DEVELOPMENT OF THE SLUDGE DISPOSAL PLAN FOR PUERTO RICO

by

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FINAL TECHNICAL REPORT
TO
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September 1992

Box 2793
San Juan, PR 00902

September 17, 1992

Dr. Rafael Munoz Candelario
Director, WRRI
School of Engineering
University of Puerto Rico
Mayaguez, PR 00681

Dear Dr. Munoz:

Enclosed please find the final report for the project titled Development of the Sludge Disposal Plan for Puerto Rico, which was Project No. 4 under Grant Agreement No. 14-08-001-G1041.

Cordially,

Rafael A. Rios, Ph.D., PE
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I. INTRODUCTION

A. The Sludge Problem

The environmental movement that started in 1970 has demanded that fewer and fewer amounts of pollutants be discharged into the navigable waters of the United States. Starting with the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), and continuing up to the Water Quality Act of 1987 (PL 100-4), successive laws have required higher levels of pollutant removals from municipal and industrial wastewaters. These increased pollutant removals have caused that the volume of solids generated from the existing treatment processes and the new ones that have been added to meet stricter requirements has increased significantly. In simple terms, which are many times forgotten by the design engineers, either the pollutants are removed as a solid or semisolid matter, or they will go out with the effluent. These solids are given the name of sludge.

The need for effective sludge management is continual and growing. The quantity of municipal sludge produced annually in the United States almost doubled from 1972 to 1984, when the Clean Water Act imposed uniform minimum treatment requirements for municipal wastewater. This corresponds to an average growth rate of 6%. In addition, the sludges generated by more advanced treatment are more difficult to handle than the sludge produced by less advanced treatment. In 1984 municipalities generated approximately 5.9 million dry metric tons of wastewater sludge a year, or approximately 25.5 dry kilograms per person per year

(1). Sludge production was expected to about double to approximately 11.8 million dry metric tons per year by the year 2000 as the population increases, as more municipalities comply with Clean Water Act requirements, and as more sophisticated wastewater treatment systems are developed and installed. In Puerto Rico the sludge production rate was estimated at 86 dry metric tons per day, or approximately 3,200,000 liters per day, considering 111 municipal wastewater treatment plants that were operating at the end of 1984(2). No reliable estimates of the sludge generated at industrial wastewater plants exists.

The sludge disposal problem in Puerto Rico was described by EPA's Region II Regional Administrator in early 1985 as follows:

> "...biggest challenge remaining in Puerto Rico's clean water program isthat there is still no island-wide sludge disposal program..."(3)

This project addresses the tail end of this concern, that is, the final disposal of the sludge from the municipal wastewater treatment plants. The chapters that follow describe the characteristics of sludge and the currently available treatment methods, and estimate the quantity and quality of the sludge produced in Puerto Rico's municipal plants. A planning methodology is then applied to this basic data in order to come up with a sludge disposal plan for the plants.

II. MUNICIPAL WASTEWATER SLUDGE

A. Sludge Characteristics

The term "sludge" refers to a combination of solid and semisolid by-products from almost all of the municipal wastewater treatment process. It usually contains 93 to 99.5 percent water as well as solids and dissolved substances that were present in the wastewater and that were added or created by wastewater treatment processes. Usually these wastewater solids are treated prior to ultimate use/disposal to improve their characteristics for these processes.

The characteristics of sludge depend on both the initial wastewater composition and the subsequent wastewater and sludge treatment processes used. Different treatment processes generate radically different types and volumes of sludge. At an individual plant, the characteristics of the sludge produced can vary annually, seasonally, or even daily because of variations in incoming wastewater composition and variations in the treatment processes. This variation is particularly pronounced in wastewater systems that receive a large proportion of industrial discharges. This is the case on several of PRASA's wastewater plants, with Barceloneta representing the extreme.

The characteristics of a sludge affect its suitability for the various use/disposal options. Thus, when evaluating sludge use/disposal alternatives, a planner should first determine the amount and characteristics of the sludge and the degree of variation in these characteristics.

FIGURE 1

PRIMARY SLUDGE

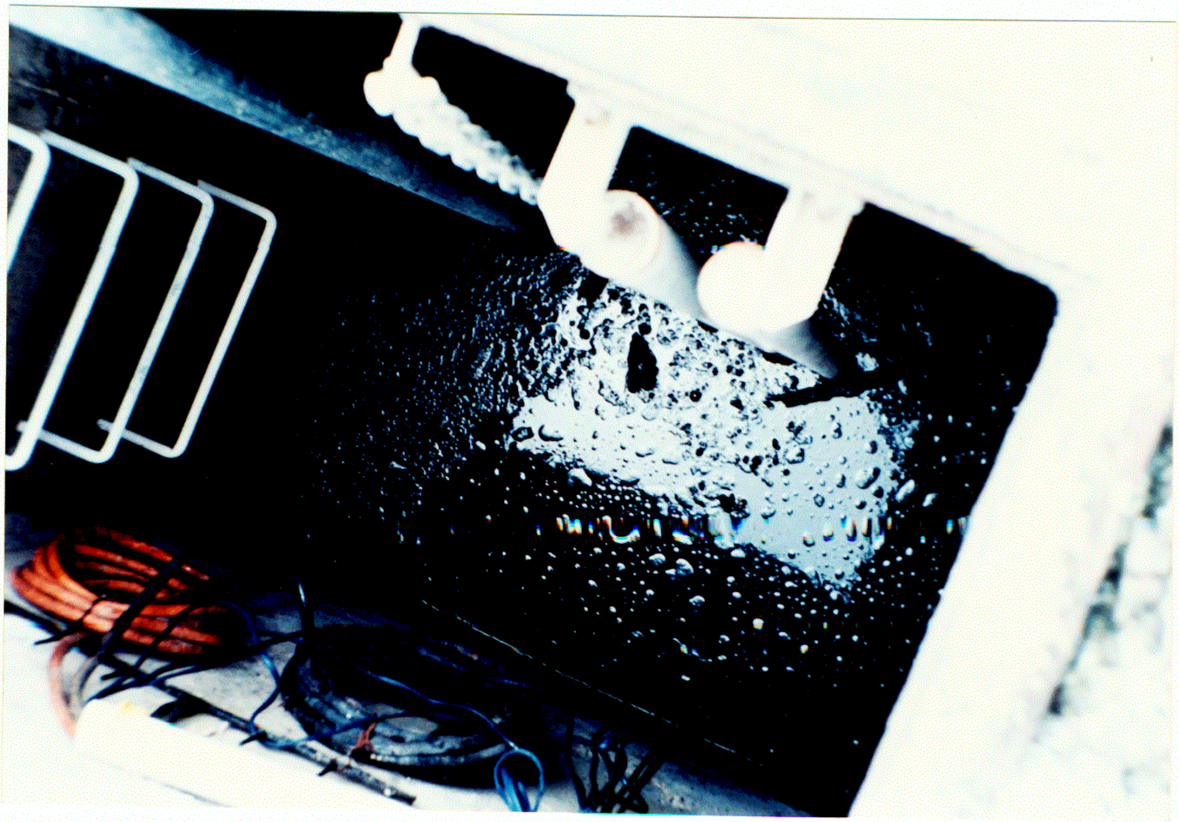


FIGURE 2

SECONDARY SLUDGE

FIGURE 3

TERTIARY SLUDGE

In general terms, sludge can be classified in terms of the treatment process which produce it, as follows:

1. Primary sludge, which is generated during primary wastewater treatment, which removes the solids that settle out readily. Primary sludge contains 3 to 7 percent solids; usually its water content can be easily reduced by thickening or dewatering.
2. Secondary sludge is often called biological process sludge because it is generated by secondary biological treatment processes, including activated sludge systems and attached growth systems such as trickling filters. Secondary sludge has a low solids content (0.5 to 2 percent) and is more difficult to thicken and dewater that primary sludge.
3. Tertiary sludge is produced by advanced wastewater treatment process, such as chemical precipitation and filtration. The characteristics of tertiary sludge depend on the wastewater treatment process that produce it. Chemical sludge results from treatment processes that add chemicals, such as lime, organic polymers, and aluminum and iron salts, to wastewater. Generally, lime or polymers improve the thickening and dewatering characteristics of a sludge, whereas iron or

aluminum salts usually reduce its dewatering and thickening capacity by producing very hydrous sludges which bind water.

Figures 1 to Figure 3 show pictures of these three types of sludge. The differences in terms of color and general appearance should be obvious.

A fourth category of solids is produced at wastewater treatment plants in the preliminary treatment phase. These are the screenings from the coarse and fine screens, grit from grit chambers,and possibly scum from some grit chambers and/or preaeration facilities. These solids have not been considered in this project because their amounts are small in relation to the amounts of the three other sludges mentioned above.

Tables 1 to Table 3 present the characteristics of primary, activated sludge and trickling filter sludges(4).

B. <u>Sludge Quantities</u>

The quantity of sludge produced at the different stages of a wastewater treatment plant is highly variable. The key factors that create this variability are the sources of the wastewater, the type of treatment process used at each stage, sludge treatment processes and the specific operating parameters of each process.

Industrial contributions to wastewater influent streams can significantly increase the sludge quantity generated from a given amount of wastewater. Pretreatment provided by an industrial facility can greatly reduce sludge

TABLE 1

PRIMARY SLUDGE CHARACTERISTICS

Characteristics	Range of values	Typical value
pH	5 - 8	6
Volatile acids, mg/l as acetic acid	200 - 2,000	500
Heating value, Btu/lb	6,800 - 10,000	-
Specific gravity of individual solids particles	-	1.4
Bulk specific gravity (wet)	-	1.02
BOD/VSS ratio	0.5 - 1.1	-
COD/VSS ratio	1.2 - 1.6	-
Organic N/VSS ratio	0.05 - 0.06	-
Volatile content, percent by weight of dry solids	64 - 93	77
Cellulose, percent by weight of dry solids	8 - 15 -	10 3.8
Hemicellulose, percent by weight of dry solids	-	3.2
Lignin, percent by weight of dry solids	-	5.8
Grease and fat, percent by weight of dry solids	6 - 30 7 - 35	- -
Protein, percent by weight of dry solids	20 - 30 22 - 28	25 -
Nitrogen, percent by weight of dry solids	1.5 - 4	2.5
Phosphorous, percent by weight of dry solids	0.8 - 2.8	1.6
Potash, percent by weight	0-1	0.4

TABLE 2

ACTIVATED SLUDGE CHARACTERISTICS

Characteristics	Range of values	Typical value
pH	6.5 - 8	-
Heating value, Btu/lb (kj/Kg)	-	6,540 (15,200)
Specific gravity of individual solid particles		1.08
Color	-	Brown
COD/VSS ratio	-	2.17
Carbon/nitrogen ratio	-	12.9
	-	6.6
	-	14.6
	-	5.7
	-	3.5
Organic carbon, percent by weight of dry solids	17 - 41	-
	23 - 44	-
Nitrogen, percent by weight of dry solids (expressed as N)	4.7 - 6.7	-
	-	5.6
	2.4 - 5.0	-
	-	6.0
Phosphorus, percent by weight of dry solids as P_2O_5	3.0 - 3.7	-
	-	7.0
	2.8 - 11	-
	-	4.0
Potassium, percent by weight of dry solids as K_2O	0.5 - 0.7	-
	-	0.56
	-	0.41
Volatile solids, percent by weight of dry solids	61 - 75	-
	-	63
	62 - 75	-
	59 - 70	-
	-	81

TABLE 2 (Cont)

Characteristics	Range of values	Typical value
Grease and fat, percent by weight of dry solids	5 - 12	-
Cellulose, percent by weight of dry solids	-	7
Protein, percent by weight of dry solids	32 - 41	-

TABLE 3

TRICKLING FILTER SLUDGE COMPOSITION

Property	**Value**
Volatile content, percent of total solids	64 - 86
Nitrogen, percent of total solids	1.5 - 5
Phosphorus as P_2O_5, percent of total solids	2.8 1.2
Fats, percent of total solids	6
Grease, percent of total solids	0.03
Specific gravity of individual solid particles	1.52 1.33
Bulk specific gravity (wet)	1.02
Color	Grayish brown Black

quantity by removing industrial contamination such as metal and organic chemicals.

