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Directorate General of Development Cooperation

GOBIERNO DE NICARAGUA,
Instituto Nicaragüense de Acueductos y Alcantarillados

MISSION REPORT

PRE-FEASIBILITY APPRAISAL WASTEWATER TREATMENT RESEARCH PROJECT IN NICARAGUA

Managua, September/October 1988
The Hague, December 1988

NETHERLANDS ECONOMIC INSTITUTE

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List of abbreviations

AUW	Agricultural University Wageningen
BOD	Biochemical Ogygen Demand concentration
CIRA	Centro de Investigaciones para los Recursos Acuàticos
COD	Chemical Oxygen Demand concentration
DGIS	Directoraat Generaal Internationale Samenwerking
ENPRA	Empresa Nicaragüense Porcina y de Reforma Agraria
FAM	Floating aquatic macrophytes
FC	Faecal coliforms
FL	Facultative lagoon
HRT	Hydraulic Retention Time
K	Potassium
INAA	Instituto Nicaragüense de Acueductos y Alcantarillados
IRENA	Instituto de Recursos Naturales
MINSA	Ministerio de Salud
N	Nitrogen
NEI	Netherlands Economic Institute
NUFFIC	Netherlands University Foundation for International Cooperation
P	Phosphorus
p.e.	Population Equivalent
SAWA	Stichting Adviesburo Werkgroep Waterbeheer
TKN	Total Kjeldahl Nitrogen concentration
TOR	Terms of Reference
TP	Total Phosphorus concentration
TSS	Total Suspended Solids concentration
TUD	Technological University Delft
UASB	Upflow Anaerobic Sludge Blanket
UNI	Universidad Nacional de Ingeneria
UvA	University of Amsterdam
WH	Water Hyancinth

Glossary

Activated sludge

Bacterial mass in a wastewater treatment plant which is actively converting organic substances supplied by the wastewater. The capacity of conversion is high as a consequence of an artificially maintained high concentration and activity of the sludge

Artificial wetlands

An layed out area with a relatively high water table and a marshy vegetation. Artificial wetlands may be used for the purification of wastewater. As such the are one of the land treatment methods (see: Land Treatment)

Anaerobic treatment of wastewater

Biological treatment of wastewater using bacteria growing in an environment from which oxygen is excluded

Aerobic treatment of wastewater

Biological treatment of wastewater using bacteria growing in an environment to which oxygen is supplied

Baffles

Partitions put up in lagoons to guide the flow of water so that plug-flow is induced and no short-circuiting and dead spaces occur

BOD_5 (Biochemical Oxygen Demand)

A measure of the concentration of biologically degradable organic substances in water
The subscript 5 denotes a five days duration of the BOD determination.

COD (Chemical Oxygen Demand)

A measure of the concentration of chemically oxydizable organic substances in water

Chlorination

A method to disinfect water by accurately adding chlorine gas or chlorine solutions to water

ClO_2-dosing

The accurate addition of ClO_2 to water for disinfection

Eutrophication

The process of enrichment of surface waters with plant nutrients, mostly nitrogen and phosphorus. Eutrophication may produce excessive and undesired growth of algae and water plants

Facultative lagoon

A lagoon used for wastewater treatment in which both anaerobic (near the bottom) and aerobic (in the upper layers) biological conversion processes take place. Microorganisms which can thrive in both conditions are called 'facultative'.
In facultative lagoons algae provide oxygen for the conversion of organic substances by bacteria

FC (Faecal coliforms)

Bacteria from faecal origin belonging to the coliform group. These bacteria are used as an indicator for feacal pollution of water

Fixed film processes

Wastewater treatment methods in which the water to be purified passes a bacterial mass which grows as a fixed biofilm on a supporting solid material

Grit chamber

Device to remove coarse particles (grit), mainly sand, from wastewater. Grit removal should take place prior to other treatment processes.

Helminth eggs

Eggs of helminths (intestinal worms). As far as these organisms can live as parasites to man these organisms should be removed from sewage

Hypertrophication

Excessive enrichment of surface waters with plant nutrients, notably phosphorus and nitrogen (see: eutrophication)

Land treatment

Wastewater treatment methods which use the purifying capacities of soil. Land treatment systems are often designed to combine wastewater treatment and simultaneous cultivation of a crop: pasture, fruit trees, vegetales, etc.

Maturation lagoon/pond

Lagoon/pond layed out as the final step of a lagoon system. A stabilization of the conversion processes in the water takes place resulting in a high degree of pathogen removal

Mutagenic Substances

Chemical compounds which exhibit the capacity to bring about mutations in the genetic codes of living organisms

Nutrients

Substances which serve as food (= fertilizer) to plants, notably nitrogen and phosphorus (see: eutrophication and hypertrophication)

Overland flow

A method of secondary wastewater treatment in which the water flows over a usually ovegrown land surface. Overland flow is one of the land treatment methods (see: Land Treatment)

Ozone dosing

The supply of ozone to water for disinfection

Pathogens (Pathogenic organisms)

Organisms which are able to cause diseases. Pathogenic organisms in sewage are excreted with the faeces and urine and may reinfect people on contact with soil, plants etc. which have been contaminated by poorly treated wastewater

Polyculture lagoon

Lagoon in which a symbiosis of higher plants and animals exists. The function of such a lagoon is a further stabilization of pretreated wastewater especially for the removal of pathogens and nutrients (compare: maturation pond)

Root zone method

A land treatment method in which pretreated wastewater passes through a the root zone of an overgrown soil. In this method a combination of filtration and biological conversion takes place.

Sludge

Several types of sludge occur in wastewater treatment stations. Generally speaking it is a moist solid material, containing water, organic and inorganic matter. It results from the sedimentation of suspended solids from sewage; it is the bacterial mass growing and maintained in both aerobic and anaerobic treatment stations; it is also the material collected at the bottom of lagoons

Splitter box

Device in a wastewater treatment station in which a flow of water is split into two or more flows

UV-radiation

UV: ultraviolet. This radiation can be used to kill microorganisms in water.

1. INTRODUCTION

1.1. Background of the mission

An International Conference on the economic significance and the environmental problems of Lake Managua was held in Managua in 1982.

This Conference considered the discharge of the untreated wastewater from the sewers of Managua as one of the main sources of contamination of the Lake. Moreover, the environmental condition of the Lake was evaluated as being "critical", and the Conference called for concerted action to improve the water quality of the Lake.

One of the results of this Conference was the project "Limnología Aplicada al Lago de Managua", a cooperation of the Universidad Autónoma de Nicaragua (UNAN) and the University of Amsterdam (UvA), which started in 1985. This project aimed at upgrading local staff and research capacity, which could contribute to more extensive knowledge about the problems of the Lake and the possible "solutions" for these problems.

In the context of this project the UvA did start a parallel research project into the potential of aquatic plants as a means for wastewater treatment. When this latter project was discussed in Nicaragua, with INAA (Instituto Nicaragüense de Acueductos y Alcantarillados, the governmental institution responsible for wastewater disposal and treatment in the country), with the Municipality of Managua, and with research institutions like CIRA (Centro de Investigaciones para los Recursos Acuáticos) and UNI (Universidad Nicaragüense de Ingeniería), these institutions showed a great interest in the further development of such an "appropriate technology" for domestic wastewater treatment.

It was decided to develop a proposal to do further research into the potentials of a wastewater treatment system consisting of:

- pre-treatment by means of an UASB reactor;
- post-treatment in ponds with algae and various species of higher waterplants;
- re-utilization of valuable components of the wastewater.

This research was to be executed by INAA, CIRA and UNI as the interested parties at the Nicaraguan side, and SAWA (Consultancy Group for Watersupply, Sanitation, Agriculture and Watermanagement) as the organization that would be capable of organizing the necessary expertise available in The Netherlands.

As a result a proposal ("Depuraciόn de las Aguas Residuales Domesticas en Nicaragua; Propuesta para un Proyecto Piloto") was developed by INAA and SAWA, to implement a three-year research project in Nicaragua.

This project proposal was presented in October 1987 to the Dutch Ministry of Foreign Affairs, Directorate General for International Cooperation, for financing under its applied research programme.

The proposal did raise a series of questions with the Ministry and its advisors, in broad terms referring to:

(a) the perspectives for practical application of the technology to be investigated, not only in Nicaragua but in (tropical) developing countries in general, and
(b) the actual limitations with respect to the research context chosen: Nicaragua, more in particular Managua.

It was decided by the Ministry to have a "pre-feasibility appraisal" made, prior to any further decision regarding the research proposal. For this purpose the Netherlands Economic Institute was asked to send a short-term mission to Nicaragua which, together with the prospective counterparts, was to consider a number of questions regarding the feasibility of the treatment technology to be investigated, and the viability of the research project itself.The Terms of Reference of the mission are presented in Annex 1, and discussed below in 1.2.

The mission consisted of Drs. Herman Specker (Netherlands Economic Institute) as mission leader and Ir. Joost van Buuren (Agricultural University of Wageningen) at the Dutch side, and Ing. Roberto Diaz (INAA) at the Nicaraguan side. The mission visited Nicaragua from september 22 to october 5. A two-day visit was paid to the Institute of Food and Agricultural Sciences of the University of Florida in Gainesville, USA. In this Institute extensive experience exists with the use of aquatic plants for the treatment of wastewater and with the utilization of valuable components in wastewater, more particularly the digestion of water hyacints and other waterplants for the production of bio-gas.

The mission's conclusions were arrived at in extensive discussions with the various parties concerned, such as INAA, UNI, CIRA, the Municipality of Managua, the Ministry of Health, IRENA and others, and were presented to the vice-minister of INAA, Ing.Carlos Espinosa, in a meeting at October 5, of INAA, UNI, CIRA and the mission. The various parties present in that meeting did agree with the main conclusions and recommendations of the mission, as summarized below in 1.3.

1.2. Summary of the T.o.R. of the mission; structure of the mission's report

The Terms of Reference of the mission identified two main areas on which the mission was to concentrate its attention:

(1) What are the perspectives for application of the (package of) treatment technologies under consideration in developing countries? More specifically, what can be said about the technical and economic viability of the proposed method, what are the institutional/organizational conditions for its succesful implementation, and what other aspects may possibly affect its practical usefulness and applicability?

(2) Regarding the research project itself, are the conditions in Nicaragua conducive to the type of research as proposed, and are the perspectives of application of the method in Nicaragua itself sufficiently positive in order to make the proposed research of more than theoretical interest to policy makers at the national and local level?
If this question would be answered in a positive sense, the mission would also discuss with the Nicaraguan authorities the various aspects of the formulation of the research project.

These issues are broken down in the T.o.R. into 8 + 2 more specific questions to be addressed by the mission (see Appendix 1). These will be discussed in this report as follows:

REPORT		T.o.R.		
Ch.2	Perspectives for application of the proposed technology	1.3 1.6	1.4 1.7	1.5
Ch.3	Location of the research project in Nicaragua	1.1 2.a	1.2	
Ch.4	Adapted Research Project Proposal	1.8	2.b	

1.3. Summary of the Mission's conclusions

GENERAL

(1) In tropical climates, at low land costs and sufficient availability of flat land, lagoon systems seem the most cost-effective option for sewage treatment.
When the treatment objective is mainly the removal of organic matter (BOD and TSS) and part of the pathogens, a system of facultative algae lagoons with a short retention time (HRT = 7 days) is preferable.
A high level of pathogen removal implies lengthening of the HRT to 20-30 days in such a system. For removal of nutrients (N, P) a lagoon system based on floating aquatic macrophytes (FAM) may be a good choice, further research in this field needs to be done.

(2) UASB-reactors are a relatively attractive pre-treatment method in situations where land is costly or simply not available e.g. in urban, or mountainous areas.
When a high removal of organic matter (TSS and BOD) is desired, an UASB followed by a small lagoon is the most cost-effective option. Nutrient removal, however, is negligible, and pathogen removal is limited. It is of great importance to study low cost anaerobic pre-treatment systems and land-saving post-treatment methods which are effective in the removal of pathogens, nitrogen and phosphorus.

(3) The most attractive re-utilization alternatives for sewage effluents are: irrigation, fish- and shrimps farming and indirect re-use after discharge into surface water. The first two may logically be combined with anaerobic pre-treatment and post-treatment in algae lagoons. The third option is linked to post-treatment with FAM, where nutrients are removed.

(4) The economic prospects of the harvesting and re-utilization of FAM are uncertain.
Bio-gas generation from FAM can not be recommended generally. Production of compost and production of cattle feed may under specific conditions be attractive economically.
In either case the economic viability depends on the existence of a substantial and continuous effective demand for the products to be re-utilized.

(5) It is recommended to execute a research project which among others is to define more precisely the parameters and conditions under which the proposed methods are attractive compared to other available treatment and re-utilization methods.

NICARAGUA

(6) In Nicaragua some 8 cities can be found with an operating sewersystem, amongst which Managua, Leon, Granada, Matagalpa, Masaya. About one third of the urban population in the country is connected to a sewersystem.

(7) Both at a scientific level and with the government institutions involved in environmental protection in general and in wastewater treatment in particular, a lively and immediate interest exists in the development of wastewater treatment technologies, which are adapted technically and economically to the actual situation of the country.

(8) The mission came to the conclusion that good conditions can be found in Nicaragua for the implementation of the type of research project as mentioned under (5). It is however <u>not</u> recommended to locate such a project in Managua (as suggested in the INAA/SAWA proposal of 1987). Instead Masaya is proposed as the location for the research project. A good infrastructure is yet available there

for the research envisaged. Furthermore, Masaya seems to offer good conditions for the actual implementation of the treatment method under consideration, and in that respect does represent the more relevant research environment.

