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Datum	Doorkiesnummer	Kenmerk
July 11, 1990	NL-70-3486480	OSAB-151868
Onderwerp		Dienstonderdeel
identification		DPO/OT

Dear Sir/Madam,

Please find enclosed a draft report of a study concerning the identification of research priorities for the waste water problem in the developing countries. The study was carried out under the Netherlands development cooperation research and technology programme.

The aim of this programme is to develop new methods, techniques and policy measures for dealing with the problems which occur in the development processes of various developing countries. Many research proposals have been financed under the programme after being carefully assessed. On the basis of experience of this reactive policy, which involves simply awaiting proposals and assessing them, efforts are now being made to find a procedure which would entail an active policy of identifying priority needs and the associated questions that need to be investigated.

There are several possible procedures which could be adopted for identifying questions for research purposes, all of them having their own procedural, substantive and financial pros and cons. It is important, however, that the opinions of the experts in the developing countries in the field concerned are taken into account as fully as possible.

It has been decided to identify the questions concerning the waste water problem on the basis of the reactions of experts from developing countries to the study, which presents the views of Dutch experts involved in activities in developing countries. The danger of this method is that it gives the impression that the donor organisation has already decided which research projects will be financed and that opinions are only requested form the Third World as a formality. The intention, however, is that the views of your Dutch colleagues should encourage you to highlight the needs and research questions which you have identified yourself. If the reactions received from the Third World show that there is a clear need for research on the waste water problem in the Third World, the next step in the procedure will be to ask for research proposals, with priority being given to the questions raised most frequently by respondents in the Third World.

Your participation in this procedure would be particularly appreciated. Your are therefore invited to send your suggestions for research questions concerning the waste water problem to the Head of the Section for Research and Technology, via the Dutch Representation in your country, by October 1990. If you are of the opinion that someone else would be better equipped to carry out this request, please provide him with these documents. It would also be appreciated if you would supply their names to the Dutch Representation.

I would like to thank you for your cooperation and look forward to receiving your reply.

Yours sincerely,

K. Soels

Head, Section for Research and Technology
For the Minister for Development Cooperation

Position paper on

LOW-COST WASTEWATER TREATMENT AND REUSE

CONTENTS

1. INTRODUCTION

Adequate protection of the environment is vitally important for the health and well-being of all living creatures.
Considering the world-wide deterioration of the environment, it is of utmost importance to find sustainable solutions in the very near future, for prosperous industrialized countries as well as for developing countries. For adequate environmental protection, methods and measures which lead to a maximum of recycling and a minimum of consumptive use should be developed and implemented.

In part, the environmental problems faced by developing countries are similar to those in developed countries (pollution problems). The greatest problems however, arise from environmental destruction and exhaustion such as massive deforestation, erosion and desertification and selling off of basic resources because of extreme poverty. Many developing countries suffer from energy and resource shortages as well as insufficient food production. Simple, inexpensive and integrated environmental protection systems are urgently needed which combine purification with recovery and reuse, e.g. in the agricultural sector (food production).

Within the context of the Dutch development cooperation policy, the Research and Technology Program intends to stimulate the development of new methods and techniques which can be replicated and used to solve structural problems in developing countries. The program is also geared towards strengthening the research capacities of developing countries by arranging, wherever possible, for activities to be implemented in their institutions.

The Research and Technology Program has started to develop 3-5 year research programs in several subject areas of attention based on position papers describing these areas' needs for research.

In 1982 the program began supporting research activities in the field of wastewater collection and treatment. Since that time the number of submitted projects in this field has increased.

The objective of this position paper is:
- to identify and discuss problem areas (technical and non-technical) in the field of wastewater collection, treatment and reuse;
- to identify fields which need research efforts in the near future (taking into account the specific Dutch expertise assessed in the light of expertise available in other countries and donor organizations) which could possibly be supported by the Dutch Research and Technology Program.

This position paper focuses on low-cost methods suitable for developing countries, which are simple in design, operation, construction and maintenance.

In Chapter 2 a concise overview of the knowledge available in waste water collection, transport, treatment and reuse is presented.

In Chapter 3 Dutch policy in the field of liquid waste is presented. In Chapter 4 an inventory of activities in the field of liquid waste which may be interesting for developing countries is given.

In Chapter 5 there is a short description of policy and activities of bilateral and multilateral donor organizations.

Many people and organizations are involved in research and implementation activities. Frequent problems which arise during the execution of these activities are described in Chapter 6.

In light of Research and Technology Program policy and specific Dutch expertise as well as the needs of developing countries, a priority list for research which could possibly be supported by the Dutch Research and Technology Program is also presented in Chapter 6.
A priority list for research and recommendations is presented in Chapter 7.

This draft is being circulated for comment to interested parties in developed and developing countries and international organizations.

2 ENVIRONMENTAL PROTECTION AND RESOURCE RECOVERY & PRESERVATION

2.1 INTRODUCTION

The most effective solution for controlling the increasing pollution of the environment is the development and implementation of methods and measures for minimizing consumption and maximizing the recycling of resources.
As wastes and wastewaters are potential sources of energy (methane) and, apart from the water itself, frequently contain components that can be recovered or should be preserved, everything possible should be done to reuse these components.

Apart from households, waste and wastewater originate from industrial (small- and large-scale) activities, trading activities (markets), hospitals, hotels and campsites.
The quality and quantity of wastewater generated by a community or industry generally vary according to the time of day, standard of living, the level of water-supply, social habits, the season and the extent and type of industrialization in the region.

2.2 INSTITUTIONAL ASPECTS

A prerequisite to any successful wastewater treatment system is an adequate institutional framework. Non-technical aspects, such as the management, legislation, law enforcement and efficient organization of the regional and national authorities, should be properly regulated. As will be discussed in Chapter 6, bottlenecks are often encountered in this area. Another non-technical aspect which should be incorporated into any project is the proper training of all staff members and technicians who will be responsible for the continued successful operation and further implementation of a wastewater treatment system after termination of the project.

2.3 WASTEWATER MANAGEMENT

When waste(water)s are treated, disposed of, and/or reused on the site where they are produced, it is referred to as **on-site treatment**. The term **off-site treatment**, refers to situations where the wastes, after having been collected, are removed from the site via buckets, tins, tanks, trucks or sewerage systems, to be treated and/or discharged elsewhere. Off-site treatment is generally applied in more densely populated areas (usually urban or suburban areas).

Another modification is a sanitation concept called **community on-site treatment** (COST). In order to save on the high costs of conventional sewer systems, the COST approach utilizes a low-cost small bore sewer for the collection of wastewater which is installed in a residential area of limited size, and can also be connected to one or more separate (larger) buildings. The wastewater is treated at a proper location on the site of the community. This system is especially attractive for areas where part of a sewer system already exists but a central collector and the wastewater treatment facilities are still lacking.

Sanitation in areas with low population density and a low water consumption generally functions smoothly without any serious technical constraints. Low-cost and hygienically appropriate systems are available in the form of latrines. These systems can function efficiently under most practical circumstances, and several modified systems are presently available (IBRD manuals, IRC 1988, Kalbermatten 1980).
In many situations the main problem is encouraging the local population to use and properly maintain the facilities. Changes in personal hygiene, rational water use and service maintenance demand a permanent and intensive health education program.

On-site treatment methods, applied according to the amount of water to be treated, can be classified as follows:

* Dry methods
* Water saving methods
* On-site methods with high water use. Such systems are found in more economically privileged rural and urban situations.

A distinction must also be made between black water (waste from toilets only) and grey water (waste from toilets plus water from the kitchen, washing water and sullage).

Off-site treatment methods can be classified according to the method used to convey the waste from the site:

* Cartage removal. The excreta are removed using tank lorries, wheelbarrows or buckets.
* Water-borne systems. In an attempt to find an adequate solution to the main constraints of conventional sewer systems, e.g. the required large excavations, high costs, the need for high water use and maintenance problems, this method uses conventional sewerage systems or more recently developed modified sewer systems.

The feasibility of a sanitation system is determined by the water-supply service level and the population density.
By assessing the combined effects of these two factors, the applicability of on-site, intermediate and off-site systems can be evaluated (fig. 2.1) (Desk study IHE, 1989).

	on-site sanitation	off-site sanitation
"dry" systems	on-site sanitation systems (pit latrines)	night-soil collection vault system
	on-site sanitation (individual or shared) with off-site disposal	
"wet" systems	on-site sanitation with leaching facilities	off-site transportation and treatment of sewage

figure 2.1 Matrix of sanitation technologies in function of water-supply service level and population density (adapted from Veenstra, 1988).

The system choice will depend on a variety of technical and non-technical factors. Non-technical factors to be taken into consideration include local geology, population density, the groundwater level, climate, financial aspects such as the educational level of the population, institutional aspects, and factors such as the expected degree of community involvement and socio-cultural factors.
Technical factors influencing system choice will be discussed in Section 2.5.

2.4 WASTEWATER COLLECTION

Households equipped with piped water-supply facilities require a sanitation system able to handle the corresponding relatively large amounts of wastewater. This can be achieved on-site through for instance, septic tanks with soak-aways, or off-site through a water-borne sewerage system.

The **conventional sewer system** can be of the combined type, designed to convey both wastewater (industrial and domestic) and rainwater, or of the separated type, designed mainly for conveying wastewater.
The water-borne conventional sewerage system, applied in most European communities and other prosperous industrialized countries, is the most convenient sanitation system for the user. Its use implies extravagant consumption of potable water.
Experience with sewer systems in developing countries over the past decades has uncovered a number of obstacles and problems associated with these systems, such as:

a. the high investment and recurrent costs of conventional sewer systems;
b. the high water use of these systems;
c. the complexity of water-borne sewerage technology;
d. the necessity of laying large central collectors in straight lines;
e. the susceptibility of conventional water-borne systems to blockage.

A more detailed explanation of these problems is given in Appendix II.

To address these problems, modified sewer systems have been devised, among them **small bore sewers** and **shallow sewers** (see Appendix I).

There is not yet a general consensus as to how best to provide the urban poor with an appropriate (see criteria in Table 1) and hygienically reliable sanitation system. In the past piped water systems were installed in many developing countries without sufficient consideration for the high costs required for wastewater collection and the adequate treatment and disposal of the resulting wastewater and sludge.
The supplying of drinking water can easily result in severe sanitation problems or an intensification of a sanitation problem (in both cases the outbreak of water-related diseases can result).
The extension of sanitation coverage in swiftly growing urban areas will require huge investments sums as well as considerable improvement in the institutional capacities of many developing countries to operate and finance the facilities (Desk study IHE, 1989).

2.5 WASTEWATER TREATMENT METHODS FOR DEVELOPING COUNTRIES

The primary purpose of wastewater treatment systems is the removal of polluting substances from wastewater and not the recovery and reuse of the pollutants. In developing countries, where the limited resources must satisfy a wide range of competing demands, wastewater treatment is often granted a low priority. This section contains a concise survey of the features of relevant available wastewater treatment technologies, considering their suitability for application in developing countries. The latter is based on the criteria for environmental protection systems/methods (Table 1) and additional criteria more specifically relevant for judging the feasibility of wastewater treatment systems in developing countries.

Important criteria for appropriate environmental protection technologies and methodologies are summarized in Table 1. These criteria were formulated on the premise that the environmental protection systems should be:
- cheap
- efficient
- easy to operate.

Table 1 Criteria to be set for environmental protection technologies and methods, specifically with respect to wastewater disposal, collection, treatment and reuse.

1. The prevention or at least limitation of the production of waste(s).
2. A sufficient (depending on restrictions for discharge of effluent) efficiency in removing various categories of pollutants, i.e.:
   - biodegradable organic matter (BOD)
   - pathogens
   - suspended solids (including non-biodegradable)
   - ammonia, organic-N compounds
   - phosphates
3. High process stability in the presence of:
   - interruptions in power supply
   - peak loads
   - feed interruptions
   - toxic pollutants
4. System flexibility (e.g. scale in which the system is applied, extension possibilities for higher efficiencies possibly required in the future).
5. Simple to operate, maintain and control.
6. Long lifetime of system.
7. Land requirements in correspondence with land availability.
8. Prevention of the dilution of pollutants with clean water.
9. The number of required (different) process steps should be as low as possible.
10. The application of the system should not suffer from serious sludge disposal problems.
11. Absence of malodorous nuisance problems, noise, insects etc.
12. The system should offer good opportunities for recovery of useful byproducts for irrigation and fertilization.
13. Maximum recovery and reuse of polluting substances, e.g. to integrated systems, especially in the field of food production, leading to self-sufficiency.
14. Preferentially no need for expensive sewerage systems.
15. Preferably low investment and recurrent costs.
16. Little if any consumption of (high grade) energy.

The ultimate system choice will depend on the technical criteria listed in Table 1 as well as the non-technical factors discussed in Section 2.3.

2.5.1 Wastewater treatment processes

Based on the level of treatment provided, wastewater treatment processes are frequently classified as preliminary treatment, primary treatment, secondary treatment or tertiary treatment.

Preliminary treatment involves the removal of coarse solids through screening and grit removal to prevent clogging in the subsequent treatment stages.