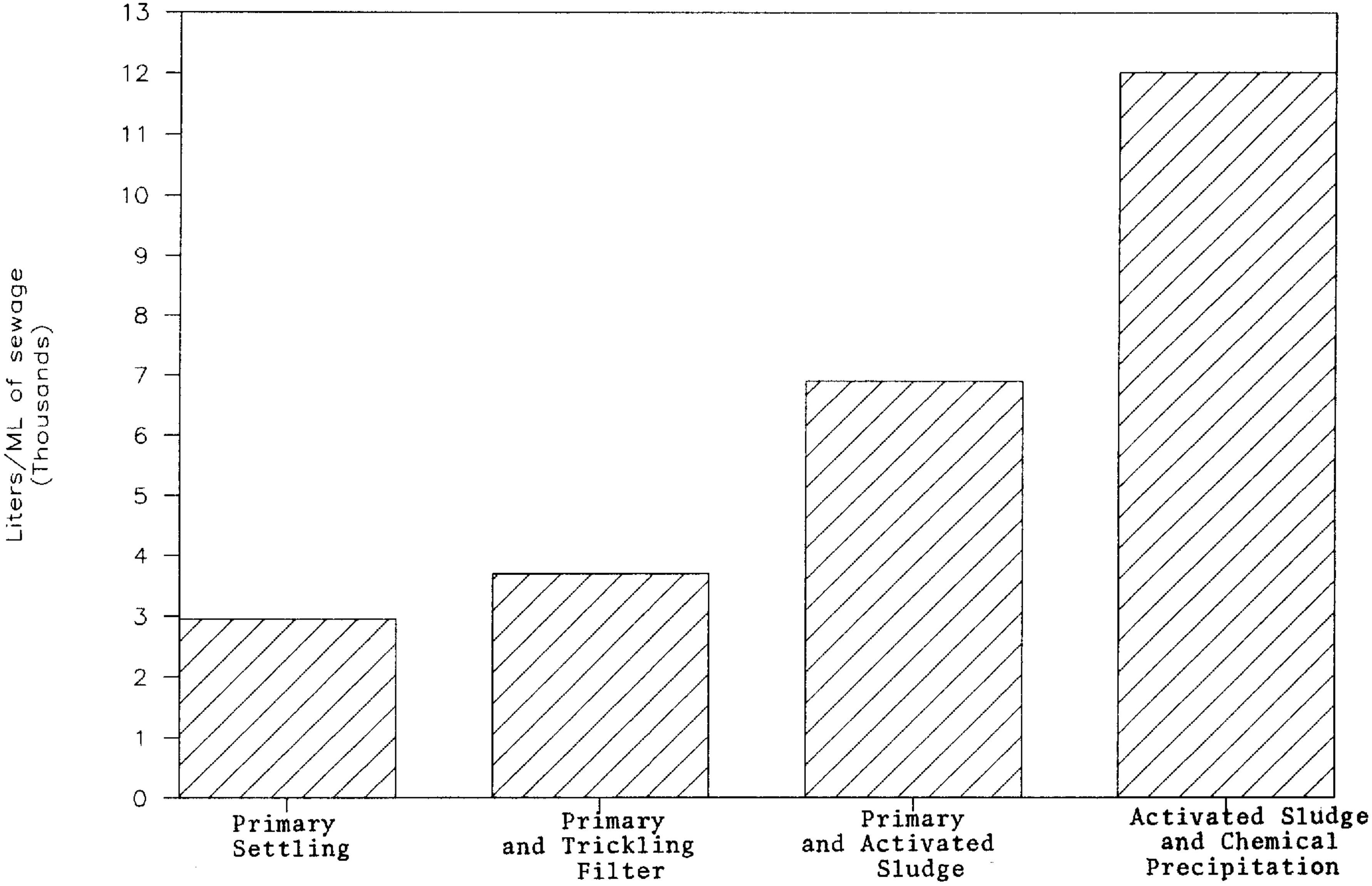
Higher degrees of wastewater treatment generally increase sludge volume (Figure 4). For example, primary treatment typically produce 2,500 to 3,500 liters of sludge per million liters of wastewater treated. Biological secondary treatment produces an additional 4,000 liters per million liters of wastewater treated. Use of chemicals for phosphorus removal during tertiary treatment increases sludge volume another 5,200 liters per million liters treated.

Some sludge treatment processes reduce sludge volume, some reduce sludge mass, and some actually increase sludge mass while improving other sludge characteristics. For example, dewatering processes reduce the amount of water in sludge without significantly reducing the mass of solids; dewatering is thus purely a volume reduction process. Anaerobic digestion of sludge results in a loss of solid material through biodegradation; it is thus a mass reduction process. Although anaerobically digested sludges have less mass than the original raw sludges, they are equally as difficult to dewater, which means they tend to have a large volume. Inorganic chemical addition generally increases sludge mass while improving other characteristics for subsequent treatment, use, or disposal. For example, lime and ferric chloride are added to enhance a sludge's dewatering characteristics; in this case, sludge mass is increased although, at a subsequent dewatering step, sludge volume will be decreased. Composting, another type of sludge

FIGURE 4

TYPICAL SLUDGE QUANTITIES GENERATED

BY VARIOUS TREATMENT LEVELS



Source: Reference (5)

treatment, significantly increases mass through the addition of a bulking agent such as wood chips.

Wastewater treatment processes are controlled using a variety of operating parameters. Since the objective of each treatment process is to produce a liquid effluent of the best possible quality at the cheapest cost, these operating parameters might be set such that by doing this they can actually increase the amount of sludge produced. An example of this is the operation of an activated sludge tank at different sludge ages. Longer sludge ages, which would tend towards having a system in the extended aeration mode, will most likely produce less biological sludge since the bacteria will be at or near the endogenous phase of their growth curve.

Table 4 from Reference (5) presents the quantities of sludge produced from different treatment processes that are used in Puerto Rico. These figures were used in the estimates of present and future sludge quantities that were made for this project.

C. Sludge Treatment Processes

There is a wide variety of sludge treatment processes available. Figure 5 presents a very general flowsheet which covers the alternatives generally available in the United States. Many of these are not used in Puerto Rico due to economic considerations, technical complexity or lack of experience with their use. The discussion that follows addresses all of the processes in Figure 5, with an emphasis on the current practice in Puerto Rico.

TABLE 4

SLUDGE QUANTITIES

Process	**Volume (L/ML)**	**Dry Solids (Kg/1,000 m)**
Imhoff tanks	500	83
Primary settling	2,950	150
Primary and activated sludge	6,900	282
Primary and trickling filter	3,695	208
Activated sludge and chemical precipitation	12,020	680

Source: Reference (5)

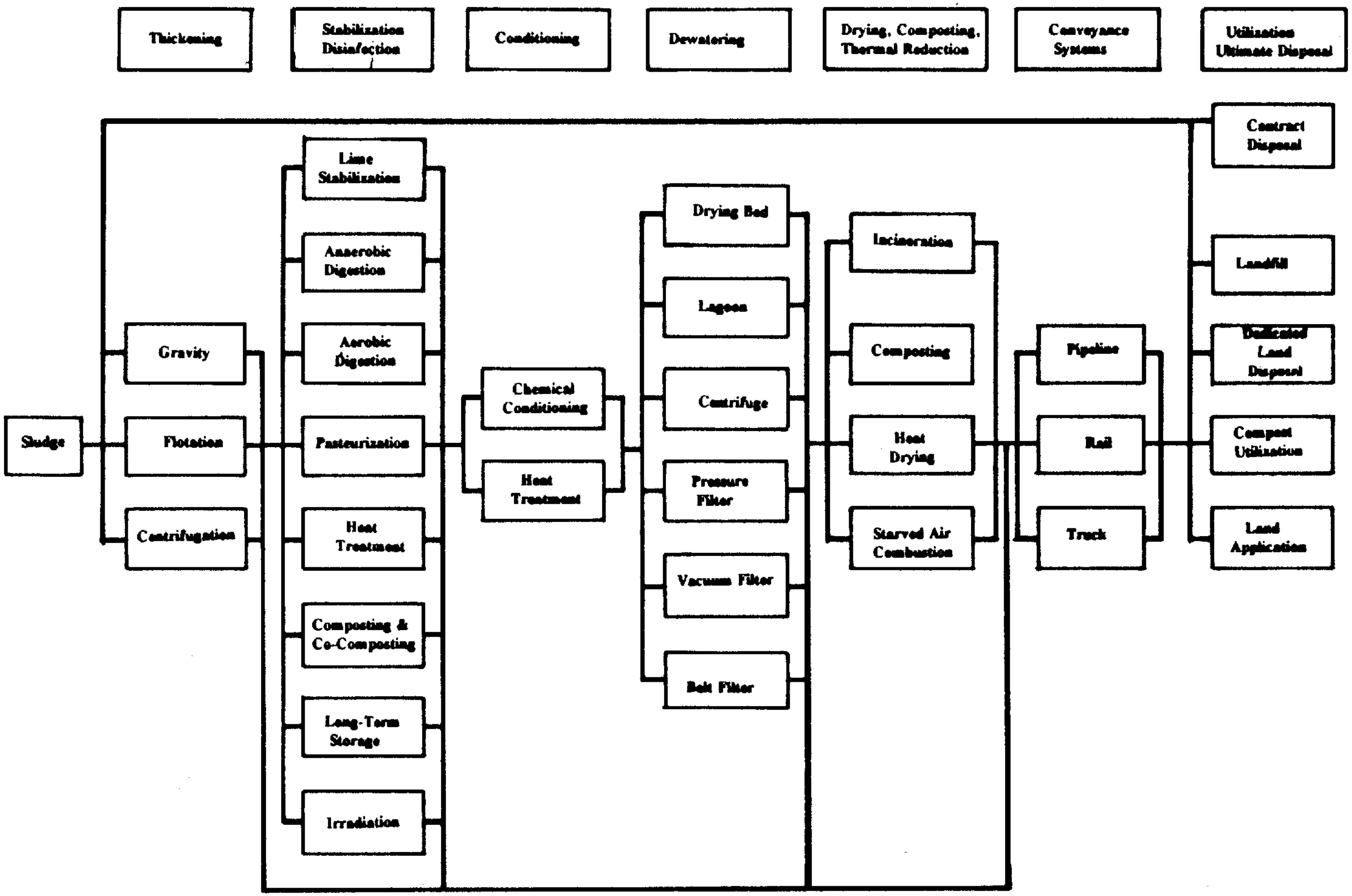


FIGURE 5.
Sludge Management Alternatives.

The path of sludge from its generation to its final grave can be divided into the seven steps which are shown in Figure 5. These are: thickening, stabilization/disinfection, conditioning, dewatering, drying/composting, conveyance, and ultimate disposal or utilization. Each of these steps can be accomplished using various alternatives, as follows:

1. Thickening

As previously discussed, raw sludge is generally very low in its solids concentration. Thickening is then necessary in order to reduce cost by transporting less water to the different sludge treatment processes. The following three thickening processes are used in the United States, but in Puerto Rico thickening is very seldom used, with only gravity thickening being done at Puerto Nuevo and some of the new regional plants, and dissolved air flotation being used at Barceloneta.

a. Gravity thickening

A gravity thickener is for practical purposes identical to a secondary clarifier, except that it does not have a clarifying function. It simply allows the sludge to thicken by the force of gravity while a supernatant is produced and usually returned to the entrance of the plant.

b. Flotation

Flotation is commonly used using dissolved air, which is injected into the liquid going into the flotation unit at a pressure greater than atmospheric (about five times atmospheric pressure). This produces a solution which is supersaturated with air. Upon decreasing the pressure to atmospheric, the dissolved air is released from the liquid in the form of tiny bubbles which rise to the surface, encouraging the sludge to also float to the surface. The flotation unit is equipped with a scrapping mechanism which picks up the sludge from the surface and moves it to a sludge pit.

c. Centrifugation

Centrifuges are major pieces of equipment that revolve at high speeds in order to separate the liquids from the solids in a sludge. Their operating principle is not different from common laboratory centrifuges. Besides their use for thickening, centrifuges can be used for dewatering, in which section they are discussed in more detail.

2. Stabilization/disinfection

The basic objective in stabilizing sludge is to reduce or inhibit the potential for putrefaction and its inherent bad odors. A side benefit of the process is the reduction of pathogenic organisms. It is a process extensively used in Puerto Rico, with both forms of digestion being the most popular, depending on the type of facility which produces the sludge.

a. Lime stabilization

This process consists of the addition of lime to sludge in sufficiently large quantities to raise the pH to at least 12. This creates an environment where the putrefying organisms can not survive, and prevents the formation of odors. A side benefit of lime stabilization is that the sludge usually dewaters better. However, by adding lime the volume of sludge to be further treated is increased. In Puerto Rico lime stabilization is used only during emergency conditions, such as when raw sludge has to be discharged directly into sludge drying beds. It has been effective in controlling odors in these cases.

b. Anaerobic digestion

Anaerobic digestion involves the decomposition of the organic matter in the sludge under anaerobic conditions in order to produce methane and water as final products. It is a process that has been used for more than a century. It consists of some type of closed vessel or tank where the sludge is allowed to decompose in the absence of oxygen. Mixing is normally provided. Heating is also necessary in temperate climates since the decomposing bacteria operate better in a thermophilic environment. The decomposition occurs in two stages, where in the first one a group of organisms, known as acid formers, transform the organic matter into volatile organic acids (propionic being prevalent) and then a second group of bacteria, the methane formers, transform the acids into methane. The equilibrium between these two groups of microorganisms is very delicate, since the volatile organic acids must be transformed almost as quickly as they are produced in order to prevent low pH values which would severely impact both groups of microorganisms. Therefore, the operation of an anaerobic digester must be done with great care. Regretfully, not one anaerobic digester in Puerto Rico is properly operated. This causes that the volumes of sludge that go into the sludge drying beds are usually bigger than those for which they were designed, causing a sludge bottleneck. Also, no digester in Puerto Rico uses the methane for anything. This is a flammable gas of fairly high heating value that in some places has been used to make wastewater treatment plants energy-independent.