(9) It is proposed to execute the research project in the framework of a cooperation of the Government of Nicaragua (INAA) and the Government of The Netherlands (DGIS). The research project then is to be carried out by the UNI, Department of Environmental/Sanitary Engineering, in cooperation with short term and (one) long term experts from The Netherlands. The project will receive support where needed from CIRA and INAA.

2. APPROPRIATE TECHNOLOGIES FOR (DOMESTIC) WASTEWATER TREATMENT IN DEVELOPING COUNTRIES

2.1. Appropriate technology options

The concentrated disposal of large quantities of domestic wastewater into the environment may have a range of negative effects, depending on the prevailing local conditions. As such do stand out:

- contamination of surface waters through the organic matter (BOD) present in the wastewater, leading to disturbance of the oxygen regime. The consequences are bad smells and a deterioration of aquatic life;
- direct health hazards for the human population living in that environment, through the pathogens present in the wastewater;
- contamination of drinking water sources and sources of human food (fish, vegetables, etc.), indirectly affecting human health;
- "overloading" of these surface waters with nutrients (phosphates, nitrogen) leading to imbalances in the photosyntetic process or hypertrophication;
- contamination of these waters with other toxic elements, endangering human health or -life.

In so-called developed countries a range of methods has been developed and is being applied for the treatment of domestic wastewaters before their disposal into the environment.

In table 2.1. the best-known of these methods and their main treatment characteristics are summarized. The treatment characteristics are indicated according to the achieved treatment result.

Primary treatment achieves at least the removal of suspended particles present in the raw wastewater by sedimentation; further in primary treatment a part of the dissolved organic matter may be mineralised, organically bound nitrogen and phosphorus may be converted to respectively ammonia and inorganic phosphorus. Only a slight removal of pathogenic organisms from faecal origin takes place.

Secondary treatment is the process following the primary treatment step. Here, a BOD-removal of 80 - 95% is achieved. Organic nitrogen and ammonia are partly converted to nitrate. Some nitrogen and phosphate removal occurs resulting from various processes: uptake in bacteria or algae, precipitation, votatilization (for N only).

Pathogenic organism removal percentages range from 90 to 99%.

Tertiary treatment methods follow primary and secondary treatment stages. These methods are applied in order to achieve an advanced removal of one or more undesired elements (e.g. pathogenic organisms) from wastewater.

Table 2.1. Conventional primary and secondary sewage treatment methods

METHOD	MAIN CHARACTERISTICS
1. Primary sludge sedimentation	Primary treatment (combined with 3, 4, 5 and 6)
2. Imhoff tank	Primary treatment + sludge digestion
3. Aerobic activated sludge	Primary + secondary treatment
4. Trickling filters	Primary + secondary treatment
5. Oxydation ditch	Primary + secondary treatment
6. Sewage sludge digestion	Used in combination with 1.,3. and 4.

For several reasons, these methods cannot automatically be considered fully appropriate for the treatment of domestic wastewaters in developing countries. Such reasons, which call for treatment methods more specifically geared to the conditions in developing countries, are a.o.:

- Differences in climatic conditions, notably the average temperature. Anaerobic (biological) treatment methods are likely to be more efficient (technically) in tropical conditions than in moderate climates, and thus may become competitive to aerobic methods in tropical countries (which they are not in moderate climates, at least not for "weak", i.e. much diluted domestic wastewaters).

- Differences in the relative scarcities (and thus in relative shadow-prices) of the production-factors or resources to be utilized in wastewater treatment, notably land, capital and energy, and perhaps also know-how/skills needed for the operation and maintenance of treatment plants. Generally, landprices in urbanized areas in developed countries are such that they render unfeasible any treatment method based on large ponds or landtreatment with high hydraulic retention times of the wastewaters. On the other hand, the relative scarcity of capital, common to many developing countries, will favor treatment methods characterized by a relatively limited use of capital (and higher uses of land and/or labour).

- Differences with respect to legally or otherwise set requirements with respect to the effluent quality of treated wastewater. In developed countries the contamination with toxic matter, or with high concentrations of nutrients in wastewaters may, relatively speaking, be the larger problem, while in developing countries often the highest priority will be attached to the removal of pathogens and or organic matter from the wastewater.

- Differences with respect to e.g. potential economic use of particular valuable components in the wastewater that may be extracted and re-utilized. Extraction and re-utilization of valuable nutrients may be an economically feasible option in many developing countries, where fertilizers, cattle feed components, etc., have to be imported and to be paid with scarce foreign exchange.

Therefore, (domestic) wastewater treatment methods have been developed in recent years, which may take better account of the conditions and relative priorities prevailing in many developing countries. Among these "appropriate technologies for wastewater treatment" are:

Table 2.2. Sewage treatment methods which may be appropriate in developing countries

METHOD	MAIN CHARACTERISTICS
1. Anaerobic lagoon	Primary treatment + sludge mineralisation
2. UASB - reactor	Primary treatment + sludge mineralisation
3. Facultative lagoons	Primary/secondary treatment
4. Maturation lagoons	Secondary/tertiary treatment
5. Waterhyacinth channels	Secondary/tertiary treatment
6. Polyculture lagoons	Secondary/tertiary treatment
7. Land treatment (Rapid and slow-rate)	Secondary /tertiary treatment

One particular method, or rather combination of methods, is the subject of the proposed research project to be considered by the mission.

The "ex-ante" evaluation of this method has been detailed in the Terms of Reference of the mission as follows:

a. The first element - the pre-treatment by means of a UASB - will be compared with a simple anaerobic pond treatment on the basis of the economic costs of both (T.o.R. 1.4). See below, par. 2.2.
b. The second element is the post-treatment in a pond-system applying algae or higher waterplants. Below, in par. 2.3, a comparison is made of 4 combined pre- and post-treatment systems, which result from combining two pre-treatment systems and two post-treatment systems (algae ponds and ponds with higher waterplants) (T.o.R. 1.5).

c. The third step - extraction of particular valuable elements from the wastewater, and their utilization (T.o.R. 1.6) - is evaluated, qualitatively and to the extent possible also quantitatively, below in par. 2.5.

2.2. Comparative analysis of anaerobic pretreatment methods

In this subsection two anaerobic pretreatment methods for sewage, i.e. anaerobic lagoons and UASB-reactors, are compared with regard to inputs and outputs, treatment efficiency and costs.

2.2.1. Systems description of anaerobic pretreatment methods

A general condition for both methods are subtropical or tropical temperatures (> 15^{o} C). The influent to both systems should have passed a screen and a sand trap.

UASB-reactor

The UASB-reactor referred to consists of a concrete tank provided with an internal gas collector/sludge separator.

The depth is 4 - 5 m. The influent enters the tank near the bottom. In order to distribute the influent evenly in the lower part of the reactor 1 inlet point per 1 - 2 m^2 (Souza, 1986) is needed. Hydraulic retention times vary from 5 - 9 hrs. Reactor start-up may take less than 1 month but longer when no adequate inoculum is available. Regular maintenance consists of cleaning the influent distribution channels and pipes and discharging excess sludge. Less frequently and depending on the local conditions removal of deposits from the bottom and scum from the surface may be necessary.

The produced biogas is collected and can be used. For sewage it amounts to 10-15 litres of CH_4-gas per capita per day. The energy value of this gas is 0.034 MJ/litre or 0.34 - 0.51 MJ/capita.day.

The excess sludge production is 7.3 - 11.0 kg TS/capita.yr in Colombia (Louwe Kooijmans & Van Velsen, 1986) and 3.3 - 4.4 kg TS/capita.yr in Brasil (Vieira, 1988). The drying of this sludge is well feasible. Its dry matter content is approximately 50 g/l. The space needed for sludge drying beds is appr. 0.04 m^2/capita.

Anaerobic lagoon

The anaerobic lagoon is a rectangular pond excavated in the soil. It has a depth of 1.65 - 4 metre and a length-width ratio of appr. 4:1 up to 12:1. In order to prevent water loss by seepage it may be necessary to cover the bottom with an impermeable layer, for example consisting of clay or a plastic foil.

The influent is introduced at the narrow end half way between bottom and the water surface. The effluent is discharged from the surface at the opposite narrow end. In large anaerobic ponds multiple inlet and exit pipes are necessary in order to avoid short circuiting and dead spaces. The produced gas escapes to the atmosphere.

Regular maintenance consists of inspection and cleaning of influent entrance and effluent exit. The border of the pond should be kept free of big plants.

Once in 2 - 5 years the anaerobic lagoon should be emptied and desludged. The sludge accumulation amounts to 30 - 40 litres/capita.yr.

The dried sludge from UASB-tanks and anaerobic lagoons can be utilized as a soil conditioner.

Due to an uncertain hygienic quality of the dried sludge (especially the presence of helminth eggs) the application in the culture of edible crops should be dissuaded.

2.2.2. Treatment efficiency of anaerobic pretreatment methods

Table 2.3. presents some data about the treatment efficiencies of anaerobic lagoons and UASB - tanks.

Table 2.3. Process conditions and treatment performance of UASB - reactors and anaerobic lagoons

System	T (^oC)	HRT (day)	BOD-loading rate (kg BOD/ha.day)	TSS-removal (%)	BOD-removal (%)	Authors
Anaerobic lagoon	summer		2116		82	Van Eck & Simpson,1966
Anaerobic lagoon	summer		2730		81	idem
Anaerobic Lagoon	20	1			50	Mara, 1976
Anaerobic Lagoon	20	2.5			60	Mara, 1976
Anaerobic Lagoon	20	5			70	Mara, 1976
Anaerobic lagoon	24 - 28	4.0	932	78	68	Silva, 1982
Anaerobic lagoon	24 - 28	2.0	1874	79	75	Silva, 1982.
Anaerobic lagoon	24 - 28	1.9	2810	82	80	idem
Anaerobic lagoon	24 - 28	1.2	6695	79	81	idem
Anaerobic lagoon	24 - 28	0.8	6695	74	76	idem
Anaerobic lagoon	23 - 24	0.42			45	Jakma et al.,1986
Anaerobic lagoon	23 - 24	0.58			54	idem
Anaerobic lagoon	23- 24	0.88			76	idem
UASB	ca. 25	0.25 - 0,33		70		Louwe Kooijmans, 1986
UASB	21 - 25	0.20 - 0.35		56 - 79	61 - 80	Vieira, 1988
UASB	23 - 24	0.22		69	80	Schellinkhout et al,1988
UASB	23 - 24	0.21		69	80	idem
UASB	23 - 24	0.38		71	77	idem
UASB	23 - 24	0.83		70	75	idem

Typical data for the removal efficiency of Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD) in UASB-reactors and anaerobic lagoons under (sub-) tropical conditions are summarized in table 2.4.

It appears that approximately the same performance (expressed as TSS - and BOD_5 - and FC-removal) is achieved by a UASB-reactor with a HRT of 6 hrs and an anaerobic lagoon having a HRT of 24 hrs.

Table 2.4. Overall comparison of the UASB - reactor and the anaerobic lagoon; FC = faecal coliforms

System	HRT (hrs)	TSS removal (%)	BOD_5 removal (%)	FC removal (%)	Parasites removal (%)
Anaerobic lagoon	19 - 24	60-80	50 - 80	50 - 80	moderate
UASB	5-9	60-75	65 - 80	50 - 80	moderate

The space required for an anaerobic lagoon system is about 4 - 10 times that of an UASB-tank of comparable treatment capacity. Nutrient removal (nitrogen and phosphorus) in an UASB-tank is insignificant (Louwe Kooimans & Van Velsen,1986 and Vieira,1988). In an anaerobic lagoon usually some N and P removal is found. At an HRT of 0.8 day Silva (1982) found a 38 % ammonia-N, a 21 % nitrate-N, a 49 % P_{tot} and a 14 % P_{sol} removal.

These removal efficiencies seem high. More detailed research is needed to assess the nutrient removal characteristics of anaerobic lagoons.

In general, pathogen removal (viruses, bacteria, protozoa and helminth eggs (parasites)) is poor in both systems.

Anaerobic lagoons are liable to emanate bad odours. For this reason they should not be located in the immediate vicinity of populated areas. UASB-reactors usually do not cause smell problems.

2.2.3. Costs and revenues of anaerobic pretreatment systems

UASB-reactors

Installation costs of UASB-reactors are estimated at US $ 300/m^3 of reactor volume or US $ 10 per capita, and for a complete sewage treatment station, including grit chamber, UASB-tank and sludge drying bed the costs would be US $ 30 per capita. Operation costs of the entire installation are estimated at US $ 0.40 per capita per year. These data are based on Brazilian experiences (Vieira, 1988).

The investment of a 30,000 p.e. UASB tank would thus amount to US $ 300,000, and the total system cost would be US $ 900,000.

Under Dutch conditions the investment costs of a UASB-based treatment station for domestic sewage of 30,000 p.e. amount to approximately Dfl 160 per capita, or US $ 80 per capita.

The biogas produced in the UASB-reactor can be used for the generation of light, electricity and power. The net revenues have been estimated at US $ 0.50 /m^3gas, or US $ 2,0 /p.e..yr at a gas production of 4 m^3/p.e.yr., to the extent that sufficient nearby demand exists for this biogas.

