
0.04
BATH
NEGL. LIQ.
0.01 #/CD (S)
GREASE SEPARATOR
BLACK WASTE
11.47
GPCD LIQ.
0.29
#/CD SOL.
GRAY WASTE: 23.75 GPCD LIQ.
0.16 #/CD SOL.
REFUSE:
0.8 #/CD LIQ.
3.2 #/CD SOL.
HEAT/POWER
IRRIGATION
PHYS-CHEM
0.07 GPCD
0.27 #/CD
INCINERATOR
STORAGE POND
SPREADING BASIN
11.40 GPCD LIQ.
0.02 #/CD SOL.
ASH
OUTFALL
*PERMEATE

CONCEPT D

C3

TABLE I CONCEPT COST COMPARISONS-PROJECTIONS TO YEAR 2000

CONCEPT	A-1						A-2						A-3						A-4					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	5.8	66.8	6.3	66.8	6.9	66.8	6.9	66.8	7.5	66.8	8.2	66.8	7.1	66.8	7.6	66.8	8.5	66.8	7.5	66.8	7.5	66.8	8.0
2. Toilet	17.8	1.5	17.8	1.7	17.8	1.8	27.9	2.9	27.9	3.1	27.9	3.4	27.9	3.0	27.9	3.2	27.9	3.5	27.9	3.1	27.9	3.1	27.9	3.4
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-		-		-		-		-		-		-	
4. Clothes Washer	6.9	0.6	6.9	0.7	6.9	0.7	6.9	0.7	6.9	0.8	6.9	0.8	8.4	0.9	8.4	1.0	8.4	1.0	6.9	0.8	6.9	0.8	6.9	0.8
5. Dishwasher	61.8	5.4	61.8	5.8	61.8	6.4	61.8	6.4	61.8	6.9	61.8	7.6	77.4	8.2	77.4	8.8	77.4	9.6	61.8	6.9	61.8	6.9	61.8	7.4
6. Building Internal Piping	25.3	2.2	25.3	2.4	25.3	2.6	25.3	2.6	25.3	2.9	25.3	3.1	25.3	2.6	25.3	2.9	25.3	3.1	51.1	5.7	51.1	5.7	51.1	6.1
7. Renovated Water Return Lines	-		-		-		-		-		-		-		-		-		-		-		-	
8. Vacuum Collection Sewer	-		-		-		-		-		-		-		-		-		-		-		-	
9. Black Water Sewer	-		-		-		-		-		-		-		-		-		100.8	11.3	123.1	13.8	125.5	15.1
10. Gray Water Sewer	-		-		-		-		-		-		-		-		-		33.3	3.7	58.8	6.5	61.5	7.4
11. Combined Sewage Sewer	215.6	18.8	247.0	23.4	263.8	27.1	103.5	10.7	132.1	14.8	145.0	17.8	95.3	10.1	121.1	13.8	131.3	16.3	-		-		-	
12. Refuse Collection	102.9	9.0	102.9	9.7	102.9	10.6	102.9	10.7	102.9	11.5	102.9	12.6	102.9	10.9	102.9	11.8	102.9	12.8	102.9	11.5	102.9	11.5	102.9	12.4
13. Grease Trap	-		-		-		-		-		-		-		-		-		4.1	0.5	4.1	0.5	4.1	0.5
14. Incinerator (Refuse and Sludge)	168.1	14.6	106.3	10.1	89.9	9.2	168.1	17.4	106.3	11.9	89.9	11.0	168.1	17.8	106.3	12.2	89.9	11.2	164.6	18.4	104.3	11.7	87.8	10.6
15. Phys-Chem: For Gray Water	-		-		-		-		-		-		-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-		-		-		-		-		-		-	
17. Bio-Treatment with AWT	283.0	24.6	162.3	15.3	106.2	10.9	218.0	22.6	130.1	14.5	80.0	9.8	192.1	20.4	114.5	13.1	73.3	9.1	89.4	10.0	53.7	6.0	23.5	2.8
18. Distillation	-		-		-		-		-		-		-		-		-		-		-		-	
19. Municipal Outfall Line	-		45.9	4.3	18.0	1.8	-		36.5	4.1	12.5	1.5	-		32.9	3.8	11.0	1.4	-		28.6	3.2	8.6	1.0
20. Cleaning Agents (Soft Water Area)	132.7	11.5	132.7	12.6	132.7	13.6	132.7	13.8	132.7	14.8	132.7	16.3	132.7	14.1	132.7	15.2	132.7	16.5	132.7	14.9	132.7	14.8	132.7	16.0
21. Water: Building, Internal	59.6	5.2	59.6	5.6	59.6	6.1	42.5	4.4	42.5	4.7	42.5	5.2	36.3	3.9	36.3	4.1	36.3	4.5	42.5	4.8	42.5	4.8	42.5	5.1
22. Water: Lawn Irrigation	0		22.1	2.1	22.1	2.3	1.0	0.1	22.1	2.5	22.1	2.7	2.1	0.2	22.1	2.5	22.1	2.7	0.8	0.1	22.1	2.5	22.1	2.7
23. Municipal Water Softening (R.O.)	-		-		-								-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-								-		-		-		-		-		-	
25. Storage Ponds	8.9	0.8	-		-		7.5	0.8	-		-		7.2	0.8	-		-		7.5	0.8	6.2	0.7	6.2	0.7
TOTAL: SOFT WATER AREA	1149.4	100.0	1057.4	100.0	973.8	100.0	964.9	100.0	893.9	100.0	816.3	100.0	942.5	100.0	874.6	100.0	805.3	100.0	893.1	100.0	893.5	100.0	831.9	100.0
ADDITIONAL FOR HARD WATER AREA	132.7		132.7		132.7		132.7		132.7		132.7		132.7		132.7		132.7		132.7		132.7		132.7	
TOTAL: HARD WATER AREA	1282.1		1190.1		1106.5		1097.6		1026.6		949.0		1075.2		1007.3		938.0		1025.8		1026.2		964.6	

TABLE I CONCEPT COST COMPARISONS-PROJECTIONS TO YEAR 2000 (Continued)

CONCEPT	B-1						B-2					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	8.8	66.8	9.5	66.8	9.7	66.8	8.6	66.8	9.3	66.8	9.5
2. Toilet	59.0	7.7	59.0	8.4	59.0	8.6	59.0	7.6	59.0	8.2	59.0	8.4
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-	
4. Clothes Washer	6.9	0.9	6.9	1.0	6.9	1.0	8.4	1.1	8.4	1.2	8.4	1.2
5. Dishwasher	61.8	8.1	61.8	8.8	61.8	9.0	77.4	9.9	77.4	10.8	77.4	11.1
6. Building Internal Piping	51.2	6.7	51.2	7.2	51.2	7.5	51.2	6.6	51.2	7.1	51.2	7.3
7. Renovated Water Return Lines	-		-		-		-		-		-	
8. Vacuum Collection Sewer	68.9	9.0	70.1	10.0	70.1	10.2	68.9	8.9	70.1	9.8	70.1	10.0
9. Black Water Sewer	-		-		-		-		-		-	
10. Gray Water Sewer	-		-		-		-		-		-	
11. Combined Sewage Sewer	-		-		-		-		-		-	
12. Refuse Collection	102.9	13.5	102.9	14.6	102.9	15.0	102.9	13.2	102.9	14.4	102.9	14.7
13. Grease Trap	4.1	0.5	4.1	0.6	4.1	0.6	4.1	0.5	4.1	0.6	4.1	0.6
14. Incinerator (Refuse and Sludge)	166.7	21.8	105.3	15.0	88.8	12.9	166.7	21.4	105.3	14.7	88.8	12.7
15. Phys-Chem: For Gray Water	-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-	
17. Bio-Treatment with AWT	-		-		-		-		-		-	
18. Distillation	-		-		-		-		-		-	
19. Municipal Outfall Line	-		-		-		-		-		-	
20. Cleaning Agents (Soft Water Area)	132.7	17.4	132.7	18.8	132.7	19.3	132.7	17.1	132.7	18.5	132.7	18.9
21. Water: Building, Internal	29.2	3.8	29.2	4.1	29.2	4.2	22.7	2.9	22.7	3.2	22.7	3.2
22. Water: Lawn Irrigation	7.7	1.0	7.7	1.1	7.7	1.1	10.8	1.4	10.8	1.5	10.8	1.6
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-	
25. Storage Ponds	6.2	0.8	6.2	0.9	6.2	0.9	5.4	0.7	5.4	0.7	5.4	0.8
TOTAL: SOFT WATER AREA	764.1	100.0	703.9	100.0	687.4	100.0	777.0	100.0	716.8	100.0	700.3	100.0
ADDITIONAL FOR HARD WATER AREA	132.7		132.7		132.7		132.7		132.7		132.7	
TOTAL: HARD WATER AREA	896.8		836.6		820.1		909.7		849.5		833.0	