Puerto Rico has four types of anaerobic digesters. The most commonly used in trickling filter plants is the clarigester, a proprietary Dor-Oliver unit where the digester is located directly below the primary tank. Mixing is provided by an extension of the sludge/scum collecting mechanism of the primary. Some trickling filter plants and some of the old, small primary plants have conventional, separate digesters, which are large concrete tanks to which varying degrees of mixing are provided. Still in use, and soon to be eliminated, there are also several Imhoff tanks, both circular and rectangular. Finally, there is the septic tank at Naguabo, which is the only treatment process for the sewage from this small town.

c. Aerobic digestion

Aerobic digestion is the process by which the organic fraction of the sludge is decomposed under aerobic conditions to form carbon dioxide and water. It consists of a tank where the biological sludge is aerated and the bacteria are allowed to operate in the endogenous phase of the growth curve. This results in a reduction in the sludge mass. The process works very well and is reasonably easy to control. The sludge that is produced tends to be more spongy than anaerobically digested sludge, but it has less odor problems.

In Puerto Rico the aerobic digestion process is extensively used in the activated sludge package plants and in most of the conventional activated sludge plants. Although few reliable data is available, it is believed that it is accomplishing its job of reducing the sludge mass.

d. Pasteurization

Heat inactivates microorganisms as well as the eggs and cysts of parasites. Pasteurization accomplishes this by holding the sludge to a predetermined temperature for a minimum time period. Typical values are 70°C for 30 minutes. The process normally takes place in a series of tanks, with steam used as the heat source. The process is commonly used in Europe, very seldom in the United States, and not at all in Puerto Rico.

e. Heat treatment

Heat drying is generally done in some type of kiln. It generally produces a sterile sludge but this is not always the case. It is not used in Puerto Rico.

f. Composting

Composting, which is further discussed as a utilization process, deals with the thermophilic conversion of the organic matter in the sludge into a soil conditioner (not into a fertilizer). A major aim of sludge composting operations is to produce a pathogen-free compost by achieving and holding a sufficiently high temperature. The results are highly dependent on the type of composting operation run (windrows, in-vessel, aerated pile, etc). Adverse environmental conditions, particularly heavy rains, can significantly lower composting temperatures. There is also the potential problem of bacterial regrowth. Although planned for use as an utilization process in two regional plants in Puerto Rico in the future, composting is not currently used, nor planned to be used, as a stabilization process.

g. Long-term storage

Long-term storage, mainly by the use of sludge lagoons, is not a practical process in Puerto Rico due to the high cost of land and the high temperatures, which would cause significant odor problems.

h. Irradiation

The use of high-energy radiation for wastewater sludge disinfection has been considered in the United States for about twenty-five years. The best potential for doing this is by using either a gamma or a beta source. Both are effective in achieving significant pathogen reduction. However, cost and safety considerations make this an impractical process for Puerto Rico.

3. Conditioning

The objective of conditioning the sludge is to prepare it for the processes that follow. Conditioning may be a necessary process, such as when belt filter presses are used for dewatering, or not needed at all, such as when drying beds are used.

a. Chemical conditioning

The most frequently encountered conditioning practice is the use of ferric chloride either alone or in combination with lime, although the use of polymers is rapidly gaining widespread acceptance. Although ferric chloride and lime are normally used in combination, it is not unusual for them to be applied individually. Lime alone is a fairly popular conditioner for raw primary sludge and ferric chloride alone has been used for conditioning activated sludges. Lime treatment to a pH of 10.4 or above has the added advantage of providing a significant degree (over 99 percent) of disinfection of the sludge. The use of lime treatment on an emergency basis is fairly common in Puerto Rico, specially when quick odor control is needed. This has been done when poorly digested sludge is discharged into drying beds, causing complaints from neighbors.

Organic polymer coagulants and coagulant aids have been developed in the past 20 years and are rapidly gaining acceptance for sludge conditioning. These polymers are of three basic types:

1) Anionic (negative charge) - serve as coagulant aids to inorganic Al+++ and Fe+++ coagulants by increasing the rate of flocculation, size, and toughness of particles.

2) Cationic (positive charge) - serve as primary coagulants alone or in combination with inorganic coagulants such as aluminum sulfate.

3) Nonionic (equal amounts of positively and negatively charged groups in monomers) - serve as coagulant aids in a manner similar to that of both anionic and cationic polymers.

The popularity of polymers is primarily due to their ease in handling, small storage space requirements, and their effectiveness. All of the inorganic coagulants are difficult to handle and their corrosive nature can cause maintenance problems in the storing, handling, and feeding systems in addition to the safety hazards inherent in their handling.

The use of polymers in municipal sludge conditioning in Puerto Rico is expected to increase in the future with the introduction of the Wedgewater media for the upgrading of sludge drying beds. This process requires that the sludge be conditioned with polymers prior to its application to a plastic media that has slots through which the water filters. The increased use of belt filter presses will also cause an increase in the use of polymers for conditioning.

b) Heat treatment

There are two basic processes for thermal treatment of sludges. One, wet air oxidation, is the flameless oxidation of sludges at temperatures of 450 to 550°F and pressures of about 1200 psig. The other type, heat treatment, is similar, but carried out at temperatures of 350 to 400°F and pressures of 150 to 300 psig. Wet air oxidation reduces the sludge to an ash and heat treatment improves the dewaterability of the sludge. The lower temperature and pressure heat treatment is more widely used than the oxidation process. The two processes are similar.

When the organic sludge is heated, heat causes water to escape from the sludge. Thermal treatment systems release water that is bound within the cell structure of the sludge and thereby improves the dewatering and thickening characteristics of the sludge. The oxidation process further reduces the sludge to ash by wet incineration (oxidation).

The same basic process is used for wet air oxidation of sludge by operating at higher temperatures (450 to 640°F) and higher pressures (1200 to 1600 psig). The wet air oxidation (WAO) process is based on the fact that any substance capable of burning can be oxidized in the presence of water at temperatures between 250 and 700°F. Wet air oxidation does not require preliminary dewatering or drying as required by conventional air combustion processes. However, the oxidized ash must be separated from the water by vacuum filtration, centrifugation, or some other solids separation technique.

None of these two processes is currently in use in Puerto Rico and the situation is not expected to change in the future.

4. Dewatering

Dewatering is a process used to increase the solids concentration of the sludge by removing as much as possible of its water. The main reason for doing this is to reduce the volume of sludge that will be transported to subsequent processes or to final disposal outside of the plant. Doing this results in significant cost reductions. Another reason for dewatering is an increase in the ease of handling. Dewatered sludge, although still containing in the vicinity of 70% by weight of water, is for practical purposes a solids and can be handled much easily, as for example , using a wheelbarrow. A third reason for dewatering is that it is used as pretreatment for certain other downstream process, such as an incinerator. Although wet sludge can be incinerated, it requires an endothermic reaction, whereas well-dewatered sludge can be burned in an exothermic reaction.

a. Drying beds

Drying beds are generally used for dewatering of well digested sludges. Attempts to air dry raw sludge usually result in odor problems which can require emergency measures such as the lime usage which was previously discussed.

Sand sludge drying beds consist of perforated or open joint drainage pipes laid within a gravel base. The gravel is covered with a layer of sand. Partitions around and between the drying beds may be of concrete, wood or earthen embankment. Drying beds are generally open to the weather but may be covered with ventilated green-house types of enclosures where it is necessary to dewater sludge in wet climates. In Puerto Rico it is expected that many plants in the interior of the Island will have this upgrading done.

The drying of sludge on sand beds is accomplished by allowing water to drain from the sludge mass through the supporting sand to the drainage piping and natural evaporation to the air. As the sludge dries, cracks develop in the surface, allowing evaporation to occur from the lower layers which accelerates the drying process.

Many design variations are used for sludge drying beds including the layout of the drainage piping, thickness and type of materials in the gravel and sand layers, and construction materials used for the partitions. The major variation used in Puerto Rico is that the floor of the beds is made of concrete with a slope that leads into a side sand strip of about one meter wide where the drainage piping is located. Although the sludge dries at a slower rate on these beds, it is believed that the ease of sludge removal by mechanical means and the need to replenish much less sand justifies the larger drying areas required.

The only side stream is the drainage water. This water is normally returned to the raw sewage flow to the plant or to the plant headworks. The drainage water is not normally treated prior to return to the plant.

b. Lagoons

Sludge lagoons are similar to sand beds in that sludge is periodically drawn from a digester, placed in the lagoon, removed after a period of drying, and the cycle repeated. Drying lagoons are not typically provided with an underdrain system as most of the drying is accomplished by decanting supernatant liquor and by evaporation. Plastic or rubber fabrics may be used as a bottom lining, or they may be natural earth basins. Supernatant liquor and rainwater drain off points are usually provided, with the drain off liquid returned to the plant for further processing.

Lagoons are not currently in use in Puerto Rico and their future use is likely to be very limited, if at all, due to the high cost of land in the Island and the lack of isolated areas where odor problems might be minimized.

c. Centrifuge

A centrifuge is essentially a sedimentation device in which the solids-liquid separation is enhanced by rotating the liquid at high speeds so as to subject the sludge to increased gravitation forces.

As previously mentioned, centrifuges have been used for both sludge thickening and dewatering, especially for waste activated sludge and digested sludges. The disc type and the solids bowl centrifuges are well suited to thickening operations. Centrifuges can be used to classify sludges according to relative specific gravity. For instance, phosphorus rich sludge can be removed from lime sludge to enable efficient recovery and reuse of the lime.

Three types of centrifuges have been used for sludge dewatering: the solid bowl, basket and disc centrifuges. The solid bowl is the most widely used type for dewatering of sewage sludge and employs the countercurrent flow of liquids and solids that occurs in a rotating solids bowl which revolves horizontally. The basket centrifuge is also referred to as the imperforate bowl, knife discharge type and is a batch dewatering unit that rotates around the vertical axis. The disc centrifuge is very similar to the basket centrifuge except that it operates continuously. Its sludge may have to be pre-screened.

The only side stream is the centrate, which is normally returned to the plant influent. There are no centrifuges in use in Puerto Rico at the present time.

d. Pressure filter

There are several types of presses available but the most common consists of vertical plates which are held in a frame and which are pressed together between a fixed and moving end. A cloth is mounted on the face of each individual plate. Despite its name, the filter press does not close to squeeze or press sludge. Instead, the press is closed and then sludge is pumped into the press at pressures up to 225 psi and passes through feed holes in the trays along the length of the press. Filter presses usually require chemical pretreatment (polymers and alum are generally used in Puerto Rico) to aid in solids retention on the cloth and release of the cake.

The water passes through the cloth, while the solids are retained and form a cake on the surface of the cloth. Sludge feeding is stopped when the cavities or chambers between the trays are filled. Drainage ports are provided at the bottom of each press chamber. The filtrate is collected in these, taken to the end of the press, and discharged to a common drain, from where it is usually moved to the influent of the plant.

Pressure filters require a minimum "threshold" level of sludge before they can economically compete with other dewatering process. In Puerto Rico their use is limited to the new regional plants.

e. Vacuum filter

A vacuum filter basically consists of a cylindrical drum which rotates partially submerged in a vat of sludge. The filter drum is divided into compartments by partitions. A vacuum is applied between the drum deck and filter medium causing filtrate to be extracted and filter cake to be retained on the medium during the pickup and cake drying cycle. The filter medium may be a cloth made of natural or synthetic fibers, stainless steel wire mesh or coil springs. Usually, the cake of dewatered sludge is removed by a fixed scraper blade, however there are alternative designs which use other methods for sludge removal.

The use of vacuum filters in Puerto Rico has been nearly disastrous. A relatively small unit was installed at the Villa Carolina plant and was never able to operate. It was finally discarded as scrap metal. The Barceloneta plant had two vacuum filters with coil springs. They operated for a short period but quickly developed mechanical problems and also ended up in the scrap heap.

f. Belt filter

A belt filter press is an adaptation of the old roller used to dry clothing right after taking it out of the washer. It consists of a moving belt where an influent mixture of sludge and polymer is discharged. Dewatering occurs as the sludge moves through a series of rollers which squeeze the sludge to the belt or squeeze the sludge between two belts much like an old washing machine wringer. The cake is discharged from the belt by a scraper mechanism.

Filtrate from the belt filtration unit is usually returned either to the primary or secondary treatment process and normally causes no problems to process operations.

Belt filter presses are being used successfully in industrial wastewater treatment plants in Puerto Rico. Their relative ease of operation and high volume of sludge that they can process using a relatively limited space makes them a primary candidate for extensive use in the future.

