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ANALYSIS OF WASTE MANAGEMENT SYSTEMS

Ponggol Pig Farming Estate
Singapore

Lynn R. Shuyler
Agricultural Engineer
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

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INTRODUCTION

This report results from the on-site review and evaluation of the pollution generated from the Ponggol Pig Farming Estate in Singapore. The request for this evaluation was from the Primary Production Department, Ministry of National Development, Government of Singapore. The involvement of the U.S. Environmental Protection Agency (EPA) was requested by the Department of State, Agency for International Development. The on-site visit in Singapore by Mr. Lynn R. Shuyler, Agricultural Engineer, EPA, was from August 19 through 27, 1977.

The purpose of the assignment was to define the waste management alternatives that could be considered for this location and to present the alternatives along with relative economic rankings.

The cooperation and assistance of the officials and staff of the Primary Production Department, the UNDP-FAO, the U.S. Embassy, and others in arranging contacts, conducting tours, and providing data and background material were most helpful and greatly appreciated.

This report contains four main sections, some of which are background in nature and will serve to brief future assistance teams working on this problem. The sections are arranged as follows: Background Information, Basic Information and Data, Control and Management Options, and Recommendations.

SUMMARY

The Government of Singapore through the Primary Production Department (PPD) of the Ministry of National Development is in the process of developing the Ponggol Pig Farming Estate. This Estate has a pig population of over 200,000 head and is designed for more than 325,000 pigs at full development. In the future, additional land will be made available for more pigs, if necessary.

The raw wastes from the Estate drain into the Ponggol and Serangoon Rivers at this time. The Government of Singapore is very interested in correcting this situation and requested a definitional study be conducted by the U.S. Department of State. The PPD and a UNDP-FAO team are undertaking waste characterization studies in the Estate along with a waste research program at the Sembawang Research Station. The team is investigating an oxidation ditch, a methane generator, algae production and harvesting, and refeeding of a fraction of the wastes.

Singapore has very little agricultural land; therefore, disposal of the solids from any treatment system remains a critical problem that must be solved. The shortage of potable water in Singapore suggests recycling the water used for flushing of the pig wastes. The PPD would like to install some type of treatment technology which would have a resource recovery option, thereby offsetting the costs of building and operating the treatment facilities.

Treatment of the wastes on the farms will be very difficult due to restricted land area and cost, and will be limited to in-house oxidation ditches for the larger farms and recycle of flushing water for the smaller farms.

A minimum of two central treatment plants will be required, one for each drainage basin. The first phase of construction should be methane plants with anaerobic lagoons for final treatment. Phase two construction will call for development of the algae production and harvest systems, operating in conjunction with the phase one system.

Prior to any construction an in-depth feasibility study should be conducted by a U.S. team of engineers and economists to provide information on full scale systems prior to the selection of any system. The feasibility report should review all possible treatment systems and present additional analysis of the most promising few. The detailed analysis would include construction costs, availability and location of material for construction, operating and maintenance costs, and labor requirements and costs to operate the systems. This report will provide the Government of Singapore with the information and data from which a sound decision can be made and should prove to be a very cost-effective expenditure for the Government.

BACKGROUND INFORMATION

Singapore, since 1976, has become self-sufficient in pork production. Figures from the 1976 annual report indicate a total pig population for the year of approximately 1,250,000, and over 800,000 head were slaughtered during the year. These figures indicate that the one time capacity of the pig farms exceeds 500,000 head, including boars, sows, and replacement animals.

Within the Ministry of National Development, the Primary Production Department (PPD) is one of six departments. PPD has agriculture as its responsibility and developed the Ponggol Pig Farming Estate idea.

The Ponggol Pig Farming Estate concept was in response to the problem of polluting a new water storage reservoir located at the lower end of the Kranji basin. It was decided to move pig production from the drainage area of the reservoir to the Ponggol area, where assurance from other Ministries have indicated that no water supply reservoirs will be developed. It is also apparent that an attempt is being made to encourage all pig production to move to the Ponggol area in the next few years. This plan allows the waste from the farms to drain into only two rivers, the Ponggol and the Serangoon.

In response to this development in Singapore and other countries in this area, a pig waste research and development project sponsored by UNDP-FAO was started in 1976, and is located at the PPD's Sembawang Research Station. This project is evaluating waste treatment systems which can be used both for on-farm control and for large area control such as the

Ponggol Estate. The UN team along with staff from PPD have started a waste discharge sampling program at Ponggol which will provide the design data for future waste treatment development.