CONCEPT	B-3						B-4					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	8.0	66.8	8.3	66.8	8.9	66.8	8.2	66.8	8.2	66.8	8.9
2. Toilet	59.0	7.0	59.0	7.3	59.0	7.9	59.0	7.2	59.0	7.3	59.0	7.9
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-	
4. Clothes Washer	6.9	0.8	6.9	0.9	6.9	0.9	8.4	1.0	8.4	1.0	8.4	1.1
5. Dishwasher	61.8	7.4	61.8	7.7	61.8	8.3	77.4	9.5	77.4	9.5	77.4	10.3
6. Building Internal Piping	42.6	5.1	42.6	5.3	42.6	5.7	42.6	5.2	42.6	5.2	42.6	5.7
7. Renovated Water Return Lines	5.4	0.6	4.5	0.6	6.0	0.8	5.4	0.7	4.5	0.6	6.0	0.8
8. Vacuum Collection Sewer	68.9	8.2	70.1	8.7	70.1	9.4	68.9	8.4	70.1	8.7	70.1	9.4
9. Black Water Sewer	-		-		-		-		-		-	
10. Gray Water Sewer	-		31.0	3.8	26.3	3.5	-		46.6	5.7	23.9	3.2
11. Combined Sewage Sewer	-		-		-		-		-		-	
12. Refuse Collection	102.9	12.3	102.9	12.8	102.9	13.8	102.9	12.6	102.9	12.6	102.9	13.7
13. Grease Trap	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5
14. Incinerator (Refuse and Sludge)	169.8	20.3	107.7	13.4	90.6	12.1	168.8	20.6	107.0	13.1	90.2	12.0
15. Phys-Chem: For Gray Water	-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-	
17. Bio-Treatment with AWT	-		-		-		-		-		-	
18. Distillation	77.8	9.3	42.3	5.3	23.8	3.2	44.6	5.4	24.3	3.0	14.2	1.9
19. Municipal Outfall Line	-		23.5	2.9	6.3		-		22.3	2.7	5.9	0.8
20. Cleaning Agents (Soft Water Area)	132.7	15.9	132.7	16.5	132.7	17.7	132.7	16.2	132.7	16.3	132.7	17.7
21. Water: Building, Internal	20.0	2.4	20.0	2.5	20.0	2.7	18.1	2.2	18.1	2.2	18.1	2.4
22. Water: Lawn Irrigation	12.5	1.5	22.1	2.7	22.1	3.0	13.1	1.6	22.1	2.7	22.1	3.0
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-	
25. Storage Ponds	6.2	0.7	6.2	0.8	6.2	0.8	5.4	0.7	5.4	0.7	5.4	0.7
TOTAL: SOFT WATER AREA	837.4	100.0	804.2	100.0	748.2	100.0	818.2	100.0	814.3	100.0	749.8	100.0
ADDITIONAL FOR HARD WATER AREA	22.9		22.9		22.9		22.9		22.9		22.9	
TOTAL: HARD WATER AREA	860.3		827.1		771.1		841.1		837.2		772.7	

TABLE I CONCEPT COST COMPARISONS-PROJECTIONS TO YEAR 2000 (Continued)

CONCEPT	B-5						B-6						B-7						B-8					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	7.4	66.8	8.1	66.8	8.7	66.8	7.4	66.8	8.1	66.8	8.7	66.8	7.9	66.8	8.3	66.8	8.9	66.8	8.0	66.8	8.2	66.8	8.9
2. Toilet	59.0	6.5	59.0	7.2	59.0	7.7	59.0	6.6	59.0	7.2	59.0	7.7	59.0	7.0	59.0	7.3	59.0	7.8	59.0	7.1	59.0	7.3	59.0	7.8
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-		-		-		-		-		-		-	
4. Clothes Washer	6.9	0.8	6.9	0.8	6.9	0.9	8.4	0.9	8.4	1.0	8.4	1.1	6.9	0.8	6.9	0.8	6.9	0.9	8.4	1.0	8.4	1.0	8.4	1.1
5. Dishwasher	61.8	6.8	61.8	7.5	61.8	8.1	77.4	8.6	77.4	9.4	77.4	10.0	61.8	7.3	61.8	7.7	61.8	8.2	77.4	9.3	77.4	9.5	77.4	10.3
6. Building Internal Piping	47.8	5.3	47.8	5.8	47.8	6.2	47.8	5.3	47.8	5.8	47.8	6.2	42.6	5.0	42.6	5.3	42.6	5.6	42.6	4.7	42.6	5.2	42.6	5.6
7. Renovated Water Return Lines	10.2	1.1	8.4	1.0	8.7	1.1	10.2	1.1	8.4	1.0	8.7	1.1	5.4	0.6	4.5	0.6	6.0	0.8	5.4	0.6	4.5	0.6	6.0	0.8
8. Vacuum Collection Sewer	68.9	7.6	70.1	8.5	70.1	9.2	68.9	7.7	70.1	8.5	70.1	9.1	68.9	8.2	70.1	8.6	70.1	9.3	68.9	8.3	70.1	8.6	70.1	9.3
9. Black Water Sewer	-		-		-		-		-		-		-		-		-		-		-		-	
10. Gray Water Sewer	-		24.3	3.0	31.4	4.1	-		24.3	3.0	29.4	3.8	-		27.4	3.4	27.4	3.6	-		41.2	5.1	24.7	3.3
11. Combined Sewage Sewer	-		-		-		-		-		-		-		-		-		-		-		-	
12. Refuse Collection	102.9	11.4	102.9	12.6	102.9	13.4	102.9	11.4	102.9	12.5	102.9	13.3	102.9	12.2	102.9	12.8	102.9	13.6	102.9	12.4	102.9	12.7	102.9	13.7
13. Grease Trap	4.1	0.4	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.6	4.1	0.5	4.1	0.5	4.1	0.5
14. Incinerator (Refuse and Sludge)	172.2	19.1	109.1	13.3	91.9	12.0	171.8	19.1	109.1	13.3	91.9	11.9	168.1	19.9	106.3	13.2	89.9	11.9	168.1	20.3	106.3	13.1	89.9	11.9
15. Phys-Chem: For Gray Water	-		-		-		-		-		-		87.1	10.3	49.7	6.2	29.8	4.0	56.9	6.9	28.8	3.5	17.8	2.4
16. Phys-Chem: For Black Water	-		-		-		-		-		-		-		-		-		-		-		-	
17. Bio-Treatment with AWT	-		-		-		-		-		-		-		-		-		-		-		-	
18. Distillation	136.4	15.1	70.9	8.7	41.2	5.4	117.8	13.1	58.6	7.1	33.4	4.3	-		-		-		-		-		-	
19. Municipal Outfall Line	-		17.2	2.1	3.9	0.5	-		16.5	2.0	3.5	0.5	-		23.5	2.9	6.3	0.8	-		22.7	2.8	5.9	0.8
20. Cleaning Agents (Soft Water Area)	132.7	14.7	132.7	16.2	132.7	17.3	132.7	14.7	132.7	16.2	132.7	17.2	132.7	15.7	132.7	16.4	132.7	17.6	132.7	16.0	132.7	16.3	132.7	17.6
21. Water: Building, Internal	9.6	1.1	9.6	1.2	9.6	1.2	7.9	0.9	7.9	1.0	7.9	1.0	20.0	2.4	20.0	2.5	20.0	2.7	18.1	2.2	18.1	2.2	18.1	2.4
22. Water: Lawn Irrigation	17.9	2.0	22.1	2.7	22.1	2.9	18.6	2.1	22.1	2.7	22.1	2.9	12.3	1.5	22.1	2.7	22.1	2.9	13.1	1.6	22.1	2.7	22.1	2.9
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-		-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-		-		-		-		-		-		-	
25. Storage Ponds	6.2	0.7	6.2	0.8	6.2	0.8	5.4	0.6	5.4	0.7	5.4	0.7	6.2	0.7	6.2	0.8	6.2	0.8	5.4	0.6	5.4	0.7	5.4	0.7
TOTAL: SOFT WATER AREA	903.4	100.0	819.9	100.0	767.1	100.0	899.7	100.0	821.5	100.0	771.5	100.0	844.8	100.0	806.6	100.0	754.5	100.0	829.8	100.0	813.1	100.0	753.9	100.0
ADDITIONAL FOR HARD WATER AREA	-		-		-		-		-		-		22.9		22.9		22.9		22.9		22.9		22.9	
TOTAL: HARD WATER AREA	903.4		819.9		767.1		899.7		821.5		771.5		867.7		829.5		777.5		852.9		836.0		776.8	