5. Drying/composting/thermal reduction

The objective of drying is further reducing the water content of the sludge by vaporization of water to the air. This is done so that sludge can then be incinerated efficiently or processed into compost.

a. Heat drying

Heat drying raises the temperatures of the incoming sludge to 212°F (100°C) to remove moisture which reduces total volume, yet retains the nutrient properties of the sludge. The end product is odor free, contains no pathogenic organisms, and contains soil nutrients. Heat drying is ideal for a subsequent composting operation.

Sludge has been heat dried in flash drying equipment and rotary kilns. However, and due to high energy costs, heat drying is considered an unlikely alternative for future use in Puerto Rico.

b. Composting

Composting was previously described as a stabilization/disinfection process and will be further described as a utilization process.

c. Incineration

There are two basic types of incinerators: the multiple hearth furnace and the fluidized bed incinerator.

A multiple hearth furnace consists of a circular steel shell surrounding a number of solid refractory hearths and a central rotating shaft to which arms are attached. The dewatered sludge enters at the top through a flapgate and proceeds downward through the furnace from hearth to hearth moved by the rotary action of the arms. The hearths are constructed of high heat duty fire brick and special fire brick shapes. Operating temperatures are usually in the 1,400-1,700°F range, but can reach as high as 2,000°F.

The arms provide mixing action as well as rotary and downward movement of the sludge. The flow of combustion air is countercurrent to that of the sludge. Gas or oil burners are provided on some of the hearths for furnishing heat for start-up or supplemental use as required. Sludge is constantly turned and broken into smaller particles by the rotating arms which exposes the sludge surface to hot furnace gases. This facilitates rapid and complete drying as well as burning of the sludge.

The fluidized bed incinerator is a vertical cylindrical vessel with a grid in the lower section to support a sandbed. Dewatered sludge is injected above the grid and combustion air flows upward at a pressure of 3.5 to 5.0 psig and fluidizes the mixture of hot sand and sludge. Supplemental fuel can be supplied by burners above or below the grid. In essence, the reactor is a single chamber unit where both moisture evaporation and combustion occur at 1,400 to 1500°F in the sandbed. All the combustion gases pass through the 1500°F combustion zone with residence times of several seconds. Ash is carried out the top with combustion exhaust and is removed by air pollution control devices.

There is one sludge incinerator in Puerto Rico. It is located at the Puerto Nuevo wastewater plant and it is composed of two parallel multiple hearth furnaces. At the present time it burns sludge from the Puerto Nuevo plant and several other regional plants in the metropolitan area. It is expected that this incinerator will play a significant role in future sludge management in Puerto Rico.

d. Starved-air combustion

Starved-air combustion (SAC) is also known as pyrolysis. It uses less than theoretical quantities of air in the furnace (30-90% of stoichiometric requirements) so that it is, in effect, incomplete combustion. The reaction products are combustible gases, tars, oils, and a solid char that can have an appreciable heating value. The relative proportion of each varies with the amount of heat applied and the feed moisture. Generally, higher reaction temperatures yield simpler products and greater quantities of low heating value gas. This is at the expense of combustible solid products. The low heating value gases may be burned, and the heat generated can be recovered and used beneficially. Alternatively, the gas may be cooled and stored for subsequent off-site use. The most effective utilization appears to be the burning of the total gas stream, with subsequent recovery of portions of the heat generated. Off-site use appears to be impractical.

SAC was considered as an alternative sludge management at the Caguas wastewater plant in the late 1970's. It was discarded because an EPA review indicated that the cost of the process could not be funded under the construction grants program. EPA also indicated that it did not consider the proposed design reliable and likely to operate in an efficient way.

6. Conveyance systems

Figure 5 shows three alternate conveyance systems: pipeline, rail and truck. Puerto Rico's rail system was virtually eliminated in 1953. The only remaining part of the system serves a very limited stretch of land between Guayama and Ponce and is used for sugarcane transportation. This virtually eliminates rail as a sludge conveyance alternative for Puerto Rico.

In the 1970's the construction of an 18" pipeline for the conveyance of sludge from the Carolina regional plant to the Puerto Nuevo incinerator was planned and construction of several sections and one pump station was completed. This pipeline was going to be 23 Km long, making it the third longest in the world at the time. However, in the early 1980's, the concept was revised and the pipeline substituted by trucking. The pump station still exists and the pipes are still buried in the ground.

Trucking is, for practical purposes, the only realistic alternative for sludge conveyance in Puerto Rico. It is used extensively both on a regular and in an emergency basis and will continue to be so.

7. Utilization/ultimate disposal

This section addresses the ultimate fate of the sludge or the remaining products from previous processes, such as ash from incinerators. The alternatives are as follow:

a. Contract disposal

Contract disposal is basically an alternative where a third party is contracted to ultimately dispose of the sludge. In Puerto Rico this is a fairly commonly used alternative in the case of municipal solid waste. There are several companies engaged in this business which operate their own landfills. The option is currently being used for final disposal at several wastewater plants and is likely to continue to be used.

b. Landfill

There are two possibilities for the landfill disposal of sludge: dedicated landfills, or co-disposal with municipal solid waste. In a dedicated landfill the trench method of landfilling is usually used with dewatered sludge at least at the 15-20% solids level. The normal sequence of operation is that the dewatered sludge is transported to the site. Then it is stockpiled or dumped directly into a 20-foot or so deep trench. A power shovel is used to place two-foot layers of sludge with one-foot intermediate layers of fill material. The final cover layer of fill is 3 to 5 feet. System modifications are made to compensate for certain climatic or soil characteristics. Equipment selection is based on site specific constraints. Transport to the landfill site in Puerto Rico would have to be done by truck, since, as previously explained, rail is not-existent and pipelines have, for all practical purposes, been written-off as too difficult to maintain. Trench depths and widths are variable. A wide, shallow trench may be excavated with a bulldozer and filled with a scraper. There are a large number of options available, but the basic system is the same.

The major concern for landfill operation is control of leachate so that groundwater supplies are not contaminated. Groundwater supplies are protected by careful site selection. A landfill must be located well above and/or away from any aquifers. An impervious layer should be located between the bottom of the fill and groundwater. When filling trenches, leachate water will often appears. This water should be pumped out to a tanker and returned to the treatment plant for treatment and disposal.

Natural drainage should be left undisturbed as much as possible. Fill trenches are arranged so that they are at least 30 feet from the drainage ditch. Farm tiles running through the site must be intercepted and routed to the nearest drainage ditch.

Co-disposal with municipal sludge in Puerto Rico is very similar to a contract operation since the municipalities own and operate the landfills and set the rules for the acceptance of sludge. The basic criteria is that it must be dry, which in technical terms means that it must dewatered. If the sludge meets this criteria, which is normally checked visually, it is dumped directly into the active area of the landfill where it joins the normal operations. Disposal at these facilities is usually free of charge but can, and has been in the past, influenced by changing political circumstances. Aside from this, this ultimate disposal method has shown reliability and flexibility as to the amounts of sludge that can be disposed.

c. Dedicated land disposal

In dedicated land disposal relatively large quantities of sludge are applied to a land area for many years. The objective of this practice is to employ the land as a treatment system by using soil to bind metals, and soil microorganisms, sunlight, and oxidation to destroy the organic matter in the sludge. Often, no attempt is made to productively use the sludge nutrients.

Dedicated land disposal allows for considerable control over the ultimate fate of the sludge, at the cost of more intensive management. Because the application area usually is owned or leased by the owner of the sludge, there is no need to convince farmers to participate in the program. The dedicated land disposal site may be located on the wastewater treatment plant grounds, thus reducing transportation cost.

At the present time dedicated land disposal is not being practiced in Puerto Rico.

d. Compost

Compost has been mentioned previously in this chapter under the stabilization/disinfection and drying/composting/thermal reduction section. In this section more details are given on the process, including its ultimate use as a soil conditioner.

Composting is one means of stabilizing raw or digested sludge through biological action (bacterial organisms). Usually , a bulking agent such as wood chips is added to maintain proper temperature and humidity levels. Heat is produced during the composting process and is generally sufficient to produce temperature above 55° to 60°C within the compost. These temperatures are high enough to kill most pathogenic organisms, therefore, composting is capable of reducing disease-producing organisms to very low levels.

Two methods have been used for composting wastewater sludge: windrow and forced air static pile. Various contained composting methods have been used for solid waste, but have not been used for wastewater sludge. Generally, the windrow method is used with digested sludge and the forced air static pile method is used with either raw or digested sludges. Composting of raw sludge can cause nuisance problems due to odors.

The equipment and methods used are somewhat different for each composting method. The type and size of equipment required also depends on the quantity of sludge to be composted, however, certain minimum sized equipment is required for any sized operation. Most composting operations use mobile type equipment, but it is also possible to use fixed type equipment for certain operations.

The composting operation procedures a soil conditioner (compost) that must be marketed. The amount of compost on a mass basis is usually bigger than the amount of sludge on a dry basis, depending on the type of process and the amounts of bulking materials used. Compost has a lower level of available nitrogen and phosphorous than commercially available fertilizer. Its main advantage is that its nutrients become available slowly over several years. Additionally, by promoting a healthy soil microflora, compost can help to prevent plant disease.

The problem with compost is what to do with it. The only experience with composting in Puerto Rico dates from the early 1960's when the city of San Juan used it for its municipal solid waste. Although the compost produced was of excellent quality (for compost), it was not possible to market it (not even give it away) and operations were summarily terminated by the mayor in early 1969. The marketing of compost in the near future in Puerto Rico is bound to be difficult due to the current low levels of agricultural activity on the Island. In addition to agricultural land not being plentiful, the existing agriculture is significantly subsidized by the government. This includes the provision of fertilizer at below-market prices. Under these conditions it is very difficult that farmers will accept a product that, at best, is perceived as being of sewage origin, even though it may be provided at site and free of charge.

e. Land application

The land application operation discussed here applies to controlled application of liquid wastewater sludge to cropland by subsurface injection or surface spreading. Injection can be accomplished by truck or tractor mounted injectors. Tank trucks are normally used for surface spreading. Dewatered sludge can also be applied, but this is not as common as liquid application.

Sludge is digested, concentrated to 6 to 8 percent solids, and then pumped into transfer trucks which haul sludge to the land application site. Sludge is then transferred to another specialized truck for application. In some cases, especially smaller operations, the transfer truck may be used for application.

Variations in the characteristics of sludge application equipment are related to local conditions and sludge solids content. Dewatered sludge (greater than 10 percent solids concentration) is not practical for injection and would normally be spread on the surface. Liquid sludge can be spread on the surface by special irrigation equipment or tanker truck. Subsurface injection of sludge can be accomplished by tank truck or tractor mounted injectors. Tractor mounted injectors require a sludge feed from a close following tank trailer or from a hose connected to a storage system. Ridge and furrow or flooding methods of application are not recommended unless there is a means of covering the applied sludge because nuisances may result.

Land application is currently in use in Puerto Rico at the Barceloneta wastewater plant. Preliminary reports from the project indicate that the operation is being successfully carried out.

III. CURRENT MUNICIPAL SLUDGE SITUATION IN PUERTO RICO

A. Introduction

The municipal wastewater treatment plants in Puerto Rico are operated by the Puerto Rico Aqueduct and Sewers Authority (PRASA), a public corporation which started to operate in 1945. PRASA is also in charge of all the water plants in Puerto Rico, together with the associated water and sewerage conveyance systems. In terms of the number of plants operated, PRASA is the biggest water and sewerage authority in the United States.

PRASA is divided into seven regions, as shown in Figure 6. Each of the regions is relatively independent and has control of all the wastewater treatment plants in its geographical area. It is also responsible for, and manages all of the sludge which is generated in the area. Table 5 shows the number of plants per region. The total of 111 plants range from septic and Imhoff tanks to secondary plants of the trickling filter and activated sludge type. A few of the secondary plants provide tertiary treatment by means of a sand filter.