Anaerobic lagoons

The investment costs of an anaerobic lagoon include the purchase of land, excavation and lining of the pond, and the construction of dikes, inlet and exit devices. For the purpose of comparison with the UASB-tank the costs of an anaerobic lagoon for a community of 30,000 inhabitants is calculated on the basis of the following assumptions:

excavated pond depth:	2.5 metre
effective pond depth:	2 metre
hydraulic retention time:	1.25 day
per capita sewage flow:	130 litres/day
land acquisition costs:	US $ 2/m^2
mechanical excavation:	US $ 6/m^3
lining:	US $ 4/m^2

The land surface to be purchased is twice as large as the effective pond surface.

Construction cost of inlet device:	US $ 5,000.
Construction cost of outlet device	US $ 5,000.

From these assumptions the following results:

Effective pond volume:	1.25 * 4,000 m^3 = 5,000 m^3.
Effective pond surface:	5,000/2 = 2,500 m^2.
Land acquisition:	2 * 5,000/ 2 = 5,000 m^2.

The costs involved are estimasted as:

Excavation	US $ 37,500
Lining	10,000
Land aquisition	10,000
Constructions	10,000
Total	US $ 67,500 for a community of 30,000 p.e.

The investment costs under these assumptions are about US $ 2.25/capita. At land costs of US $ 50 /m^2 the total cost would be (appr.) US $ 307,500, which is about equal to the capital costs of an UASB-tank.

Maintenance costs of an anaerobic lagoon are estimated at US $ 0.35/capita.yr.

2.2.4. Conclusions: anaerobic pretreatment systems

Table 2.5. summarizes the cost data.

Table 2.5. Investment and O & M costs of the anaerobic lagoon and the UASB-reactor. (Scale: 30,000 p.e.)

Systems	HRT (days)	Investment cost (US $/capita)		Maintenance (US $/capita.yr)
Land acquisition cost		US $ 2/m^2	US $ 50/m^2	
Anaerobic lagoon	1.25	2.20	10.20	0.35
UASB-reactor	0.25	10.00	10.00	0.40

The investment costs of an UASB-tank (US $ 10/cap.) and anaerobic lagoon (US $ 2.20/cap.) of comparable capacity are in the proportion of 5 : 1 in rural and semi-urban conditions. It is assumed here that the land acquisition costs do not significantly influence the investment costs of an UASB-reactor: thus, investment costs of the UASB-reactor at land costs of US $ 2/m^2 and US $ 50/m^2 are the same.

Maintenance cost of the anaerobic reactor and the UASB-tank are in the same order of magnitude. The anaerobic lagoon needs a complete desludging once in several years but little regular maintenance. The UASB-reactor needs a more regular, in fact daily, surveillance.

UASB-reactors are relatively attractive in situations where land is costly (appr. US $ 50/m^2) or simply not available; i.e. in urban or mountainous areas. The risk of bad odours from anaerobic lagoons requires a considerable distance (approx. 500 m) between inhabited areas and lagoon facilities.

The capabilities (treatment efficiencies and costs) of UASB-reactors and anaerobic lagoons under various conditions should be studied in more detail, as up to now no straightforward comparisons between UASB-reactors and anaerobic lagoons are reported in the literature.

2.3. Comparative analysis of combined pretreatment and posttreatment systems

The quality of the effluent of the pretreatment systems described in 2.2. in general will be such that under particular conditions some form of secondary treatment will be desirable or needed. The type of secondary treatment to be selected will depend on the targets with respect to effluent quality.

Generally speaking, the conditions in many LDC's - in situations where central collection and treatment of sewage is practised - may require a further treatment of anaerobically pretreated wastewater with an emphasis on pathogen and nutrient removal.

Table 2.6. Secondary treatment methods, following an anaerobic pretratment step, in relationship with environmental conditions and treatment aims (in tropical climates)

Environmental condition	Treatment aim	Secondary treatment method
Flat land available, effluent discharge into surface water, no eutrophication	Pathogen removal Advanced BOD-removal	Facultative lagoon system
Flat land available, effluent discharge into surface water, eutrophication	Pathogen, nutrient and advanced BOD removal	Facultative lagoon system or Lagoon system with FAM
Flat land available effluent discharge on land	Pathogen removal	Facultative lagoon system + land treatment
No flat land, effluent discharge into surface water	Pathogen removal Advanced BOD removal	Facultative lagoon + chemical disinfection

The following secondary systems are discussed here:

a. anaerobic lagoon + aerobic lagoons containing algae;

b. anaerobic lagoon + channel (or lagoons) covered with FAM;

c. UASB-reactor + aerobic lagoons (algae);

d. UASB-reactor + channel (or lagoons) containing FAM.

The comparison of these methods is in fact the objective of the proposed research project in Nicaragua. Rather ample data is available on a. Method c. was studied in the framework of the DGIS-project in Cali (Colombia) (Haskoning et al., 1985) and by Schellinkhout et al. (1988). On methods b and d. no straightforward data is available yet. The set-up of the work published by Orth et al.(1987) closely resembles b. These data are used to indicate the results expected under b. Method d. has not been studied yet.

As there is much less data about the sewage treatment using other floating aquatic macrophytes, waterhyacinth is chosen as the FAM applied in the discussions below.

The information about mixed systems (polycultures) using a combination of algae, higher water plants and aquatic animals is very limited. Some data will be mentioned in subsection 2.4.

2.3.1. System description of combined pretreatment and posttreatment methods

(a) Systems of anaerobic plus facultative lagoons

The effluent of anaerobic lagoons is led into facultative lagoons. The lagoons may be laid out in series or in parallel. The size of facultative ponds as a secondary system is about 0.1 ha/1,000 inhabitants. Hydraulic retention time: 7 days. The length: width ratio is about 4 : 1. The depth is 1.2 - 1.5 meters. As a consequence of the lower loading rate (100 to 500 kg BOD_5/ha.day) the facultative lagoon is aerobic in the top layers and anaerobic near the bottom. Algae play an important role as they provide oxygen to the bacteria which mineralize organic matter.

Wind has a positive influence as it mixes the lagoon contents and prevents the formation of scum layers.

Maintenance consists of keeping the borders free from bushes (access of the wind). Sludge accumulation in facultative ponds is little, but depends on the type of pretreatment. Sludge should removed from the facultative ponds once in 10 -15 years.

(b) Floating aquatic macrophyte (FAM)-systems

The FAM systems described in the literature mostly are channels for the treatment of primary or secondary effluent. The depth varies from 0.3 to 1.0 metre. Retention times range from 4 to 8 days. The size is about 0.2 ha/1,000 inhabitants. They are fully covered (90% or more) with waterhyacinth and the plants are harvested on a regular $\pm$ weekly) basis. The plant density (wet weight) is about 15 kg/m^2. The waterhyacinth production varies between 500 and 1300 tonnes fresh plants/ha.yr. Water plant growth is influenced by many factors. Some insects can badly damage the plant production.

The evaporation of FAM systems is 1.5 - 3 times lake evaporation. Sludge accumulation in a waterhyacinth pond system used for the treatment of pretreated domestic effluent is reported to amount to 5.4 tons/ha.yr, or 0.6 cm/yr (Reddy & Debusk,1987). This number would suggest that desludging would have to take place every 10 years (6 cm accumulation).

(c) UASB + aerobic or facultative lagoons

The UASB-reactor + facultative lagoon as posttreatment facility consists of a UASB-reactor, described in subsection 2.2.1. followed by a lagoon. The depth of the lagoon is 1.50 m. The hydraulic retention time of the wastewater in the lagoon depends on the treatment objectives. For advanced BOD-removal a retention time of 1 day will be sufficient. For pathogen removal retention times of about 10 days are necessary. Baffles may be useful. A sludge drying bed is necessary.

(d) UASB + lagoons with FAM

A system consisting of an UASB-pretreatment and a system of posttreatment lagoons with water plants (as is proposed in the original project) is new. The floating aquatic macrophytes are expected to promote uptake of N and P, and an effective removal of suspended particles from the UASB-effluent.

For effective nutrient removal a retention time of about 7 days (0.2 ha/1,000 inhabitants) will be necessary. Under these conditions pathogen removal will be less effective than of the system mentioned under (c). A study of this system was the main element of the original research proposal.

2.3.2. Treatment efficiency of the combined pre/post treatment systems

Table 2.7. presents some selected data about the sewage (raw domestic wastewater or primary effluent) treatment efficiencies of the various sewage treatment systems. All data are derived from field studies; these studies were conducted under (sub)tropical conditions or during the summer in moderate climates.

Table 2.7. Process conditions and treatment performance of combined primary and secondary treatment systems

System	HRT (days)	removal efficiencies (%) TSS	BOD_5	TKN	NH_4-N	TP	FC	Author(s)
a. Anaerobic + facultative lagoons	29	-	82	89	73	67	99.99	Neel,1961
	22	-	81	89	71	67	99.99	idem
	17	-	82	89	72	67	99.99	idem
	29	61	93	-	81	54	99.9999	Silva,1982
	8.5	83	89	-	32	36	99	Silva,1982
	7.5	-		38	-	39	-	Silva,1982
	5.2	83	82	-	28	35	91	Silva,1982
	3.6	82	77	-	26	33	96	Silva,1982
	5.2	68	85	-	-	-	88	Schellinkhout,1988
	4.3	68	85	-	-	-	87	
	42	-	-	56	-	-	-	Reed,1985
b. Anaerobic pretreatment + waterhyacinth channel	10	94	94	83	-	96	-	Orth,1987
	7.6	90	81	70	-	57	-	idem
	2.6	92	70	18	-	38	-	idem
	5.3	73 - 96	85 - 95	20 - 85	-	30 - 70	-	Schwegler,1983
	4.3	73 - 95	75 - 93	10 - 67	-	5 - 55	-	idem
	3.6	65 - 93	75 - 88	5 - 57	-	5 - 50	-	idem
	12	72	87	41	-	31	-	Reddy,1987
	6.4	83	84	20	-	16	-	idem
	3.2	80	81	14	-	16	-	idem
c. UASB + facultative lagoon	1.7	80	89	-	-	-	82	Schellinkhout,1988
	1.2	82	89	-	-	-	83	idem
d. UASB + FAM - lagoon/channel			no data available					

The table shows that treatment efficiencies, especially for waterhyacinth based treatment systems, do vary considerably. This is due to variations in climate, wastewater characteristics, pond operation, and pond depth.

As a summary of the above table and for reasons of easy comparison the estimated performances of the systems are arranged in table 2.8. The efficiencies of the pretreatment systems discussed in subsection 2.2., i.e. the anaerobic lagoon and the UASB-reactor, are shown as well.

Table 2.8. Summary of hydraulic retention times and treatment efficiencies of primary and primary plus secondary treatment systems; (FL = facultative lagoon, WH = water-hyacinth)

System	HRT (days)	Removal efficiencies (%)					
		TSS	BOD_5	TKN	TP	FC	Parasites
Anaerobic lagoon	1	75	65	20	20	70	moderate
UASB	0.25	70	70	0	0	70	moderate
a. Anear. + fac. Lagoons	7	75	80	30	35	99	considerable
b. An. pretr. + waterhyac.	7	85	80	50	50	95	considerable
c. UASB-reactor + FL	1.2	80	90	0	0	85	?
d. UASB-reactor + WH		no data available					

It is remarkable that the treatment efficiency (TSS and BOD_5) of a system consisting of UASB -reactor plus facultative algae lagoon (FL) is higher than of a comparable system of anaerobic and facultative lagoons or waterhyacinth channels. The existing data indicates that in UASB plus lagoon systems TSS- and BOD_5-efficiencies are attainable which other systems would only achieve at very long hydraulic retention times or not at all. (Schellinkhout,1988).

In the next table 2.9. the three systems for which data is available are compared, summarizing their advantages and limitations.

Table 2.9. Advantages and limitations of algae lagoons, waterhyacinth channel and UASB-reactors with a small posttreatment lagoon

System	Advantages	Limitations
Anaerobic lagoon	Low cost Simplicity	Bad odours
UASB-reactor	Short retention time, little space	No nutrient removal, little FC removal Skilled labour
a. Anaer. + fac. Lagoons	High FC - removal	Algae in effluent
b. Anaer. pretr. + Waterhyacinth channel	Uptake in plants and denitrification	FAM harvesting Low effluent dissolved oxygen
c. UASB - reactor + Facultative Lagoon (HRT = 1.25 days)	Short retention time, little space High BOD - removal	No nutrient removal little FC removal Skilled labour

2.3.3. Costs and revenues of combined pre/posttreatment methods

a. Anaerobic plus facultative lagoons

* Investment costs

The investment cost of lagoons can be estimated in the same way as those for anaerobic lagoons (See subsection 2.2.3). The costs are calculated for an installation consisting of one anaerobic lagoon plus two facultative lagoons in series for 30,000 p.e. (flow: 4,000 m^3/day). The depth of the anaerobic lagoon is 2 m, the depth of the facultative lagoons is 1.5 m, hydraulic retention time: 7 days. The total surface needed for the facultative lagoons is 1.5 times the effective pond surface. The total surface of the anaerobic plus facultative lagoons is 2.8 ha. When land acquisition costs are US $ 2/m^2 investment costs are US $ 12 per capita. At land acquisition costs of US $ 50/m^2 costs are US $ 57/capita.