TABLE I CONCEPT COST COMPARISONS-PROJECTIONS TO YEAR 2000 (Continued)

CONCEPT	B-9						B-10						C-1						C-2					
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	7.1	66.8	8.0	66.8	8.5	66.8	7.4	66.8	7.9	66.8	8.5	66.8	7.4	66.8	7.9	66.8	8.2	66.8	7.2	66.8	7.5	66.8	7.9
2. Toilet	59.0	6.3	59.0	7.0	59.0	7.5	59.0	6.5	59.0	7.0	59.0	7.5	27.9	3.1	27.9	3.3	27.9	3.4	27.9	3.0	27.9	3.1	27.9	3.3
3. Wash Water Toilet Flush Unit	-		-		-		-		-		-		15.3	1.7	15.3	1.8	15.3	1.9	15.3	1.7	15.3	1.7	15.3	1.8
4. Clothes Washer	6.9	0.7	6.9	0.8	6.9	0.9	8.4	0.9	8.4	1.0	8.4	1.1	6.9	0.8	6.9	0.8	6.9	0.8	8.4	0.9	8.4	0.9	8.4	1.0
5. Dishwasher	61.8	6.6	61.8	7.4	61.8	7.9	77.4	8.5	77.4	9.1	77.4	9.9	61.8	6.9	61.8	7.3	61.8	7.5	77.4	8.4	77.4	8.7	77.4	9.1
6. Building Internal Piping	47.8	5.1	47.8	5.8	47.8	6.2	47.8	5.3	47.8	5.6	47.8	6.2	59.0	6.6	59.0	7.0	59.0	7.2	59.0	6.4	59.0	6.6	59.0	6.9
7. Renovated Water Return Lines	10.2	1.1	8.4	1.0	8.7	1.1	10.2	1.1	8.4	1.0	8.7	1.1	-		-		-		5.4	0.6	4.5	0.5	6.0	0.7
8. Vacuum Collection Sewer	68.9	7.4	70.1	8.3	70.1	9.0	68.9	7.6	70.1	8.2	70.1	9.0	-		-		-		-		-		-	
9. Black Water Sewer	-		-		-		-		-		-		100.8	11.2	123.1	14.5	125.5	15.3	100.8	10.9	123.1	13.8	125.5	14.8
10. Gray Water Sewer	-		25.5	3.1	33.7	4.3	-		24.3	2.9	31.4	4.0	33.3	3.7	58.8	6.9	61.5	7.5	33.3	3.6	58.8	6.6	61.5	7.2
11. Combined Sewage Sewer	-		-		-		-		-		-		-		-		-		-		-		-	
12. Refuse Collection	102.9	11.0	102.9	12.3	102.9	13.1	102.9	11.4	102.9	12.1	102.9	13.1	102.9	11.5	102.9	12.1	102.9	12.6	102.9	11.1	102.9	11.6	102.9	12.1
13. Grease Trap	4.1	0.4	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.5	4.1	0.4	4.1	0.5	4.1	0.5	4.1	0.4	4.1	0.5	4.1	0.5
14. Incinerator (Refuse and Sludge)	168.1	18.0	106.3	12.7	89.9	11.5	168.1	18.5	106.3	12.5	89.9	11.5	166.7	18.5	105.3	12.4	88.8	10.8	169.8	18.3	107.7	12.1	90.6	10.7
15. Phys-Chem: For Gray Water	173.6	18.6	89.9	10.7	56.6	7.2	129.0	14.2	89.2	10.5	44.9	5.7	-		-		-		-		-		-	
16. Phys-Chem: For Black Water	-		-		-		-		-		-		76.8	8.5	35.7	4.2	17.8	2.2	76.8	8.3	35.7	4.0	17.8	2.1
17. Bio-Treatment with AWT	-		-		-		-		-		-		-		-		-		-		-		-	
18. Distillation	-		-		-		-		-		-		-		-		-		-		-		-	
19. Municipal Outfall Line	-		17.6	2.1	3.9	0.5	-		16.9	2.0	3.5	0.5	-		-		-		-		15.7	1.8	3.1	0.4
20. Cleaning Agents (Soft Water Area)	132.7	14.2	132.7	15.8	132.7	17.0	132.7	14.6	132.7	15.6	132.7	16.9	132.7	14.8	132.7	15.6	132.7	16.2	132.7	14.3	132.7	14.9	132.7	15.6
21. Water: Building, Internal	9.6	1.0	9.6	1.2	9.6	1.2	7.9	0.9	7.9	0.9	7.9	1.0	29.0	3.2	29.0	3.4	29.0	3.5	29.0	3.1	29.0	3.3	29.0	3.4
22. Water: Lawn Irrigation	17.3	1.8	22.1	2.6	22.1	2.8	18.3	2.0	22.1	2.6	22.1	2.8	7.7	0.9	14.6	1.7	14.6	1.8	10.6	1.2	17.7	2.0	17.7	2.1
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-		-		-		-		-		-		-	
24. R. O. Concentrate Distribution System	-		-		-		-		-		-		-		-		-		-		-		-	
25. Storage Ponds	6.2	0.7	6.2	0.7	6.2	0.8	5.4	0.6	5.4	0.6	5.4	0.7	6.2	0.7	4.8	0.6	4.8	0.6	5.5	0.6	3.8	0.4	3.8	0.4
TOTAL: SOFT WATER AREA	935.9	100.0	837.7	100.0	782.8	100.0	906.9	100.0	849.7	100.0	783.0	100.0	897.9	100.0	848.7	100.0	819.4	100.0	925.7	100.0	890.5	100.0	849.5	100.0
ADDITIONAL FOR HARD WATER AREA	-		-		-		-		-		-		132.7		132.7		132.7		132.7		132.7		132.7	
TOTAL: HARD WATER AREA	935.9		837.7		782.8		906.9		849.7		783.0		1030.6		981.4		952.1		1058.4		1023.2		982.2	

TABLE I CONCEPT COST COMPARISONS-PROJECTIONS TO YEAR 2000 (Continued)