The development of the Ponggol Estates is a very interesting concept and should be explained in order that others dealing with future pig waste problems in Singapore can better understand the underlying social and economic problems. The land is owned by the government and is leased to the farmers. The area was cleared and graded, and roads and drainage were installed prior to relocation of the farmers. The drainage is accomplished by means of concrete-lined ditches along the roads. These road ditches lead to concrete-lined natural drains or streams which are undeveloped when they leave the Ponggol Estate. The streams lead to the two rivers through swamps along the rivers. The natural runoff from the land surface flows through this network along with the waste from the pig farms. At the farms the systems are designed to allow natural runoff to enter the drainage ditches below the outlet for the pig wastes, thereby allowing separation of the flows, unless cleaning of the pig houses is taking place during a period of natural runoff.

Since Singapore is very water short, the farmers are encouraged to store runoff from the building for use as flushing water for the pig wastes. Also, flushing water is obtained from large open dug wells. The water in these wells did not appear to be potable.

The design of the drainage system dictates that any central treatment plant would have to bypass storm water runoff, and the farmers should be encouraged to flush the pig houses when it is not raining.

The selection of the farmers for relocation to the Ponggol Estate is very strict. They are usually among the top five percent of the producers who are being forced to stop pig production. This means that by selection, the farmers raising hogs in the Ponggol area are among the best managers in the country. Therefore, they should be relatively easy to work with if on-farm controls or changes in management for better waste control are needed.

The government ownership of the land poses an economic problem for the farmers. They must pay for all the buildings on their rented farm (a house, feed storage building, pig houses, and a cesspit) and buy additional animals. This has, in many cases, exhausted all their capital. They are unable to borrow money from banks to further expand their operations unless they have mortgageable property. This fact may cause severe problems when and if changes are required in on-farm management to assist with the control of the waste from the farms.

Allowing the pig wastes from Ponggol to go untreated into the Ponggol and Serangoon Rivers produces a very significant environmental impact. After full development of the area the pig wastes could destroy the present fisheries of these rivers and in the Johore Straits. The Serangoon River is already highly polluted, based on observation, from the discharge of one municipal treatment plant and runoff from a landfill on the other side of the river.

BASIC INFORMATION AND DATA

Pig production farms in the Ponggol Pig Farm Estate are divided into two types, Temporary Occupation License (TOL) and Commercial Lots (CL). The TOL farms are small family-owned units usually less than two acres in size. A typical TOL farm unit consists of the family house, a feed storage building, one or more pig houses, and a cesspit. The pig houses are roofed with open sides and concrete floors sloped to a gutter along the outside edge of the building. The wastes are flushed from the pens manually with high pressure water hoses into the gutters. There was no sign of any automatic flushing systems in any of the farms visited. Once the wastes are in the gutters, they flow by gravity into the cesspits for solids retention and from there into the roadside ditches. The cesspits appear to be similar in size regardless of the number of pigs they serve. They are required by building code to be 15 feet long, 7 feet wide, and 5 feet deep. There is usually an open dug water well for flushing water supply, and some farms channel roof runoff into these wells.

The CL farms are larger in size and use a somewhat different animal production system. These farms have a house or office building, a large feed processing and storage building, several pig houses and an open water supply well. The pig houses are all designed with slotted floors over open pits. The pits must hold at least a 21 day's supply of wastes, and most have several month's capacity. The CL farms must keep 1.5% of the land area open for future waste treatment systems. This land must be located on the lower portion of the lot so the waste will flow by

gravity through the area. To date none of the CL farms have had to discharge the contents of the pits. When one of these pits does get full, it will all be discharged at once into the roadside drains.

The present plan for development of the Ponggol Estates (phase one and part of phase two) projects 375,000 head to be moved into the Estate. Ponggol Road roughly divides the watershed between the two [illegible]s. The area between Ponggol Road and the Ponggol River will contain about 225,000 pigs. At least 70% of these will be CL farms. The land between Ponggol Road and the Serangoon River is scheduled to have the 150,000 head capacity developed in the near future, with more to be added later as phase two is completed. At present most of the farms will be TOL.