B. Sludge Management

Chapter II indicated which of the multiplicity of sludge management alternatives were currently in use in Puerto Rico. In summary, the processes that are more commonly used are: aerobic and anaerobic digestion, sludge drying beds, and sanitary landfills for final disposal. Aerobic digestion is used almost exclusively at the activated sludge plants while anaerobic digestion is used at the trickling filters and the

FIGURE 6

PRASA OPERATIONAL REGIONS

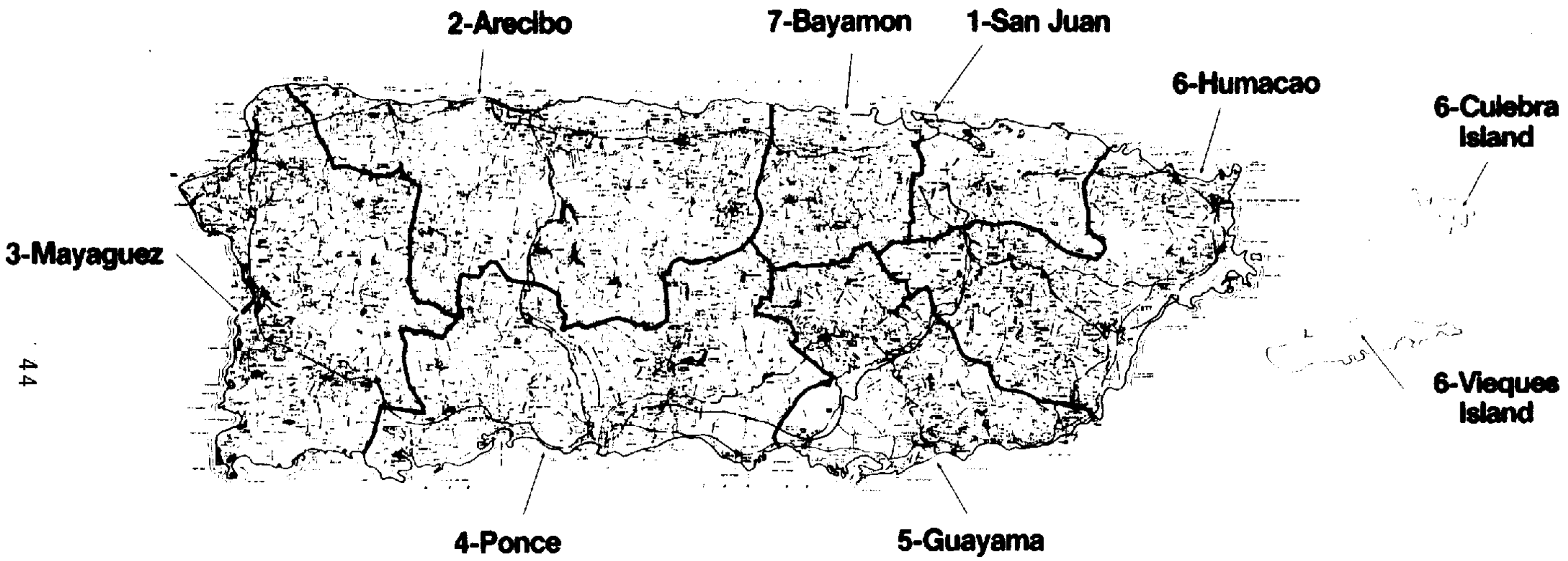


TABLE 5

PRASA PLANTS PER REGION

Region	Number of Wastewater Treatment Plants
Arecibo	13
Bayamón	12
Guayama	12
Humacao	22
Mayaguez	23
Ponce	12
San Juan	17
	111

various primary facilities. Anaerobic digestion at the trickling filters is mostly by the use of clarigesters, which incorporate a digestion chamber which is physically located below the primary tank. This chamber is mixed by the clarifier's sludge/scum collecting mechanism and as such operates as a slow rate digester. Besides sanitary landfills, incineration is used to dispose of the sludge of the regional plants in the metropolitan area.

Table 6 shows, on a plant-by-plant basis, the current sludge management practices at PRASA's plants. The information in this table has been gathered from a multiplicity of sources including PRASA's Monthly Purification Reports and Discharge Monitoring Reports, the Sewer Operation's Area Annual Report (7), the Monitor's reports (8), field visits, and interviews with regional engineers and operational personnel. The different types of plants are described at the end of the table. The first six types are well known. The seventh one, the treated wood biofilter, is a PRASA invention that has been shown to be worthless from a treatment point of view. Nevertheless, it is used at Peñuelas and Hormigueros, and was almost used at Guánica.

The third column in Table 6 shows the average daily flow at each plant for 1986, while the fourth column shows the plant's design flow. The next two columns show the estimated sludge production for 1986, both in terms of gallons/day and lbs/day. These figures have been calculated using data from Table 4 since no sludge records are kept at the plants. There

TABLE 6
SLUDGE MANAGEMENT

ARECIBO REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Ciales	1	0.18	0.6	3,499	405	Landfill Ciales	Aerobic dig Drying beds
Domingo Ruiz	1	0.426	0.3	8,281	959	Landfill Arecibo	Aerobic dig Drying beds
Isabela	1	1.1	1	21,384	2,475	Landfill Isabela	Aerobic dig Drying beds
Jayuya	1	0.332	0.5	6,454	747	Landfill Jayuya	Aerobic dig Drying beds
Barceloneta	1	5.673	8.33	110,283	12,764	Land application	Aerobic dig Drying beds
Florida	2	0.326	0.167	1,205	563	Landfill Florida	Anaerobic dig Drying beds
Hatillo-Camuy	2	0.768	0.382	2,838	1,326	Landfill Arecibo	Anaerobic dig Drying beds
Lares	2	0.289	0.553	1,068	499	Landfill Lares	Anaerobic dig Drying beds
Morovis	2	0.205	0.5	757	354	Landfill Morovis	Anaerobic dig Drying beds
Utuado	2	0.398	0.709	1,471	687	Landfill Utuado	Anaerobic dig Drying beds
Vega Baja	2	1.761	1.6	6,507	3,039	Landfill Vega Baja	Anaerobic dig Drying beds
Quebradillas	4	0.18	0.15	90	124	Landfill Quebradillas	Anaerobic dig Drying beds
Arecibo RWWTP	3	3.11	40	9,175	3,888	Incineration	Thickener Filter press
TOTALS		14.74	54.79	173,012	27,829		

TABLE 6
SLUDGE MANAGEMENT

BAYAMON REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Bayamon RWWTP	6	12.69	40	37,462	15,874	Incineration	Thickener
Bayamon Gardens	2	0.617	0.67	2,280	1,065	Landfill Bayamon	Anaerobic dig Drying beds
Dorado	2	1.207	1.218	4,460	2,083	Landfill Dorado	Anaerobic dig Drying beds
Las Teresas	2	0.243	0.375	898	419	Landfill Bayamon	Anaerobic dig Drying beds
Royal Town	2	1.706	2.052	6,304	2,945	Landfill Bayamon	Anaerobic dig Drying beds
Santa Juanita	2	0.846	1.026	3,126	1,460	Landfill Bayamon	Anaerobic dig Drying beds
Corozal	1	0.543	0.5	10,556	1,222	Landfill Toa Alta	Aerobic dig Drying beds
Covadonga	1	0.415	1	8,068	934	Landfill Toa Baja	Aerobic dig Drying beds
Naranjito	1	0.213	0.5	4,141	479	Landfill Toa Alta	Aerobic dig Drying beds
Toa Alta Height	1	0.317	0.5	6,162	713	Landfill Bayamon	Aerobic dig Drying beds
Toa Alta	4	0.455	0.1	228	314	Landfill Toa Alta	Anaerobic dig Drying beds
Vega Alta	4	0.616	0.25	308	425	Landfill Toa Alta	Anaerobic dig Drying beds
TOTALS		19.87	48.19	83,991	27,933		

TABLE 6
SLUDGE MANAGEMENT

GUAYAMA REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Aibonito	1	0.633	0.36	12,306	1,424	Landfill Aibonito	Anaerobic dig Drying beds
Arroyo	1	0.359	0.7	6,979	808	Landfill Arroyo	Aerobic dig Drying beds
El Coqui	1	0.189	0.2	3,674	425	Landfill Salinas	Aerobic dig Drying beds
El Torito	1	0.134	0.249	2,605	302	Landfill Cayey	Aerobic dig Drying beds
Vista Monte	1	0.036	0.08	700	81	Landfill Cidra	Aerobic dig Drying beds
Patillas	1	0.479	0.3	9,312	1,078	Landfill Patillas	Anaerobic dig Drying beds
Barranquitas	2	0.257	0.283	950	444	Landfill Barranquitas	Anaerobic dig Drying beds
Cayey	2	1.482	1.37	5,476	2,558	Landfill Cayey	Anaerobic dig Drying beds
Cidra	2	0.611	0.296	2,258	1,055	Landfill Cidra	Anaerobic dig Drying beds
Comerio	2	0.158	0.23	584	273	Landfill Comerio	Anaerobic dig Drying beds
Maunabo	2	0.221	0.107	817	381	Landfill Maunabo	Anaerobic dig Drying beds
Salinas	4	0.426	0.25	213	294	Landfill Salinas	Anaerobic dig Drying beds
TOTALS		4.985	4.425	45,872	9,122		

TABLE 6
SLUDGE MANAGEMENT

HUMACAO REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Gurabo	1	0.558	0.6	10,848	1,256	Landfill Juncos	Aerobic dig Drying beds
Ceiba	1	0.3	0.4	5,832	675	Landfill Luquillo	Anaerobic dig Drying beds
Col del Yunque	1	0.055	0.17	1,069	124	Landfill Luquillo	Aerobic dig Drying beds
Humacao	1	2.148	2	41,757	4,833	Landfill Las Piedras	Aerobic dig Drying beds
Las Leandras	1	0.08	0.253	1,555	180	Landfill Las Piedras	Aerobic dig Drying beds
Las Piedras	1	0.4	0.3	7,776	900	Landfill Las Piedras	Aerobic dig Drying beds
Pueblito d. Rio	1	0.121	0.1	2,352	272	Landfill Las Piedras	Aerobic dig Drying beds
Ramon Rivero	1	0.169	0.12	3,285	380	Landfill Las Piedras	Aerobic dig Drying beds
Rio Blanco He.	1	0.052	0.45	1,011	117	Landfill Las Piedras	Aerobic dig Drying beds
Rio Grande	1	1.054	0.9	20,490	2,372	Landfill Luquillo	Aerobic dig Drying beds
Rio Grande Est.	1	0.166	0.375	3,227	374	Landfill Luquillo	Aerobic dig Drying beds
Villa Palmira	1	0.345	0.38	6,707	776	Landfill Las Piedras	Aerobic dig Drying beds

Aguas Buenas	2	0.271	0.23	1,001	468	Landfill Aguas Buenas	Anaerobic dig Drying beds
Caguas	2	5.364	6	19,820	9,258	Incineration	Trucking
Fajardo	2	1.46	1.77	5,395	2,520	Landfill Luquillo	Anaerobic dig Drying beds
Juncos	2	0.547	0.513	2,021	944	Landfill Juncos	Anaerobic dig Drying beds
Luquillo	2	0.561	0.831	2,073	968	Landfill Luquillo	Anaerobic dig Drying beds
San Lorenzo	2	0.531	0.67	1,962	917	Landfill Juncos	Anaerobic dig Drying beds
Vieques	2	0.151	0.167	558	261	Landfill Vieques	Anaerobic dig Drying beds
Yabucoa	2	0.601	0.67	2,221	1,037	Landfill Yabucoa	Anaerobic dig Drying beds
Naguabo	5	0.35	0.1	315	283.5	N/A	None
Palmer	1	0.07	0.25	1,361	158	Landfill Luquillo	Aerobic dig Drying beds
TOTALS		15.35	17.24	142,636	29,072		

TABLE 6
SLUDGE MANAGEMENT

MAYAGUEZ REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Alturas de Maya	1	0.202	0.3	3,927	455	Landfill Mayaguez	Aerobic dig Trucking
Villa Taina	1	0.116	0.35	2,255	261	Landfill Cabo Rojo	Aerobic dig Drying beds
Cabo Rojo	1	1.026	0.7	19,945	2,309	Landfill Cabo Rojo	Aerobic dig Drying beds
El Valle	1	0.021	0.1	408	47	Landfill Lajas	Aerobic dig Drying beds
Maricao	1	0.049	0.175	953	110	Landfill Maricao	Aerobic dig Drying beds
Moca	1	0.511	0.3	9,934	1,150	Landfill Aguadilla	Aerobic dig Drying beds
San German	1	0.881	1	17,127	1,982	Landfill San German	Aerobic dig Drying beds
Guanajibo Homes	1	0.068	0.1	1,322	153	N/A	None
Lajas	1	0.186	0.12	3,616	419	Landfill Lajas	Anaerobic dig Drying beds
Anasco	2	0.376	0.67	1,389	649	Landfill Anasco	Anaerobic dig Drying beds
Hormigueros	7	0.368	0.5	184	254	Landfill Hormigueros	Anaerobic dig Drying beds
Marbella I	2	0.198	0.203	732	342	Landfill Aguadilla	Anaerobic dig Drying beds
Marbella II	2	0.431	0.543	1,593	744	Landfill Aguadilla	Anaerobic dig Drying beds
Ramey	2	0.75	1.587	0	0	Raw discharge	Raw discharge