CONCEPT	C-3						C-4						D											
POPULATION	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%	$/FY	%
1. Water Fixtures	66.8	6.9	66.8	7.4	66.8	7.9	66.8	6.8	66.8	7.3	66.8	7.9	66.8	6.6	66.8	7.2	66.8	7.8						
2. Toilet	27.9	2.9	27.9	3.1	27.9	3.3	27.9	2.8	27.9	3.1	27.9	3.3	27.9	2.7	27.9	3.0	27.9	3.2						
3. Wash Water Toilet Flush Unit	15.3	1.6	15.3	1.7	15.3	1.8	15.3	1.6	15.3	1.7	15.3	1.8	-		-		-							
4. Clothes Washer	6.9	0.7	6.9	0.8	6.9	0.8	6.9	0.7	6.9	0.7	6.9	0.8	6.9	0.7	6.9	0.7	6.9	0.8						
5. Dishwasher	61.8	6.4	61.8	6.9	61.8	7.3	61.8	6.3	61.8	6.8	61.8	7.3	61.8	6.1	61.8	6.7	61.8	7.2						
6. Building Internal Piping	50.5	5.2	50.5	5.6	50.5	6.0	50.5	5.2	50.5	5.6	50.5	6.0	59.0	5.8	59.0	6.3	59.0	6.9						
7. Renovated Water Return Lines	5.4	0.5	4.5	0.5	6.0	0.7	5.4	0.6	4.5	0.5	6.0	0.7	-		-		-							
8. Vacuum Collection Sewer	-		-		-		-		-		-		-		-		-							
9. Black Water Sewer	100.8	10.4	123.1	13.7	125.5	14.9	100.8	10.3	123.1	13.5	125.5	14.8	100.8	10.0	123.1	13.3	125.5	14.6						
10. Gray Water Sewer	33.3	3.4	58.8	6.5	61.5	7.4	33.3	3.4	60.7	6.7	60.7	7.1	33.3	3.3	58.8	6.3	61.5	7.2						
11. Combined Sewage Sewer	-		-		-		-		-		-		-		-		-							
12. Refuse Collection	102.9	10.6	102.9	11.4	102.9	12.2	102.9	10.5	102.9	11.3	102.9	12.2	102.9	10.2	102.9	11.1	102.9	12.0						
13. Grease Trap	4.1	0.4	4.1	0.5	4.1	0.5	4.1	0.4	4.1	0.4	4.1	0.5	4.1	0.4	4.1	0.4	4.1	0.5						
14. Incinerator (Refuse and Sludge)	169.8	17.5	107.7	12.0	90.6	10.8	168.1	17.2	106.3	11.7	89.9	10.6	166.7	16.5	105.3	11.3	88.8	10.3						
15. Phys-Chem: For Gray Water	-		-		-		87.8	9.0	49.7	5.5	29.5	3.5	-		-		-							
16. Phys-Chem: For Black Water	76.8	7.9	35.7	4.0	17.8	2.1	76.8	7.8	35.7	3.9	17.8	2.1	76.8	7.6	35.7	3.9	17.8	2.1						
17. Bio-Treatment with AWT	-		-		-		-		-		-		-		-		-							
18. Distillation	77.8	8.0	42.3	4.7	23.8	2.8	-		-		-		-		-		-							
19. Municipal Outfall Line	-		15.7	1.7	3.1	0.4	-		15.7	1.7	3.1	0.4	-		20.0	2.2	5.1	0.6						
20. Cleaning Agents (Soft Water Area)	132.7	13.7	132.7	14.7	132.7	15.8	132.7	13.6	132.7	14.6	132.7	15.7	132.7	13.1	132.7	14.3	132.7	15.5						
21. Water: Building, Internal	19.8	2.0	19.8	2.2	19.8	2.4	19.8	2.0	19.8	2.2	19.8	2.3	29.0	2.9	29.0	3.1	29.0	3.4						
22. Water: Lawn Irrigation	12.3	1.3	19.4	2.1	19.4	2.3	11.9	1.2	20.6	2.3	20.6	2.4	1.0	0.1	1.0	0.1	1.0	0.1						
23. Municipal Water Softening (R.O.)	-		-		-		-		-		-		122.6	12.1	77.1	8.3	51.5	6.0						
24. R. O. Concentrate Distribution System	-		-		-		-		-		-		11.8	1.2	9.8	1.1	9.8	1.1						
25. Storage Ponds	6.2	0.6	4.8	0.5	4.8	0.6	6.2	0.6	4.8	0.5	4.8	0.6	7.5	0.7	6.2	0.7	6.2	0.7						
TOTAL: SOFT WATER AREA	971.1	100.0	900.7	100.0	841.2	100.0	979.0	100.0	909.8	100.0	846.6	100.0												
ADDITIONAL FOR HARD WATER AREA	22.9		22.9		22.9		22.9		22.9		22.9													
TOTAL: HARD WATER AREA	994.0		923.6		864.1		1001.9		932.7		869.5		1011.6	100.0	928.1	100.0	858.3	100.0						

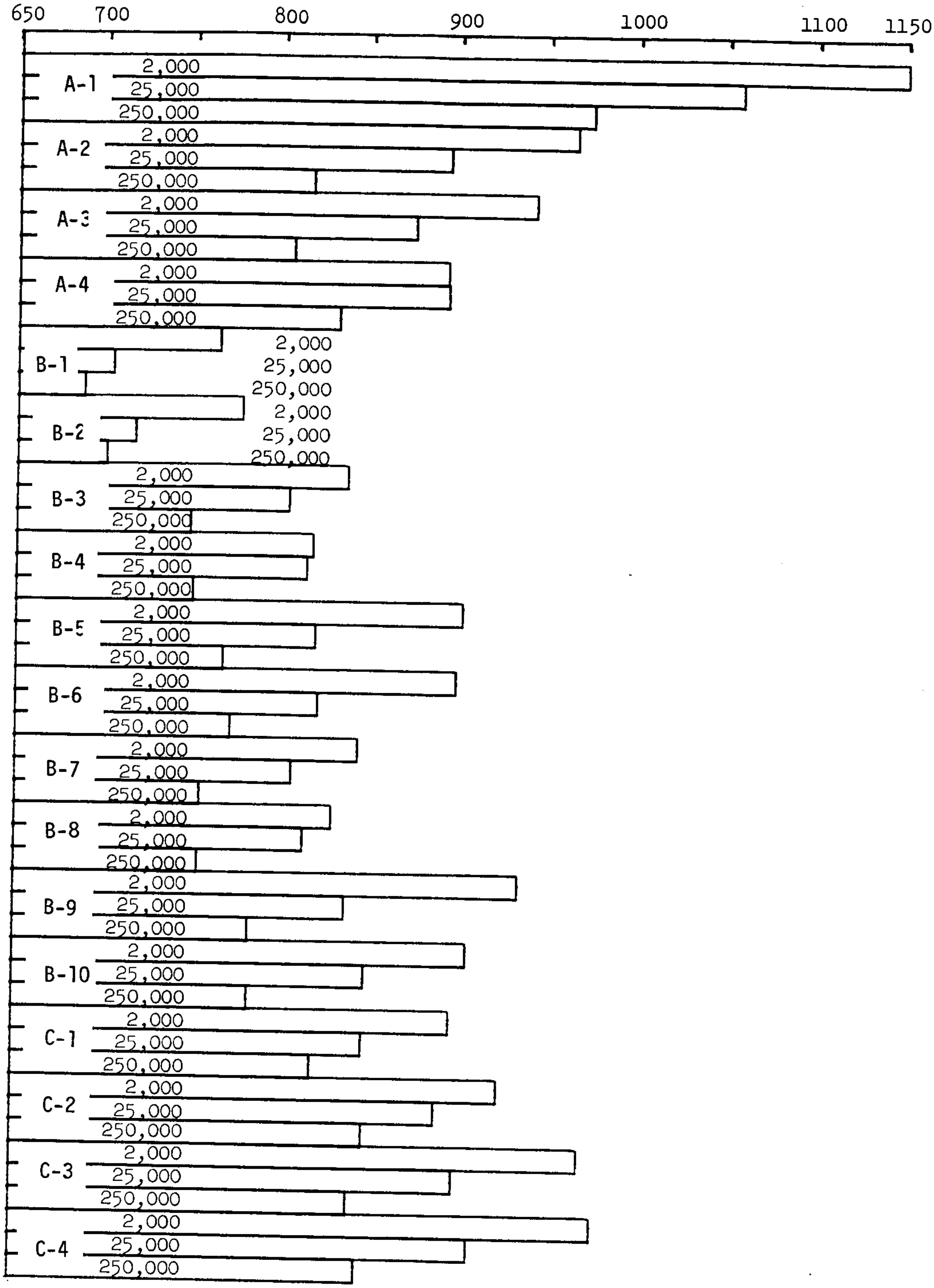


Figure I Total Cost ($/Family-Year) Soft Water Area 2000 A.D.