Primary treatment involves the separation of solids, either by settling or flotation. The settleable solids and up to 60% of the suspended solids corresponding to approximately 35% of the BOD can be eliminated in a primary treatment step.
The separated solids are poorly stabilized and require additional treatment to prevent serious nuisance problems to the direct environment. Anaerobic sludge digestion can significantly reduce the total amount of excess sludge to be disposed. Biogas, a useful byproduct, can be produced and the remaining solids can be profitably applied as soil conditioner and fertilizer. Primary treatment is a necessary step for the proper application of various secondary treatment systems. A further function of this step is the reduction in the energy necessary for aeration during secondary treatment.

Secondary treatment, generally consisting of a biological treatment step, can provide BOD removal efficiencies ranging from 35% to 95%, and for coliform bacteria, up to 99%.
The different types of secondary treatment systems include various modes of aerobic and anaerobic systems. Depending on the system, particularly with respct to the loading rate applied, secondary treatment systems can be operated with or without primary treatment.
Some constraints of conventional aerobic systems are:

a. they all consume energy and generally require connection to a power circuit;
b. some popular aerobic systems are fairly complex both in construction and operation, and consequently require skilled engineering for design and construction (generally expensive foreign expertise), as well as for operation, control and maintenance;
c. the investment costs are rather high for developing countries because of the required import of specific expensive hardware;
d. large amounts of excess sludge are produced which generally require further processing.

On the other hand, there is a great deal of experience with these systems in western countries, and generally very satisfactory treatment efficiencies can be achieved with various categories of pollutants.
There is considerable need for more appropriate secondary treatment systems which better meet the criteria mentioned in Table 1 than conventional aerobic systems, especially in cases where large volumes of wastewater require treatment, e.g. sewage from urban areas. Systems which combine primary and secondary treatment, or even tertiary treatment are preferred.

Tertiary treatment or post-treatment serves for polishing the effluent from secondary treatment steps prior to their discharge into receiving waters or prior to reuse. Tertiary treatment can be applied for removing nutrients such as phosphorus and nitrogen, sulfides, suspended solids, remaining BOD and particularly pathogens. Tertiary treatment processes include various chemical-physical methods such as adsorption, stripping, coagulation, sedimentation, filtration, chlorination as well as biological methods, such as slow sand filtration and maturation ponds.

Low-cost and intermediate-cost wastewater treatment systems, including those combining primary, secondary and/or tertiary treatment, are available or will likely become available in the near future (Desk study IHE, 1989) in the form of:

a. septic tanks (primary treatment);
b. Imhoff tank (primary treatment + sludge digestion);
c. lagoons (primary and secondary and sometimes tertiary treatment):
   anaerobic lagoons/ponds
   facultative lagoons/pond
   aerated lagoons/ponds
   maturation lagoons/ponds
   water hyacinth channels
   polyculture lagoons;
d. oxidation ditch (secondary treatment);
e. biorotor (secondary treatment);
f. trickling filters (secondary treatment):
   low-rate trickling filters
   high-rate trickling filters;
g. modern high-rate anaerobic treatment systems (secondary treatment):
   anaerobic filter
   Upflow Anaerobic Sludge Blanket;
h. land treatment:
   slow-rate land treatment
   rapid land treatment
   wetland treatment systems;
i. slow sand filters
   rapid sand filters.

In Appendix II information on some important low-cost methods is presented.

2.6 REUTILIZATION

Wastes have often been called "resources out of place". In many developing countries these resources have traditionally been recognized as such and consequently are reused as important agricultural inputs. The East and West have diverged on this point. During the last century in the West human wastes (excreta) have increasingly been regarded as highly undesirable and to be flushed away for treatment and dumped elsewhere (IDRC manuscript report, April 1986).
In Islamic cultures human excreta are regarded as spiritual pollutants and are therefore not reused. Constraints on the reuse of human excreta are also common in many parts of sub-Saharan Africa although in some cases the effluent of treatment plants and sludge of on-site systems are used.

There are a number of possibilities for accomplishing the desirable long-term reuse of the potential resources contained in wastewater. Such methods, when properly designed, located and managed, can provide both environmental and economic benefits without jeopardizing public health. One or more methods may be applied to meet the financial and environmental constraints and opportunities of a community.

From the treatment of domestic and agro-industrial wastewater, the following main reusable products can be distinguished:

a. The effluent can be reused for irrigation and/or fertilization (by utilizing its nutrients), for groundwater body replenishing, and by discharging into ponds, for the cultivation of fish.
b. Production and recovery of byproducts of the treatment itself such as organic sludge and biogas.
c. Recovery of ammonia, phosphate salts and elementary sulfur.

2.6.1 Irrigation and fertilization by the use of effluent

Controlled irrigation using treated domestic wastewater can be an economically viable means of wastewater disposal and reuse in arid, semi-arid and temperate climates if extensive areas of irrigable land are locally available and if cultural, social, political and institutional factors are favorable.
The main benefits of wastewater irrigation are:

- irrigation can be applied in regions where water is scarce or unavailable;
- scarce water resources are conserved for more appropriate use such as the provision of potable water supplies or the protection of fish stocks;
- groundwater reserves are replenished when part of the irrigation water infiltrates into the groundwater body. This form of incidental groundwater recharge can help prevent salt water intrusion and the lowering of the water-level of lakes;
- the nutrients left in the wastewater can be profitably used for growing crops.

The main possible disadvantages of wastewater irrigation are:

- the possibility of disease transmission.
  Uncontrolled irrigation with insufficiently treated or non-treated domestic wastewater containing a variety of pathogens provides numerous pathways for the transmission of diseases to the consumer of wastewater irrigated crops, to sewage farm workers, agricultural workers and the local resident population;
- salinity and waterlogging in arid and semi-arid climates when the water is too salty;
- pollution with heavy metals when the heavy metal content is too high;
- pollution of surface waters and groundwater;
- soil clogging by suspended solids.
  Most suspended solids are filtered out in the upper few centimeters of the soil where they may undergo decomposition as far as they are biodegradable.

2.6.2 Use of primary and/or secondary sludge and biogas

All wastewater treatment methods are accomplished with the production of sludge which is considered a waste product requiring disposal or treatment when not used as a resource. Various disposal options are available, some of which offer the opportunity for reuse.

Sludge disposal options include:
landfilling, landfarming, incineration, land stabilization, and disposal of sludge into coastal waters.

Reuse options include:
cultivation and harvesting of aquaculture & algae, production of compost fertilizer, biogas and animal feed (e.g. water hyacinth).

The excess sludge from wastewater treatment plants generally contains the full range of pathogenic microorganisms present in raw excreta, as well as heavy metals and other toxic compounds originating from industrial wastewater. This often limits its possibilities for reuse in agriculture.

Treated sludge added to the fields however, may replenish the soil with organic matter. Mineral fertilizers do not improve or maintain the soil in this way. Sometimes the sludge can be used for animal fodder. In Peru, India and several other eastern countries, sludge is used for pisciculture and aquaculture.

When the sludge originates from mainly human excreta and household waste there is a risk of spreading viral, bacterial, protozoan and helminthic infections. Contamination of root crops and vegetables with pathogens represents a major problem, and leaching of pathogens to ground or surface water may occur if application is followed by heavy rainfall. Composting of organic waste is, when properly managed, an efficient and low-cost technology for transforming the waste into a valuable fertilizer. Due to the high temperatures of this process, composting also has the effect of eliminating the pathogens.

Aerobic treatment plants produce large amounts of sludge which generally require further treatment. The excess sludge from aerobic treatment can be digested and can yield biogas.
Anaerobic treatment systems produce a well digested stable sludge which will not rot when exposed to air. As previously mentioned, when both types of sludge are considered for use as fertilizer, for agriculture or for horticulture, public health aspects need careful evaluation.

During the treatment of high strength wastewaters (> 2000 mg COD/L) and during the digestion of organic sludge, biogas can be generated.
The energy of the gas can be used in the following ways:
- burnt in a boiler;
- in households for cooking and heating;
- converted on-site into electricity with gas motors.

2.6.3 Recovery of ammonia and phosphate salts and elementary sulphfur

The recovery of ammonia and phospate salts can be obtained with physical-chemical separation techniques combined with or without biological methods. The separation and recovery of ammonium salts can be achieved with processes such as ammonia stripping with air and subsequent absorption in an acid solution, steam stripping and with reversed osmosis.

Phosphate salts can be recovered from wastewaters with new physical-chemical techniques such as high gradient magnetic separation or crystallization on a support particle in fluidized reactors.

Sulphur can be removed biologically by sulphide oxydation to elementary sulphur.

The techniques for N, P and S recovery are relatively new and require further development before more inexpensive and appropriate designs are available. Moreover, in the absence of strict legislation regarding the discharge of these nutrients, the initiation of projects in this area will be difficult despite the considerable level of environmental pollution which can result from eutrophication by discharged N and P.

3. THE DUTCH DEVELOPMENT COOPERATION POLICY IN THE FIELD OF THE DISPOSAL, TRANSPORT, TREATMENT AND REUSE OF LIQUID WASTE.

On a general level the aim of the Dutch Development Aid Program is to combat poverty and to contribute to processes leading to greater self reliance in the Third World. The majority of the programs are directed towards rural areas, regional centers and/or smaller cities.

In February 1989 a sector note entitled "Water Supply, Sanitation, Drainage and Waste Removal" was published. The experiences during the International Drinking Water Supply and Sanitation Decade, 1981-1990 (IDWSSD) played an important role in the formulation of the Dutch policy, which is reflected in this paper.
The need for adequate environmental protection measures and the increasing needs for water-supply and sanitation facilities in the rapidly growing cities in developing countries is recognized. As a result of increased water consumption by households and industries leading to a proportional increased production of wastewater, pollution in cities is growing and endangering public health. For effective treatment, aspects like participation, institutional development knowledge, cost recovery, coordination and cooperation, etc. should be thoroughly considered.

In many of the Dutch supported water-supply programs a sanitation component is included, often in the form of latrines as well as the education on how to use them in Primary Health Care programs.
There is an increase in long-term integrated projects encompassing water-supply sanitation, drainage and waste removal in regional cities in developing countries.
In the field of wastewater treatment, few projects have been supported by the Dutch development cooperation (see also Table 3.1). It is expected that this will gradually change.

The Research and Technology Program, amongst others, concentrates on developing new methods and techniques which can be replicated and used to solve structural problems in developing countries. Emphasis is also directed at strengthening the research capacity of developing countries by arranging activities wherever possible to be implemented at institutions in those countries.

In 1982 the Research and Technology Program began to support research for the development of anaerobic sewage treatment technology using the UASB concept in developing countries. Two major field research projects were conducted in Cali, Colombia (1982-1987) and in Bandung, Indonesia (1985-1989).
Since 1987 several small full-scale reactors (100-500 m^3) and a demonstration plant of 1100 m^3 have been or will be put into operation. The latter project is supported by the Dutch Research and Technology Program.
In March 1989, a 1200 m^3 UASB reactor for domestic wastewater in Kanpur (India) was put into operation. This activity is part of an integrated environmental project in which considerable attention is also paid to socio-cultural aspects. This project is supported via the bilateral allocation of which India is one of the target countries.

Large integrated projects have been implemented in Pakistan and North Yemen, both supported via the bilateral allocation. In Pakistan the domestic wastewater of the city Quetta will be treated by a pond system. The effluent of the ponds will be used for irrigation purposes. In Yemen the sewage of the city Rada'a will be treated by a facultative pond and an oxidation ditch. Another project with a wastewater component in Yemen is a slaughterhouse project. In five cities, treatment plants (lagoons) for five slaughterhouses (built with Dutch support) will be constructed.

In Bangladesh and in Sri Lanka studies on wastewater treatment for tannery and rubber industries were carried out,
both supported by the Industrial Development Program.

A summary of the main activities in the field of liquid waste by the Dutch Development Cooperation is given in the following table:

Table 3.1 Summary of the main activities of the Dutch Development Cooperation in the field of liquid waste.

Country	Place	Activity	Duration	Expenditures
Bangladesh	Hazaribagh,Dhaka	wwt (fs)	1986-1987	255.000
Colombia	Cali	wwt (r)	1982-1989	ca. 2 mill.
	Pereira/Bucaramanga	techn. ass.	1989-	...
Egypt	Helwan	sd + wwt	1980-1990	11.900.000
	Fayoum	sf + sd + wwt	1989-present	...
India	Kanpur/ Mirzapur	sf + sd + wwt	1987-1990	61.200.000
Indonesia	Bandung West Java	wwt (r)	1984-1989	775.000
	Tangerang West Java	sd	1980-1989	7.516.000
Nicaragua	Massaya	wwt (fs)	1988	...
North Yemen	Rada	sf + sd + wwt	1987-1990	ca. 7 mill.
	Sana'a, Ho Deida, Dahmaar, Tiaz, Al, Bayda and Ibb	wwt	1988-present	3.6 mill.
Mozambique	Maputo	sd	1985-present	47 mill.
Pakistan	Quetta	sf + sd + wwt	1986-1992	ca. 29 mill.
Sri Lanka	Colombo	wwt (fs)	1987	188.000

sf = Construction of sanitation facilities
sd = Construction of a sewerage and drainage system
wwt= Construction of a wastewater treatment system
r = Research
fs = Feasibility study

Other programs within the Dutch Development Cooperation which cover activities in the fields of sanitation sewerage and wastewater treatment are:
- International Education Program
- Fellowships Program
- Non-Governmental Organizations Program
- Rural Development Program

4 INVENTORY OF ACTIVITIES IN THE NETHERLANDS

Most of the sanitation and waste water treatment projects executed for (possible) implementation in developing countries by Dutch universities, institutes or consultancies concern systems and methods similar to those applied or investigated for application in the Netherlands, i.e. systems like the septic tank, the Imhoff tank, oxidation ditch, trickling filters and activated sludge plants.
Not all projects proved to be succesful, which sometimes can be due to non-technical reasons, in other cases the failure(s) can be attributed to mainly technical reasons and/or to the fact that there existed a (big) need for the development of more appropriate - low(er) cost-technologies.
In the following the most relevant Dutch research issues in the field of appropriate liquid waste treatment systems will be mentioned. Major part of this research is directed towards the development of low-cost anaerobic treatment systems.