Under the present management systems used on the farms, the waste characteristics can be approximated. Actual data will be available early in 1978 from PPD through joint efforts with the UNPD-FAO project.

To arrive at the estimated characteristics in Table 1, a 45 kg pig was assumed. Since pigs are marketed at about 90 kg, this is not far from the average weight of the pigs in the Ponggol Estate.

The wastes from the CL farms would have undergone some anaerobic digestion in the pits and may vary some from the values in Table 1. The wastes being flushed from the TOL farms will be greatly reduced in concentration due to the addition of about 20 liters of water per pig or per 3.8 liters of waste. Also, waste from the TOL farms passes through a cesspit, which when operating correctly should reduce the total solids to some degree. The effectiveness of the cesspits ranged from nearly zero percent reduction of BOD_5 to as much as 40 percent

TABLE 1. SUMMARY OF SWINE WASTE GENERATION FROM CONCRETE SLAB AND SLOTTED FLOOR-PIT PRODUCTION UNITS

Parameter	Generation rate, g/d/45 kg hog
Total waste mass (density ~ 1.0 g/cm^3)	3800 (3.8ℓ/d/45 kg hog)
Total solids	230
Volatile solids	180
Total suspended solids	180
Volatile suspended solids	160
Nitrogen	18
Ammonia - Nitrogen	9
Phosphorus	6
Potassium	8
Calcium	9
Magnesium	2
Sodium	2
Chloride	14
Sulfur	3
Chemical oxygen demand	300
Biochemical oxygen demand (5 day)	120
Total organic carbon	90
Volatile acids (as acetic acid)	15
Inorganic carbon	18

reduction in BOD_5. Therefore, it is easy to see that the waste from TOL and the CL farms will vary greatly unless on-farm management is changed.

The field data necessary for any construction planning is not contained in this report. The PPD already has topographic maps of the area; however, more detail will be needed for actual site planning. It is suggested that if construction planning is needed, detailed topographic maps, structural soils map and soil foundation data be obtained by the Government of Singapore and furnished to the design team.

The present drainage system in the Ponggol Estate has at least nine different river discharge points. If large treatment plants are constructed, the location, elevation and volume of waste discharge for each discharge point will be needed. This will allow for the design and location of pumping stations or gravity canals to bring the waste to a few (at least two) central locations for treatment.

CONTROL AND MANAGEMENT OPTIONS

The control options for pig waste management for Ponggol are not as numerous as could be desired. The use of land as a receiver for any or all of the pig wastes in Singapore is not practical since very little land is cultivated. The few acres that are cultivated are fertilized using dry chicken wastes. In fact, some chicken waste is trucked over the causeway into Malaysia. Religious beliefs in Malaysia do not allow pig wastes to be used by farmers; therefore, only the chicken wastes can be exported to Singapore's close neighbor. Export of pig waste for fertilizer would require transport by ship, and the economics of this are very doubtful. These constraints reduce the options to those of treatment and resource recovery. The water shortage in Singapore also suggests recycling of water for flushing the pens.

ON-FARM WASTE TREATMENT AND RECOVERY

The use of on-farm treatment and resource recovery can be used to a limited degree of accomplishment. The presently operating TOL farms have no land for construction of treatment facilities, and the pig houses have solid concrete floors. This means that without extensive remodeling and rebuilding the only improvement in waste management could be the installation of automatic flushing for the pens. Even this may require some modification to pens and floors. If this could be accomplished, water could be recycled from central treatment plants, therefore, saving some water resources.

The CL farms provide a much greater possibility for on-farm treatment. The existing CL pig houses have slotted floors with pits under the floor. These could be modified without great expense into racetrack oxidation ditches. This has already been accomplished at the Sembawang Research Station where one pig house was converted for testing and evaluation of the oxidation ditch system. The CL farms also have 1.5% of the land area available for waste control structures. This area could be used for a small methane plant, or, if an oxidation ditch was used in the houses, a small gravity separation system could be installed. The discharge from the gravity separator could be pumped to the TOL farms and used for flushing water. Refeeding of the mixed liquor from the oxidation ditchs has been demonstrated in the U.S. under controlled conditions. This possibility should be studied at the Sembawang Research Station prior to recommending refeeding to the Ponggol farmers.

The use of oxidation ditchs in the pig houses on the CL farms could reduce the discharge strength of the wastes from the values shown in Table 1 to the values shown in Table 2.