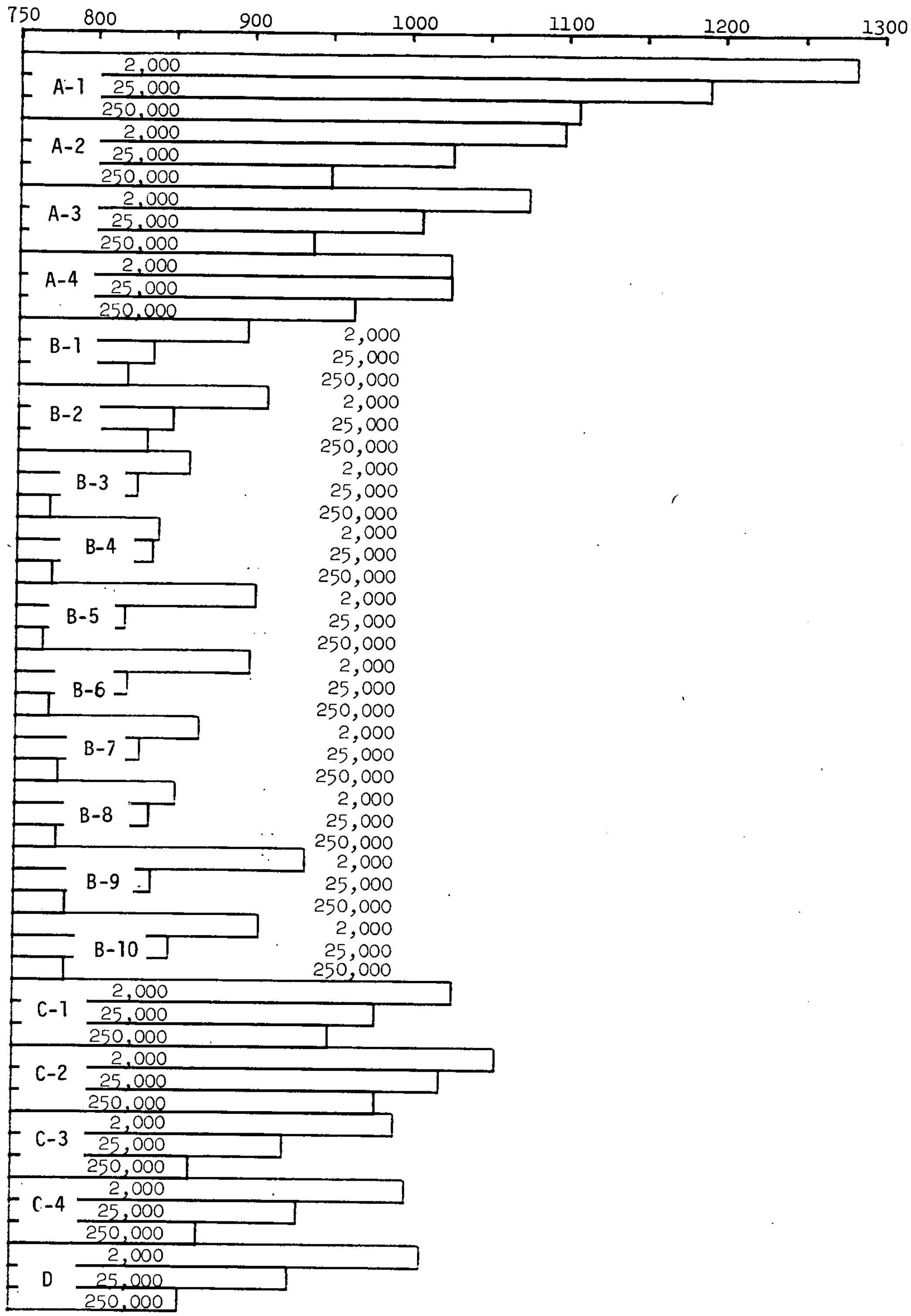


Figure II Total Cost ($/Family-Year) Hard Water Area 2000 A.D.

APPENDIX B

POWER GENERATION SYSTEMS

Although the consideration of total energy systems or even simple power generation is beyond the scope of the study contract, a preliminary review of thermal-power systems was made. This review compared methods and requirements of integrating power generation, water purification, air conditioning, space heating, water heating, etc. in a 500 unit, 2000 population garden apartment complex. Distillation was included in this review in order to understand the effects of all thermal aspects of the total energy approach.

The temperature levels at which various processes would normally take place were investigated first to establish the order in which energy should be used as it degrades in availability during its use. For example, heat supplied at 250^{o}F to distill water could be rejected in a water condenser at 215 - 220^{o}F and then used in an absorption refrigeration system which needs a heat input in the 150 - 200^{o}F range. Also, consideration was given to the various outputs of the different processes, whether as work, heat, hot water, hot gas, etc.

As suggested in the referenced NASA Report, a gas turbine was considered as a primary means of electrical power generation. The configuration shown in the report was a regenerative Brayton Cycle with external heat addition from combustion of fuel and/or refuse. A refuse incinerator which would operate most effectively at about 1800^{o}F was assumed. This temperature was also assumed for the combustion of fuel. This implies the use of about 200% excess air or an air-fuel ratio of about 44. This permits a 1500^{o}F turbine inlet temperature for the gas turbine. Reference to the NASA Report for this condition indicates that the air temperature leaving the regenerator and entering the main heater is at 1071^{o}F. This means that the burner exhaust gas can only be cooled to around 1100^{o}F. Since the heating value normally quoted for a fuel considers that it will be cooled back to ambient temperature, it can be seen that less than one-half the available energy in the fuel is actually being used for the gas turbine, i.e. it is cooled from 1800 to 1100^{o}F for a Δt of 700^{o}F rather than 1800 to 100^{o}F for a Δt of 1700^{o}F. This residual energy obviously can be used for other purposes such as water purification. It however, represents relatively high grade energy which might better be used for power generation. For this reason it was decided to study a compound system using a non-regenerative gas turbine at the higher temperature levels as discussed above and a bottoming Rankine cycle to use the energy from the gas turbine exhaust and the combustion system exhaust.

Rankine cycle systems have been the most popular for central station power generation for many years. Steam has almost universally been used as the working fluid. In recent years, however, as the result of the space program and a search for lower pollution automotive power plants other fluids have increasingly been studied. Liquid metals, mercury, potassium, sodium, and rubidium have been the major contenders for high temperature use while various organic fluids have been shown to provide good efficiency even at moderate temperatures. The choice of working fluid can be made based on power level, available temperatures, etc. One of the major advantages of the Rankine cycle particularly with the organics, is the use of moderate temperature in the 500-800^{o}F range. Virtually any heat source can be used with this cycle such as concentrated sunlight, waste heat from combustion processes or even gas turbine exhaust. The waste heat available from this type of system is generally at temperature levels compatible with domestic water heating and space heating. If a Rankine cycle is used as a "bottoming" engine to a gas turbine, the overall specific fuel consumption can be as low as 0.35 lb./HP hr.