** Maintenance costs

The maintenance costs of a combined anaerobic plus facultative lagoon system (HRT = 7 days) are estimated at US $ 0.50/cap.yr.

b. and d. Waterhyacinth based systems

* Investment costs

Systems consisting of an anaerobic lagoon plus a waterhyacinth channel (or lagoon) having the same retention time as anaerobic plus facultative lagoons are more expensive because these systems - due to the lesser depth - need a larger surface. On the other hand these systems exhibit a higher removal of nitrogen and phosphorus. At a land cost of US $ $2/m^2$ the installation cost is US $ 16/cap. and at US $ $50/m^2$ it is US $ 88/cap.

The investment costs of the waterhyacinth based Iron Bridge Plant, Orlando, USA amounted to US $ 3.3 million. The design flow of this plant is ca. 30,000 m^3/day, which is the flow of 150,000 inhabitants. Investment cost : US $ 22/capita.

** Maintenance costs

Costs of waterhyacinth harvesting

According to Philip, Koch & Köser (1983) one labourer may be able to harvest 300 - 1,100 kg of wet plants per day at a cost of 1 - 3 Sudanese pound/raw ton (In 1979 the exchange rate of the Sudanese pound was 1 Sud. pound = US $ 2).

At a local salary of US $ 3/day (developing country) the handpicking would cost US $ 3 - 10/raw ton.

According to Bagnall et al. (1979) mechanical harvesting would cost about US $ 2-5/raw ton depending on the scale of operations. At higher capacities processing costs would be reduced considerably (US $ 0.70/raw ton at 100 tonnes/hr).

Mara (1975) calculates a waterhyacinth harvesting cost of US $ 1.50/raw ton harvested from lakes using a mobile harvester.

The costs of harvesting, chopping and dumping the plants (further called 'harvesting') depend on their actual growth-rate.

If the growth-rate is 500 wet tonnes/ha.yr and harvesting costs are estimated at US $ 5/raw ton, harvesting cost are US $ 2,500/ha.yr. For a sewage treatment station of 30,000 p.e. (effective surface 3 ha) the harvesting costs amount to US $ 7,500/ha.yr. or US $ 0.25/p.e.yr. As a growth rate of 1,000 Wet tonnes/ha.yr. the harvesting costs amount to US $ 0.50/p.e.yr. The maintenance of an anaerobic + FAM-channel system ,excluding the costs of harvesting, is estimated at US $ 0.50/cap.yr. Thus, the total maintenance costs, including FAM harvesting, are estimated at 0.50 + 0.50 = US $ 1/cap.yr.

When it would be possible to re-utilize the plants in a profitable way, with benefits equal to or larger than the costs of harvesting, the maintenance cost would amount to approx. US $ 0.50/cap.yr. (This aspect is discussed further in paragraph 2.5 below).

c. <u>UASB pretreatment followed by a lagoon</u>

* Investment costs

In Bucaramanga (Colombia) a full-scale sewage treatment station based on UASB pretreatment and lagoon posttreatment will be built. The total HRT is about 1 day. The installation costs of the treatment facility (80,000 p.e.) aiming at 90 % BOD-, 70% COD,- and 80% TSS-removal are estimated at US $ 2.1 mln., which is US $ 26 per capita (Schellinkhout).

** Maintenance costs

Widely varying annual costs of O & M can be found in the literature, ranging from US $ 0.50 - 3.50.

Re-utilization of biogas and sludge is not considered.

The data of investment and maintenance costs of the three systems a., b., and c. are summarized in table 2.10.

Table 2.10. Investment and maintenance costs of primary and primary plus secondary sewage treatment systems for 30,000 p.e. (unless stated otherwise)

SYSTEMS	HRT	INSTALLATION COSTS (US $/capita)		MAINTENANCE COSTS (US $/cap.yr)
Land acquisition cost		2 US $/m^2 (rural)	50 US $/m^2 (urban)	
Primary treatment				
Anaerobic lagoon	1.25	2.2	10.2	0.35
UASB reactor	0.25	-	10	0.4
Primary & Secondary treatment				
a. Anaerobic + facultative lagoons	7	12.0	58.8	0.5
b. Anaerobic + waterhyacinth channel	7	15.8	87.8	1.0*
c. UASB + facultative lagoon**	1.25	-	28	0.50-3.50
d. UASB + waterhyacinth channel	1.25	no data available		

* Not considering possible benefits from re-utilization (see 2.5).
** Scale: 80,000 p.e.

2.3.4. Conclusions on primary and combined primary and secondary treatment systems

1) Sewage treatment in rural and semi-urban conditions

When land costs are relatively low and sufficient flat land is available the above comparison of treatment systems shows that the treatment in lagoon systems is the most cost-effective option.

When the treatment objective is the removal of about 80 % of the organic matter (BOD and TSS) and 99% of pathogens, a system of anaerobic and facultative algae lagoons with a short retention time (7 days) is preferable. The surface amounts to 0.1 ha/1,000 inhabitants.

The effluent could be re-utilized for irrigation of non-food crops, fish raising, or it could be discharged into flowing waters, which are not subject to immediate re-use as drinking water.

When irrigation of vegetables eaten raw is considered and a high level of pathogen removal (99.99% of faecal coliforms) is required, an algae lagoon system of long retention time (20 - 30 days) is the best choice. The surface of such a system amounts to 0.2 - 0.3 ha/1,000 inhabitants.

When nitrogen and phosphorus have to be removed, lagoon/channel systems based on floating aquatic macrophytes may be a good choice. The surface is approx. 0.2 ha/1,000 inhabitants.

As know-how about the full-scale application of FAM systems in tropical developing countries is limited, further research is needed.

2) Sewage treatment in urban conditions

In urban areas or in mountainous regions the application of relatively large lagoon systems (0.1 ha/1,000 inhabitants) is impossible.

Here, high-rate anaerobic pretreatment systems like the UASB-reactor or the UASB-reactor followed by a small lagoon do seem cost-effective options (see table 2.10).

The UASB-reactor + small lagoon exhibits a high removal efficiency for organic substances (TSS, BOD). Plant nutrient removal is negligible and pathogen removal is limited.

The effluent can be re-used in irrigation of non-food crops, and can be discharged to flowing surface water.

In some situations it may be possible to combine an UASB + lagoon treatment system with naturally available surface waters. In this case, the latter act as a posttreatment step and may have a function in fish raising and recreation.

It is of great significance to study land-saving post-treatment methods which aim at removal of pathogens, nitrogen and phosphorus.

2.4. Comparative analysis of wastewater treatment systems for nutrient removal and disinfection

Low-cost primary plus secondary treatment systems are capable of merely a partial elimination of nutrients and pathogens from domestic wastewater.

Various biological and physico-chemical tertiary treatment methods are known which establish a more advanced removal of nutrients and pathogens. Generally, a distinction is made between extensive treatment methods requiring relatively much land space but few other inputs and intensive methods requiring expensive equipment, chemicals, energy and skilled labour.

2.4.1. Systems description

Extensive methods

The extensive biological methods imply a long hydraulic retention time and correspondingly a large surface. The long HRT is needed for pathogen die-off and nutrient removal, which are relatively slow processes. Pathogen removal is brought about by sedimentation, adsorption and die-off. Nutrient removal proceeds through a combination of processes of sedimentation, nitrification - denitrification, ammonia and phosphorus adsorption, uptake in harvested biomass and volatilization (NH_3). Maintenance is relatively simple and cheap.

Examples of these systems are:

- Extensive lagoon systems including fish ponds or lagoons with FAM (floating aquatic macrophytes) for nutrient removal.
- Land treatment systems including such methods as rapid and slow-rate infiltration, overland flow, the root zone method, and artificial wetlands.

Intensive methods

Pathogen removal (disinfection) can be brought about by the following physico-chemical processes:

- chlorination
- UV-radiation
- Ozone dosing
- ClO_2-dosing

Nitrogen removal requires such intensive processes as biological nitrification - denitrification and ammonia stripping; phosphorus removal can be brought about by biological phosphate removal and by chemical precipitation plus filtration or sedimentation.

2.4.2. Cost & revenues of wastewater treatment systems for nutrient removal and disinfection

It is beyond the scope of this study to discuss the capabilities and limitations of all methods mentioned above.

Crites (1979) made an economic comparison between several extensive treatment methods and a so called advanced wastewater treatment system (AWT). The latter system consists of activated sludge treatment, chemical precipitation plus filtration for phosphorus removal, and nitrification - denitrification for nitrogen removal.

Table 2.11. shows a comparison of annual operation costs of the four systems at land acquisition costs of US \$ 1/m^2 and at a scale of 3,800 m^3/day.

Table 2.11. Cost comparison of wastewater treatment systems including nutrient and pathogen removal. Total annual costs of operation, including capital cost and land costs ($ 1/m^3) After Crites, 1979).
Scale: 3,800 m^3/day

System	US $/cap.yr.
Oxidation lagoon plus polyculture plus rapid infiltration	7.4
Overland flow plus waterhyacinth lagoon	11.4
Slow-rate land treatment	15.8
Advanced wastewater treatment	34.6

The table shows that the combined system consisting of screening, grit removal, polyculture and rapid infiltration is the cheapest under the prevailing conditions. Installation costs of this system (at a capacity of 3,800 m^3/day) are US $ 53/capita under the assumption of a sewage discharge of 150 litres/capita.day. When rapid infiltration is not possible because of unsuitable soil characteristics waterhyacinth lagoons may be a good option for nutrient removal.

The extensive systems mentioned can be appropriate in rural or semi-urban areas. When land costs are high intensive methods are required.

In effluent disinfection chlorination is the cheapest but is associated with problems of formation of carcinogenic and mutagenic chlorinated hydrocarbons and the toxicity of residual chlorine. Other methods are studied, but all of them are much more expensive than chlorination. A comparison of operation and maintenance costs is presented in the table 2.12.

Table 2.12. Comparison of O & M costs of physico - chemical disinfection systems. Scale: 10,000 - 100,000 inhabitants. (After: Rijkswaterstaat, 1988)

System	Costs (US $/cap.yr)
Chlorination	0.07 - 0.16
ClO_2	1.5 - 3.0
UV	2.5 - 4.0
Coagulation + filtr.	3.5 - 7.7
Ozone	5.4 - 11.8

2.4.3. Conclusions on treatment systems for pathogen and nutrient removal

When cheap flat land is available combined methods of lagoons and land treatment are the most cost-effective. In some situations waterhyacinth lagoons may be a good choice.

For urban conditions in developing countries no satisfactory low-cost tertiary treatment methods have been found yet.

2.5. Re-utilization alternatives

2.5.1. Survey of re-utilization alternatives

Wastewater can be regarded as a potential resource. The water, the organic matter and the fertilizing substances can be used beneficially, either separately or in combination.

The re-utilization alternatives known in the literature are summarized in table 2.13.

Table 2.13. Survey of wastewater re-utilization alternatives

Re-utilization alternative	Components re-used		
A. Irrigation	Water	Fertilizing components	
B. Fish- and shrimp-farming	Water	Fertilizing components	
C. Artificial recharge of groundwater	Water		
D. Indirect re-use	Water		
Systems based on harvested water plants			
E. Generation of biogas			Energy
F. Organic fertilizer		Fertilizing components	Organic matter
G. Cattle feed		Fertilizing components	

The viability of a re-utilization alternative will depend on local conditions of physical, technical, institutional and economic nature. The benefits from useful products should outweigh the supplementary expenditures involved in the re-utilization. The alternatives mentioned are discussed below. Direct re-use in industry and the household are omitted as they do not seem viable in developing countries at this moment. The alternatives E., F., and G. in the above table are associated with wastewater treatment systems which include the harvesting of biomass (i.e. floating aquatic plants). As was shown in tables 2.2, 2.8 and 2.11 these systems may be a useful alternative when advanced nitrogen and phosphorus removal is required: i.e. at discharge into stagnant surface waters or at groundwater recharge.

(A) Irrigation

There are many projects in the world in which purified wastewater is used in agriculture. Irrigated agriculture can make full use of available components in wastewater. Effluent containing fertilizing N, P, K as well as organic matter is used for irrigation; dried sludge is spread over the soil and improves the water retaining capacity. Agricultural re-use requires however some special conditions.

1. The effluent used as irrigation water should satisfy the standards set for irrigation. Problems may arise with respect to salts (salinization of the soil), toxic substances (e.g. heavy metals) and hygienic quality (pathogenic organisms).
   Irrigation of non-food crops requires a relatively simple pretreatment such as a lagoon system with a retention time of some days; irrigation of crops that are eaten raw requires extensive systems with a longer retention time or an advanced intensive treatment system in order to meet with hygienic norms. The cost of an extensive system may be considerable in urban areas, where the land costs are high.

2. Wastewater irrigation puts requirements to the availability and quality of agricultural soil. Limitations exist as to the distance between the sewage treatment facility and the agricultural area, the pumping height, the permeability of the soil,etc.

It is usually well possible to treat wastewater of domestic origin up to an adequate irrigation water quality. Lagoon systems (possibly including an UASB-reactor as a primary treatment step) based on algae are the preferable treatment system.

(B) Fish- and shrimp-farming

Wastewater treatment and fish farming can perfectly be integrated into a treatment/re-use system, and is widely practiced in South-East and East Asia. In fish-farming systems algae lagoons are probably the best treatment alternative as algae may serve as food for several fish species.

As no experience in this field exists in Nicaragua, this possibility is left out of the following considerations.

(C) Artificial recharge of groundwater

Treated sewage can be infiltrated into the soil resulting in a recharge of groundwater supplies. As the effluents bear a potential to pollute the groundwater, artificial recharge either needs an advanced effluent treatment prior to infiltration or an infiltration site where the influence of the addition of wastewater substances (salts) is not detrimental to further water use. Treatment systems using FAM could be well feasible as they provide a more advanced removal of nitrogen and phosphorus

Artificial recharge was not studied as a re-utilization alternative as other methods seem more appropriate under Nicaraguan conditions.