If about 190 grams of O_2/day/45-kg hog is assumed as the oxygen input, the power required to accomplish this should not exceed 0.22 kw/45-kg hog per day or 80,300 kw/year/1000 head. This system would not result in a desirable effluent for discharge without other treatment or a large dilution factor.

The concept of on-farm treatment must be considered as a pretreatment system. The reconstruction or remodeling necessary to accomplish on-farm pretreatment would make it very costly for the farmers, although actual costs are difficult to calculate without plans for the remodeling work.

TABLE 2. APPROXIMATE PRETREATMENT PERFORMANCE OF OXIDATION DITCHES FOR SWINE WASTES WITH INPUT DEFINED IN TABLE 1

Parameter	Effluent, g/d/45-kg hog
Nitrogen-removal strategy	3.5
Phosphorus	6
Potassium	8
Sodium	2
Calcium	9
Magnesium	2
Copper	0.02-0.2
Zinc	0.14
Manganese	0.055
Chloride	14
Chemical oxygen demand	75
Biochemical oxygen demand (BOD_5)	12
Volatile solids	45

CENTRAL TREATMENT CONCEPTS

The concept of using centralized treatment plants is not new in pollution control. Cities have been doing it for years, but agriculture has usually constructed the waste control facility at the site of the production unit. The idea of processing the wastes from many animal production farms has historically been hampered by the distance between the production units and the location of a treatment plant. Singapore has, with the development of the Ponggol Pig Farming Estate, brought the

animal production units into one concentrated area, thereby solving the problem of distance between units. Through prior planning and site development, they have also provided a transportation system for the wastes to several collection points.

Central waste treatment plants for Ponggol will be located on the banks of the Ponggol and Serangoon Rivers. They must be designed to process the waste from the maximum pig population in the drainage area they serve. The plants and the auxiliary pumping stations must be designed to by-pass storm water flows.

Pumping Plants

The design and cost of pumping plants at the end of each drain will be about the same for any central treatment plant concept, unless treatment plants are installed at each drain. The pumping plants should have a small holding pond to collect the waste as it flows by gravity from the production houses. These ponds should store the wastes and flushing water generated during one day from the area served. For 10,000 pigs at 20 liters per pig, the holding ponds would need to store 200,000 liters or 200 cu. m. The pumps from various locations could be sequenced to operate in rotation, which would provide a somewhat constant flow to the main plants they serve. They could also all be set to start about 12 noon, after the morning cleaning of the pig houses. The pumps should operate about 4 to 6 hours per day, insuring that any problems which might develop could be corrected by maintenance crews within 24 hours. A pump would need to deliver 220 gallons per minute or 0.83 cu. m per minute. Pumps should be of the same manufacturer and size, if possible,

and for larger drains they should be installed in multiples to get the desired capacity. This will insure that spare pumps and parts will be on hand to quickly correct failures.

The inlets for the holding ponds should be designed as automatic side channel inlets. This concept allows low flows (waste from the pig houses) to enter the holding pits and high storm flows to pass outside the pit. This can be accomplished by automatic closing gates controlled by channel flow depth.

Central Treatment Plants

Central treatment plants must reduce the waste strength to a level which will allow discharge into the rivers. The exact value for BOD_5 was never specified; however, a BOD_5 of 200 was suggested, although a BOD_5 of 50 would be desirable. Recovery of useful products was also a goal of PPD. These conditions lead to the consideration of several types of treatment processes: methane production, ethylene and ammonia synthesis gas production, processing for refeeding, and algae production. Currently the most promising systems would be methane production and refeeding. Refeeding would be difficult since there are few cattle in Singapore, and refeeding pig manure to pigs will require considerably more research before it can be recommended. Ethylene and ammonia synthesis gas production systems look very promising from an economic standpoint; however, the technology has not progressed to full scale at this time. This means that such systems are several years in the future and must await more development before actual design data are available.

The system for algae production and harvest is already being tested at pilot scale at the Sembawang Research Station; therefore, design, operating, and cost data will be available in Singapore in the near future.

This leaves only methane production as a viable system for resource recovery at this time. Many assumptions must be made regarding loading rates and gas produced for a methane system. For this analysis, the following assumptions were used:

1) loading rate = 2.5 kg of VS per day cu. m,

2) a detention time of 10-12 days, and

3) 0.5 cu. m of gas produced per kg of VS loaded.