Assuming the same turbine conditions as in the NASA study but with ambient air entering the compressor of the gas turbine, the combustion exhaust gas can be cooled to at least 500°F while the gas turbine exhaust is on the order of 1100°F. Mixing these can provide a heat source at about 800°F for the boiler of the Rankine cycle. There are a number of potential working fluids available which are thermally stable to around 700°F which is compatible with this heat source. The work produced in this cycle is approximately equal to that of the gas turbine which reduces the specific fuel consumption of the combined system to about half that of the gas turbine.

Heat rejection from the condenser of the Rankine cycle (80-85% of the input) will take place by condensation at typically 200 - 300°F which when combined with the residual energy from the burner and gas turbine exhaust streams can provide the energy for a considerable amount of distillation for water purification.

Data from the NASA Report indicates the need for electrical power generation for the 500 apartment complex at about 630 KW peak and about 480 KW average exclusive of water purification. This latter function can be performed in several ways. If sufficient waste heat is available for simple distillation this could be used. Additionally, some electrical or combustion energy could be supplied if sufficient waste heat were not available. Another method would be vapor recompression in which the steam produced is compressed to a higher pressure and temperature such that its condensation provides the heat required for boiling. The review done here assumed that supplemental combustion provides heat where the waste heat is insufficient.

An average power requirement of 500 KW was assumed for this review. A comparison was also made between the performance of the closed regenerative Brayton (Gas Turbine) System with and without the bottoming Rankine cycle and the non-regenerative Brayton cycle with a Rankine. The results are summarized in Table I. These results should be considered only as showing trends rather than as absolute values for design use since some simplifying assumptions were made. A more detailed thermal analysis is obviously required to more accurately define system and component performance characteristics. In addition, optimum temperature levels of operation for the various processes would result from more detailed analysis.

It can be seen that insufficient heat is available to perform all the necessary functions. With any of the power cycles, additional fuel is required to augment the waste heat in order to operate the air conditioning system at high average loads. An absorption refrigeration system is assumed.

Two approaches to combining the refrigeration machine and distillation process were examined. The approach reflected in the table is the utilization of the heat being rejected by the absorption cycle, as the input for distillation. This provides 16,300 lbs./hr. of distilled water. The other approach is having the waste heat provide energy for boiling water and the heat rejected by the condensing water as the input to the absorption machine. Since the heat into the absorption machine is significantly less than that being rejected, the amount of water distilled is marginally adequate. This approach remains viable because the temperature relationships are better.

TABLE I POWER SYSTEM COMPARISON

		Regenerative Brayton	Regenerative Brayton with Organic Rankine	Non-regenerative Brayton with Organic Rankine	Diesel
Electrical Power	KW	500	500	500	500
Fuel for Power Generation	#/hr	890	708	510	300
Peak Summer Air Conditioning Input	BTU/hr	12.4 mil	12.4 mil	12.4 mil	12.4 mil
Waste Heat Available from Power Gen.	BTU/hr	9.4 mil	6.4 mil	5.9 mil	0.98 mil
Supplemental Heat Required for A/C	BTU/hr	3.0 mil	6.0 mil	6.5 mil	11.4 mil
Supplemental Fuel for A/C Input	#/hr	272	460	492	723
Water Distilled from Waste Heat	#/hr	16,300	16,300	16,300	16,300
Water Distilled from Supplemental Heat	#/hr	0	0	0	0
Total Water Distilled	#/hr	16,300	16,300	16,300	16,300
Peak Winter Heat Required	BTU/hr	9.4 mil	9.4 mil	9.4 mil	9.4 mil
Waste Heat Available from Power Gen.	BTU/hr	9.4 mil	6.4 mil	5.9 mil	0.98 mil
Supplemental Heat Required for Heating	BTU/hr	0	3.0 mil	3.5 mil	8.4 mil
Supplemental Fuel for Heating	#/hr	0	189	221	530
Water Distilled from Waste Heat	#/hr	8320	5660	5220	870
Water Distilled from Supplemental Heat	#/hr	0	2660	3100	7450
Total Water Distilled	#/hr	8320	8320	8320	8320
Incinerator Net Heat	BTU/hr	1.25 mil	1.25 mil	1.25 mil	1.25 mil
Fuel Equivalent for Incinerator Heat	#/hr	79	79	79	79
Total Fuel Consumption with Incinerator					
Summer		1083	1089	923	944
Winter		811	818	652	751

In the winter operation, where the absorption system heat rejection is not available, the regenerative Brayton cycle is capable of providing building heat and distilling 8320 lbs./hr. of water without any supplemental fuel. When the other cycles are supplemented to provide sufficient building heating, the same quantity of water can be distilled. To distill 16,300 lbs./hr. of water each cycle would require the same increment of fuel above that required for power and building heating. The table shows the comparison for the lower distillation rate.

A brief look was taken at the use of a diesel engine to provide the required electrical power. The efficiency of the diesel is superior to that of the gas turbine or combined cycles. As a result less fuel is required for power generation. Since less heat is available for distillation and/or air conditioning, the additional fuel required to provide these services brings the total to about the same as for the other systems.

The results of the tabulation show that on a fuel basis, the non-regenerative Brayton cycle with an organic Rankine cycle is least expensive. It uses an average of 160 lbs./hr. less than the other turbines and 60 lbs./hr. less than the diesel. At a bulk price of 12¢ per gallon of oil, the savings would be $24,000 and $9,000 per year, respectively.

REFERENCE

"NASA Report on Housing Development - Illustration of The Application of NASA Technology to Housing Problems", National Aeronautics and Space Administration, 1971

APPENDIX C

POWER USE AND COSTS

The purpose of this investigation was to evaluate the impact of current and projected power use and cost on system concepts and on-site power generation.

Daily, weekly and seasonal residential power use varies widely with regional weather patterns, social and economic factors, and the cost of power relative to other forms of energy. Over the past few decades, increases in personal income have been accompanied by steady decreases in the cost of electrical power. These factors have stimulated the development and use of electrical appliances and devices to the extent that per capita residential power consumption has doubled every ten (10) years since 1950. This historical growth pattern is expected to continue into the 1980's. Demand should continue to grow beyond this point; but at a somewhat slower rate due to the following factors:

- An expected slowdown in population growth and resultant reduced family sizes.
- "Saturation" of households with electrically powered devices and appliances.
- Expected increases in the cost of power to the consumer - primarily as a result of increasing emphasis on environmental protection. As power costs rise, the point will most likely be reached where residential users will be motivated to be less wasteful in their use of electricity.
- Increases in efficiency of electrical devices and appliances. As the populace becomes more aware of the cost of power use, it is reasonable to expect that manufacturers will respond by developing more efficient equipment. Consumers currently pay little attention to wide variations in power requirements in appliances that perform identically.

Major factors which are expected to override the above considerations are:

- A continuing and growing trend toward the use of electricity for functions now performed by other types of energy. It is estimated, for example, that electricity's share of total energy consumed on Long Island, New York will rise from 26 percent in 1970 to 50 percent in the year 2000 - primarily at the expense of fossil fuel heating. Such forecasts are reinforced by a power survey conducted in 1970 by the National Power Commission[1]. It predicts that all electric dwellings, which currently account for one-third of new construction, will reach 40 and 50 percent levels in the 1980's and 1990's, respectively. It also forecasts half as many conversions as there are new installations. The average all electric home consumed approximately 20,000 kWh in 1970 - more than twice the average of all residential consumers.
- Development of convenience equipment and appliance "over saturation". Although no major electrical appliances are expected to be developed over the next thirty years, more widespread use of convenience equipment can

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be expected as living standards increase (i.e., compactors, saunas, mechanical work savers, etc.).