(D) Indirect re-use

In many instances treated wastewaster is discharged into surface water and re-utilized after some time: for the production of drinking water, recreation, etc. Sewage discharged into stagnant surface waters should be well purified in order to prevent eutrophication.
Here, lagoon systems using the action of FAM to remove nutrients can be an asset.

2.5.2. Re-utilization of harvested waterplants

(E) Biogas generation

The organic matter contained in the water or biomass (for example waterhyacinth) in lagoons can be partially converted to biogas. The production necessarily is of limited scale (at a maximum 15 litre of CH_4-gas per capita per day). This implies gas re-utilization at the site of production. Biogas production in the UASB-reactor has been discussed in subsection 2.2.1. It was noticed during the mission's visit to the University of Florida that biogas generation from harvested waterhyacinth and other floating aquatic macrophytes often meets with technical difficulties and requires a know-how and skill which are not yet available in most developing countries, including Nicaragua.

Scientists of the University of Florida furthermore believe that waterhyacinth digestion in combination with other types of waste containing less moisture shows better perspectives (Chynoweth, pers. comm.).

Philip et al. (1983) studied the small-scale digestion of harvested waterhyacinth in Sudan.

The costs (investments + O&M excluding the harvesting of the plants) exceeded the benefits of the gas. Only at much higher (future) prices of alternative fuels would waterhyacinth digestion become cost-effective.

As it is the mission's conclusion, that the perspectives of a viable re-utilization of harvested plants by biogas production are meager, it is recommended to exclude this re-use alternative from the project proposal.

(F) Compost production from harvested water plants

System description:

The system implies the manual or mechanical harvesting of FAM. The plants are then dried to some extent, piled and processed to compost. 1 ton of fresh water plants (dry matter = 5%) produces 200 - 350 kg of compost (dry matter = 15 - 25%). This process takes 1 - 3 months.

When the drying is accomplished by mechanical pressing of the harvested water plants, a juice remains. This juice contains an appreciable part of the valuable components of the plant. It can be made useful by solar evaporation of the liquid. Alternatively, water plants are dried by exposing the plants to sunlight and finally burning the plants. The remaining ash could be used as a fertilizer. The plants can be used as mulch. Fresh plants are worked into the ground thus enhancing the moisture retaining capacity of the soil. This procedure however is not clearly succesful (Philip et al., 1983).

In culture experiments it turned out that waterhyacinth compost (as compared to a control without fertilizers) brought about yield increases for onions, carrots and cow beans, but not for cucumbers. It can thus be regarded as a suitable fertilizer for a selection of crops.(Philip et al., 1983). In experiments by Singh (1962) compost produced from Pistia stratiotes (water lettuce) turned out a better organic fertilizer than compost from some other waterplants including waterhyacinth.

Cost & revenues of compost production:

The costs of producing compost from water plants consist of harvesting and processing cost. Data from literature on the economics of this system of fertilizer production is scarce and often confusing. The costs of mechanical harvesting at the scale of a wastewater treatment plant are estimated at US $ 2 - 3/raw ton in the USA. These costs were discussed in subsection 2.3.3.

The costs of processing to compost are estimated at US $ 3/raw ton in the US and 1 Sudanese pound/raw ton (US $ 2/raw ton) in Sudan. The total cost of producing compost in the US is US $ 5/ton fresh water plants, which is about US $ 15/ton compost. Waterhyacinth compost has been sold in the US for about US $12 /cubic yard (US $ 17/m^3)(Bagnall et al. 1973).

Crites (1979) assumes that 50% of the harvesting cost can be recovered from the revenues from compost.

Philip et al.(1983) compared prices of inorganic fertilizers, waterhyacinth compost and waterhyacinth ash in Sudan. The results are given in table 2.14.

Table 2.14. Comparison of wholesale prices of various types of fertilizer

Type of fertilizer	Sudanese pound per kg basic substance
N-P-K (15x15x15)	0.37
WH-compost (26% d.m.)	0.81
WH-ash	2.00

It is concluded from the above, that organic fertilizers produced from waterhyacinth - under present conditions - do not seem competitive to inorganic fertilizers when the costs of harvesting are included.

(G) The conversion of waterplants to livestock feed

System description:

In several ways harvested water plants can be processed to livestock feed. Direct use of fresh plants is possible, but the nutrient value is limited and the wet plants easily putrify. Bagnall (1979) states that ensiling is the most feasible conservation method for waterhyacinth.

The production of ensiled cattle feed implies the following process steps: harvesting, chopping, pressing, adding carbohydrates (e.g. 4 - 5% of dried citrus pulp) and 0.5% propionic acid, and finally ensiling.

In this procedure the moisture content of the water plant mass (waterhyacinth) decreases from 95% to appr. 85%.

The juice which is produced by pressing the water plants contains valuable nutrients and can be processed to livestock feed components, but little experience is available in this respect.

Costs & revenues of producing waterhyacinth silage:

The costs of producing silage were calculated at US $ 7-8/raw ton of waterhyacinths (Bagnall et al., 1973; Bagnall & Hentges, 1979).

Philip et al. (1983) found that a cost-effective fattening of bulls on a mixed feed of waterhyacinth silage/cotton seed cake/molasses/rice straw was possible in Sudan. The silage was about one quarter of this feed. The profit margin amounted to 34 % of the total costs of bull fattening.

It can be concluded that water plants may under specific conditions be effectively used as a supplementary food source for livestock. Whether in a particular situation the production of cattle feed is a feasible economic option will depend on many factors such as transport distance and costs and the prices of available alternative livestock feeds.

In fact the experiences are very limited and mostly based on waterhyacinth harvested from surface waters.

2.5.3. Conclusions regarding re-utilization alternatives

1. The most attractive re-utilization alternatives for sewage effluents in developing countries are the following: irrigation, fish- and shrimp-farming, and indirect re-use after discharge into surface water. Preceding irrigation and fishfarming a wastewater treatment system including anaerobic pretreatment and secondary treatment in algae lagoons is the most appropriate method. When effluents are discharged into surface waters waterhyacinth based secondary treatment systems can be effective as they exhibit a relatively high nutrient removal.

2. Re-utilization of sewage effluent for irrigation, although often feasible, is tied to a set of conditions. (See pages 32). Decisions on the feasibility in a particular locality and the requisite degree of sewage treatment need a thorough preparation based on the already existing experience in irrigation re-use.

3. The economic perspectives of the harvesting and re-utilization of floating aquatic macrophytes is uncertain.
   - Biogas generation from FAM may perhaps be feasible in combination with other waste materials; technically it is not simple enough to recommend its general application.
   - The production of compost is technically simple, but further research is needed to assess its economic viability in developing countries. The application of Pistia may be more promising than waterhyacinth.

- Harvested waterhyacinth can be processed to a cattle feed of nutritional value. Depending on specific conditions, positive financial returns may be possible when silage is used as a partial feed.

2.6. Conclusions and research questions

2.6.1. Survey of wastewater treatment and re-utilization systems and the conditions for their succesful application

In table 2.15 below the specific conditions are presented under which the actual application of anaerobic pretreatment/aerobic posttreatment/re-utilization systems for wastewater treatment is to be conceived.

On top of these, the following "general" conditions would apply for all of the treatment (sub-)systems considered.

* Presence of a sewer system.
* Absence of too high concentrations of toxic substances, which would interfere with the treatment process and/or the re-utilization of effluent and solid matter.
* Existence of a Watertreatment Authority, preferably also an operational sewertax or -tariff system.

For the various (components of) treatment systems discussed in the preceding paragraphs, table 2.15 presents some of the more important conditions for their successful application.

Table 2.15. Conditions for Succesful Application of the Proposed Method

COMPONENT	PHYSICAL	TECHNICAL	INSTITUTIONAL/ECONOMICAL
1. Anaerobic lagoon	Temp. $> 20^{o}C$ Sufficient distance to inhabitation		Rural and semi-urban areas
2. UASB	Temp. $> 20^{o}C$	Techn. know-how Skilled surveill.	Urban areas
3. Anaerobic/ Facultative lagoon system	Temp. $> 20^{o}C$ Space needed: 0.1 ha/1,000 p.e.		Rural and semi-urban areas
4. Anaerobic/ FAM-lagoon system	Temp. $> 20^{o}C$ Good climatic conditions for water plants Space needed: 0.2 ha/1,000 p.e.	Harvesting equipment	Rural and semi-urban areas Good organization for the operation and maintenance of the ponds Effective demand for the harvested/processed product
5. UASB/ facultative lagoon	Temp. $> 20^{o}C$	Techn. know-how Skilled surv.	urban/mountainous areas
6. Re-utilization			
* re-use of effluents for irrigation (no need for algae removal):			
	nearness agri-culture non-food crops	pumpcapacity permeable soil limited salt-content water hygienic quality	demand for irrig.water waterdistr.organization
* fishculture (no need for algae removal):			
	space for fish ponds (10-100 kg BOD/ha.day	hygienic quality of water know-how harvesting additional food source	market demand
* re-use of harvested plants:			
** composting:			
	space organic solid waste nearby available	know-how special equipment	effective, nearby demand for organic fertilizer
** cattle-feed:			
	nearby supply of comple-mentary feeds (e.g.melasse, citrus pulp)	know-how cattle feed blending equipment	effective demand the year around (c.q.alternative use) for cattle feed

Table 2.15. (continued)

COMPONENT	PHYSICAL	TECHNICAL	INSTITUTIONAL/ECONOMICAL
** digestion:	organic solid waste nearby available	well-developed technical know-how equipment	nearby, continuous, effective demand for energy in the form of bio-gas

2.6.2. Selected treatment and re-utilization systems

With regard to low-cost sewage treatment and re-use systems in developing countries the following main distinctions should be made:

1. The extensive lagoon and land treatment systems which require flat land in the order of magnitude of 0.1 ha/1,000 inhabitants for primary and secondary treatment. These methods can be applied in the semi-urban areas on the border of towns. These extensive treatment systems can be well integrated into re-utilization systems. The most promising are re-use for irrigation and fishfarming.

2. The systems which do not require much land space and which are suitable for densily populated urban areas. The UASB -reactor belongs to this category of treatment methods. At present high-rote anaerobic pretreatment systems like the UASB-reactor seem to present a viable and attractive treatment method under urban conditions. Anaerobic pretreatment methods as compared to conventional treatment methods are characterized by low land and little if any energy needs, low investment costs, low excess sludge production and a relatively easy operation and maintenance.

The UASB-reactor as compared to the anaerobic lagoon is characterized by higher investment costs and the need for more skilled surveillance particularly during the starting-up period.

Because of the difference in installation cost and the skills required for operation and maintenance it does not seem sensible to suggest application of the more complicated methods, like the UASB-reactor in its present design, whenever land is available and land costs are limited.

The experience in the application of treatment methods using floating aquatic macrophytes is still limited. The question is: under which conditions can these FAM-methods compete (in terms of TSS, BOD_5, nutrient and pathogen removal) with the more conventional anaerobic and facultative lagoons, which do not require plant harvesting.

When FAM channels/lagoons are used with the purpose of advanced nutrient removal the required surfaces will be rather large and their application will be limited to less densily populated areas (the first category). Re-utilization of the harvested plants is necessary and should be cost-effective. This implies that the benefits of the sale of processed FAM should be larger than (or equal to) the costs involved in harvesting, processing and marketing of the product. Re-utilization as an additive to cattle feed seems the most promising alternative but its perspectives are as yet uncertain.

2.6.3. Research questions

In the research the distinction into the two categories mentioned above should be borne in mind:

a. Research questions concerning the extensive treatment methods for semi-urban and rural areas

Primary treatment

Simple low-cost anaerobic pretreatment systems should be further developed, which combine the benefits of the UASB-reactor with the low cost and easy maintenance of the anaerobic lagoon. The horizontal-flow baffled anaerobic reactor is an example of this development.

A better insight should be gained into the problems of bad odours from anaerobic systems under specific conditions. Methods should be developed to avoid them.

Primary plus secondary treatment

How can the wash-out of suspended matter, especially algae, from facultative lagoons be diminished effectively and by simple means? In order to optimize lagoon systems, models should be designed to predict the nitrogen and phosphate removal in these systems. More fundamental research is needed into the question of pathogen removal in lagoons. Too little is known on the influence of algae and competing wastewater bacteria. A general problem associated with lagoon systems is the hydraulic flow pattern. A plug-flow should be promoted and short-circuiting and dead spaces prevented: how can this be accomplished at minimal costs?

The possible role of floating aquatic macrophytes (FAM) in the removal of nutrients, pathogens and suspended matter from primary effluent should be studied in order to answer the question under which conditions the application of FAM is a cost-effective treatment method.

Special attention should be paid to the effect of FAM in the elimination of algae from facultative lagoon effluent (adsorption in the root-zone and shading-out effect).

Re-utilization

As little reliable information is available about the re-utilization of FAM in developing countries, this subject needs further investigation. In this respect it is recommended to study the possibilities of the addition of water plants to cattle feed. Furthermore, the processing and the possibilities of re-use of the juice from pressed water plants needs study.

b. Low-cost methods for urban areas

Primary and secondary systems

The development and implementation of cheaper anaerobic pretreatment systems as suggested above would also be beneficial to urban sewage treatment.