Methane production from the pig operations located between Ponggol Road and Ponggol River would utilize the wastes from approximately 225,000 pigs, 70% of which would be raised on CL farms. If the CL farms are operated as presently designed, the total volume of wastes plus flushing water from the TOL farms would equal 855 cu. m of wastes plus 1,500 cu. m of flushing water from the TOL farms, totaling 2,355 cu. m per day. Additional water may have to be added to the wastes from the CL farms to insure good transport of these wastes to the plant site. This would require concentration of the wastes prior to loading into the methane reactors, thereby producing an effluent which could be recycled for flushing or used for algae production.

A methane plant serving the Ponggol drainage could be sized as follows:

Total waste volume/day = 225,000 X 3.8 l = 855,000 l/day

Total solids/day = 225,000 X 0.23 kg = 51,750 kg/day

Volatile solids/day = 225,000 X 0.18 kg = 40,500 kg/day

Reactor loading rate = 2.5 kg VS/day/cu. m

Reactor size = 40,500 ÷ 2.5 = 16,200 cu. m

Gas produced = 0.5 cu. m/kg VS loaded

Gas produced/day = 40,500 X 0.5 = 20,250 cu. m

The above figures are maximum values and should be reduced to account for the actual kg of volatile solids reaching the production site and delivered to the reactor. The actual amount should come from the UNPD-PPD studies now underway.

The drainage area between the Ponggol Road and the Serangoon River contains approximately 150,000 pigs and could be expanded in the future. Nearly all of these are TOL farms with flushing systems. A methane plant operating in this drainage area must have a very efficient concentration system prior to loading the wastes into a methane reactor. The volume of pig wastes would be approximately 570 cu. m plus about 3,000 cu. m of flushing water per day. If this flow can be concentrated and fed into a methane reactor, 1,350 cu. m of methane could be produced. The volume of methane produced must be adjusted to account for the actual kg of volatile solids reaching the reactor site and delivered to the reactor.

The methane plants will produce an effluent with the characteristics shown in Table 3. This effluent could be used in algae production

TABLE 3. APPROXIMATE PRETREATMENT PERFORMANCE OF METHANE DIGESTERS RECEIVING SWINE WASTES, TABLE 1

Parameter	Effluent, g/d/45-kg hog
Nitrogen	18
Phosphorus	6
Potassium	8
Sodium	2
Calcium	9
Magnesium	2
Copper	0.02-0.2
Zinc	0.14
Manganese	0.055
Chlorine	14
Chemical oxygen demand	175
Biochemical oxygen demand (BOD_5)	70
Total organic carbon	47
Volatile solids	95

when that process is developed and installed. The effluent should not be discharged; therefore, it should be treated prior to discharge in order to protect the environment of the receiving streams.

Anaerobic lagoons should be designed to treat the effluent from the methane plants. These lagoons would be one half the size of the lagoons without the pretreatment by methane production. This is because the volatile solids content has been reduced by about 50%.

Anaerobic Lagoons

The treatment of the pig wastes for discharge only, without the prospect of reducing the cost by product sales, must be considered for the Ponggol Pig Farm Estates.

The anaerobic lagoon is the most basic system that could be designed and installed for partial treatment. It is very easy to operate, requires very little maintenance, and has a long, useful life if the sludge is removed periodically. Anaerobic lagoon loading rates vary depending on climate and type of wastes, etc. from 0.015 to 0.240 kg VS/day/cu. m. For control of odor a loading rate of 0.030 kg VS/day/cu. m is usually used; however, since odor did not seem to be a problem in the Ponggol area, a higher loading rate could be considered. Using the 0.030 kg VS/day/cu. m as an example, a lagoon for 10,000 pigs would require a volume of 60,000 cu m, which is quite large. If, however, maximum loading is allowed, the volume would only be 7,500 cu. m. The actual final design volume would lie between these two volumes. The effluent for three other loading rates are shown in Table 4.