Figure I illustrates the historical[2] and projected average annual electrical energy consumed by residential households. It reflects the stated consensus of opinion that projects the rate of increase experienced over the past two decades to continue into the 1980's and decline somewhat thereafter.

The impact of water recovery and solid waste processing equipment on either municipal or on-site power supplies is strongly influenced by their effect on system design load profiles. Characteristically, household power comsumption increases rapidly at sunrise, levels off or decreases somewhat during mid-day and again increases to a peak during the early evening hours before decreasing to very low levels after midnight. Industrial and commercial loads have a dampening effect on residential variations. In regions with extreme or widely varying temperature conditions, heating and air conditioning equipment play a dominant role in establishing power supply requirements. The unpredictable nature of environmental control requirements is particularly troublesome to power utilities. Figures II through V illustrate average daily variations that are typically experienced in single family dwelling and apartment units[3]. Power use is expressed as a percentage of the average peak hour demand.

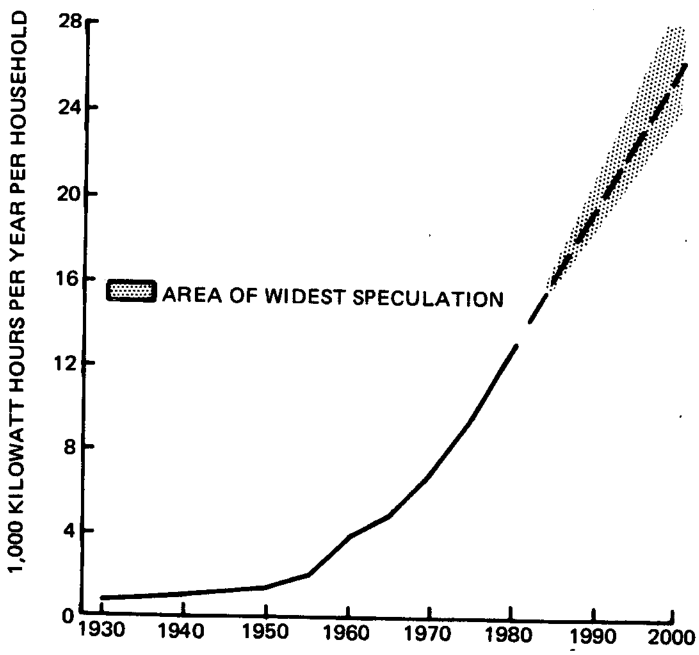

Figure I Average Residential Power Use

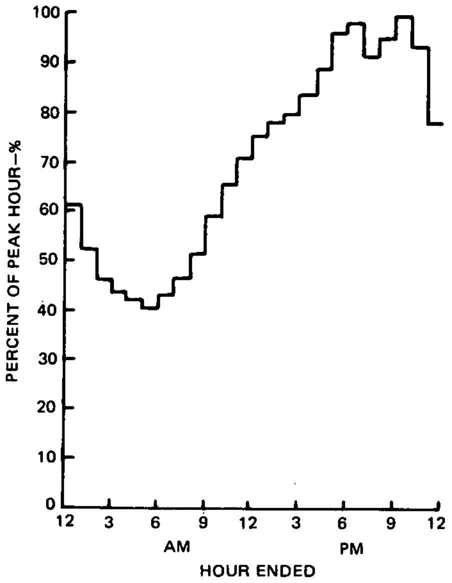

Figure II Power Demand Profile Single Family Dwelling Typical Summer Day

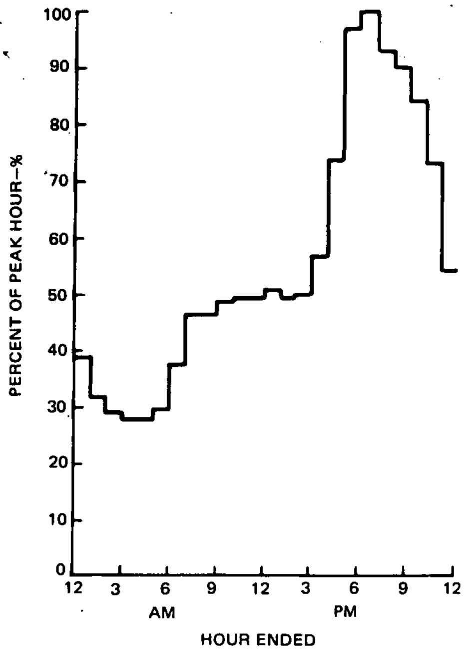

Figure III Power Demand Profile Single Family Swelling Typical Winter Day

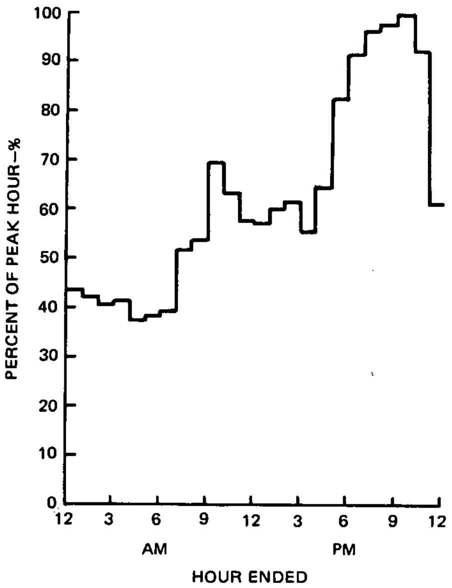

Figure IV Power Demand Profile Apartment Unit Typical Summer Day

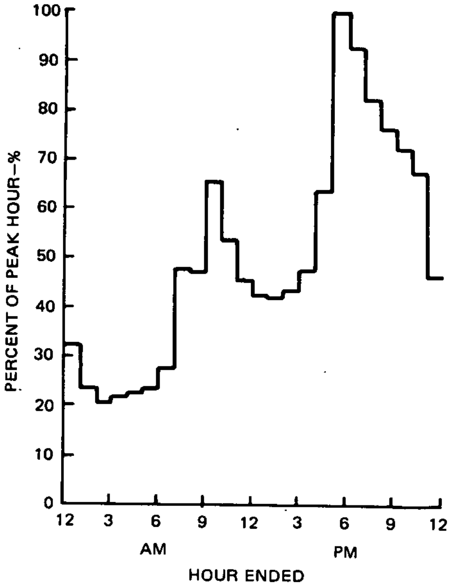

Figure V Power Demand Profile Apartment Unit Typical Winter Day

While the profiles can vary considerably on an absolute basis, their personality is very predictable. They illustrate the potential for programming water and waste processing equipment duty cycles into off peak hours. In this manner, the impact of increased energy requirements on existing power facilities could be significantly reduced.

Long range projections of power costs vary widely as a result of many intangibles - not the least of which is the impact of increasing national emphasis on environmental protection. Past forecasts[2] relied heavily on historical data which shows that the cost of power to all consumer classes has gradually but steadily decreased over the past forty years. This trend could be expected to continue if future power generation facilities were constructed and operated in the manner that they have in the past. More recent forecasts such as those contained in the previously referenced 1970 Federal Power Commission Survey recognize the increasing costs of meeting the country's environment protection objectives. They predict that the great number of very recent requests by power utilities for rate increases represent a trend that will continue in the future in spite of greater efficiencies incurred by technological advances and increased per capita use. The power cost projections that follow rely heavily on the comprehensive FPC survey.

The cost of power is generally expressed in terms of its three basic elements - production, transmission, and distribution. Power use has grown an average of 7 percent per year over the past half century. Only 1.3 percent per year is attributable to population growth - the remainder being due to industrial growth and increased per capita residential use. In addition, population growth is expected to slow, if not terminate over the next few decades. As a result, production and transmission costs may be expected to comprise an increasing percentage of the total cost of power supply.