The posttreatment of effluents from primary treatment, such as UASB-effluents, should be studied with an emphasis on pathogen and nutrient removal. The most promising methods are: small lagoons (possibly with FAM), mechanically aerated lagoons, aerobic/anaerobic activated sludge and fixed-film processes and disinfection by chlorination, ClO_2 addition and UV-radiation.

Re-utilization of effluents

In re-utilization the emphasis should be on indirect re-utilization (re-use after discharge to surface water) and on re-utilization for industrial applications.

3. POSSIBILITIES AND LIMITATIONS OF NICARAGUA AS THE LOCATION OF THE RESEARCH PROJECT

3.1. General findings of the mission in Nicaragua

3.1.1. Findings of the Mission with respect to City of Managua

Drinking Water

The development of the city's drinking water supply system has lagged behind the development of the urban population, as a result of which large parts of the urban area are not connected to safe drinking water supply.

Drinking water production capacity also is insufficient, and in 1984 a rationing system had to be introduced and all parts of the city are disconnected during two or more days per week.

Potable water is supplied from Lake Asososca and some 70 tubewells. Contamination of these sources however must be feared by groundwater movements from Lake Managua and industrial wastewater discharges.

An extensive investment programme will be implemented as from next year, with a.o. the construction of 79 new tubewells. In the longer run drinking water for Managua is expected to be supplied from Lake Nicaragua.

Sewerage

An estimated 50% of the houses in Managua is reported to be connected to the sewer system, which consists mainly of 24" concrete pipes. This system discharges directly, i.e. without treatment, into Lake Managua via about 20 outlets along the Lake's shore. Little is known about the technical state of the sewers, as hardly any monitoring and maintenance takes place. No discharge data - per outlet or aggregate - are available since 1982.

A sewerage masterplan was prepared in 1977, which included the construction of an interceptor trunksewer, and either limited treatment (part of Lake Managua to be transformed to a large stabilization pond) of the effluent, or re-use of the effluent for irrigation purposes in "Los Brasiles" (an agricultural area at a distance of about 30 km) after pumping up the effluent to a height of about 100 meters. No part of this Masterplan has been implemented, mainly because of lack of investment funds available.

At a pilot scale a plan exists to construct 2 stabilization ponds (of 2.06 ha each) at Santa Clara, in the eastern part of the city at the Lake's shore. Lack of funds has prevented implementation.

There exists a general agreement that the present sanitary conditions in Managua are poor, and detoriating, with the inadequate sewersystem, inadequate sanitary facilities for the rest of the population not connected to that system, and the direct disposal of untreated effluent into the Lake. However, both INAA, the Ministry of Health (MINSA) and the city authorities report not to have at their disposal the resources for the formulation and implementation of an adequate sanitary policy covering Managua.

Drainage

The drainage and sewer systems in Managua are separated in principle. The open drainage system collects stormwater plus surface wastewater, and discharges to the Lake, directly and via manholes through the sewers, and to the sub-soil. In this way a significant part of the human waste produced in the city is discharged directly to the Lake, without entering the sewersystem.

Solid waste

Only a small part of the solid waste generated in Managua is collected from the neighbourhoods, because of the limited number of operating collecting cars and other facilities needed. The part of the refuse that is collected is disposed at a huge refuse dump, located centrally in Managua, at the Lake's shore. This dump drains directly to the Lake, constituting a massive source of contamination of the Lake, as well as posing a direct health hazard to the surrounding population and producing bad odours and other nuisances to the city. Although again general agreement exists that this dump should be relocated (two new dumps are planned, east and west of the city), and the present site be cleaned, lack of resources prevent the city authorities to actually take action.

Industrial wastewater disposal

In the western part of Managua, between the Lake Managua and the Laguna de Asososca, an industrial area is located, accomodating several oil refineries and a chemical factory (Pennwalt from the US) producing a.o. chlorine. Wastewaters from these industries are discharged without treatment into the Lake, and thus constitute an important source of contamination of the Lake with toxic chemicals, amongst which substantial amounts of heavy metals, notably mercury. Government institutions responsible for environmental protection, both at the central government level (IRENA) and at the Municipality of Managua, clearly are aware of the negative, dangerous effects on the environment of such discharges, and have attempted to change this situation in direct negotiations with the industries concerned. It appears that substantial improvements (e.g. reductions of the amounts of mercury discharged) are considered unfeasible economically. Environmental legislation in this sense is said to lead to the closing down of the industries concerned and of many dependent ("downstream") industries, and has therefore not been attempted by the authorities.

Lake Managua

The detoriating quality of the water in Lake Managua is a great concern for the responsible authorities and for the population of Managua. On top of the various sources of contamination of the Lake mentioned above, other factors do play a role. Vulcanic activity inside the Lake appears to raise its borium content, contributing to an alarming rate of salinization of Lake Managua. Deforestation in the Lake Managua-basin leads to continuously increasing sedimentation. Increasing use of pesticides in the agriculture in the basin once more adds to the Lake's contamination. An evaluation of the dynamics of these processes is furthermore obscured by the fact, that the the outlet of Lake Managua via Tipitapa river to Lake Nicaragua seems to have stopped functioning for several years now, putting an end to a natural "refreshment" of the waters of Lake Managua. (Not clear is (yet), whether this actually is happening, and if so what would be the causes of such a change).

There exists a general awareness of the alarming state of the Lake, and of the health risks to the surrounding population, both with the authorities and with the people themselves. In fact the Lake is not used by the people of Managua, fish from the Lake is not eaten, a strip of over 100 m width along the shore is practically abandoned by the inhabitants of Managua. In a sense, the people seem to have turned away from the Lake.

On the other hand, the available information with respect to the vital parameters of the state of the water is very limited, notwithstanding the fact that several partial research projects regarding Lake Managua have been or are being executed. Some basic data, e.g. regarding the actual state of affairs with respect to the assumed eutrofication of the Lake, the oxygen content of the water in various parts of the Lake, its "self-purifying potential", etc. simply seem not to be available.

Furthermore, the relative contributions of the various sources of contamination of the Lake (industrial discharges, agriculture, domestic wastewater, the solid waste dump, vulcanic activity, etc.) have not been assessed. A programme aiming at a close monitoring of the waterquality of the Lake in fact is gradually being started now. Given this situation it has clearly not been possible for the government to formulate even the outlines of a comprehensive policy vis-à-vis Lake Managua. And, not surprisingly, clear policies at the implementation level do not exist either. The general lack of resources for the substantiation of such policies does of course also play an important role in this respect.

Conclusions

The city of Managua and the Lake of Managua both are confronted with large (and related) environmental problems. The discharge of perhaps half of the domestic wastewater generated in the city of Managua into the Lake, without any form of pre-treatment, clearly is one of these problems. However, the available information does not permit the assessment of the relative importance of this problem in the overall environmental problematic. In the mission's view this constitutes an important consideration not to locate a research project regarding domestic wastewater treatment in Managua: government and population on the one hand are aware of the threatening environmental conditions and the need to do something about it, but on the other hand show a tendency to literally turn away from the Lake, to blame the past regime for the present problems, and to hesitate to act even where action seems to be needed urgently. Given this ambiguity towards the Lake, the implementation of a research project as the one considered by the mission could not be expected to contribute to the needed clarity with respect to the overall problematic. (On the contrary, such a project might give the impression that something is done about the contamination of Lake Managua, while in reality the central problems may very well be other than the discharge of less than 50% of the domestic wastewater of the city.)

3.1.2. Findings of the Mission with respect to City of Granada

One other town visited by the mission is Granada, located south of Masaya at Lake Nicaragua, with about 50.000 inhabitants. The town of Granada also has got a sewersystem, discharging to a treatment facility. About 20 to 30% of the population has got a connection to the sewersystem.

The treatment facility consists of a grit chamber and two parallel stabilization ponds of 1.87 ha each, and a design depth of 1.2 m. The influent enters the ponds via a pipe, which leads some 25 m. into the ponds.

At the moment of the mission's visit only one of the two ponds was in use. The grit chamber contained a lot of dirt, and apparantly had stopped functioning because of lack of maintenance. No effluent water was flowing out of the oulet structure of either pond: it disappears by evaporation and infiltration into the sub-soil.

Apparantly, the treatment plant is underloaded and is lacking maintenance. Improvements can be attained at a higher influent flow, by converting it to a in-series operation of the two ponds, and by shortening the influent pipe.

Conclusions

It is not clear whether the physical space needed for the proposed research project would be available at the Granada site. Furthermore, quite some improvements and additional investments would be needed before such a project could be executed here.

As finally the distance from Granada to the main laboratory facilities of UNI, CIRA and INAA, to be utilized by the proposed research project, would be quite large, this particular treatment plant has been left out of the further considerations of the mission.

3.1.3. Findings of the Mission with respect to City of Masaya

Masaya has about 80.000 inhabitants. The town is located at a distance of less than 30 km from Managua; a good road allows for a driving time of about 30 min. to the capital. The town is surrounded by a vast and fertile agricultural area. In the immediate surroundings the magnificent National Park of the Masaya Volcano and the Lake of Masaya can be found.

It is a town of commerce and small workshops (pottery, textile, leather).

Drinking water for the town is extracted from wells, the consumption of drinking water is estimated at 120 liters/capita/day.

Masaya does have a sewer system, to which the houses of an estimated 60.000 inhabitants are connected. The collected wastewater is treated in a treatment plant recently (1980/81) constructed by INAA. This plant is situated on a plateau between the town and Lake Masaya, and consists of three parallel systems of stabilization ponds, each consisting of two ponds in series. The plant presently lacks a sand trap (which would have to be installed for the purpose of the proposed research project). The total surface of the ponds is about 7 ha. The effluent is discharged to the Lake. Presently research is done into a number of aspects of this treatment facility, in the framework of the ongoing "NUFFIC" cooperation programme of UNI, Department of Environmental Engineering, and the Technical University Delft, Department of Sanitary Engineering.

Not much is known yet with respect to the waterquality of the Lake of Masaya; it is said that it suffers from eutrofication. Ideas exist to utilize the effluent of the treatment plant for irrigation purposes for intensification of agricultural production in the area (cotton, maize, sorghum, watermelon, etc.).

Conclusions

The premises of the wastewater treatment plant of Masaya do offer good conditions for a research project as the one considered by the mission. The following assets may be mentioned:
- the availability of a considerable and easily accessible flow of domestic wastewater;
- a meteorological station is already installed at the site;
- the availability of small buildings for use as office and on-site laboratory (water and power are present);
- sufficient space to install an anaerobic pre-treatment system, tanks and other implements to be constructed for the purpose of the proposed research project;
- a good working environment for the research team concerned.

3.2. Applicability of the considered domestic wastewater treatment systems in the Nicaraguan context

It should be concluded from the comparison of low-cost wastewater treatment systems in chapter 2 that a clear distinction should be drawn between the (land-) extensive and the intensive systems.

Anaerobic and facultative lagoons possibly followed by a tertiary treatment system and integrated into a re-utilization scheme constitute the most cost-effective sewage treatment alternative whenever sufficient flat land is available.

A UASB pretreatment followed by a small lagoon or another intensive posttreatment method may be a good option in urban circumstances.

The application of floating aquatic macrophytes (FAM) such as water hyacinth and watter lettuce is most compatible with the - extensive - lagoon system for an additional removal of plant nutrients and suspended solids.

The application of FAM in the posttreatment of UASB-effluent has never been tried yet. As such systems should have a short retention time they would serve mainly organic matter removal.

Especially under urban conditions it is questionable whether the higher treatment efficiency would trade-off the effort of plant harvesting and disposal/re-use.

In Nicaragua both extensive and intensive sewage treatment methods are likely to be applicable under certain conditions.

3.2.1. Applicability in rural conditions with availability of flat land

In the lower areas in the southern and western regions of the country the land seems available to lay-out lagoon systems. Several forms of re-utilization of the end products of sewage treatment are possible. As indicated above (3.1.) some cities already have a lagoon system for sewage treatment. The present research project on low-cost lagoon systems may contribute to an improved design and operation practice of the existing and future lagoon systems. Direct effluent re-utilization is not yet practised. This mission recommends to start studies in the field of irrigation and fish-farming.

Floating aquatic macrophytes hold some promise for the improvement of lagoon systems in Nicaragua. It has to be studied whether the harvesting and processing of the plants can be supported economically by a profitable re-utilization. Re-use as cattle feed seems to be one of the more promising alternatives.

3.2.2. Applicability in urban and mountainous regions

In the more mountainous North of the country, e.g. near Matagalpa and Jinotega, the land space for extensive lagoons is not available. Here, the UASB-reactor, possibly followed by a small lagoon (HRT = approx. 1 day), may be an effective sewage treatment alternative.

3.2.3. System selection for further research

The mission recommends to emphasize research supportive to the development of an extensive treatment system which complies with the following conditions:

a. municipal wastewater is to be collected in a sewer system;
b. due account is to be taken of the scarcity of capital and of skilled labour for operation and maintenance: the system is to be affordable, and manageable to developing countries' responsible institutions;
c. tropical and subtropical climatic conditions;
d. availability of flat land (0.1 - 0.2 ha/ 1,000 inhabitants) for a lagoon system at the outfall of the sewer system;
e. discharge into surface waters liable to the deleterious effects of eutrofication;

f. required elimination of organic matter : 80 - 90%
   of nutrients : 60 - 90%
   of E. coli : 99.9%
   of parasites : 99.9%

g. high potential demand for useful materials recycled from wastewater (water, biogas, plant nutrients).