Table 4.1, 4.2 and 4.3 summarize the main research activities at the various university-departments and institutes, i.e. for mainly applied and more fundamental research activities respectively.

TABLE 4.1 **Main applied research activities at the various Dutch universities and institutes.**

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1. Domestic waste water treatment

AUW- Env. Techn.: (> 1968)

- anaerobic treatment using UASB, EGSB, FB, AF, moduled reactor systems; settled and raw sewage, black and grey water (on-site systems), temperature range: 5 - 30 °C.
- post-treatment of anaerobic effluents for N-, P-, S- and pathogen removal, using lagoons, conventional aerobic (biodisk, trickling filters, activated sludge), microaerophilic methods, physical-chemical methods.
- sludge digestion using conventional systems and accumulation systems at temp. 15 - 40 °C.
- aerobic methods: super high-rate aerobic pretreatment combined with sludge digestion.
- extensive methods like lagooning.
- biological sulphide removal.

TUD- Env. Health Techn.: (> 1970)

- anaerobic treatment using AF.
- post-treatment: N-, P- and pathogen-removal using conventional aerobic systems and extensive methods.
- extensive methods like algae and reed-marsh ponds.

DWB-RIZA (National Institute for Wastewater Treatment): (> 1987)

- anaerobic treatment using conventional-UASB reactors at ambient temperatures (8 - 20 °C)
- sewage sludge digestion under thermophilic conditions.
- extensive methods like reed-mars fields under Dutch ambient conditions.

UvA, Microbiology. (> 1987)

- extensive treatment of sewage using algae ponds under Dutch conditions.

IHE (> 1986)

- studies on sanitation technology and strategy for industrialized and developing countries.
- studies on anaerobic treatment in UASB.
- studies on self-purification phenomena in drains and sewers; sediment transport in sewers.

2. Industrial wastewater treatment

AUW- Env. Technology. (> 1970)

- anaerobic treatment using UASB, EGSB, hybrid AF-UASB systems, one step and multi-step moduled reactor systems, on-site systems; low-, medium and high strength effluents, soluble and partially soluble; psychrophilic, mesophilic and thermophilic conditions;
- application of sulphate reduction.
- post-treatment of anaerobic effluents for N-, P- and S- removal using conventional aerobic (biodisk, activated sludge), microaerophilic methods for S^{2-}-removal and S-recovery), physical-chemical methods.
- separate digestion of floating or settling solids using conventional systems and accumulation systems at temp. 15 - 40 °C.
- aerobic methods: conventional low-cost methods, combined with sludge digestion.

U.v.A. (Chem Techn.) (> 1980)

- anaerobic treatment, including acidogenesis (phase separation in anaerobic treatment) using gas-lift loop reactor systems.

U.v.A. (Microbiology (> 1986)

- granulation in acidogenic reactors (project ended in 1989)

CUN, (Microbiology) (> 1982)

- anaerobic treatment of acidified effluent from 'rumen' based liquifaction/acidogenic reactor using UASB-reactors.

TNO-leather institute (> 1976)

- treatment of tannery wastewater, particularly the recovery of Cr.

ATO, Wageningen (> 1974)

- UASB-technology for potato processing wastewater.

IHE, Delft (> 1986)

- studies on the removal of heavy metals using physical chemical methods.
- studies on the anaerobic treatment in upflow and contact-process reactors.

3. Slurry digestion (except sewage slurries)

AUW, Env. Technology (> 1975)

- manure digestion using conventional systems and accumulation systems, psychrophilic, mesophilic and thermophilic conditions.

TNO-MT, (> 1982)

- thermophilic digestion of manure-slurries and/or condensate liquor(s) (in cooperation with AUW).

TNO-CIVO, (> 1980)

- anaerobic digestion of manure, seeweeds and (water)-plants for energy (biogas)-generation.

TABLE 4.2 **Applied fundamental (not pure!) research activities at the various Dutch universities and institutions relevant for developing countries.**

AUW, Microbiology (> 1983)

- biological phosphate removal
  fill and draw system
  metabolism of polyphosphate in <u>Acetinobacter</u> spp., (> 1987).
- physiology of anaerobic methanogenic sludge, (> 1983).
- sulphate reduction versus methanogenesis, (> 1988).
- syntrophic degradation, (> 1985).
- thermophilic propionate formation and degradation, (> 1985).
- methanogenic acetate cleavage and acetate threshold,(> 1986).

AUW, Env. technology (> 1970)

- reactor development, modelling.
- kinetics of various steps, toxicity, environmental factors.
- sludge immobilization, viz. attachment and granulation, granular sludge detroriation and growth.
- sulphate reduction, substrates, environmental factors.

CUN, Microbiology (> 1986)

- sludge immobilization in high rate anaerobic treatment systems, i.e. F.B.reactors, start-up UASB reactors.

UvA, Microbiology (> 1980)
- microbiological and biochemical aspects of acidogenesis,

UvA, Chem Technology (> 1985)

- granulation in acidogenic reactors (gas-lift reactors), micro-kinetics and mass transfer using micro-electrodes

TUD, Microbiology (> 1979)

- microbiogical aspects of the biological conversion of sulphide into elementary sulfur.
- nitrification and denitrification in attached growth systems (FB)
- development and physiological effect of growth in biofilms

IHE, Delft (> 1987)

- modelling of microbiological processes in relation to diffusion and mass transport.

IHS/IRC
- review of per

add IRC

TABLE 4.3 **Transfer of know-how activities (courses, training activities) conducted for developing countries.**

1. **courses** (MSc, PhD-courses, short courses)

IHE (> 1961)

- one-year international postgraduate course in Sanitairy Engineering (65 participants)
- one-year Specialization Course in Sanitairy Engineering for Indonesian engineers (25 participants).
- advanced Course in Integrated Urban Infrastructure Development: Water Supply and Sanitation (2 months) (15 participants).
- one-year international post-graduate course in Environmental Science and Technology (15 participants).
- one-year international post-graduate course in Environmental Science and Technology.
- short course in Anaerobic Wastewater Treatment and Anaerobic Digestion (in cooperation with AUW, Department of Environmental Technology) (20 participants).
- short Course on Low-Cost Water Supply and Sanitation (30 participants).
- short Course on Applied Ecology (15 participants).

AUW, Environmental Technology (> 1983)

- specialized course on anaerobic wastewater treatment and anaerobic digestion (in cooperation with IHE).
- various courses in developing countries on invitation (Colombia, Peru, Brasil, China, Taiwan).

CUN, Microbiology and Evolution

- training and Ph.D.-program for Tanzanians of the University of Dar es Salaam.
- participation in organizing a workshop on "Environmental Pollution and its Management in Eastern Africa", in Dar Es Salaam, 4 days in 1989 (100 participants).

2. **Training activities** (e.g. fellowships, or training in operation treatment plants)

AUW, Environmental Technology (> 1983)

- various training activities (Cuba, Colombia, China, Brasil).

IHE, Delft (> 1987)

- assistance to training and educational programs in Indonesia and The Philipines (World Bank project on International Training Network on Water and Waste Management), India, P.R. China, N-Yemen, Egypt.

CUN, Microbiology and Evolution

- training of M.Sc.-students of the University of Dar Es Salaam and consultants in Tanzania.

3 generation + transfer

+ IHS/IRC + review
+ res handling

5. INVENTORY OF ACTIVITIES IN THE FIELD OF LIQUID WASTE BY MULTILATERAL AND BILATERAL ORGANIZATIONS

5.1 INTRODUCTION

This chapter is based on information received in response to a questionnaire sent to organizations and major research institutes. Since only 25% of the contacted organizations responded, this is not a complete overview.

5.2 MULTILATERAL ORGANIZATIONS: WORLD BANK, UNDP, WHO, UNICEF

These international organizations took the lead in organizing the International Drinking-Water Supply and Sanitation Decade (IDWSS) (1981-1990) for the international community.
The UNDP assumed overall leadership at the global and country levels.
The World Bank accepted the responsibility for developing and promoting the use of appropriate low-cost alternatives to conventional water-supply and sewage systems, helping governments in improving their ability to prepare investment projects for financing, and serving as a source for investment finance through its lending program.
The WHO assisted governmental efforts by setting up National Action Committees and formulating strategies.
UNICEF supported water-supply and sanitation programs.

The water and sanitation sector is said to be a closely knit fabric of economical, social, political, technical, institutional and policy factors.
Sustained development was achieved in this sector, reflected in World Bank publications.
However coordinated activities over several years are still needed.
During 1988-90 the program's activities are concentrated in primary focus countries selected according to their capacity for achieving significant research and demonstration results pertinent to other countries.
The main programs are carried out in China, Ethiopia, Ghana, India, Indonesia, Nigeria, Pakistan and Zimbabwe.
Shifting the emphasis away from technology, social sciences, community development, public health, economics, etc. have been added to the program.

United Nations Development Program (UNDP) and the World Bank

Part of the UNDP World Bank Water and Sanitation Program's approach is to develop innovative implementation strategies for extending service coverage to low income groups which can be replicated on a national scale.
The Program conducts applied research and executes individual country programs which include demonstration projects, initiatives to foster cooperation among governments and support agencies, training activities, and assistance in the design and implementation of large-scale investments.
In 1988 the program strengthened Regional Water and Sanitation Groups (RWSG's) in West and East Africa, and created a third group in New Delhi for South Asia. RWSG's are multidisciplinary teams consisting of to five to ten sector specialists who assist governments in a full range of sector development activities. Through working with individual country governments, their goal is to develop institutional capacity for large-scale investment in the sector. The teams are designed to coordinate these efforts between donors and individual country governments with which they closely work.
The RWSG-West Africa (RWSG-WA) presided over the preparation and launching of a large demonstration project; an urban sanitation project in Kumasi City, Ghana, which will be one of the first intermediate sanitation technologies in urban West Africa.
The CREPA (Centre regional pour l'eau potable et l'assainissement à faible coût) was launched in Ouagadougou, Burkina Faso in 1988 and will set up training activities in Ouagadougou and at key institutions in other countries. CREPA also supervises the only scientifically monitored wastewater stabilization pond in the region.

Through this program, Germany (GTZ) has supported a series of research and dissemination activities on sewage-fed aquaculture, including the San Juan Aquaculture Demonstration Project in Lima, Peru, as well as an Expert meeting on Aquaculture in Lima in March 1985, the preparation of a scientific review of sewage-fed aquaculture, and the International Seminar on Wastewater Reclamation and Reuse for Aquaculture in Calcutta, India in December 1988.
The research on waste-fed aquaculture in Peru and Thailand has been finalized.
In Mexico City the UNDP is installing a demonstration project for solid waste recycling; this may include a component on the reuse of wastewater in agriculture.
In Chili the UNDP has performed an epidemiological study onthe effect of wastewater treatment on the occurence of typhoid in Santiago.

World Health Organization (WHO). In future policy it is expected that environmental health will become an increasingly important issue.
WHO programs focus on:
- human resource development;
- coordination of the many functions of the 'water-supply and sanitation decade';
- continuation of the achievements of the 'water-supply and sanitation decade';
- strengthening national capabilities;
- technology development, including operation and maintenance and the traditional technologies.

The stimulation of discussions on the international and national levels between multilateral, bilateral and non-governmental organizations is important.
The WHO initiated a joint project with UNEP (United Nations Environmental Program) on the health hazards associated with the use of human wastes. The WHO/UNEP are collaborating with the London School of Hygiene and Tropical Medicine and the IRCWD (International Center for Waste Disposal) for the promotion of new epidemiological studies and the creation of a network for the exchange of information.

United Nations Children's Fund (UNICEF). UNICEF is currently assisting governments in approximately 95 nations in the water and sanitation sector. UNICEF has a very strong bias towards low-cost technologies applicable to rural areas. UNICEF is not involved in liquid waste treatment.

Food and Agricultural Organization (FAO). The Land and Water Division of the FAO is establishing a network in the eastern Mediterranean region for promoting the treatment and use of wastewater for irrigation.

United Nations Educational, Scientific and Cultural Organization (UNESCO). UNESCO has no programs in the field of liquid waste.

African Development Bank.

5.3 BILATERAL ORGANIZATIONS

All respondents reported that in general a large number of water-supply and sanitation activities, mainly rural, were supported, but that activities in the field of fluid waste were limited.

Canadian International Development Agency (CIDA). The International Development Research Center (IDRC) is sponsored by the government. The IDRC's mandate is to stimulate and support scientific and technical research undertaken by developing countries. The IDRC has a long history of supporting studies concerning waste reuse, mostly involving the monitoring of the microbiological content of different types of waste.
In Peru at CEPIS the IDRC is supporting a study concerning the relationship between pond effluent quality and irrigated vegetable quality.

In Thailand an agro-based wastewater project is being supported by the IDRC which explores the potentials of a relatively novel, cost-effective waste treatment technology treating wastes from a slaughterhouse and from piggeries, which reduces the high levels of pathogenic microorganisms normally discharged into small watercourses frequently used by villagers for drinking water purposes.