San Sebastian	2	0.764	0.553	2,823	1,319	Landfill San Sebastian	Anaerobic dig Drying beds
Valle Hermoso	2	0.494	0.67	1,825	853	Landfill Hormigueros	Anaerobic dig Drying beds
Zona Libre	2	0.299	0.553	1,105	516	Landfill Mayaguez	Anaerobic dig Drying beds
Las Marias	2	0.127	0.055	469	219	Landfill Las Marias	Anaerobic dig Drying beds
La Victoria	2	0.18	0.15	665	311	Landfill Aguadilla	Anaerobic dig Drying beds
Rincon	3	0.164	0.1	484	205	Landfill Aguadilla	Anaerobic dig Drying beds
Sabana Grande	3	0.397	0.848	1,171	496	Landfill Sabana Grande	Anaerobic dig Drying beds
Aguada	5	0.32	0.1	288	259.2	Landfill Aguadilla	Drying beds
Aguadilla RWWTP	6	2.7	8	7,965	3,375	Landfill Aguadilla	Thickener Filter press
TOTALS		10.62	17.67	80,179	16,426		

TABLE 6
SLUDGE MANAGEMENT

PONCE REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Orocovis	1	0.161	0.5	3,130	362	Landfill Orocovis	Aerobic dig Drying beds
Alt de Orocovis	1	0.078	0.05	1,516	176	Bayamon RWWTP	Aerobic dig Trucking
Playa Santa	1	0.001	0.5	19	2	Landfill Guanica	Aerobic dig Drying beds
Adjuntas	2	0.245	0.553	905	423	Landfill Adjuntas	Anaerobic dig Drying beds
Coamo	2	0.604	1.267	2,232	1,043	Landfill Coamo	Anaerobic dig Drying beds
Guanica	3	0.95	0.328	2,803	1,188	Landfill Guanica	Anaerobic dig Drying beds
Guayanilla	2	0.432	0.328	1,596	746	Landfill Guayanilla	Anaerobic dig Drying beds
Juana Diaz	2	0.705	0.16	2,605	1,217	Landfill Juana Diaz	Anaerobic dig Drying beds
Penuelas	7	0.471	0.3	236	325	Landfill Penuelas	Anaerobic dig Drying beds
Santa Isabel	2	0.584	1	2,158	1,008	Landfill Santa Isabel	Anaerobic dig Drying beds
Villalba	2	0.151	0.113	558	261	Landfill Villalba	Anaerobic dig Drying beds
Yauco	2	1.132	1.68	4,183	1,954	Landfill Yauco	Anaerobic dig Drying beds
Ponce	6	12.56	12	37,052	15,700	Landfill Juana Diaz	Anaerobic dig Drying beds
TOTALS		18.07	18.77	58,992	24,403		

TABLE 6
SLUDGE MANAGEMENT

SAN JUAN REGION

Plant Name	Type	1986 Flow	Design Flow	1986 Estimated Sludge Produced (Gal/Day)	1986 Estimated Sludge Produced (Lbs/Day)	Sludge Disposal Method	Sludge Processes
Puerto Nuevo	6	52.27	72	154,202	65,340	Incineration	Thickener
						Landfill	Centrifugues
Rosa Maria	3	0.328	0.341	968	410	Landfill	Anaerobic dig
						San Juan	Drying beds
Guaynabo	2	1.693	1.924	6,256	2,922	Landfill	Anaerobic dig
	1	0.3	0.3	5,832	675	Guaynabo	Aerobic dig
							Drying beds
Rolling Hills	2	0.661	0.954	2,442	1,141	Landfill	Anaerobic dig
	1	0.221	0.3	4,296	497	Carolina	Aerobic dig
							Drying beds
Lago Alto	2	0.111	0.222	410	192	Landfill	Anaerobic dig
						Carolina	Drying beds
Loiza Valley	2	0.27	0.513	998	466	Landfill	Anaerobic dig
						Carolina	Drying beds
Round Hill	1	0.268	0.341	5,210	603	Landfill	Aerobic dig
						Carolina	Drying beds
Villa Carolina	2	5.446	8	20,123	9,400	Landfill	Anaerobic dig
						Carolina	Drying beds
Palmarejo	1	0.651	0.336	12,655	1,465	Landfill	Aerobic dig
						Carolina	Drying beds
Vistamar	2	1.661	1.825	6,137	2,867	Landfill	Anaerobic dig
						Carolina	Drying beds
Brisas de Loiza	1	0.556	0.375	10,809	1,251	Landfill	Aerobic dig
						Carolina	Drying beds

El Conquistador	1	0.407	0.5	7,912	916	Landfill Carolina	Aerobic dig Drying beds
Loiza Aldea	1	0.507	0.3	9,856	1,141	Landfill Carolina	Aerobic dig Drying beds
Lomas de Caroli	1	0.663	0.75	12,889	1,492	Landfill Carolina	Aerobic dig Drying beds
Villas del Sol	1	0.106	0.1	2,061	239	Landfill Carolina	Aerobic dig Drying beds
Villas de Loiza	1	0.269	0.75	5,229	605	Landfill Carolina	Aerobic dig Drying beds
Trujillo Alto	4	0.142	0.1	71	98	Landfill Carolina	Anaerobic dig Drying beds
TOTALS		66.53	89.93	268,356	91,718		

Key to plant type:
1. activated sludge
2. trickling filter
3. primary plant
4. Imhoff tank
5. septic tank
6. primary regional plant
7. treated wood biofilter

are no figures showing, for example, the gallons of sludge that are discharged to the drying beds. It is believed that this estimate provides as good a figure as can be obtained on current sludge production.

The last two columns of Table 6 present the ultimate sludge disposal method and the treatment processes which are used.

IV. PREDICTED FUTURE SLUDGE QUANTITIES

A. Assumptions

Flow projections for PRASA's plants are generally not available or are outdated. Most of the planning for the regional wastewater treatment system which is projected to eliminate at least 50% of the current plants was done in the mid to late 1970's. Since then the financial condition of PRASA and Puerto Rico's economic and population development has changed in such a way that the Facility Plans that were made are very seldom applicable. In addition, it is now recognized that these plans used somewhat inflated flow projections in order to build bigger plants than what was actually necessary. Therefore, a projection was made for this study based on population estimates and current knowledge of the future construction plans of the Authority. Table 7 presents the percentage increase in population for each PRASA region based on the 1980 population projections made by the Puerto Rico Planning Board (9). The figures for 1986 have been used as the base figure (100%) and the figures for each year are expressed as a percentage of this base value.

Table 8 presents the plants that are expected to be eliminated by PRASA's projected capital improvement program, and the plants where this flow will be diverted to. Table 9 shows the expected new regional wastewater treatment plants and the flows which they are expected to receive. In addition, it was also assumed that the upgrading/rehabilitation program which is currently being developed by PRASA will be successful

TABLE 7

POPULATION INCREASE BY REGION

	Year					
Region	1986	1991	1996	2001	2006	2011
Arecibo	100.0	102.6	106.1	110.3	114.1	117.1
Bayamon	100.0	104.5	110.3	116.9	123.0	128.3
Guayama	100.0	101.6	104.1	107.1	109.7	111.2
Humacao	100.0	104.5	110.5	117.5	124.4	129.4
Mayaguez	100.0	103.8	108.6	114.2	119.3	123.8
Ponce	100.0	100.6	101.6	102.9	103.9	104.6
San Juan	100.0	100.6	101.2	102.2	102.8	103.6

TABLE 8

WASTEWATER TREATMENT PLANT THAT WILL BE ELIMINATED

	Region	Plant	Year	Flow Will Be Diverted to
1.	Arecibo	Florida	1990	Barceloneta RWWTP
		Vega Baja	2000	Dorado RWWTP
2.	Bayamón	Covadonga	1988	Bayamón RWWTP
		Las Teresas	1988	Bayamón RWWTP
		Santa Juanita	1988	Bayamón RWWTP
		Dorado	2000	Dorado RWWTP
		Toa Alta	2000	Dorado RWWTP
		Toa Alta Heights	2000	Dorado RWWTP
		Vega Alta	2000	Dorado RWWTP
3.	Guayama	Salinas	1990	Guayama RWWTP
		Arroyo	1990	Guayama RWWTP
		El Coquí	1990	Guayama RWWTP
		Patillas	1995	Guayama RWWTP
4.	Humacao	Aguas Buenas	2000	Caguas RWWTP
		Caguas	2000	Caguas RWWTP
		Ceiba	2000	Fajardo RWWTP
		Fajardo	2000	Fajardo RWWTP
		Gurabo	2000	Caguas RWWTP
		Humacao	1990	Humacao RWWTP
		Juncos	2000	Caguas RWWTP
		Las Leandras	1990	Humacao RWWTP
		Las Piedras	1990	Humacao RWWTP
5.	Mayaguez	Alturas de Mayaguez	1989	Mayaguez RWWTP
		Cabo Rojo	1987	Mayaguez RWWTP
		Añasco	1995	Mayaguez RWWTP
6.	Ponce	Guánica	1990	Union Carbide WWTP
		Guayanilla	1990	Union Carbide WWTP
		Juana Díaz	1989	Ponce RWWTP
		Peñuelas	1990	Union Carbide WWTP
		Villalba	1989	Ponce WWTP
7.	San Juan	Canóvanas	1987	Carolina RWWTP
		El Conquistador	1988	Carolina RWWTP
		Loíza Aldea	1988	Carolina RWWTP
		Lomas de Carolina	1988	Carolina RWWTP
		Palmarejo	1988	Carolina RWWTP
		Brisas de Loíza	1995	Carolina RWWTP
		Villas de Loíza	1995	Carolina RWWTP

TABLE 9

NEW REGIONAL WASTEWATER TREATMENT PLANTS

Region	Plant	Type of Plant	Will Receive Flow From	Year
Bayamón	Dorado RWWTP	6	Dorado	2000
			Toa Alta	2000
			Toa Alta Heights	2000
			Vega Alta	2000
Guayama	Guayama RWWTP	1	Salinas	1990
			Arroyo	1990
			El Coquí	1990
			Patillas	1995
Humacao	Caguas	1	Aguas Buenas	2000
			Caguas	2000
			Gurabo	2000
			Juncos	2000
			San Lorenzo	2000
	Fajardo RWWTP	1	Ceiba	2000
			Fajardo	2000
			Luquillo	2000
			Palmer	2000
	Humacao RWWTP	1	Humacao	1990
			Las Piedras	1990
			Naguabo	1990
			Villa Palmira	1990
Ponce	Union Carbide RWWTP	1	Guánica	1990
			Guayanilla	1990
			Peñuelas	1990

and that all of the non-regional plants will be operating at secondary treatments levels.

B. Results

The assumptions discussed in the previous sections were combined to obtain plant-by-plant projections for sludge production for the years 1991, 1996, 2001, 2006 and 2011. The specific figures for each plant are given in Appendix A. Tables 10 and 11 summarize these data on a region-by-region basis, where Table 10 presents the sludge projection in terms of gallons/day while Table 11 presents the mass in terms of lbs/day. Table 12 presents the estimated wastewater flows for the same time periods.

Table 10 shows a 5.6% decrease in the total volume of sludge produced in the island from 1986 to 1991, even though Table 12 shows an 8.5% increase in flow. Table 11, however, shows a 3.6% increase in the mass of sludge produced. The decrease shown in Table 10 is due to the elimination during the period of a number of secondary treatment plants by their connection to primary regional facilities. The best example of this is the Mayaguez region, where the two regional primary plants at Mayaquez and Aguadilla will account for 81.4% of the flow in 2011 while they only accounted for 25.4% in 1986. As shown in Table 4, there is a 57.2% decrease in volume of sludge produced when this occurs, while the decrease in mass is 46.8%. These different decreases explain that the overall volume decreases while the mass increases.

TABLE 10

ESTIMATED SLUDGE PRODUCTION(GAL/DAY)

Region	Year 1986	1991	1996	2001	2006	2011
Arecibo	173,012	185,389	191,710	192,117	206,597	212,027
Bayamon	83,991	70,968	74,930	78,761	82,871	86,441
Guayama	45,872	49,829	43,205	44,450	45,529	46,152
Humacao	142,636	124,447	131,593	132,863	140,666	146,321
Mayaguez	80,179	61,531	64,397	67,718	70,742	73,411
Ponce	58,992	98,831	99,813	101,090	102,072	102,759
San Juan	268,356	214,507	202,155	204,152	205,350	206,947
TOTAL	853,039	805,501	807,803	821,150	853,827	874,059

TABLE 11

ESTIMATED SLUDGE PRODUCTION(LBS/DAY)

Region	Year 1986	1991	1996	2001	2006	2011
Arecibo	27,829	34,767	35,953	34,022	36,586	37,548
Bayamon	27,933	24,096	25,441	28,619	30,113	31,410
Guayama	9,122	14,379	14,472	14,889	15,250	15,459
Humacao	29,072	27,271	28,837	30,424	32,211	33,506
Mayaguez	16,426	19,172	20,065	21,099	22,042	22,873
Ponce	24,403	29,709	30,004	30,388	30,683	30,890
San Juan	91,718	85,287	85,016	85,856	86,360	87,032
TOTAL	226,503	234,681	239,789	245,298	253,245	258,717

TABLE 12

ESTIMATED FLOWS(MGD)

	Year					
Region	1986	1991	1996	2001	2006	2011
Arecibo	14.7	19.5	20.2	19.0	20.5	21.0
Bayamon	19.9	18.4	19.4	20.9	22.0	23.0
Guayama	5.0	7.9	8.1	8.4	8.6	8.7
Humacao	15.4	14.4	15.3	16.2	17.2	17.9
Mayaguez	10.6	14.0	14.7	15.4	16.1	16.7
Ponce	18.1	21.1	21.3	21.6	21.8	21.9
San Juan	66.5	67.5	67.9	68.6	69.0	69.5
TOTAL	150.2	162.9	166.9	170.1	175.1	178.7

The overall result for the 25 years projection is that the wastewater flow will increase by 18.9%, the sludge volume by 2.5%, and the sludge mass by 14.2%. Sludge mass will go down in the San Juan region, increase moderately in the Humacao and Bayamón regions, and have a significant increase in the Arecibo, Guayama, Mayaguez and Ponce regions.