A sewage treatment system satisfying these requirements and conditions consists of the following steps:

* (upgraded) anaerobic lagoons as a pretreatment system;
* facultative lagoons with algae and floating aquatic macrophytes, such as water hyacinth and water lettuce (Pistia stratiotes), as a posttreatment system;
* harvesting and re-utilization of water plants. Re-utilization as livestock feed seems one of the more promising alternatives, but needs further research.

The proposal is further justified and discussed in chapter 4.

3.3. Conditions for the implementation in Nicaragua of a research project regarding sewage treatment

The conditions of the research project should comply with the following requirements:

* meet with local demands and developmental priorities;
* meet with interest of the local scientific community;
* be favourable to transfer of knowledge to counterparts and a wider circle of interested people;
* be favourable to a smooth execution of the research work.

These aspects will be discussed in the below paragraphs.

3.3.1. Developmental priority of the intended research

The original project raised a number of questions, in Nicaragua as well as in The Netherlands, essentially related to the question of the relative developmental priority for Nicaragua of appropriate technologies for wastewater treatment and research into this subject.

In the larger Nicaraguan cities where a sewage collection system exists, the treatment of sewage is either non-existent or partial and limited.

Existing treatment systems are of the facultative pond type. Their use is such that the removal of pathogens and nutrients should be considered insufficient.

Insufficient pathogen removal implies health hazards; disposal of large quantities of nutrients into more or less stagnant surface waters like lagoons and lakes means eutrophication, and ultimately "poisening" of these waters.

It is the mission's impression that the Nicaraguan authorities concerned are well aware of this kind of relationships. The extreme shortage of resources, however, which is facing the Nicaraguan government, in practice results in a higher priority for e.g. drinking-water supply and for the time being a rather modest investment level in wastewater treatment.

On the other hand, the authorities consulted by the mission did acknowledge the fact that the present practices in the handling of - domestic and industrial - wastewaters do represent a considerable claim on the available natural resource base.

The system to be studied (anaerobic pretreatment + facultative lagoons + FAM re-use) will be relevant for the treatment of sewage in tropical developing countries, where flat land is available (see 3.2.1). Such conditions are found in several towns in Nicaragua (including Managua) and in many places in the world. Lagoon systems are generally recommended, e.g. by the World Bank, and applied all over the world.

3.3.2. Interest at the scientific level

The support to the project proposal is appraised by recalling its history and the interest this mission met among local organizations.

The idea of the intended project emerged from a cooperation of Nicaraguan institutions and the University of Amsterdam in the framework of the limnological work on the lake of Managua. It turned out, and this was confirmed during the present mission, that several institutions (INAA, UNI, CIRA, IRENA) do show a great deal of interest in the project. Especially, the staff of the Department of Environmental Engineering of UNI, consisting of 16 people, were eager to start this project and gave a strong support to the work of this mission. Postgraduate students are intended to do their practical training in the intended project.

3.3.3. Transfer of knowledge

Prerequisites for a succesful transfer of knowledge are:
- interested people;
- perspective of the application of the transferred knowledge, and
- organizational facilities.

The transfer of knowledge should not only be effectuated within Nicaragua but to a wider community, at least to other Latin American countries.

* Interested people

It was pointed out above that several Nicaraguan institutions and individuals, especially within UNI, INAA and CIRA, showed a great interest in the project proposal, and in the prospect to possibly be involved in its execution.

* Perspectives of application

  As was pointed out above, the perspectives for application of the treatment system to be investigated do seem favourable in the flat regions in Nicaragua and probably also in other countries of Latin America.

* Organizational facilities for the transfer of knowledge

  The project will be carried out in a cooperation between DGIS (supported by Dutch institutions, such as the Agricultural University Wageningen) and INAA/UNI. The cooperation between implementing organisations, responsible for water pollution control (INAA), and educational organisations (UNI, TUD and AUW) seems an useful basis for the transfer of knowledge.

Furthermore, the mission considers the already existing institutional and educational support to UNI by Technological University of Delft in the framework of the DGIS/NUFFIC project an asset to the intended research project.

3.3.4. Research staff and facilities

The execution of the research project requires staff and facilities.

* Local research staff

  A group of about 6 staffmembers of UNI would directly participate in the execution of the project. These people are sufficiently qualified in chemistry, microbiology, waste water engineering and water analysis to support the project and benefit from it. The ongoing DGIS/NUFFIC interuniversitary cooperation project is helping them to upgrade their scientific level. Knowledge in other fields relevant to the project, like aquatic plant biology and the production of livestock feed can be contributed by other institutions like CIRA and ENPRA. It will be necessary to strengthen the local staff with experts (full-time and short missions) having

knowledge of project management, extensive waste water treatment methods, especially the treatment with floating aquatic macrophytes, and the harvesting and processing of plants.
INAA is interested in the possible application of the research findings. It will supervise the project and make available the research facilities at the Masaya treatment station.

* <u>Laboratory and pilot-plant facilities</u>
The existing sewage treatment plant in Masaya seems a fine place to start the research project because of the availability of sewage, space, laboratory and office buildings, and a meteorological station. Also, there is a close correspondence between the conditions of the intended research and its future implementation. Since the effluent of the existing sewage treatment station is discharged into the stagnant lake of Masaya, the full-scale application of the research results may be desirable on the site of the research in Masaya.
The distance between Masaya and Managua allows for good contacts between people working in Masaya and in Managua.
The project will have to improve the laboratory facilities in Masaya, because they are not sufficient for the intended research and the number of people working on it. This laboratory building will be used for most of the conventional water quality determinations. Determinations requiring instrumental analysis (gaschromatography, atomic absorption spectrofotometry, etc.) are carried out in the UNI laboratories in Managua.

The project could possibly be influenced in a negative way by consequences of the present economical crisis in Nicaragua, e.g. by a scarcity of services and materials, a strong mobility of personnel and relatively few investments in environmental affairs.

3.4. Conclusions

The proposed research project can be expected to contribute to the development of knowledge and of skilled people, urgently needed by the country in the near future. In that sense the introduction of "appropriate technologies for wastewater treatment", a field in which INAA, UNI and others appear to be well-informed, is welcomed by the Nicaraguan government.

The intended research project on wastewater treatment could be well executed in Nicaragua.

For several reasons the mission proposes to take the grounds of the existing sewage treatment station of Masaya instead of Managua as the locality of the research project.

The following positive aspects of the Nicaraguan context were found:

- favourable physical and technical opportunities for future implementation of the research results;
- a good site for project execution at the sewage treatment plant in Masaya;
- the Department of Environmental Engineering of UNI, which as a possible counterpart organisation seems to be well capable to carry out the research project and would be responsible for the training of Nicaraguan scientists and technicians;
- INAA is prepared to act as a counterpart organisation responsible for the implementation of the projects' results;
- good contacts of the counterpart organisations with local and foreign professional organisations.

The project could possibly be affected in a negative way by effects of the present economic crisis in Nicaragua.

4. RESEARCH PROJECT PROPOSAL

4.1. Appraisal and modification of the October 1987 INAA/SAWA proposal

In this subsection an appraisal and modification of the October 1987 SAWA/INAA project proposal (further called: the original proposal) will be presented based on the findings of the mission described in the chapters 2 and 3 of this report.

4.1.1. Outline of the October 1987 proposal

The aims of the October 1987 proposal were :

* The development of an integrated low-cost sewage purification system suitable for tropical countries, especially for Nicaragua.

** The transfer of knowledge to local people and institutions.

The treatment system to be studied consisted of the following three subsystems:

a. Anaerobic pretreatment by means of an UASB-reactor.
b. A lagoon system using algae and floating aquatic macrophytes.
c. Generation of biogas from the harvested plant material.

This system is aiming at an advanced removal of suspended and dissolved organic matter, nutrients and pathogens. The lagoon system acts as a posttreatment step of the UASB-effluent. By a combination of algae and water plants a higher treatment efficiency, particularly of suspended solids and nutrients is expected. The production of biogas in c. was seen as an indispensible incentive for continuous harvesting of the plants.

The emphasis in the 1987 research proposal was on:

a. Posttreatment of the UASB-effluent, especially aiming at nutrient and pathogen removal, at relatively short retention times. In this field the proposal aimed at a comparison of the treatment efficiencies of lagoons containing algae, water hyacinth and water lettuce and lagoon systems containing combinations of algae and higher plants.

b. The production of biogas from the harvested plant material.

c. The transfer of knowledge on the three steps: UASB pretreatment, posttreatment and plant re-utilization.

4.1.2. Appraisal of the October 1987 proposal

The original proposal is appraised in relationship with the conditions under which it should be applied.

The findings of the mission in this respect have been discussed above in chapter 3.2. ("Applicability..."). It was recommended (3.2.3.) to emphasize research and development of an extensive treatment system complying the following conditions:

a. municipal wastewater collected in a sewer system;

b. developing country, i.e. low availability of investment capital and skilled personnel;

c. tropical and subtropical climatic conditions;

d. availability of flat land (0.1 - 0.2 ha/1,000 inhabitants) for a lagoon system at the outfall of the sewer system;

e. discharge into surface waters liable to the deleterious effects of eutrofication;

f. required elimination of organic matter: 80 - 90%
of nutrients : 60 - 90%
of E. coli : 99.9%
of parasites : 99.9%

g. high potential demand for useful materials recycled from wastewater (water, biogas, plant nutrients).

These conditions are found in several towns in Nicaragua.

In view of the conditions mentioned in 3.2.3, the following comments are made with respect to the original proposal:

a. The combined primary plus secondary treatment system including reutilization of harvested plants.

The system of a UASB-reactor + lagoon system + biogas generation from plants as a whole implies the incompatibility of the intensive UASB-reactor and the extensive posttreatment system. The UASB-reactor is better suited to conditions where flat land is not available. Posttreatment methods to be combined with the UASB-reactor should be equally land saving. Lagoon systems including re-utilization of water plants are more geared to rural or semi-urban conditions.

b. The anaerobic pretreatment method.
The UASB-reactor, although low-cost as compared to conventional aerobic systems, is in its present form a rather expensive proposition for the poorer developing countries like Nicaragua and requires skilled personnel which will often not be available.

c. The posttreatment system using algae and higher water plants seems - under the given conditions - promising enough to justify further research. The need of regular harvesting of the floating plants implies the economically feasible re-use of the plant material.

d. The production of biogas from harvested water plants is possible but considered technically too difficult under Nicaraguan conditions and probably economically less efficient than other forms of plant re-utilization.

The mission therefore suggests the following modifications of the October 1987 proposal:

a. The combined primary plus secondary treatment system including re-utilization of harvested plants.
The modified system to be investigated in Nicaragua should consist of the following treatment steps:
- anaerobic pretreatment in an improved version of the anaerobic lagoon;
- posttreatment in facultative lagoons with algae and floating aquatic macrophytes;

- re-utilization of harvested plants as livestock feed or soil conditioner.

Below, each of the treatment steps are discussed in more detail.

b. Primary anaerobic treatment

Instead of the original UASB-reactor an anaerobic pretreatment method should be used and further developed which satisfies the following conditions: considerably lower capital costs than the UASB-reactor, no need of skilled labour, easy start-up and low maintenance costs, retention time 24 hrs or possibly less, organic matter removal 70-80%, no bad odours. The baffled anaerobic lagoon (Orozco, 1988) and the covered RALF- UASB (Sanz, 1988) indicate interesting approaches to this method.

c. Secondary (post-)treatment of anaerobically pretreated wastewater

A lagoon system using algae and water hyacinth or water lettuce seems a useful proposition and the research on this system should be undertaken as originally planned.
The retention time of the secondary system should not exceed 10 days.

d. Re-utilization of the harvested plants

Instead of the anaerobic digestion of the water plants for biogas production re-utilization by addition of ensilaged plants to livestock feed seems the first alternative to be studied in Nicaragua. A second alternative is composting of the plants to produce a soil conditioner.

4.2. Objectives and research questions

4.2.1. Objectives

The objectives of the proposed research project are as follows:

a) The development of a wastewater treatment system which meets the following criteria:
   - treatment of wastewater from sewered communities in tropical developing countries where flat land is sufficiently available;
   - removal efficiencies of components from the wastewater should comply with the following figures:
     * organic matter: 80 - 90%
     * nutrients : 60 - 90%
     * E. coli : 99.9 %
     * parasites : 99.9 %
   - a cost-effective re-utilization of water plants harvested from the treatment system.

b) The transfer of know-how to local counterpart staff and the wider dissemination of research findings to individuals, scientific institutions and authorities involved in sewage treatment, both in Nicaragua, other Latin-American countries and other developing countries.

4.2.2. Research questions

A survey of research recommendations related to the proposed system is presented in subsection 2.6.3. These questions may be summarized as follows:

1. How should a low-cost anaerobic pretreatment system be designed and constructed which complies with the requirements of sewage treatment in rural and semi-urban areas in LDC?

Special attention should be paid to the question how problems of bad odours can be prevented.

2. Which are the treatment characteristics, maintenance inputs and costs of this anaerobic pretreatment system as compared to the conventional anaerobic lagoon.

3. Which are the efficiencies, maintenance inputs needed and costs involved of lagoons using algae, and floating aquatic macrophytes in the secondary treatment of anaerobic lagoon effluent. The FAM investigated will be waterhyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes).

4. How should a secondary treatment system using algae and floating aquatic macrophytes be designed? The research will be focussed at hydraulic retention time/organic loading rate, pond depth and the ratio between the surfaces of algae ponds and FAM ponds.