Ministry for Foreign Affairs of Finland (FINNADA). FINNADA began their development cooperation in the water-supply and sanitation sector in 1971, mainly in the field of rural water-supply with a sanitation component. Health education has been an integral part of their projects. During the last half of the 1980's, projects in the areas of urban water-supply and sanitation have been included in the cooperation. Only recently have wastewater treatment and whole sewerage systems been included on the agenda.

Ministry of Foreign Affairs of Italy. Italian cooperation has supported projects especially on the African continent. A project in Turkey is being financed for the treatment of fluid waste in the framework of a broader project in the city of Conkiri. A somewhat similar project has been approved for the city of Mbabane in Swaziland. A project concerning wastewater treatment for industrial reuse and pollution control in the area of Tlanepantla, near Mexico City, is under examination.

Norwegian Agency for Development cooperation (NORAD). Norwegian development assistance in the water and sanitation sector is basically directed towards simple technologies, viz. domestic solutions which hardly produce wastewater.

Federal Department of Foreign Affairs of Switzerland. The Swiss Federal Department of Foreign Affairs has been cooperating closely with IRCWD (International Reference Center for Waste Disposal in Duebendorf)) for the last 10 years. This international organization plays an important role in the IDWSS.

Over the past six years the IRCWD has been engaged in investigating the practice and health implications of excreta and wastewater use in agriculture and aquaculture. IRCDW has been closely cooperating with the London School of Hygiene and Tropical Medicine, which focuses on the epidemiological perspective of wastewater and excreta use and continues to be engaged in respective studies in Indonesia and Mexico. In the course of these activities there was also close collaboration with WHO's (Geneva) Division of Environmental Health, the UNDP/World Bank Program on resource recovery, FAO and IDRC. As an outgrowth of the collaboration among these institutions, project meetings on reuse were held in 1985 and 1987, revised guidelines were issued in early 1989 and a more extensive health protection guideline book was published by WHO in late 1989.

Agency for International Development (AID), United States of America. AID's investments in urban water-supply and sanitation are currently focused in Egypt and Oman. The technologies involved are fairly traditional in nature and do not involve water reuse. For expertise in water and wastewater treatment and reuse, AID relies extensively on its Water and Sanitation for Health Project (WASH) which is funded to provide technical assistance to the agency in this sector. The project has skills in wastewater treatment and reuse through its prime contractor, subcontractors and consultants.

Bremen Overseas Research and Development Association (BORDA), West Germany. Since 1977 BORDA has been working in the field of biogas in rural and urban settings in developing countries with small-scale and simple biogas plants. in this respect, water pollution control was merely a byproduct since the main concern was energy and fertilizer production.
BORDA has begun negotiations with partners in India concerning the use of water hyacinth ponds for sewage treatment and biogas production. In the near future, BORDA will begin treating organic wastes derived from sisal production.

Swedish Agency for Research Cooperation with Developing Countries (SAREC). Within SAREC there is no expertise in the field of wastewater treatment.

SAREC has been supporting a sewer engineering project at Cape Verde since 1982; a pilot study for wastewater treatment. The collaboration institution in Sweden is the Department of Environmental Engineering, Lund Institute of Technology, University of Lund.

6 TECHNICAL AND NON-TECHNICAL BOTTLENECKS AND A DESCRIPTION OF REQUIRED RESEARCH AND STUDY AREAS.

6.1 INTRODUCTION

Despite the fair amount of research already performed in the field, the implementation of wastewater collection and treatment technology is frequently accompanied by many technical and/or non-technical problems, particularly when a completely or partially new concept of environmental protection is introduced.

In the following sections an overview of important bottlenecks which can occur in the implementation of wastewater collection and treatment technology is presented. This overview has been compiled on the basis of answers to questionnaires sent to various organizations, institutes, consultancies and pollution control industries as well as interviews with employees of these organizations.

On the basis of these bottlenecks, study and research items were formulated.

The study and research items discussed in this chapter are based mainly on information received from developing countries, however further insight into the real needs and demands of the different developing countries in liquid waste collection, treatment, reuse and recovery is needed before final specific conclusions can be formulated.

Technical as well as non-technical bottlenecks and research needs will be discussed in this chapter. The technical components are subdivided in:
- prevention of wastewater production;
- collection and transport;
- treatment technologies.

6.2. NON-TECHNICAL COMPONENTS

The importance of the non-technical components of a development project is generally underestimated. This concerns research, feasibility studies, demonstration and the implementation of projects.

Lack of or insufficient functioning of organizational relationships or institutional structures was often mentioned as a serious problem in projects. These problems, stemming from a wide variety of causes and of a managerial, financial or social nature, can be tackled in several ways:

a. proper coordination between the national organizations, donors and/or multilateral organizations;
b. strategies to improve international cooperation and coordination in this development sector;
c. adequate know-how transfer. International and national training and educational institutes are not sufficiently informing students and engineers about the relevant and appropriate wastewater treatment and collection methods and technologies. More attention should be directed to developing tools and strategies for the adequate diffusion of existing knowledge on all kinds of appropriate technologies to potential users in less developed countries. Universities and international educational institutes should be equipped to to meet this demand;
d. proper project preparation and execution.

/ capacity building

/ how to raise the political commitment

A Bottlenecks
(especially experienced by foreign executers)

a. Selecting the proper counterpart(s), whether an institute, company, contractor or individual, is difficult. Various aspects must be considered, e.g. the primary, secondary, short-term and long-term interests and intentions of the counterpart and the Dutch parties as well as their experience in the field, contacts, additional jobs/employment, interests, and commercial activities, etc. For all participants, the execution of a project means money for employment, and this may sometimes prevail over the objectives of the project itself.
In many cases, due to socio-cultural differences, different approaches, long- and short-term interest(s) etc. cooperation with a counterpart may become increasingly difficult .

b. Execution organization and management are (or can be) a matter of serious concern. When too many sub-contractors are involved, considerable delays in execution can result, often leading to quality and budget constraints. In such situations a clear picture of the different responsibilities of the participating project partners becomes difficult to maintain.

c. Inadequate legal protection and improper use of research project results. Monopolization of gained knowledge for private commercial purposes should be prevented.

d. Performance evaluations of implemented systems are often insufficient or not included in the project proposals.

e. Time stress during the preparation, execution, implementation and dissemination phases.

f. Lack of project continuity, resulting in executors gradually diverting their attention to preparing new proposals, initiating tendering activities, etc.

g. Institutional bottlenecks (organizational & legal):
   - poor legislation, control mechanisms and sanctions in many developing countries;
   - law enforcement, institutions cannot or will not force polluters to take adequate steps to meet legal standards;
   - lack of relevant knowledge and training of involved scientists, chemists and operators, and lack of training facilities;
   - lack of an institutional framework for operations and maintenance;
   - insufficient allocation of responsibilities and resources for operation and maintenance at the local and municipal levels;
   - revenue collection, recurrent costs and money collection from system-users;
   - governmental permission to solve financial constraints;
   - poor financial organization of the local authorities (i.e. the municipal accounting system and other municipal services) often leads to problems with the spendings of the collected money;
   - economical crises and new political balances in societies can render institutional structures ineffective;
   - sanitation projects frequently suffer from:
     - a lack of awareness of and interest in existing sanitation problems within the target group,
     - insufficiently understood and recognized related socio-cultural aspects.

B Research and/or study needs

a. Research on the status of sanitation (on user- and delivery-sides at different levels).
b. Development of a proper methodology for preparatory studies in this sector.
c. Establishment of existing non-technical reasons for the slow and sometimes very troublesome implementation and application of basically quite attractive collection, treatment and reuse methods, and what measures should be taken to ease them. It is worthwhile:
   - to identify possible gaps in the knowledge of and experiences with conventional and recent wastewater treatment and resource recovery methods;
   - to assess the reasons in various countries/regions for their lack of real interest in new wastewater treatment and resource recovery methods;
   - to improve strategies for the implementation of appropriate technologies in developing countries, e.g. by attracting the attention of national and international financing organizations, local policymakers and politicians, and the public in general.
d. Development of an adequate management information system (study).
e. An evaluation of the kinds of institutions involved in the realization of Dutch financed activities in this sector, how they were involved, what kind of support they received and what the results were achieved (study).
f. A study of the relationship between the legal system and the sanitation sector in various less developed countries.

6.3 PREVENTION OF WASTEWATER PRODUCTION

A Bottlenecks

Adequate sanitation requires a mimimum use of water. This also applies for various industrial production processes.

B Research and/or study needs

Assessment of how and to what extent practical feasible methods can be developed to reduce the quantity of wastewater originating from:
- households,
- household industries,
- various industries:

studies on waste(water) production prevention in some important polluting industries in the less developed countries, e.g. by studying the production process and comparing possible solutions with those applied in developed countries.

6.4 COLLECTION AND TRANSPORT

A Bottlenecks

a. In developing countries there is general lack of practical experience in the field of sewage collection and disposal. These countries therefore, must depend on the knowledge of available foreign consultants.
b. Very little is known about the possibilities of low-cost alternative sewage systems.
c. Installing urban drainage systems frequently is difficult, especially in the case of on-site sanitation in slum areas.

B Research and/or study needs

a. An inventory and analysis should be made of the relevant reasons for the malfunctioning of sewer systems in various specific situations. Based on this information, more appropriate sewerage systems applicable to these situations in developing countries should be developed, designed and implemented.
b. The development of low-cost 'community on-site sewerage systems', if possible in combination with proper low-cost 'community on-site treatment systems';
c. The development of low-cost decentralized sewerage and treatment systems in various specific situations;
d. The development of sanitation systems for urban slum areas with a high water-table or rocky underground.

6.5 TREATMENT TECHNOLOGIES

6.5.1 Introduction

In this section the problems and research needs related to the following treatment technologies will be discussed:
- Lagooning;
- Aerobic treatment systems;
- Anaerobic treatment systems;
- Post-treatment methods;
- Recovery and reuse methods.

First an overview of general bottlenecks and research needs will be presented.

Community on-site and intermediate technologies are treated in the section "Anaerobic treatment systems".

6.5.2 General bottlenecks and research needs

A Bottlenecks

a. Relevant information on all existing systems is often not available.
b. Lack of knowledge of suitable, cheap and locally available construction materials.
c. Lack of knowledge of proper troubleshooting and repair of treatment plants.
d. Too little information is available for adequate treatment of mixed wastewater streams. Mixed wastewater streams occur especially in urban slum areas with a considerable amount of house industries (e.g. tanneries, textile businesses, tahoe making, etc.)
e. The high toxicity of various industrial wastewaters frequently requires the development of specially adapted treatment strategies.
f. Industrial effluents vary greatly in origin and composition. Too little is known about the possibilities of employing various anaerobic and other low-cost treatment systems.
g. Knowledge is still insufficient regarding the recovery of valuable materials from wastewaters such as ammonium salts, phosphates, elementary sulphur, etc. On the other hand, available experience with the reuse of recovery technologies has barely found its way to practical application.

B Research and/or study needs

In the selection of technology to be implemented in a specific situation, the long-term interests of the local population should always prevail.
Before a final decision is made, it is generally advisable to:

a. investigate the system on pilot- and/or demonstration-scale;
b. investigate the possibility of using locally available construction materials;
c. assess the requirements for the operation and maintenance of the system;
d. educate and train operators.

6.5.3 Lagooning

Various types of lagoon systems are suitable for wastewater treatment (for complete treatment and/or post-treatment) in developing countries, viz. anaerobic, facultative, maturation lagoons, mechanically aerated lagoons, as well as lagoons making use of higher water plants. Moreover, interesting new developments might be found, e.g. for post-treatment in fresh and salty aquacultural systems such as those containing Daphnia and other types of zooplankton, mussels and shrimp, and filamentous algae.

A Bottlenecks

a. Large land requirements of conventional lagoon systems. Design improvements may decrease the land requirements.
b. There are problems with the proper operation of lagoons due to:
    - short-circuiting;
    - blocking of in- or outlet points;
    - insufficient knowledge of the best recirculation conditions under different circumstances;
    - algae growth, which may require an extra treatment step;
    - lack of maintenance and desludging;
    - the pond was not being designed for the specific conditions of developing countries.
c. In many developing countries there are no guidelines for the operation and maintenance of pond systems.
d. Lack of knowledge of the possibilities of alternative combinations of ponds under different climatological, geographical and economical conditions for different types of wastewater with emphasis on lower land requirements and water and trient reclamation.
e. Minimal knowledge of the design criteria for lagoon systems under various conditions. Procedures should be based on more adequate knowledge of the efficiency of various lagoon types in the removal of specific categories of pollutants such as malodorous compounds, nitrogen compounds, heavy metals, organic microcontaminants and pathogenic organisms. The conversion and removal of ammonia deserves special attention.
f. Lack of knowledge of the suitability of different lining materials under various conditions.
g. Little knowledge about the complex biological/microbiological/chemical/physical processes prevailing in lagoons i.e.:
    - symbiosis of the main biological species;
    - elimination of pathogenic organisms under various conditions;
    - conversion and elimination of nitrogen compounds;
    - possible toxic effects related to the treatment of industrial wastewater.
h. For anaerobic lagoons the general bottlenecks of anaerobic treatment are valid, mentioned in 6.5.5.