SOLIDS DISPOSAL

The greatest problem facing any treatment and/or recycling system used in Singapore will be the disposal of solids. Since there is very little land under cultivation, the fertilizer value of the solids is not important, and discharge of the solids to the rivers is of concern to the government. The final disposal is an unanswered question at this time. The four possible solutions to this situation all have inherent problems. The possible solutions are:

TABLE 4. APPROXIMATE PRETREATMENT PERFORMANCE OF ANAEROBIC SWINE LAGOON BASED ON PRODUCTION RAW WASTE INPUT, TABLE 1

Parameters	Lagoon loading rate, kg VS/day/cu. m lagoon 0.15	0.078	0.018
	Effluent, g/d/45-kg hog		
Nitrogen	13	5-9	1.5-3.5
Phosphorus	0.6	0.4	0.2
Potassium	6	6	6
Sodium	1.5	1.5	1.5
Calcium	1.5	1.5	1.5
Magnesium	0.2	0.2	0.2
Zinc	0.01	0.01	0.01
Manganese	0.005	0.005	0.005
Chloride	10	10	10
Chemical oxygen demand	115-185	35-75	10-30
Biochemical oxygen demand (BOD_5)	30-45	15-25	5-10

1) Treat to maximum--this includes incineration or burning to generate power. This presents added expense and creates air pollution problems.

2) Stabilize in the form of sludge, dewater the sludge, and use ocean dumping. This was discussed with PPD staff and ruled out because of expense at this time.

3) Stabilize via composting and develop market with other nations for the fertilizer value of the product. The concept is good, but it is doubtful that the markets can be developed.

4) Stabilize via composting or dewatered sludge, and use in land reclamation project within Singapore. The material would provide some additional volume in the fill areas and, when mixed with the fill material, would provide a rich soil for vegetative growth.

As can be seen, any of the above mentioned systems have some objectional features connected with them. System 1, treat to maximum, could create severe air pollution problems and would require energy for drying prior to burning, or would require additional fuel to be added during the incineration process. Also, ash will remain, which must be removed; however, it could be used in earthen construction throughout the country. There is some heat value to the solids, and a plant using solids from the pig wastes plus other solid wastes for fuel might be developed for power generation.

System 2, ocean dumping of sludge, was discussed with PPD staff members and was ruled out because of cost at this time; however, it should not be forgotten for future consideration.

System 3, composting, while requiring additional energy and labor to process the waste, might be worth considering if a market for such a product could be developed. This product should be very easy to handle and could be shipped without great difficulty, since it has a good shelf life.

System 4, using as fill material, provides an interesting concept since Singapore has several ongoing projects to expand the size of the country by reclaiming land from the sea. This material could be used in

areas where construction was not planned and/or could be mixed with the material pumped from sea to provide a good organic content to these soils.

COST OF VARIOUS SYSTEMS

The actual costs of the systems presented herein are very difficult to develop until an actual full scale engineering study is completed. However, cost estimates can be made for some of the systems described in this report. The costs shown in this report are in U.S. dollars and do not include local factors which may influence the total costs significantly.

Oxidation Ditch - 10,000 head capacity

Investment Cost - $160,000

Annual Investment Cost	- $ 27,000
Annual Operating Cost (3.0¢/kw)	- 24,090
	$ 51,090

Waste control cost per head capacity = $5.11

Transfer Pump for 10,000 head

830 l/min. (220 gal./min.) pump and motor

Investment Cost = $1,250

Annual Investment Cost	- $200
Annual Operating Cost	- 360
	$560

Pumping Cost Per Head - $ .056

Methane Plant

Cost data on large scale reactors is very difficult to obtain; therefore, we must rely on incomplete data sets which will not be on a per head basis, but will represent a four million gallon plant being built in the U.S.

Investment Costs

2 - 7,600 cu. m reactors with pumps $800,000 each	=	$1,600,000
Sludge dewatering system	-	24,000
Gas scrubbers	-	300,000
Total Investment	-	$1,924,000

This plant would be nearly large enough for the Ponggol drainage area and would require an initial investment of nearly $8.50 per head capacity. However, the annual investment cost would be less than $1.40 per head capacity. The annual operating costs are not known at this time, but they will be more than offset by the sales of gas produced. It is expected that all costs could be recovered in 6 to 10 years.

Anaerobic Lagoon

An anaerobic lagoon to serve 10,000 pigs would require a pond with a volume of 60,000 cu. m. Assuming that the lagoon could be constructed by building the dikes with 20,000 cu. m of material total, the cost of construction would be $20,000 at $1.00/cu. m. Additional costs for pumps, pipe, and control valves would raise the total cost to $24,000.