V. DEVELOPMENT OF SLUDGE MANAGEMENT ALTERNATIVES

A. General Approach

Chapter II discussed the multiplicity of sludge management processes that are available. Comments were made as to the applicability of each of these processes to Puerto Rico in the near future. These comments, together with the following general guidelines, have been used to select the alternatives that follow:

1. Processes must be simple to operate since PRASA's operating staff is not used to working with highly sophisticated equipment.
2. If at all possible, capital expenditures must also be minimized due to PRASA's precarious financial condition, which is not expected to improve markedly in the near future.
3. Maximum utilization must be made of existing sludge handling capabilities, or of those that are already in the pipeline of construction grant financing.
4. If possible, alternatives that increase the reuse of sludge should be encouraged.

B. Alternatives for Each PRASA Region

The alternatives that follow consider mainly the means of ultimate disposal of the sludge. This is so because, as shown in Table 6, there is currently an appropriate amount of processes at the plant for the stabilization and dewatering of the sludges. The only conveyance system that is available in

Puerto Rico is trucking, so there is no alternative available there neither.

1. Arecibo
    a. Truck of all of the region's sludge to the Arecibo regional plant to be converted into compost.
    b. Use the compost facility in Arecibo for the regional plants at Arecibo and Camuy. Continue with the land application operation at Barceloneta. Continue with the landfilling operation at the remaining small plants.
    c. Construct an incinerator at the Arecibo regional plant to incinerate all of the region's sludge.
2. Bayamón
    a. Incinerate the sludge from Bayamón and Dorado at the Puerto Nuevo incinerator. Landfill the sludge from Corozal and Naranjito.
    b. Incinerate the sludge from Bayamón at Puerto Nuevo. Landfill the sludge from the other three plants using municipal landfills.
3. Guayama
    a. Landfill the sludge at all the plants using nearby municipal facilities.

   b. Operate a dedicated landfill at Guayama for all the plants in the region.

4. Humacao
   a. Landfill the sludge from all the plants at nearby facilities except Caguas, which will be incinerated at Puerto Nuevo.
   b. Incinerate the sludge from Caguas and Humacao at Puerto Nuevo and landfill the sludge from the other plants at nearby facilities.
   c. Construct an incinerator at Fajardo to incinerate the sludge from Fajardo, Ceiba and Humacao. Landfill the sludge from the other plants at nearby facilities. Continue trucking the sludge from Caguas to the Puerto Nuevo incinerator.

5. Mayaguez
   a. Use the Mayaguez compost facility to process all the sludge from the region .
   b. Use the Mayaguez compost facility to process the sludge from the Mayaguez and Aguadilla plants and use nearby landfills for the other plants.
   c. Construct an incinerator at Mayaguez to process the sludge from all the plants in the region.

6. Ponce

   a. Construct an incinerator at Ponce to process the sludge from all the plants in the region except Orocovis, Alturas de Orocovis and Adjuntas, who will use nearby landfills.

   b. Continue the current practice of landfilling the sludge at nearby facilities.

   c. Build a composting facility at Ponce to process the sludge from all the plants in the area except Orocovis, Alturas de Orocovis and Adjuntas.

7. San Juan

   a. Continue the current practice of incinerating all of the sludge from the region at Puerto Nuevo.

   b. Build a compost facility at Carolina to process the sludge from that plant. Incinerate the rest of the sludge at Puerto Nuevo.

   c. Build an incinerator at Carolina to burn the sludge from that plant and continue to burn the sludge from the other plants at Puerto Nuevo.

C. Alternative Evaluation Criteria

A point system was used to evaluate the alternatives at each region. The specific criteria and their respective point categories were:

1. Capital cost: high = 1, medium = 2 and low = 3
2. Operating cost: high = 1, medium = 2 and low = 3
3. Regulatory constraints: many = 1, average = 2 and few = 3
4. Public acceptability: low =1, medium =2 and high =3
5. Simplicity of implementation: hard =1, medium = = 2 and easy = 3
6. Flexibility: low =1, medium =2 and high =3
7. Environmental impact: high = 1, medium = 2 and low = 3
8. Technical complexity: high = 1, medium =2 and low = 3

Table 13 presents the assignment of point that were made to each alternative based on the above system. The next chapter discusses the results.

TABLE 13

ALTERNATIVE EVALUATION

	Criteria								
Region/alternative	1	2	3	4	5	6	7	8	Total points
Arecibo/a	3	1	3	3	2	2	3	2	19
/b	3	3	3	2	3	2	2	2	20
/c	1	2	1	1	1	3	2	1	12
Bayamón/a	3	2	2	2	3	3	2	2	19
/b	3	3	3	2	3	2	3	3	22
Guayama/a	3	3	2	3	3	2	2	3	21
/b	2	2	3	2	2	3	2	2	18
Humacao/a	3	3	3	2	3	2	3	2	21
/b	1	2	1	1	1	2	1	1	10
Mayaguez/a	2	2	3	2	3	2	3	2	19
/b	2	3	3	2	3	3	2	2	20
/c	1	2	1	1	1	2	1	1	10
Ponce/a	1	2	1	1	1	2	1	1	10
/b	3	2	2	2	3	3	2	3	20
/c	2	2	3	2	2	3	3	2	19
San Juan/a	3	2	2	2	3	3	2	2	19
/b	2	3	3	3	2	2	3	2	20
/c	1	2	1	1	1	2	1	1	10

VI. CONCLUSIONS AND RECOMMENDATIONS

1. This study has analyzed and evaluated the current municipal wastewater sludge management practices in Puerto Rico. It has been found that there is almost a total absence of operational data concerning the performance of the different processes, in particular of anaerobic digestion. It is suspected that the mere collection of data would go a long way towards concluding that more sludge is ending up for final disposal than what would be expected if the digestion processes were properly controlled.
2. Several quick measures can be taken to improve the overall management program in addition to controlling it better. The first measure would be to cover the sludge drying beds at those areas with high rainfalls. Maricao and Las Marías would be prime candidates. It is suggested that care be taken in the selection of the cover material, which not necessarily has to be translucent.
3. There is a need to develop better operational practices for the sludge drying beds. A technique that warrants further evaluation is the successive discharge of 3-4 inches of sludge to the beds on successive days rather than 12-18 inches on just one day.

4. The removal of dry sludge from the beds should be better managed since it is the most common source of sludge bottlenecks.
5. This study attempted to quantify the current sludge production at the plants and use this data to project future production levels. The results have shown that the volumetric increase in production is not as large as expected since a significant number of secondary plants, particularly in the metropolitan area, are being connected to primary plants which produce less sludge since they remove less contaminants from wastewater.
6. The above mentioned sludge projections, together with good engineering judgement, were used to formulate final sludge disposal alternatives for each of PRASA's regions. These alternative were evaluated using eight different criteria and a point system. The suggested alternatives for each region are:
   a. Arecibo

      Use the compost facility currently being built at the Arecibo regional plant to process the sludge from the Arecibo and the Camuy regional plants. The sludge from Barceloneta will continue to be applied to the land at a farm adjacent to it and the other plants will continue to landfill their sludge at nearby municipal sanitary landfills.

b. Bayamón

Incinerate the sludge from the Bayamón regional plant at he Puerto Nuevo incinerator and continue to land fill the sludge from the other plants at nearby sanitary landfills.

c. Guayama

Use the municipal landfills currently available to landfill the sludge from the plants.

d. Humacao

Use the municipal landfills currently available to landfill the sludge from all the plants except for Caguas, which will be trucked to Puerto Nuevo for incineration.

e. Mayaguez

Use the future Mayaguez compost facility to process the sludge from the Mayaguez and Aguadilla regional plants and use municipal landfills to dispose of the sludge of the other plants.

f. Ponce

Use the landfills currently available to dispose of the sludge from all the plants.

g. San Juan

Incinerate the sludge from Puerto Nuevo and Villas del Sol at the Puerto Nuevo incinerator.

Build a compost facility at Carolina to process the sludge of this plant.

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APPENDIX A

SLUDGE PROJECTIONS

1991
SLUDGE PROJECTIONS

ARECIBO REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Ciales	0.184	3,592	416
Isabela	1.129	21,949	2,540
Jayuya	0.340	6,624	767
Barceloneta	5.822	113,195	13,101
Camuy RWWTP	3.4	12,563	5,868
Lares	0.296	1,096	512
Morovis	0.210	777	363
Utuado	0.408	1,509	705
Vega Baja	1.807	6,679	3,120
Arecibo RWWTP	5.9	17,405	7,375
TOTALS	19.50	185,389	34,767

BAYAMON REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Bayamon RWWTP	14.9	43,955	18,625
Dorado	1.261	4,660	2,177
Corozal	0.567	11,029	1,276
Naranjito	0.222	4,326	501
Toa Alta Height	0.331	6,439	745
Toa Alta	0.475	238	328
Vega Alta	0.643	322	444
TOTALS	18.40	70,968	24,096

1991
SLUDGE PROJECTIONS

GUAYAMA REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Aibonito	0.643	12,502	1,447
Guayama RWWTP	3.86	14,263	6,662
El Torito	0.136	2,647	306
Vista Monte	0.036	711	82
Patillas	0.486	9,461	1,095
Barranquitas	0.261	965	451
Cayey	1.505	5,564	2,599
Cidra	0.620	2,294	1,071
Comerio	0.160	593	277
Maunabo	0.224	830	388
TOTALS	7.935	49,829	14,379

1991
SLUDGE PROJECTIONS

HUMACAO REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Gurabo	0.582	11,333	1,312
Ceiba	0.313	6,093	705
Col del Yunque	0.057	1,117	129
Humacao RWWTP	2.96	57,542	6,660
Pueblito d. Rio	0.126	2,458	284
Ramon Rivero	0.176	3,433	397
Rio Blanco He.	0.054	1,056	122
Rio Grande Est.	0.173	3,372	390
Aguas Buenas	0.283	1,046	489
Caguas	5.604	20,708	9,673
Fajardo	1.525	5,636	2,633
Juncos	0.571	2,112	986
Luquillo	0.586	2,166	1,012
San Lorenzo	0.554	2,050	958
Vieques	0.157	583	272
Yabucoa	0.627	2,320	1,084
Palmer	0.073	1,422	165
TOTALS	14.42	124,447	27,271

1991
SLUDGE PROJECTIONS

MAYAGUEZ REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
El Valle	0.021	424	49
Maricao	0.050	988	114
San German	0.914	17,771	2,057
Lajas	0.192	3,752	434
San Sebastian	0.792	2,929	1,368
Las Marias	0.131	487	227
La Parguera	0.09	333	155
Sabana Grande	0.411	1,215	515
Mayaguez RWWTP	8.2	24,190	10,250
Aguadilla RWWTP	3.201	9,443	4,001
TOTALS	14.00	61,531	19,172

1991
SLUDGE PROJECTIONS

PONCE REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Orocovis	0.162	3,150	365
Alt de Orocovis	0.078	1,526	177
Playa Santa	0.001	20	2
Adjuntas	0.246	911	426
Coamo	0.607	2,246	1,049
Union Carb RWWTP	1.86	36,158	4,185
Santa Isabel	0.587	2,172	1,014
Yauco	1.139	4,210	1,966
Ponce	16.42	48,439	20,525
TOTALS	21.10	98,831	29,709

SAN JUAN REGION

Plant Name	1991 Flow	1991 Estimated Sludge Produced (Gal/Day)	1991 Estimated Sludge Produced (Lbs/Day)
Puerto Nuevo	52.56	155,066	65,706
Carolina RWWTP	13.98	41,241	17,475
Brisas de Loiza	0.559	10,869	1,258
Villas del Sol	0.106	2,072	240
Villas de Loiza	0.270	5,259	609
TOTALS	67.48	214,507	85,287