B Research and/or study needs

The improvement of individual types of lagoon systems

a. Improving insight into the various processes (e.g. the importance of the presence of different types of organisms and the symbiosis between various organisms, chemical and physical processes, the effect of weather, etc.) involved in the removal of various categories of pollutants in specific types of lagoon systems, i.e. removal mechanisms of:
   - biodegradable matter in various systems, treatment efficiency, excess sludge;
   - pathogens in facultative and aerobic (micro-aerophilic) lagoons;
   - nitrogen compounds;
   - malodorous compounds;
   - microcontaminants, organic as well as inorganic.

b. Improving the design and construction of various systems, at temperatures exceeding 20 °C, i.e.:
   - assessment of design criteria for more conventional lagoon systems under different climatological conditions, particularly tropical, and for the treatment of various types of wastewater, particularly sewage;
   - improving the hydraulic flow pattern in lagoons to optimize treatment efficiency;
   - development and demonstration of high-rate, upflow type anaerobic lagoon systems according to the idea underlying the UASB concept.

c. As (b), but at temperatures of 15-20 °C.

Improvements at the lagoon system level

a. The development of integrated sets of lagoon systems with the goal of reaching an optimal combination of various pond types under different climatological and geographical conditions, also aimed at various types of effluent reutilization, saving land space, and water and nutrient reclamation, should be studied.

6.5.4 Aerobic treatment systems

Although, for reasons previously discussed (see Table 1, Chapter 2), most conventional aerobic methods are ranked low for their complete treatment of wastewater, these methods still deserve consideration for application in developing countries, either for complete treatment or for post-treatment. Proper systems could be fixed film methods, e.g. biorotors, trickling filters and submerged filters. Just as for activated sludge processes, little if any research will be required for these well-established methods, at least as far as they will be applied for complete treatment.

A Bottlenecks

a. The majority of conventional aerobic systems in developing countries suffer from problems associated with operation & maintenance, electricity supply shutdowns and processing of the excess sludge.

b. The design of systems like oxidation ponds is still not optimal under tropical conditions.

B Research and/or study needs

a. Ultra high-rate activated sludge pretreatment systems such as the A-step of the A/B process. Such an ultra high-rate treatment step may in some cases be applicable in combination with low-cost anaerobic digestion systems (see 6.5.5.2) for sludge stabilization and energy generation. Sufficient reliable information is unavailable about the real potentials of such an A-step, particularly in developing countries.
b. Application of cascades, which might represent an attractive proposition when gravity flow can be applied.
c. Application of various conventional aerobic treatment systems for post-treatment of anaerobic effluents (see 6.5.6).

6.5.5 Anaerobic treatment systems

6.5.5.1 General bottlenecks

General problems related to anaerobic systems such as septic tanks, UASB-reactors and anaerobic lagoons are:

a. relatively little knowledge about the relatively high complexity of the microbiology and biochemistry of the anaerobic digestion process in developing countries;
b. limited information about the applicability at lower ambient temperatures;
c. possible malodorous nuisance due to the presence of sulphate in the wastewater;
d. the reuse possibilities of biogas from large-scale wastewater treatment plants are not known;
e. insufficient knowledge about the suitability of low-cost aerobic and micro-aerophilic systems for the post-treatment of anaerobic effluents for:
   - removing remaining BOD, SS, pathogens (see 6.5.6);
   - recovery of valuable compounds such as ammonia, phosphate, sulphur etc.

6.5.5.2 On-site and intermediate anaerobic technologies

A Bottlenecks

a. The lack of proper operation & maintenance of on-site sanitation systems, e.g. the regular removal of accumulated sludge from the pits and septic tanks frequently constitutes one of the major bottlenecks.
b. Scarce experience with small-scale treatment systems (10-100 households) with the possibility of collecting and draining the effluent or sewering it outside the town for centralized post-treatment.
c. How can a technology be made upgradable and adaptable to changing conditions?

B. Research and/or study needs

In general can be noticed that there is a need for the development, demonstration and implementation of effective compact anaerobic reactors for domestic wastewater and household industrial wastewater treatment, viz. house on-site and community on-site scale.
Apart from treatment efficiency, an important aspect to be considered is the extent of sludge stabilization which can be achieved.

More especifically research needs can be identified in the following areas:

a. Black water treatment and night soil digestion:
   - at temperatures 10 - 15 °C (little information available);
   - at temperatures 15 - 20 °C (some information available, but more information required);
   - at temperatures > 20 °C (reasonable design possible).

b. Combined black and grey water treatment:
   - at temperatures 10 - 15 °C (little information available);
   - at temperatures 15 - 20 °C (more information required);
   - at temperatures > 20 °C (reasonable design possible).

c. Domestic and household industrial wastewater, e.g. the tahoe-industry, and tanneries:
   - at temperatures 10 - 15 °C (no information available);
   - at temperatures 15 - 20 °C (little information available);
   - at temperatures > 20 °C (little information available).

d. Treatment of wastewater from flat buildings, barracks, hospitals, hotels, etc.:
   - at temperatures 10 - 15 °C (little information available);
   - at temperatures 15 - 20 °C (more information required);
   - at temperatures > 20 °C (reasonable design possible).

6.5.5.3 Off-site anaerobic technologies

A Bottlenecks

Apart from the general bottlenecks related to anaerobic technologies (mentioned in 6.5.5.1) some problems specifically related to high-rate anaerobic technologies can be identified:

a. Due to insufficient expertise and lack of seed sludge, the start-up may represent a serious problem, particularly for industrial wastewater treatment.
b. Limited information about the feasibility of treatment at lower temperatures of low-strength cold wastewater, wastewater containing toxic or inhibiting compounds, and complex high-strength wastewater, with respect to reactor design, process layout, operation and control, and construction materials.
c. Little practical experience in developing countries.
d. The high variability in composition, strength, temperature, etc., of various types of industrial wastewaters requires a good knowledge of and sufficient insight into the aerobic digestion process for the development of proper design and application.

B Research and/or study needs

Reactor technology

Although several proper reactor systems are available, important work can still be done in this field for the benefit of developing countries, i.e.:

a. Development of low-cost designs and constructions for sludge (and night soil, manure) digestion and for high-rate anaerobic wastewater treatment systems (see section under Lagooning).
b. Development and demonstration of moduled reactor concepts, possibly integrated with hybrids of various high-rate systems.
c. Development of integrated anaerobic/aerobic or anaerobic/micro-aerophilic reactor concepts..

Anaerobic reactors for sewage treatment

a. Assessment of the feasibility of the process in the wastewater temperature range 10 - 15 °C. There is evidence that anaerobic treatment may be feasible, provided this low temperature doesn't last for more than 2 - 4 months.
b. Assessment of the feasibility of the process in the wastewater temperature range 15 - 20 °C. Pilot-plant results demonstrate the principle feasibility of the UASB system, however it is essential to conduct research on large pilot-plant scale in regions where such wastewater temperatures prevail.
c. The extent of sludge stabilization which can be achieved;
d. The treatment efficiency which can be obtained in relation to hydraulic loading rates;
e. Process layout and reactor design aspects;
f. Assessment of the effects of sewage pollution strength, the complexity of the pollutants, the presence of toxic or inhibitory compounds, the occurrence of incidental high or low pH-values, e.g. due to industrial discharges.

Industrial wastewater treatment

a. Feasibility studies for various industrial wastewaters should be performed, e.g. wastewater from the electroplating industry, the textile industry, tanneries, treatment of SS-rich wastewaters in combination with heavy metals and wastewaters containing pesticides.
b. As is mentioned in 6.3 possibilities of reducing wastewater production have to be investigated, evaluating production processes.

6.5.6 Post-treatment methods

This chapter will be focussed on the post-treatment of anaerobic effluents. Although in many cases anaerobic treatment may tentatively suffice in developing countries, it is important to emphasize the development and implementation of low-cost post-treatment systems, since few additional costs will be required to achieve a better treatment efficiency. Post-treatment will be more attractive when some form of recovery and/or direct reuse of resources can be accomplished or when the production of food can be reinforced.

A Bottlenecks

Little relevant information is available so far about:

a. the various methods potentially attractive for the elimination of specific remaining pollutants;
b. the design and operation of various available methods for application to anaerobic effluents.

B Research and/or study needs

a. Assessment of the proper application of lagoons and/or fish ponds. In principle these systems are effective for all the pollutants still present in the anaerobic effluent. Very likely these systems can be considerably optimalized by relatively simple means, but more basic insight is required.
b. Assessment of the applicability of conventional aerobic methods, e.g. cascades, biodiscs and trickling filters. These methods are especially attractive when gravity flow can be applied.
c. Assessment of the feasibility of physical-chemical methods, e.g.:
   - disinfection methods such as chlorination, UV-radiation, ozonization;
   - SS-removal by applying chemical-coagulation;
   - chemical phosphate removal;
   - application of a combined stripping-absorption process for the removal of ammonia.
d. Development of cheap methods to remove sulphide by recovering it as elemental sulphur. Such methods, presently under development, are particularly interesting for specific industrial wastewaters.
e. Assessment of the applicability of various filtration methods, e.g.:
   - upflow, downflow and horizontal-flow gravel filtration systems for suspended solids removal;
   - slow sand filtration, which should particularly be investigated for removing NH_4^+, PO_4^{3+} and pathogens from anaerobic effluents;
   - soil infiltration (land treatment) in integrated wastewater treatment systems. Apart from crop growing, special attention should be directed to the possibilities of reclaiming and reutilizing the drainage water.
f. Assessment of the use of wetland systems such as shallow reed ponds and marshlands. Special attention should be paid to the risks of vector diseases related to stagnant waters.

6.5.7 Recovery and reuse methods

A Bottlenecks

a. All of the possible uses of biogas are not yet known.
b. Sludge disposal is a major problem. More information is needed about safe and simple possibilities for the use of sludge for agricultural purposes with special attention on the presence of pathogens and heavy metals.
c. The possibilities of the most profitable uses of anaerobic effluents, specifically for food production, have not been assessed.

B Research and/or study needs

a. Biogas production and utilization (heating, cooking, lighting, electricity generation as power source), especially when relatively small amounts of biogas are involved.
b. Utilization of excess sludge for soil conditioning and fertilization.
c. Reuse of anaerobic effluents for:
   - irrigation
   - fertilization
   - fish-breeding
   - groundwater replenishment and the successive production of potable water.
d. Recovery of useful resources such as:
   - ammonia
   - phosphate
   - elementary sulphur.

7. CONCLUSIONS

To sustain a future for all life, the development and immediate implementation of proper, low-cost and effective **environmental protection and resource preservation** methods are needed, particularly in the "Third World".

With the present "state of the art" in technological developments, the rapid development and implementation of such low-cost wastewater treatment and resource preservation systems are within reach. However, in order to achieve our goal, it is of crucial importance to swiftly reinforce a variety of activities in this field as well as to establish priorities.

Considering the many issues requiring further attention, a priority list for study and/or research activities has been made. This list is based on the criteria cited in Table 1 (Chapter 2), the needs of the developing countries (as far as they could be estimated on the basis of information received), the comparative expertise of The Netherlands assessed in the light of other countries and donor organizations (Chapters 4 & 5), and the policy of the Research and Technology Program of DGIS (Chapter 3).

The criteria considered are:

- Appropriateness of the methodology or technology for developing countries, both for environmental protection and resource preservation;
- Effectiveness of the technology as treatment method with respect to categories of pollutants which are considered most hazardous;
- Short-term feasibility and applicability of the technology and/or methodology;
- The extent to which the production of wastewater and wastes will be prevented;
- The process stability with respect to fluctuations in e.g. the composition and amount of wastewater, powersupply interruptions, temperature, etc.;
- System flexibility with respect to scale at which it can be applied, whether it can be extended in the future if larger amounts of wastewater have to be treated, and whether it can be adapted when effluent restrictions become more stringent;
- Simplicity of operation and maintenance;
- Lifetime of the system;
- Land requirements;
- Possibilities for house on-site, small-scale community on-site sanitation systems and decentralized sewage treatment;
- Extent to which the technology will lead to a reduction in the costs of wastewater collection and transport systems;
- Extent to which the activity will lead to self-sufficiency of the developing country with respect to environmental protection;
- Extent to which the system will lead to an improvement in conditions for the poorest classes of people;
- Absence of nuisance problems to the environment.

Three priority categories have been distinguished on the basis of these criteria, viz.:

A. **First priority.**
Immediate action required.

B. **Second priority.**
Mid-term action required.

C. **Third priority.**
Long-term action required.

The different research and development needs are listed in Tables 7.1, 7.2 and 7.3 according to these priority categories.

TABLE 7.1. **Activities required in the field of development and implementation of low-co wastewater collection and treatment and recovery methods.**

Category A: First priority.

Non-technical.

1. Development of a manual for policymakers with general guidelines for the management of low-cost wastewater treatment systems.

2. A (case) study of the existing non-technical reasons for the slow and sometimes very troublesome implementation and application of basically quite attractive collection, treatment and reuse methods and which measures should be taken (6.2).

3. Research on the status of sanitation (6.2).

4. Development of guidelines for preparatory studies in this sector to study technological aspects as well as prospects for cost recovery (6.2).

Technical.

1. Wastewater collection and transport (6.4). The development of low-cost "community-on-site" sewerage systems, if possible in combination with appropriate treatment systems (6.5.5.2).

2. Development of low-cost designs and constructions for:
   - sludge, night soil or manure digestion,
   - high-rate anaerobic wastewater treatment systems. (6.5.5.2).