Investment Cost - $24,000

Annual investment cost	-	$3,840
Annual operating costs	-	1,000
Total Annual Cost	-	$4,840

This would require a capital investment of $2.40/per head and an annual cost per pig of about $0.50.

Cost for the other systems mentioned will not be calculated because of lack of design information and lack of useful cost data.

Summary Cost Data

Oxidation Ditch

Investment Cost - $16.00/head

Annual Cost - $5.11/head

Annual Income - 0

Transfer Pumps

Investment Cost - $0.13/head

Annual Cost - $0.056/head

Annual Income - 0

Methane Plant

Investment Cost - $8.00-$10.00/head

Annual Cost - ?

Annual Income = vol. gas X $0.40/$m^2$ = ?

Anaerobic Lagoons

Investment Cost - $2.40/head

Annual Cost - $0.50/head

Annual Income - 0

RECOMMENDATIONS

The treatment and disposal of pig waste and/or the recovery of resources from these wastes at the Ponggol Pig Farming Estates presents an interesting challenge for anyone involved in waste control management. The development of a workable system, made up of components which can be installed in phases, will require a complete review of the alternative components.

Even though this report does not review all theoretical possibilities, nor does it provide complete data sets for those discussed, it does, however, suggest that sufficient technology exists to solve the pig waste problem in Singapore. It is recognized that more information regarding costs of construction, sale of products, costs of labor and energy, characteristics of the waste streams, and the desired quality of effluent will be required before an in-depth study of the various alternatives presented herein can be completed.

Once such a study is completed, the Government of Singapore should be able to make a sound decision regarding the most practical solution for the problem. Therefore, it is recommended that PPD contract with the U.S. Government to retain a team of U.S. engineers and economists to develop an in-depth feasibility study of the alternatives for control of pig wastes in Singapore. The study should be divided into two areas of concern: on-farm management and central waste management systems. The scope of the study should focus on my recommendations and suggestions regarding each area, which are as follows:

ON-FARM MANAGEMENT

- The amount of flushing water used on the TOL farms seems excessive and should be reduced. Studies should be made to determine the minimum volume necessary to carry the wastes through the existing drainage systems, and establish this volume per pig as the maximum flushing volume for the TOL farms.
- New TOL production facilities should be developed with automatic flushing systems using either slotted floors or flushing gutters.
- Methods for recycling flushing water at the farm should be investigated and incorporated into new designs, adding to existing facilities where possible.
- Use of oxidation ditch treatment systems for existing and new CL farms should be considered in place of large scale treatment facilities. These could be used for areas having a small number of animals in a drainage area instead of pumping to a central treatment site, or where farmers are considering refeeding of the mixed liquor from the ditch.

CENTRAL WASTE MANAGEMENT SYSTEM

- The present drainage system delivers pig wastes and storm water runoff to several discharge points in two river systems. A treatment plant should be considered for each of the two major drainage basins.
- The final treatment plant selection and design should provide a dischargeable effluent as first priority and provide, if possible, an economic return from the wastes as a second priority.

- The central treatment plant concept should be developed in phases. The first phase would require selection of a plant site and installation of transfer pumps to move the wastes from remote drainage discharge points to the plant site. The design and construction of the first phase treatment system must allow for additional construction of the phase two system.
- The first phase treatment facility should include waste concentration facilities, with the liquid recycled for flushing or discharged to lagoons for partial treatment and final discharge.
- The main component of the phase one system should be a methane plant, with the effluent discharging into anaerobic lagoons before discharge into the rivers.
- Phase two should include consideration of ethylene and ammonia synthesis gas plants to replace the methane systems. The use of algae production along with the methane plants should be strongly considered.
- PPD should investigate all possible solutions for solids disposal which would be unique to Singapore and the neighboring countries.

A study of the scope and nature outlined above will require approximately nine to twelve months to complete. The team staff should include four engineers, two economists, and a team leader. The team will need the support of a secretary and a draftsman at various times during the study. Approximately 40 man-months of professional time and 12 man-months of support time will be necessary to complete the study.

Travel to Singapore will be held to a minimum by having the senior members of the staff gather data and information during a visit early in the study period and obtaining additional information by mail after the first contact. Also, once the study is completed, senior team members should return to Singapore for a formal presentation to PPD and others as desired by PPD. All of this should be accomplished with five to seven man-trips of various durations.