1996
SLUDGE PROJECTIONS

ARECIBO REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Ciales	0.191	3,714	430
Isabela	1.167	22,697	2,627
Jayuya	0.352	6,850	793
Barceloneta	6.021	117,054	13,548
Camuy RWWTP	3.515	12,991	6,069
Lares	0.306	1,133	529
Morovis	0.217	804	376
Utuado	0.422	1,561	729
Vega Baja	1.869	6,906	3,226
Arecibo RWWTP	6.101	17,998	7,626
TOTALS	20.16	191,710	35,953

BAYAMON REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Bayamon RWWTP	15.73	46,409	19,665
Dorado	1.331	4,920	2,298
Corozal	0.599	11,645	1,348
Naranjito	0.234	4,568	529
Toa Alta Height	0.349	6,798	787
Toa Alta	0.501	251	346
Vega Alta	0.679	340	469
TOTALS	19.42	74,930	25,441

1996
SLUDGE PROJECTIONS

GUAYAMA REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Aibonito	0.658	12,810	1,483
Guayama RWWTP	4.454	16,458	7,688
El Torito	0.139	2,712	314
Vista Monte	0.037	729	84
Barranquitas	0.267	989	462
Cayey	1.542	5,701	2,663
Cidra	0.636	2,350	1,098
Comerio	0.164	608	284
Maunabo	0.230	850	397
TOTALS	8.130	43,205	14,472

1996
SLUDGE PROJECTIONS

HUMACAO REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Gurabo	0.616	11,984	1,387
Ceiba	0.331	6,443	746
Col del Yunque	0.060	1,181	137
Humacao RWWTP	3.129	60,847	7,042
Pueblito d. Rio	0.133	2,599	301
Ramon Rivero	0.186	3,630	420
Rio Blanco He.	0.057	1,117	129
Rio Grande Est.	0.183	3,565	413
Aguas Buenas	0.299	1,106	517
Caguas	5.926	21,897	10,229
Fajardo	1.613	5,960	2,784
Juncos	0.604	2,233	1,043
Luquillo	0.619	2,290	1,070
San Lorenzo	0.586	2,168	1,013
Vieques	0.166	616	288
Yabucoa	0.663	2,453	1,146
Palmer	0.077	1,503	174
TOTALS	15.25	131,593	28,837

1996
SLUDGE PROJECTIONS

MAYAGUEZ REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
El Valle	0.022	443	51
Maricao	0.053	1,034	120
San German	0.956	18,598	2,153
Lajas	0.201	3,927	454
San Sebastian	0.829	3,066	1,432
Las Marias	0.137	510	238
La Parguera	0.094	348	163
Sabana Grande	0.431	1,272	539
Mayaguez RWWTP	8.581	25,317	10,727
Aguadilla RWWTP	3.350	9,883	4,188
TOTALS	14.65	64,397	20,065

1996
SLUDGE PROJECTIONS

PONCE REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Orocovis	0.163	3,181	368
Alt de Orocovis	0.079	1,541	178
Playa Santa	0.001	20	2
Adjuntas	0.249	920	430
Coamo	0.613	2,268	1,060
Union Carb RWWTP	1.878	36,518	4,227
Santa Isabel	0.593	2,193	1,025
Yauco	1.150	4,251	1,986
Ponce	16.58	48,920	20,729
TOTALS	21.31	99,813	30,004

SAN JUAN REGION

Plant Name	1996 Flow	1996 Estimated Sludge Produced (Gal/Day)	1996 Estimated Sludge Produced (Lbs/Day)
Puerto Nuevo	52.91	156,094	66,141
Carolina RWWTP	14.90	43,975	18,633
Villas del Sol	0.107	2,086	241
TOTALS	67.92	202,155	85,016

2001
SLUDGE PROJECTIONS

ARECIBO REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Ciales	0.198	3,861	447
Isabela	1.213	23,595	2,731
Jayuya	0.366	7,121	824
Barceloneta	6.259	121,686	14,084
Camuy RWWTP	3.655	13,505	6,309
Lares	0.318	1,178	550
Morovis	0.226	836	390
Utuado	0.439	1,623	758
Arecibo RWWTP	6.342	18,711	7,928
TOTALS	19.02	192,117	34,022

BAYAMON REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Bayamon RWWTP	16.67	49,186	20,841
Dorado	3.354	12,394	5,789
Corozal	0.634	12,341	1,428
Naranjito	0.249	4,841	560
TOTALS	20.91	78,761	28,619

2001
SLUDGE PROJECTIONS

GUAYAMA REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Aibonito	0.677	13,179	1,525
Guayama RWWTP	4.582	16,932	7,909
El Torito	0.143	2,790	323
Vista Monte	0.038	750	87
Barranquitas	0.275	1,017	475
Cayey	1.587	5,865	2,740
Cidra	0.654	2,418	1,129
Comerio	0.169	625	292
Maunabo	0.236	875	409
TOTALS	8.365	44,450	14,889

HUMACAO REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Col del Yunque	0.064	1,256	145
Humacao RWWTP	3.970	77,183	8,933
Pueblito d. Rio	0.142	2,763	320
Ramon Rivero	0.198	3,860	447
Rio Blanco He.	0.061	1,188	137
Rio Grande Est.	0.195	3,791	439
Caguas	7.897	29,182	13,631
Fajardo RWWTP	2.808	10,376	4,847
Vieques	0.177	655	306
Yabucoa	0.706	2,609	1,219
TOTALS	16.22	132,863	30,424

2001
SLUDGE PROJECTIONS

MAYAGUEZ REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
El Valle	0.023	466	54
Maricao	0.055	1,088	126
San German	1.006	19,557	2,264
Lajas	0.212	4,129	478
San Sebastian	0.872	3,224	1,506
Las Marias	0.145	536	250
La Parguera	0.099	366	171
Sabana Grande	0.453	1,337	567
Mayaguez RWWTP	9.024	26,622	11,281
Aguadilla RWWTP	3.522	10,392	4,404
TOTALS	15.41	67,718	21,099

2001
SLUDGE PROJECTIONS

PONCE REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Orocovis	0.165	3,222	373
Alt de Orocovis	0.080	1,561	181
Playa Santa	0.001	20	2
Adjuntas	0.252	932	435
Coamo	0.621	2,297	1,073
Union Carb RWWTP	1.902	36,985	4,281
Santa Isabel	0.601	2,221	1,038
Yauco	1.165	4,306	2,011
Ponce	16.79	49,546	20,994
TOTALS	21.58	101,090	30,388

SAN JUAN REGION

Plant Name	2001 Flow	2001 Estimated Sludge Produced (Gal/Day)	2001 Estimated Sludge Produced (Lbs/Day)
Puerto Nuevo	53.43	157,636	66,795
Carolina RWWTP	15.05	44,409	18,817
Villas del Sol	0.108	2,107	244
TOTALS	68.59	204,152	85,856

2006
SLUDGE PROJECTIONS

ARECIBO REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Ciales	0.213	4,152	481
Isabela	1.305	25,373	2,937
Jayuya	0.393	7,658	886
Barceloneta	6.731	130,858	15,146
Camuy RWWTP	3.930	14,523	6,784
Lares	0.342	1,267	592
Morovis	0.243	899	420
Utuado	0.472	1,745	815
Arecibo RWWTP	6.820	20,121	8,526
TOTALS	20.45	206,597	36,586

BAYAMON REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Bayamon RWWTP	17.54	51,752	21,929
Dorado	3.529	13,040	6,091
Corozal	0.667	12,985	1,503
Naranjito	0.262	5,094	590
TOTALS	22.00	82,871	30,113

2006
SLUDGE PROJECTIONS

GUAYAMA REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Aibonito	0.694	13,499	1,562
Guayama RWWTP	4.693	17,343	8,101
El Torito	0.146	2,858	331
Vista Monte	0.039	768	89
Barranquitas	0.281	1,042	487
Cayey	1.625	6,007	2,806
Cidra	0.670	2,477	1,157
Comerio	0.173	640	299
Maunabo	0.242	896	418
TOTALS	8.568	45,529	15,250

HUMACAO REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Col del Yunque	0.068	1,330	154
Humacao RWWTP	4.203	81,716	9,458
Pueblito d. Rio	0.150	2,926	339
Ramon Rivero	0.210	4,086	473
Rio Blanco He.	0.064	1,257	146
Rio Grande Est.	0.206	4,014	465
Caguas	8.361	30,896	14,432
Fajardo RWWTP	2.973	10,986	5,132
Vieques	0.187	694	324
Yabucoa	0.747	2,762	1,290
TOTALS	17.17	140,666	32,211

2006
SLUDGE PROJECTIONS

MAYAGUEZ REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
El Valle	0.025	487	56
Maricao	0.058	1,136	132
San German	1.050	20,431	2,365
Lajas	0.221	4,313	499
San Sebastian	0.911	3,368	1,573
Las Marias	0.151	560	261
La Parguera	0.103	382	179
Sabana Grande	0.473	1,397	592
Mayaguez RWWTP	9.427	27,811	11,784
Aguadilla RWWTP	3.680	10,857	4,600
TOTALS	16.10	70,742	22,042

2006
SLUDGE PROJECTIONS

PONCE REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Orocovis	0.167	3,253	377
Alt de Orocovis	0.081	1,576	182
Playa Santa	0.001	20	2
Adjuntas	0.254	941	440
Coamo	0.627	2,320	1,084
Union Carb RWWTP	1.920	37,344	4,322
Santa Isabel	0.607	2,243	1,048
Yauco	1.176	4,348	2,031
Ponce	16.95	50,027	21,198
TOTALS	21.79	102,072	30,683

SAN JUAN REGION

Plant Name	2006 Flow	2006 Estimated Sludge Produced (Gal/Day)	2006 Estimated Sludge Produced (Lbs/Day)
Puerto Nuevo	53.74	158,561	67,187
Carolina RWWTP	15.14	44,670	18,928
Villas del Sol	0.108	2,119	245
TOTALS	69.00	205,350	86,360

2011
SLUDGE PROJECTIONS

ARECIBO REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Ciales	0.219	4,261	493
Isabela	1.339	26,040	3,014
Jayuya	0.404	7,859	910
Barceloneta	6.908	134,297	15,544
Camuy RWWTP	4.033	14,905	6,962
Lares	0.351	1,300	607
Morovis	0.249	922	431
Utuado	0.484	1,791	837
Arecibo RWWTP	6.999	20,650	8,750
TOTALS	20.99	212,027	37,548

BAYAMON REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Bayamon RWWTP	18.29	53,982	22,874
Dorado	3.681	13,602	6,354
Corozal	0.696	13,545	1,568
Naranjito	0.273	5,313	615
TOTALS	22.95	86,441	31,410

2011
SLUDGE PROJECTIONS

GUAYAMA REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Aibonito	0.703	13,684	1,584
Guayama RWWTP	4.757	17,580	8,212
El Torito	0.149	2,897	335
Vista Monte	0.040	778	90
Barranquitas	0.285	1,056	493
Cayey	1.647	6,089	2,844
Cidra	0.679	2,510	1,173
Comerio	0.175	649	303
Maunabo	0.245	908	424
TOTALS	8.685	46,152	15,459

HUMACAO REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Col del Yunque	0.071	1,383	160
Humacao RWWTP	4.372	85,001	9,838
Pueblito d. Rio	0.156	3,043	352
Ramon Rivero	0.218	4,251	492
Rio Blanco He.	0.067	1,308	151
Rio Grande Est.	0.214	4,175	483
Caguas	8.697	32,138	15,012
Fajardo RWWTP	3.092	11,427	5,338
Vieques	0.195	722	337
Yabucoa	0.777	2,873	1,342
TOTALS	17.86	146,321	33,506

2011
SLUDGE PROJECTIONS

MAYAGUEZ REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
El Valle	0.025	505	58
Maricao	0.060	1,179	136
San German	1.090	21,202	2,454
Lajas	0.230	4,476	518
San Sebastian	0.945	3,495	1,632
Las Marias	0.157	581	271
La Parguera	0.107	397	185
Sabana Grande	0.491	1,450	614
Mayaguez RWWTP	9.783	28,860	12,229
Aguadilla RWWTP	3.819	11,266	4,774
TOTALS	16.71	73,411	22,873

2011
SLUDGE PROJECTIONS

PONCE REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Orocovis	0.168	3,275	379
Alt de Orocovis	0.081	1,587	184
Playa Santa	0.001	20	2
Adjuntas	0.256	947	442
Coamo	0.632	2,335	1,091
Union Carb RWWTP	1.933	37,596	4,351
Santa Isabel	0.611	2,258	1,055
Yauco	1.184	4,377	2,044
Ponce	17.07	50,364	21,341
TOTALS	21.94	102,759	30,890

SAN JUAN REGION

Plant Name	2011 Flow	2011 Estimated Sludge Produced (Gal/Day)	2011 Estimated Sludge Produced (Lbs/Day)
Puerto Nuevo	54.16	159,795	67,710
Carolina RWWTP	15.26	45,017	19,075
Villas del Sol	0.109	2,135	247
TOTALS	69.53	206,947	87,032