3. Development, demonstration and implementation of effective, compact reactors to operate on house on-site and community on-site scale at temperatures exceeding 15 ^{o}C for the treatment of:
   - domestic wastewater (black and grey, combined and/or separate),
   - household industrial wastewater. (6.5.5.2).

4. Sewage treatment by anaerobic systems in the temperature range 15 - 20 ^{o}C (6.5.5.3).

5. Development, demonstration and implementation of moduled anaerobic reactor concepts, possibly integrated with hybrids of various high rate systems (6.5.5.3).

6. Post-treatment of anaerobic effluents:
   - application of conventional aerobic methods, e.g. cascades, bio-disks, and trickling filters,
   - application of lagoons and/or fish ponds for anaerobic effluents. (6.5.6).
   - development of appropriate systems for removing sulphide (as sulfur).

7. Prevention of industrial wastewater production (6.3) by stimulating of on-site treatment of the wastewater.

8. Development of a manual for technicians with guidelines for the design, construction, operation and maintenance of low-cost wastewater treatment systems.

9. Reinforcement of transfer of know-how concerning low-cost appropriate treatment systems and methodologies in order to make developing countries self-sufficient with respect to environmental protection.

TABLE 7.2. Activities required in the field of development and implementation of low-cos wastewater collection and treatment and recovery methods.

Category B: Second priority.

Technical

1. Development of low-cost decentralized sewerage and treatment systems in various specific situations (6.4).

2. Further development of lagoon systems:
   - development of integrated sets of lagoon systems,
   - improvement of individual types of lagoon systems when applied at temperatures in the range 15 - 20 ^{o}C (6.5.3)

3. Development of integrated anaerobic- aerobic/micro-aerophilic reactor concepts (6.5.5.3).

4. Reuse of anaerobic effluents (6.5.7).

5. Soil infiltration (land treatment) in integrated wastewater treatment systems (6.5.6).

6. Use of wetland systems, such as shallow reed ponds and marshlands (6.5.6).

7. Physical-chemical post-treatment methods and disinfection methods, such as chlorination, UV-radiation, ozonization (6.5.6).

8. Filtration methods for post-treatment, e.g. upflow, downflow and horizontal flow gravel filtration systems for suspended solids removal (6.5.6).

TABLE 7.3. Activities required in the field of development and implementation of low-cos wastewater collection and treatment and recovery methods.

Category C: Third priority.

Technical

1. Possibilities of the anaerobic treatment for sewage in the temperature range of 10-15 °C (6.5.5.3).

2. Physical-chemical methods:
   - SS-removal by applying chemical-coagulation,
   - chemical phosphate removal,
   - application of a combined stripping-absorption process for removing and recovering ammonia. (6.5.6).

3. Recovery of useful resources such as:
   - ammonia,
   - phosphate,
   - elementary sulfur
     (6.5.7).

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APPENDIX I SURVEY OF DRAWBACKS AND POSSIBLE ALTERNATIVES TO CONVENTIONAL SEWER SYSTEMS

I.1 DRAWBACKS

a. The investment and recurrent costs of conventional sewer systems are high. The lifespan of a sewer system is limited so their implementation implies repeated significant financial expenditures.
b. High water use of these systems (generally expensive and scarce potable water) for the dilution and transport of solid materials through the sewer pipes. Through this process, large amounts of clean water are polluted (a waste of resources!), and consequently require expensive treatment. Whether this extravagant use of water is socio-economically justified is questionable, even in countries with ample resources and a well-established water distribution system.
Water-borne systems can be installed in communities provided with (expensive) individual home tapwater connections. The supply of potable water is inherently accompanied by the production of wastewater and consequently, with the need to collect and treat the wastewater, either on- or off-site.
c. Water-borne sewerage is a complex technology which requires skilled construction for smooth performance. The skills necessary to design and install such a system are generally insufficiently available in developing countries. The engagement of expensive expatriate expertise results in the considerable loss of hard currency or increasing debts.
d. Large central collectors must be laid in straight lines.
Digging large trenches in straight lines through scattered settlements will necessitate the demolition of a substantial number of houses which is often socially and politically unacceptable.
e. Conventional water-borne systems are prone to blockage
when large objects are discharged in the sewer, and/or when inadequate quantities of water are available for flushing. Communities inexperienced with water-borne sewerage sometimes utilize the system for removing a variety of household wastes, some of which may block the sewers.
Materials traditionally used in certain areas for anal cleansing, such as corn cobs and stones, also seriously risk sewer obstruction.

I.2 ALTERNATIVES

a. Small bore sewers. These systems are applicable when the domestic wastewater, prior to discharge into the sewerage, is subjected to on-site settling in a small vault. An advantage of this system is that it does not require high water use. Moreover, unlike conventional sewerage systems, small bore sewers do not require large excavations. Small bore sewer systems can be used in community on-site treatment (COST).
b. Shallow sewers. These are similar to the conventional sewerage systems, however they are installed at a lower depth and are built according to less conservative standards, e.g. they require fewer manholes. They are meant to collect toilet and other liquid household wastes which at the outfall of the sewer, are subjected to treatment (Macoun & Semb, 1989).

APPENDIX II LOW-COST WASTEWATER TREATMENT SYSTEMS

II.1 SEPTIC TANK (PRIMARY TREATMENT) (see fig. II.1)

A septic tank is a closed tank in which the black or grey wastewater from one or several houses (up to fifty households) is treated. Consisting of sedimentation and to some extent anaerobic stabilization of the settled sludge, this treatment process is in fact, only a treatment step. The liquid can be disposed of via a leaching pit or leaching trench (infiltration into the soil), or into some kind of sewer system.
Infiltration into the soil is a good solution as long as the amount of wastewater does not exceed the natural capacity of self-purification and dilution.
Depending on the capacity, the tank must be desludged within a period of one to several years. The amount of produced sludge varies from 20 to 60 liters per user per year. When the tank is not regularly desludged, solids may wash out and clog the soil infiltration system. This is the reason that in practice many septic tanks discharge directly into the surface water or storm water drain, although the effluent is certainly not suitable for this purpose.
Although the system is simple as it is, great care should be taken when designing a septic tank. The tank is usually made of concrete, however asbestos cement can also be used. The system is used all over the world with considerable variations in design: the tank can be divided into two or more compartments and the volume per user is dependent on the ambient temperature (Desk study IHE, 1989).

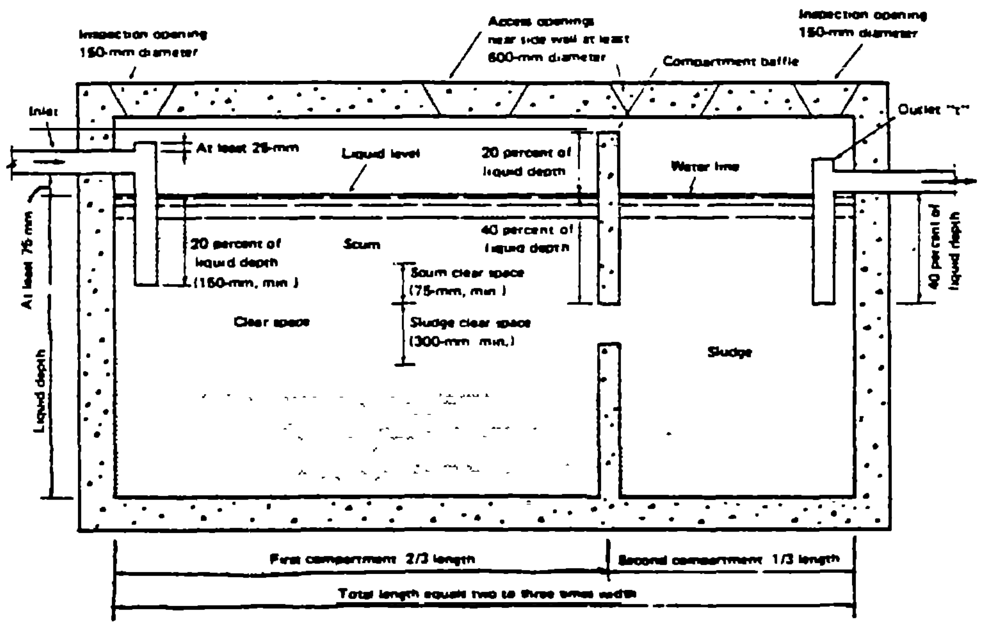


figure II.1 Septic tank (from Kalbermatten, 1981)

II.2 THE IMHOFF TANK (PRIMARY TREATMENT AND SLUDGE DIGESTION) (see fig. II.2)

In a single structural unit, these two-story tanks perform the dual function of sedimentation and digestion. Used throughout the world, particularly in smaller communities, they have not been used for larger plants in industrialized countries because of the high construction costs for the required excavation and the rather complex concrete form.
The Imhoff tank consists of an upper chamber for sedimentation and a slot which permits the settled sludge to flow into a lower digestion chamber. Since the digestion chamber cannot be heated, this system is more suitable in areas with higher temperatures, as in many developing countries.

Little mechanical equipment is required and maintenance requirements are minimal.

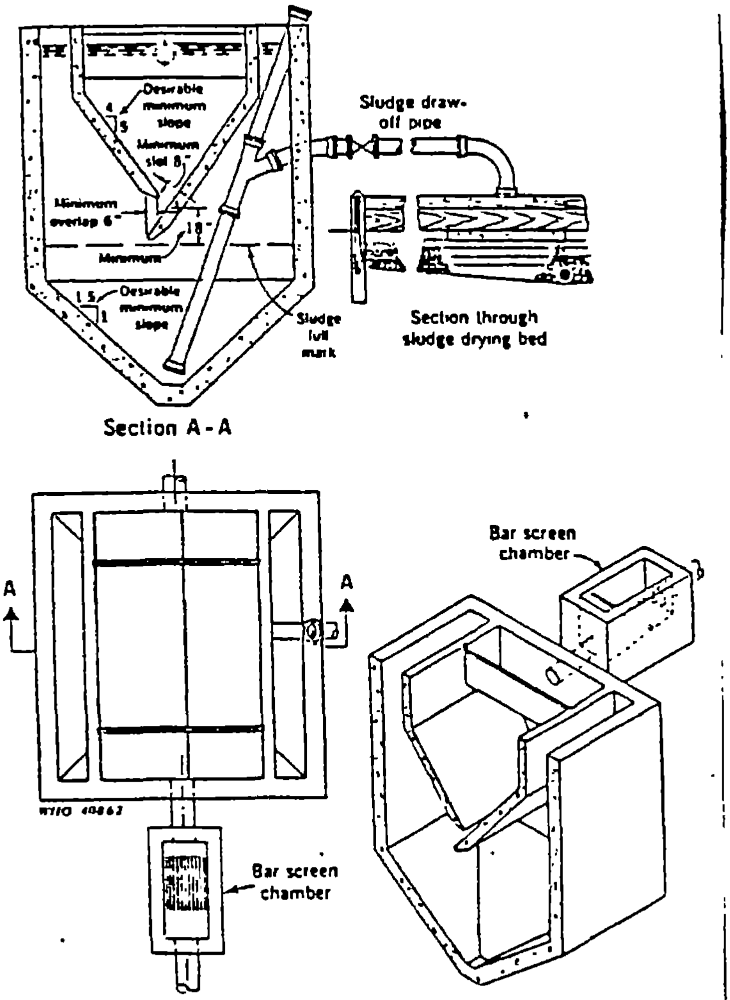


figure II.2 Imhoff tank (from OKUN, 1975)

II.3 LAGOONS (PRIMARY + SECONDARY TREATMENT) (see fig. II.3)

Lagoons can consist of anaerobic ponds/lagoons combined with facultative lagoons, aerated lagoons and/or maturation ponds, and/or water hyacinth channels or polyculture lagoons (ecoponds).
Dependent on the combinations, moderate to very high treatment efficiencies can be achieved. Applying the criteria from Table 1, the following can be said:

Lagoons do not generally require power specialized equipment. Anaerobic lagoons can be 3 to 4 meters deep, and therefore have relatively low land requirements. Effluent from anaerobic ponds or lagoons generally require further treatment before discharge into receiving waters or reuse on land. Anaerobic ponds can provide BOD reductions of 30-70%, and consequently can be considered a combined primary + partial secondary treatment. Anaerobic ponds can be an odor nuisance and therefore should be situated downwind and at some distance from settlements (Ahmad, 1988; Yhedego, 1989; Specker & van Buuren 1989).
These systems are quite feasible in tropical areas.
Waste stabilization ponds are the most simple of all comprehensive waste treatment processes. The incoming wastewater is held in shallow ponds (depth of 1 to 1.5 meters)

for a relatively long detention period (up to 20 days) to allow organic matter to be stabilized by microbial activity. A protracted detention period in a series of stabilization ponds yields a highly polished product which is virtually pathogen free. When the series is completed with a maturation pond, a fish pond, water hyacinth channels or polyculture lagoons, the degree of treatment is considered tertiary.
A considerable amount of research is spent on the use of macrophytes in wastewater treatment schemes. Reddy and Debusk (1987) give an overview. Ponds with macrophytes can have various functions in the treatment process including:
- removal of nutrients and heavy metals via the plant;
- input of oxygen into the system by the transport of oxygen from the leaves to the roots and from the roots' diffusion into the water;
- production of potentially useful resources, namely biomass. This vegetal material can be used as animal fodder, as a source of biogas, or to improve the fertility and structure of the soil (raw or composted).