Table I contains current and projected (1968 and 1990) costs of producing, transmitting and generating power[1]. The major elements contained in each cost component are included to provide visibility into the effects of various forms of increased demand.

TABLE I COMPONENT COSTS OF POWER (1968 DOLLARS)

	1968		1990	
	Mills/ kWh	% of Total	Mills/ kWh	% of Total
Production Costs	7.75	50%	10.83	60%
Transmission Costs	1.98	13%	2.99	16%
Distribution Costs	5.69	37%	4.43	24%
Total Cost of Power	15.42	100%	18.25	100%

Figure VI illustrates the historical and projected average cost of power to all consumer classes[1]. Costs, expressed in 1968 dollars, must be adjusted to reflect inflation. If adjusted for a three percent inflation rate (consistent with recent government estimates of requirements for economic health) power costs would exceed six cents per KWH in thirty years.

Throughout the country, power rates are structured on a declining basis with increased per customer use. Table II shows, by geographical region, the average 1968 cost of power to the two basic customer classes - residential and industrial/commercial. The relationship between these rates should not change significantly in future years.

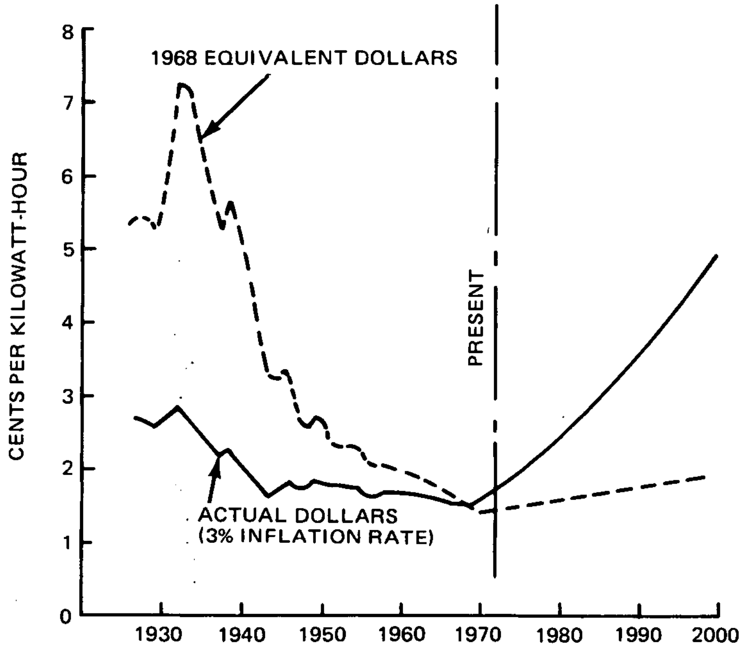

Figure VI. Price of Electricity to Ultimate Consumers

TABLE II 1968 COST OF ELECTRICITY BY USER CLASSIFICATION

Region	Cents/kWh		
	Residential	Industrial/ Commercial	Average
Northeast	2.36	1.66	1.92
Southeast	1.69	1.10	1.27
East Central	2.08	1.18	1.45
South Central	2.17	1.18	1.48
West Central	2.30	1.53	1.82
West	2.0	1.19	1.40
Contiguous United States	2.15	1.37	1.54

Total power costs to the consumer vary significantly - primarily with geographical area. In certain instances there are also significant variations within such areas. For example, where geography permits the generation of large quantities of hydro-electric power costs are low due to the absence of fuel expenditures (15 to 20% of the total cost in most cases). Other factors are labor and fuel costs, number and composition of consumers served, overall efficiency of operation, and local anti-pollution ordinances. Current and projected power costs are shown in Figure VII by geographical region[1].

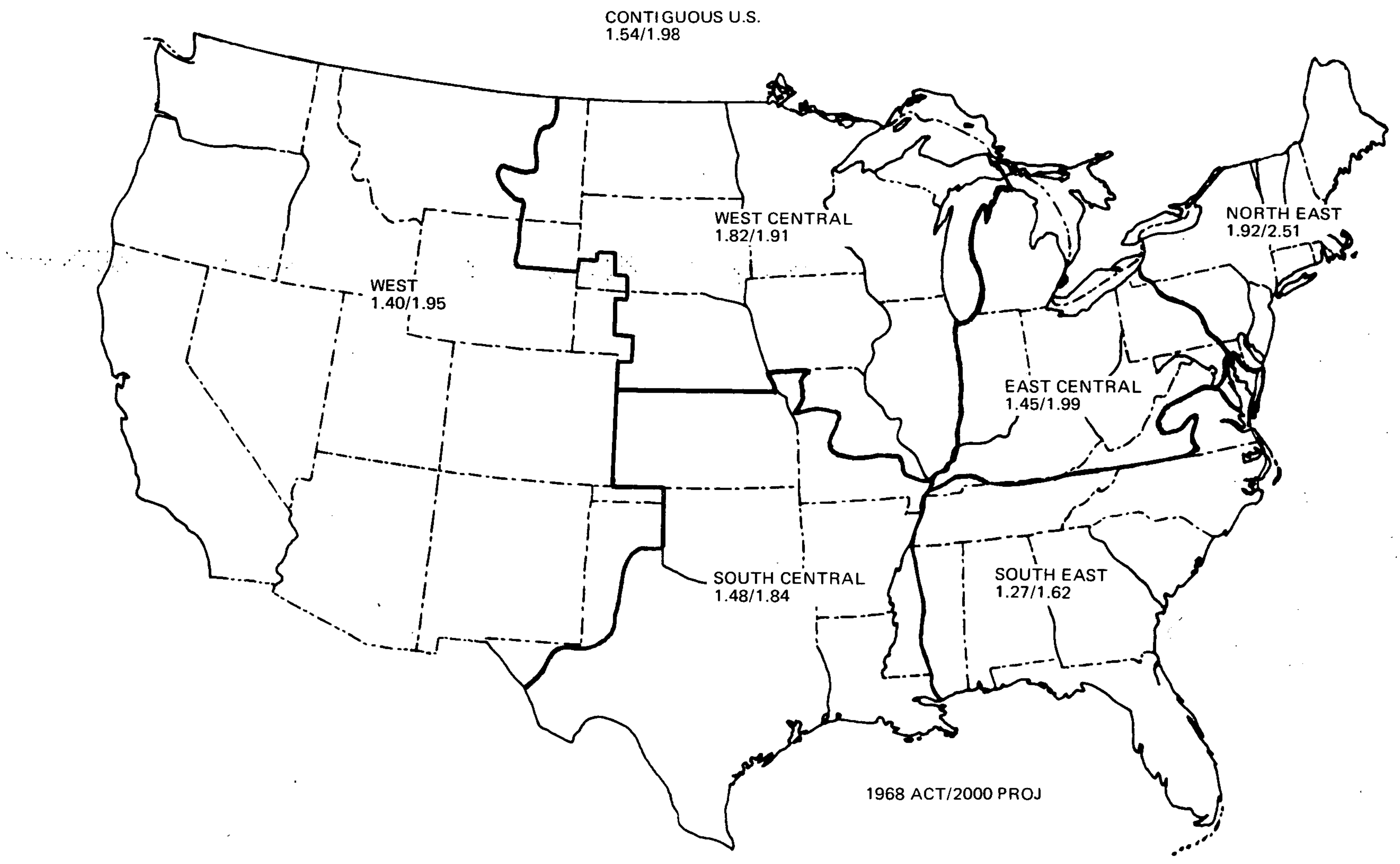

Figure VII Current and Projected Electric Power Costs Cents/KWH (1968 Dollars)

REFERENCES

1. The 1970 National Power Survey, Part I, Guidelines for Growth of the Electric Power Industry, Federal Power Commission, 1972

2. Energy - The Ultimate Resource, Environmental Policy Division of the Library of Congress, 1971

3. Electric Class of Customer Study, Long Island Lighting Company, Economic Research Department, 1971