The use of harvested biomass is not always technically or economically feasible and sometimes the macrophyte ponds are an ideal environment for the growth of mosquitoes.
Stabilization ponds operate under natural conditions and do not require sophisticated equipment (Ahmad, 1988). These systems are well applicable under warm climatic conditions and where cheap land is readily available.
Mechanically aerated lagoons for secondary treatment and/or post-treatment of the effluent of anaerobic or facultative ponds use only 10-20% of the land area required for stabilization ponds, mainly because of their greater depth (2.5-5.0 meters) and the significantly shorter liquid detention times required. Facultative aerated lagoons provide BOD removals up to 80% when directly applied to domestic sewage. Coliform removal is insufficient, i.e. between 90-99% at warm temperatures and using single-celled lagoons. No nitrification takes place.
Only the very low loaded types (with sludge recycling) meet the discharge standards. Several types of aerated lagoons can be distinguished, depending on loading rate and sludge recycling (Desk study IHE, 1989).

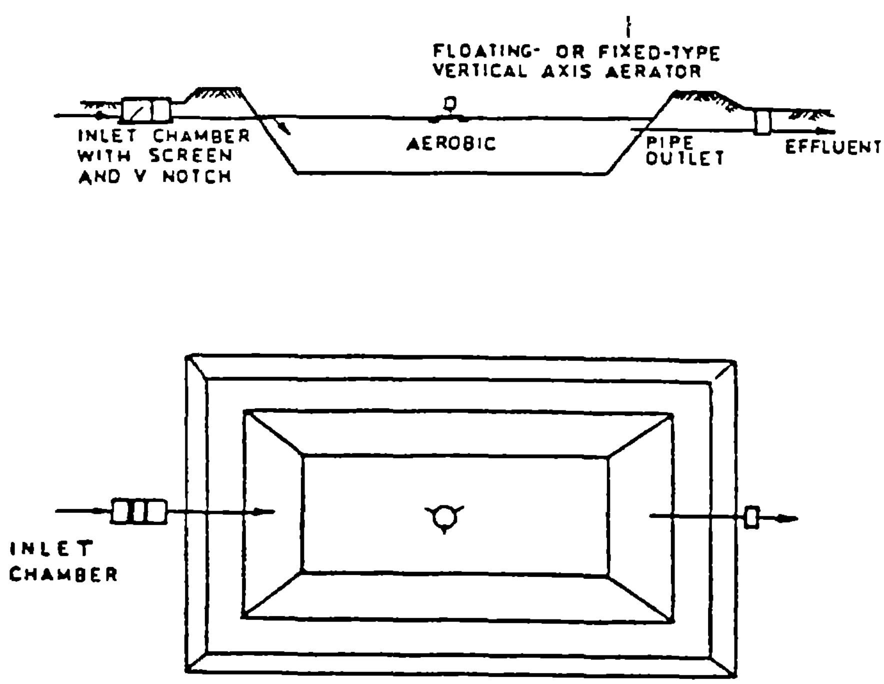


figure II.3 Aerated lagoon (from Arceveila, 1981)

II.4 TRICKLING FILTERS (SECONDARY TREATMENT) (see fig. II.4)

A trickling filter is a bed filled with a coarse carrier material (lava stones, plastic shapes). Wastewater is percolated downward through the filter bed. A biological layer develops on the carrier consisting of bacteria, protozoa and some inert material. Aeration takes place through a spontaneous (influenced by temperature differences) or forced air flow through the filter.
Presedimentation is necessary to avoid blockage of the distribution device. Post-sedimentation is also necessary since excess sludge growth (parts of the biofilm) are washed out with the effluent. When ambient temperatures are sufficiently high and the organic loading is not too big, nitrification can take place and the effluent quality is quite good.
An advantage of this system is its simple operation. Its disadvantages include limited flexibility of the process and limitations on the removal of nutrients (denitrification and dephosphation).

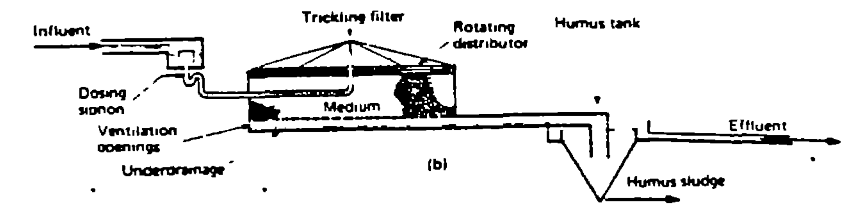


figure II.4 Trickling filter plant (from: Barnes et. al., 1981)

II.5 OXIDATION DITCH (see fig. II.5)

Although it is strictly a modification of the activated sludge process, the oxidation ditch is often regarded as a rather specific wastewater treatment technology.
The wastewater is, without presedimentation, pumped into a closed loop (carrousel) and mixed with the activated sludge. the contents of the aeration tank are mixed and aerated by rotors or cones. The position and speed of the rotors facilitate precise control of the oxygen concentration at the various places in the ditch.
This provides high process flexibility and possibilities for nitrification/denitrification within one tank. Oxidation ditches are low loaded; sludge load approx. 0.05 kg BOD//kg d.s.
Consequently, the sludge is aerobically stabilized in the aeration tank and sludge production is small. Anaerobic sludge digestion is not feasible. Construction costs are relatively low compared to operation and maintenance costs.
With this system, sludge handling is simpler and contrary to activated sludge plants, primary sedimentation is unnecessary. This process requires therefore little supervision, and is very popular for small towns.
Effluent quality is excellent with regards to BOD, TSS and ammonium (Desk study IHE, 1989).

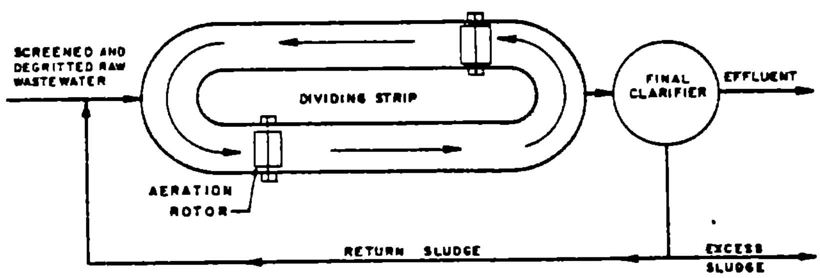


figure II.5 Flow scheme of an oxidation ditch (from: Vernick and Walker, 1981)

II.6 BIOROTOR OR ROTATING BIOLOGICAL CONTACTORS (RBC'S)

(see fig. II.6)

Rotating biological contactors (RBC's) are discs rotating with the lower part of the circle in a shallow tank through which the water flows. The disc is covered with an aerobic biofilm which is alternatively exposed to the air, taking up oxygen, and to the wastewater, absorbing organic matter. This process requires less energy than the activated sludge process (energy consumption is 500kWh/ 100 kg BOD removed), however land requirements are greater. A well functioning RBC is reliable and highly efficient: it can be a complete treatment or it can be used as a post-treatment step. The effluent quality can be very good, determined by the organic loading (in kg BOD per m^2 disc surface) and by the number of stages, usually 3 or 4. Sludge production is low: 0.06 kg d.s./kg BOD removed, and the sludge volume index is well below 100 ml/g. Organic matter dissolved or suspended in the wastewater is rapidly adsorbed by the biolayer and later degraded. Because of this, the system is capable of handling peak-loading as well as periods of starvation. Due to the module type of the RBC, it is a suitable system for upgrading existing treatment plants.
A disadvantage of this system is its sensitivity to temperature and toxic compounds, and the slow start-up. This technique is still quite young.

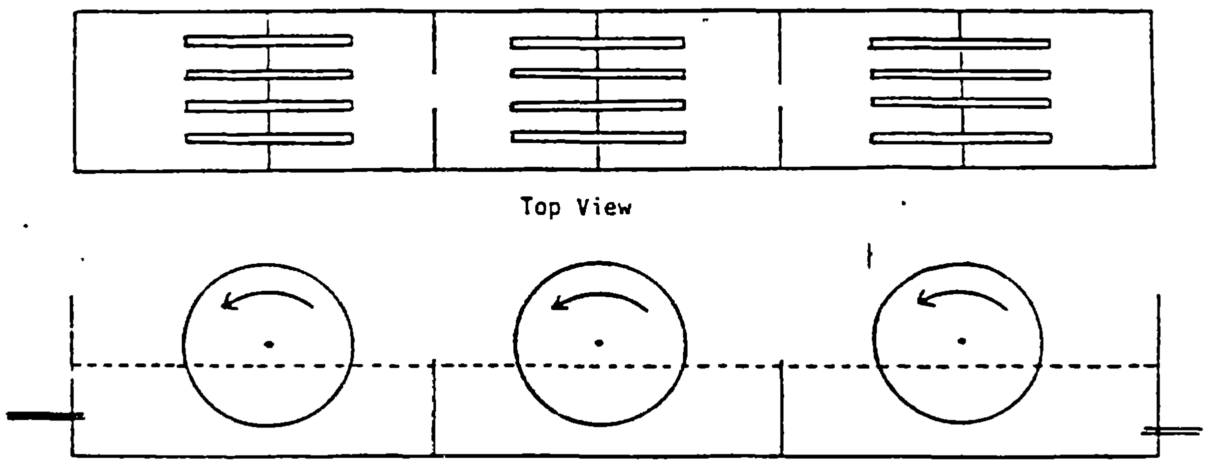


figure II.6 Schematic drawing of a RBC-unit

II.7 MODERN HIGH-RATE ANAEROBIC TREATMENT SYSTEMS INCLUDING THE UASB PROCESS AND SYSTEMS SUCH AS ANAEROBIC FILTERS.

Presently, the UASB reactor concept (see figures II.7.1 and II.7.2) is successfully applied for wastewater flows from paper mills, sugar and starch industries and breweries. For the treatment of domestic sewage with the UASB process, research has been performed over the last decade. Promising results have culminated in the start-up of a pilot-plant project utilizing the UASB system for domestic sewage in Cali, Colombia (1983-1987). Since 1987 several small full-scale reactors (100-500 m^3) and a plant (1100 m^3) have been or will be put into operation for domestic wastewater in Kanpur (India). UASB technology has been studied on-site in a slightly modified reactor (Bandung, Indonesia).

In these types of reactors the wastewater flows upward through a layer of active anaerobic sludge with very good settling capacities. At the top of the reactor a gas-solid-liquid device separates the three fractions.
The UASB process and the anaerobic filter (secondary treatment) are both high-rate reactor concepts.
Anaerobic filters (see figure II.7.3) are used in upflow and downflow modes, with the upflow type achieving better removal of suspended solids. It is expected that in five to ten years this system will be used for the treatment of domestic wastewater under Dutch conditions. Together with the UASB, this is the most applied anaerobic reactor type for the treatment of industrial wastewater.
Nutrient removal (phosphorus and nitrogen) is insignificant. As in other anaerobic waste treatment systems, the removal of coliforms is poor. For achieving satisfactorily effluent quality, post-treatment of the effluent is necessary.
On the other hand, helminth eggs are captured in the sludge blanket. Since the helminth is very resistent, when emptying the reactor, the sludge, which contains large amounts of these parasites, should be handled with care.

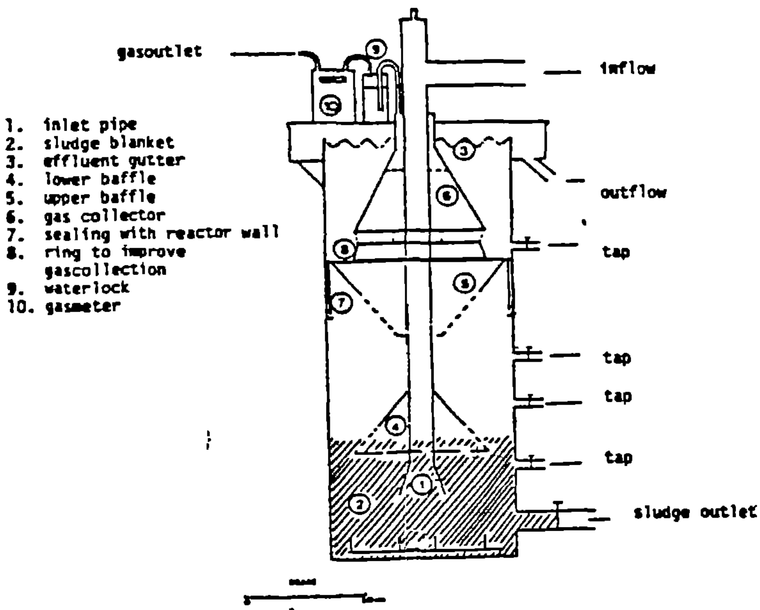
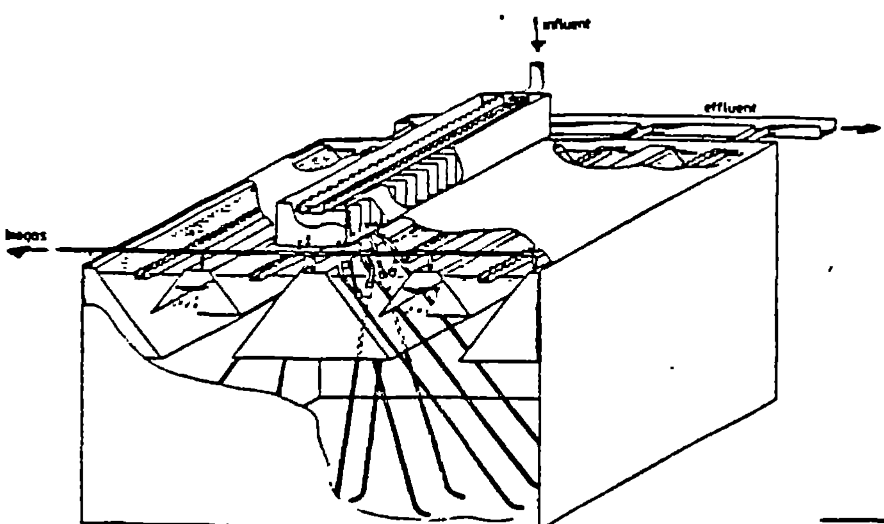


fig. II.7.1
UASB for on-site treatment



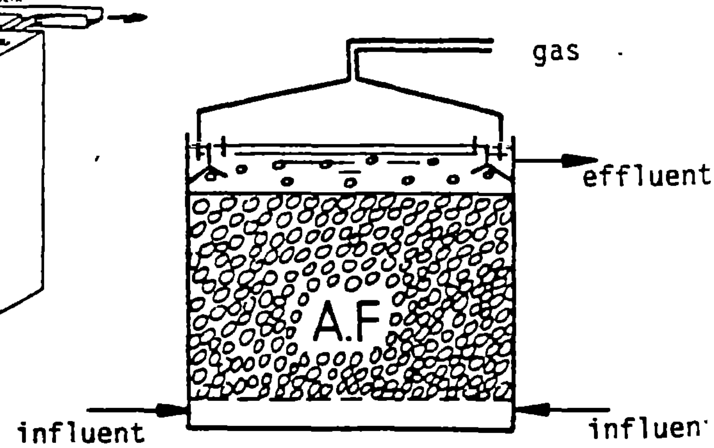


fig. II.7.2 full scale UASB

fig. II.7.3 anaerobic filter

II.8 LAND TREATMENT (see figure II.8)

The spreading of waste and wastewater on land is one of the oldest treatment and reuse techniques. For centuries it was necessary to bring animal and human excreta to the land as fertilizer. Doing the same with urban wastes and wastewater seemed to be a logical continuation of this practice. The principal processes of land treatment are irrigation or slow-rate/rapid filtration and overland flow. Other land treatment methods include wetland and sub-surface application.
Interest in the treatment of wastewater on land has grown, particulary in developing countries (India, China, Thailand, Vietnam). The principle reason is the possible reuse of valuable substances in the wastewater. The fact that land treatment is a simple technique and does not require highly skilled personnel for operation and maintenance also makes it an attractive alternative. Land treatment has no start-up problems and is relatively insensitive to peak loads and so may be favorable in the treatment of wastewater of seasonal industries.

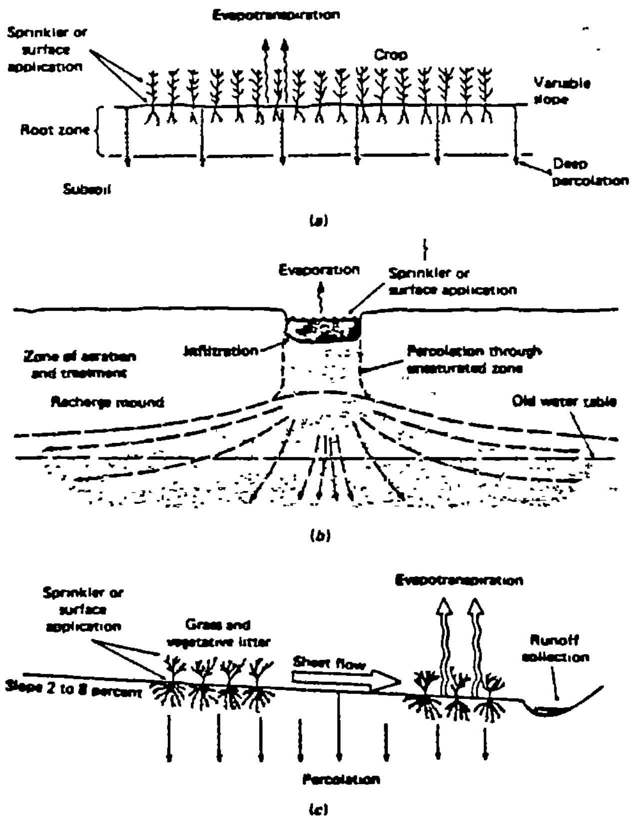


figure II.8 The principal systems of land treatment (from: Metcalf and Eddy, 1979)
a. irrigation
b. rapid infiltration
c. overland flow

IRC

International Water and Sanitation Centre

Centre international de l'eau et l'assainissement

WHO Collaborating Centre / Centre Collaborant de l OMS

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our ref / ref	your ref / votre ref	date
46.236/ls	OSAB-151868	18 October 1990

Dear Mr de Lange,

Further to our discussions, I herewith enclose some comments on the position paper on Low-cost Waste Water Treatment and Reuse. I also enclose a list of institutions which have been identified in a initial search in our documentation base. The list is not exhaustive and can be expanded if so required, in that case, we would have to explore linkeages with external data basis.

Please advise me whether you would like to receive the addresses of the institutions indicated on the list, and if you would like to have an indication of the possible cost involved in a more extensive search on institutes working in developing countries in the field of Waste Water Treatment and Reuse.

With kind regards,

Jan Teun Visscher
Senior Programme Officer

INTERNAL copy to Eveline Bolt.

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A N N E X E "A"

Comments to the position paper on Low-Cost Waste Water Treatment and Reuse.-

Development of the position paper is a quite interesting approach and provides an overview of many of the research activities in the field of Waste Water Treatment and Reuse which primarily are being implemented by European based Institutions in developing countries. Unfortunately, to a much lesser extent are research activities of developing countries based Institutions covered in the overview. There are, for example, interesting developments in vast countries such as Brasil and China.

The focus of the document is by nature oriented primarily towards the urban setting and industry, and to a much lesser extent to the rural poor and urban slum dwellers. This brings about the question of the relative priority of research in waste water treatment as opposed to other sanitation issues such as the efficient use and large scale introduction of latrines, treatment of latrine sludge and solid waste disposal and treatment. It may be worthwhile to try and give an indication in the introduction of the paper concerning this relative priority.

The paper mentions the low-cost sanitation concept but only addresses in a very limited way that present technology concepts seem to be still wide out of the range which developing countries can afford. It appears that a much more innovative approach towards sanitation will be required in many situations. Approaches which promote a sustainable development of viable technology at a service level which is acceptable and affordable for the communities. This may well be a much lower service level than presently is being applied in a number of urban areas in developing countries. In this context, it is very important to look into willingness to pay for different sanitation options. The enormous magnitude of the sanitary problems in urban areas in developing countries is not sufficiently coming to the fore in the present paper. Nevertheless not only the sanitary problems in urban areas require attention.

We do not concern with the statement in section 2.3 that sanitation in low density areas is reasonably smoothly. Several problems are still to be solved in these areas, particularly in relation to the relative high cost of solutions and possible soil pollution problems from existing techniques. Another area of research concerning these types of systems relate to the institutionalization of latrine construction and implementation programs to enable the necessary scaling-up which is required to cope with the low coverage figures in many countries.

It is interesting to note that legislation and law enforcement are important issues mentioned under the institutional aspects. However, without adequate motivation and involvement of the community in support of legislation, it will not be possible in most cases to really come to grips with law enforcement. How to support this motivation and how to best involve the communities is still a matter which needs to be explored further.

Another general statement which needs to be put into some perspective is the issue that low-cost techniques are or are becoming available. It should be noted that still many of these techniques are not affordable and several of them have only been implemented on small scale under real life conditions in developing countries. Taking into account that the conditions in many of these countries differ considerably, it can be stated that these techniques require further testing in a number of cases particular emphasis. This view is supported by the statement in chapter 4 which states that the systems which are being applied in Dutch finance programs, often are comparable to those being applied in the Netherlands. However, not all of them are equally successful. Some definitely fail, and this in my view, calls for a careful review to find why they fail and how they perform.

Reuse of waste and waste water appears to be a very challenging problem and may be the best possibility to solve the constraints involved in waste water disposal. Hence RSD in this area including biogas production and particularly land treatment appears to be very useful. A recent consultation organised by WHO and FAO on legal issues in water supply and sanitation addressed the issue of waste water reuse, and for your information, the background paper for this meeting has been attached. The full report of this consultation will be available shortly. In this consultation, it was quite clear that cultural aspects of waste water are an important issue, and this issue is only very briefly mentioned in your position paper, and not at all in the chapter 6.2 on non-technical aspects. As culture acceptance is a prerequisite for successful implementation of any project, more emphasis should be given to this issue.

An issue which is becoming a very serious problem and which appears to be insufficiently stressed in the present position paper is the sludge which is being generated in waste water treatment. Although it is mentioned the magnitude of this problem will very quickly increase in future, and adequate treatment and disposal of this sludge will be very necessary.

One of the current research activities not indicated in the document is the review of urban sanitation systems in India and Thailand carried out by IHS in collaboration with HSMI, HUDCO and IRC. Also there are some indications in chapter 5.3 which can be misinterpreted for example, CIDA, the Canadian International Development Agency is not the same organisation as IDRC.

The description of the bottlenecks as well as the priority research issues is not always sufficiently substantial to enable clear interpretation. It is therefore difficult to assess whether the issues are the real priority issues. An important issue to be looked into under non-technical aspects which appears not to have been included, concerns the possibilities which are available to enhance the priority which waste water treatment can get in the national policies of developing countries. It appears that a kind of

promotional and explanatory effort still is required to stress the benefits which adequate waste and waste water treatment can have. In line with this issue, also the social cultural reasons for the non-acceptance of the reuse of waste water could have high priority as this is one of the very important problems faced by waste water reuse programs.

An issue which would link the technical and the non-technical aspects would be the establishment of a manual on Waste Water Treatment options for developing countries. Preferably such a manual would be established by a majority of developing country nationals with experiences in the field of waste water disposal and treatment. This would be quite an interesting effort if it would be based on an initial review of a number of existing systems in different developing countries. Such an evaluation would bring out the main problems in the systems and would, of course, have to be supported by some preliminary studies concerning some of the most interesting technologies that can be adopted. The Manual should be subsequently reviewed by a number of international experts in this field. It would be comparable to the IRC technical paper No. 18 on drinking water technologies for developing countries.

A N N E X E "B"

PRELIMINARY LIST OF SELECTED INSTITUTIONS INVOLVED IN WASTE WATER RESEARCH IN DEVELOPING COUNTRIES

- Tampere University of Technology (Tampere, FI), Department of Civil Engineering, Finland.
- Universidad del Valle, Sección Saneamiento Ambiental, Colombia.
- Environmental Technology Research and Development Centre, (Instanbul, Turkey).
- Polytechnic University (Ho Chi Minh City). Department of Environmental Engineering, Vietman.
- Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente - CEPIS, Lima, Perú.
- National Laboratory of Civil Engineering, Lisbon, Portugal.
- Centro Interamericano de Desarrollo Integral de Aguas y Tierra, CIDIAT (Merida), Mexico.
- CETESB, Sao Paulo, Brasil.
- Commonwealth Scientific and Industrial Research Organization, (Melbourne, Australia.)
- Centre for Water Resources Development & Management, Water Quality & Environment Division, Kerala, India.
- Instituto Nicaraguense de Acueductos y Alcantarillados, (Managua, Nicaragua).
- BCEOM (Paris).
- Universidad Federal do Rio de Janeiro, Brasil.
- UNCHS United Nations Centre for Human Settlements, (HABITAT) Nairobi, Kenya.
- Companhia de Saneamento do Parana. Pontificia Universidade Catolica do Parana (Curitiba, Brasil), Instituto de Saneamiento Ambiental.
- Thailand Institute of Scientific and Technological Research, (Bangkok, Thailand).
- Grupo de Tecnología Alternativa, Mexico.

- National Botanical Research Institute, Rana Pratap, Marg., Lucknow 226001, India.
- NEERI, Nehru Marg., Nagpur 440 020, India.
- The United Nations Centre for Regional Development (UNCRD), Nagoya, Japan.
- PEPAS, Kuala Lumpur, Malaysia

II.9 TERTIARY TREATMENT

Tertiary treatment plants are applied for removing specific wastewater constituents. They can be complex in design, construction and operation and generally require highly skilled personnel. As previously mentioned, this is not the case for stabilization ponds.

II.9.1 Chlorination

Treated wastewaters are sometimes subjected to disinfection by chlorination. This is especially true for wastewaters to be used for drinking, bathing and irrigation purposes. However, chlorination does not yield a complete pathogen-free effluent and chlorine itself has polluting effects by forming chlorinated compounds, for instance in its disruption of the self-purifying capacity of rivers. The de-chlorination of effluent may therefore be a necessary step prior to their use or disposal. Standards should be introduced to regulate the toxic effects of chlorinated effluent in the aquatic environment. Difficulties however, may preclude the use of this form of treatment (Ahmad, 1988).

II.9.2 UV-radiation

In order to remove pathogens, UV-radiation of the wastewater effluent could represent an attractive alternative since no harmful pollutants are added.