5. Is the use of floating macrophytes for the removal of algae from facultative ponds a viable possibility (so called shading-out effect)?

6. What technical solutions exist for the harvesting of water plants and what are the related investment and operating costs? How should this havesting be organised, such that the continuous and regular operation of the lagoon system is secured?.

7. How should re-utilization of harvested water plants be carried out in Masaya and which are the related maintenance inputs and costs?. In what way will benefits be generated form re-utilization? Is this re-utilization a cost-effective proposition?

8. How can the cooperation of the various parties involved in the treatment system investigated - both public institutions such as the Municipality or the Water Treatment Authority, and private organizations and people such as the farmers using the end products

of the treatment system - be organized? Is this re-utilization a cost-effective proposition?

4.3. Planning of activities and time schedule

Among the project activities the following elements are distinguished:

- project preparation;
- research activities;
- transfer of know-how.

4.3.1. Project preparation

The project preparation phase comprises design and construction of the pilot plant and the supply of equipment, chemicals and vehicles.

The pilot-plant should include the following components (see also fig. 4.1.):

- full-scale unit for grit removal (flow = ca. 2,000-4,000 m^3/day);
- pumping pit and installation of electric pump;
- splitter box and flow measurement device;
- conventional anaerobic lagoon (50 m^3);
- experimental improved anaerobic lagoon (50 m^3);
- 12 experimental tanks for research on water plants (25 m^3 each);
- water plant harvester and processor;
- handling site for harvested water plants;
- extension of laboratory building;
- emergency electricity supply.

For most of these components a standard method of the design is available. Exceptions are the experimental improved anaerobic lagoon and the water plant harvester.

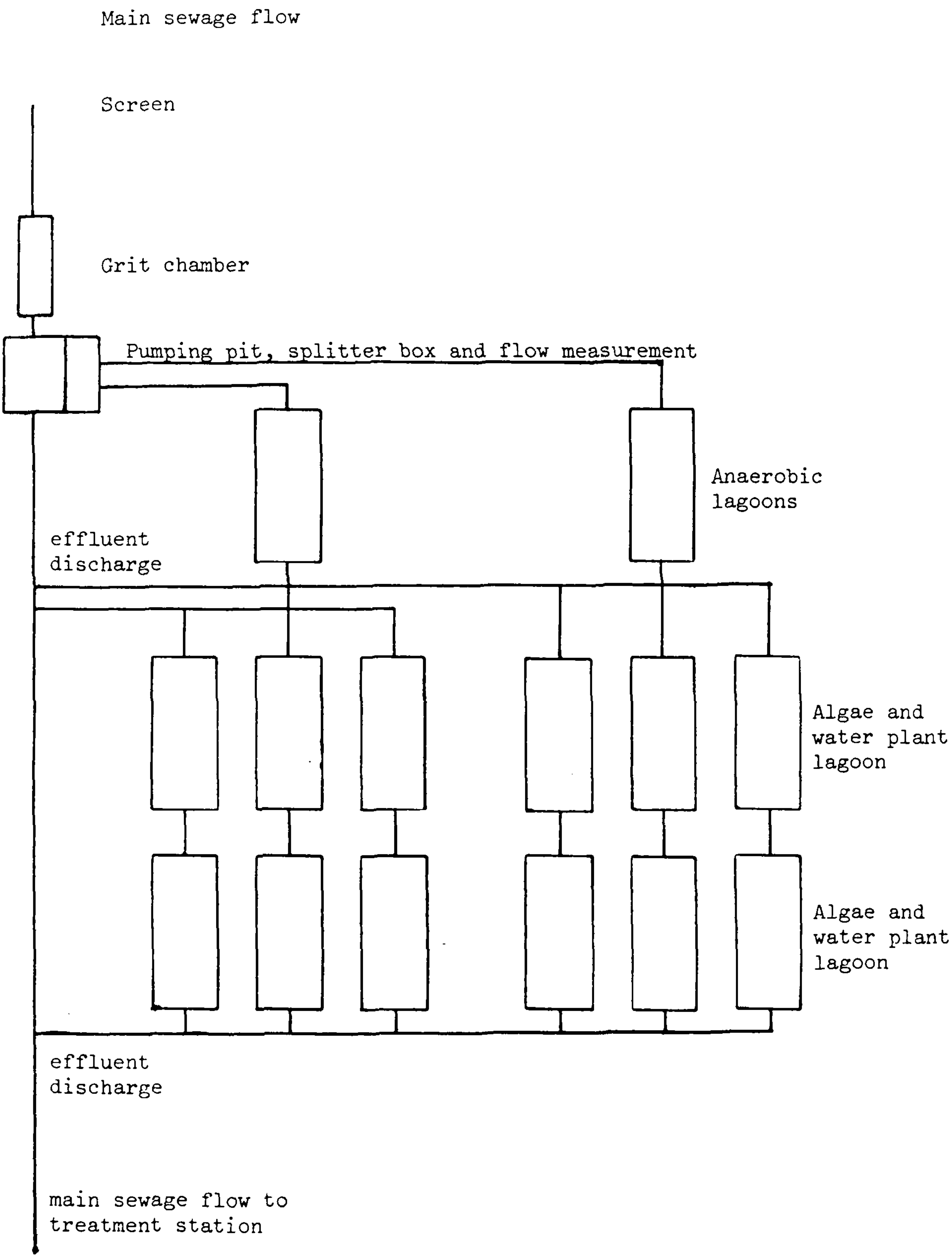


Figure 4.1. Diagram of proposed pilot plant.

4.3.2. Research

The research may be divided into four parts I, II, III, IV.

Part I. The Anaerobic Pretreatment in Lagoons

Contents : Start-up, optimization and comparison of the conventional and improved anaerobic lagoon.

Variables : design and construction of the experimental lagoon
hydraulic retention time.

Experiments: variation of inlet and exit constructions
variation of number of baffles
analysis of influent and effluent hydraulic flow pattern
sludge activity and accumulation
determination of odour development.

Duration : 30 months.

Part II. Posttreatment in Lagoons with Algae, Water hyacinth and Water lettuce

II.A.:

Contents : Growth of algae, water lettuce and water hyacinth in the effluents of anaerobic lagoons. The treatment efficiency of lagoons with algae and floating aquatic macrophytes.

Variables : Lagoon depth
Plant density
Harvesting frequency

Experiments: Analysis of influent and effluent determination of growth-rate of algae and plants.
Sludge quality and sludge accumulation

Determination of the fate of carbon, nitrogen and phosphorus.
E. coli die-off.
Removal of parasites.
Hydraulic flow pattern.

Duration : 24 months.
This phase can be started after the start-up of the anaerobic lagoons.

II.B.:

Contents : The effect of floating aquatic macrophytes on the effluent of algae ponds.

Variables : Type of FAM (Water lettuce and Water hyacinth) hydraulic retention time.

Fixed parameters:
Lagoon depth
Harvesting frequency

xperiments: Analysis of influent and effluents of the tanks.
Sludge quality and accumulation.
Balances of carbon, nitrogen and phosphorus.
Uptake of potassium, nitrogen and phosphorus by the plants.
Pathogen die-off.
Harvesting of the FAM.

Duration : 18 months.
This phase may be started ca. 6 months after II.A.

Part III. Re-utilization of harvested water plants

Contents : Study of feasible mechanical harvesters/processors.
Study of re-utilization as livestock feed additive and as soil conditioner.

Experiments: Application of the mechanical harvester.
Handling of the harvested FAM.
Ensiling of FAM.
Composting FAM.

Duration : 27 months.

Part IV. Full-scale application of treatment with FAM at the sewage treatment station of Masaya (optional)

Contents : Experiments with a system consisting of an anaerobic, facultative (algae) and FAM lagoon in series.

Determinations:
Treatment efficiencies of the consecutive lagoons.
FAM growth-rate.
Nutrient-uptake in the FAM.
The cost-effectiveness of FAM re-utilization.

Duration : This part of the project may be started if the results of former parts appear sufficiently promising.
This decision should be taken after approximately 18 months in the context of an evaluation of the project.
The total duration of this phase would be about 12 months.

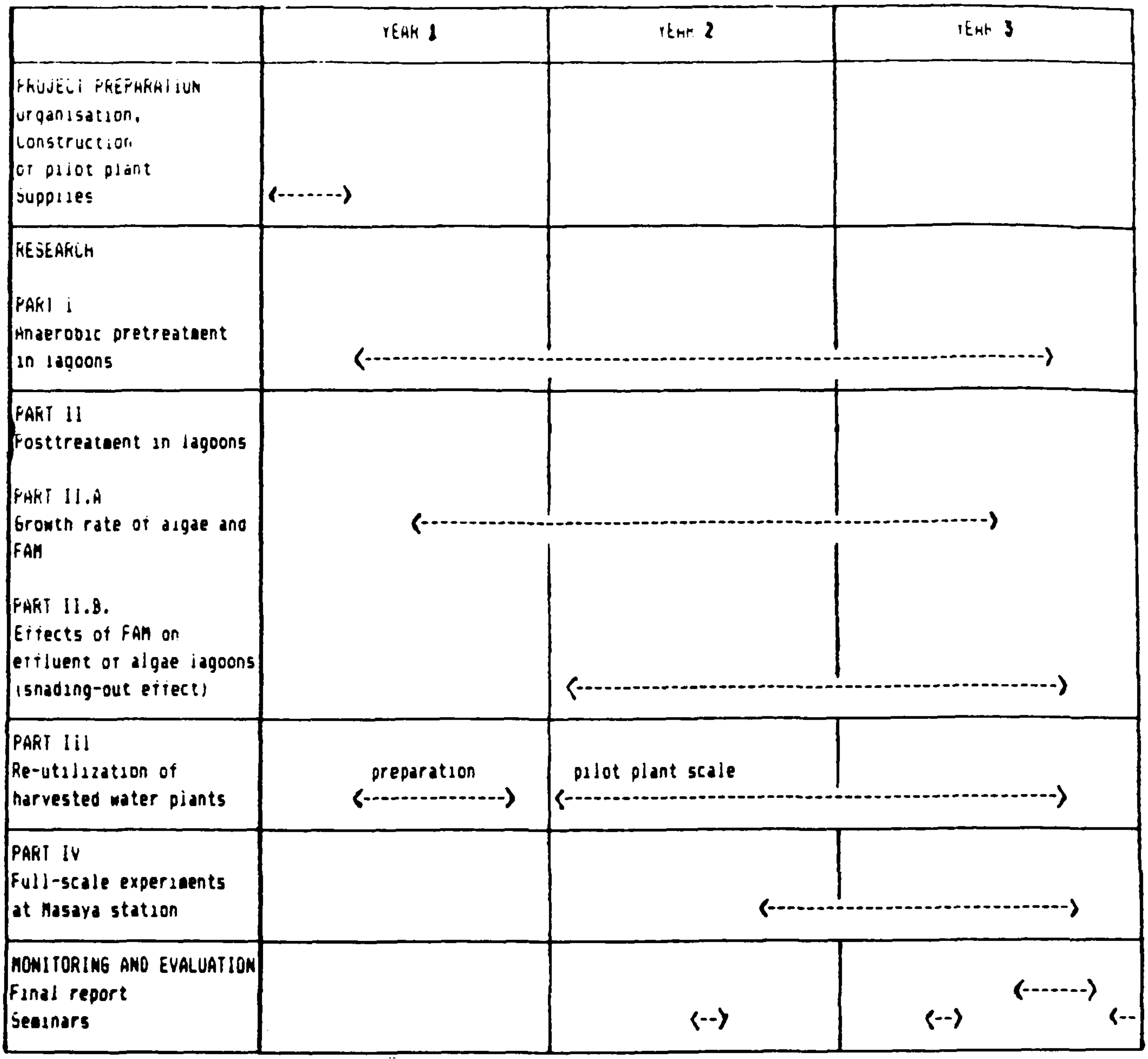


Figure 4.1. Bar-chart: schedule of planned activities.

4.3.3. Transfer of know-how

The transfer of know-how to Nicaraguan experts will comprise the following elements:

- Local training of Nicaraguan staff members and students within the project.
- Training periods of Nicaraguan staff members in The Netherlands. If suitable courses are available within Latin American countries the Nicaraguan attendance of these courses should be stimulated.
- Seminars aiming at the national level.
- One or two international workshops will be organized mainly aiming at scientists and engineers from Central and South America.
- Presentation of project results at one or two international conferences.

4.4. Institutional and organizational framework

The following considerations are taken as point of departure for the determination of the institutional framework for the execution of the proposed research project:

- The project is a cooperation of the Government of Nicaragua - by means of INAA - and the Government of the Netherlands, Ministry of *Foreign Affairs, Directorate-General of International Cooperation* (DGIS).
- As the project basically is a research project, both parties may charge other (scientific) institutions with executive responsibilities and tasks. INAA however will be the principal counterpart in Nicaragua, coordinating the various institutions involved at the Nicaraguan side. DGIS may also choose to contract out the Dutch contribution to a party capable of providing the required know-how, expertise and management.
- The execution of the research project will be charged by INAA to UNI, Department of Environmental Engineering. This Department does

have the necessary scientific background to be able to carry the executive responsibility for the research. Specific expertise regarding the treatment technology to be investigated, as well as the needed material and logistic support will be provided by DGIS, c.q. the party charged by DGIS to perform these tasks.

- To the extent that it is considered necessary, or desirable with a view at the dissemination of research findings, other institutions in Nicaragua - such as CIRA - may be involved in the research project. INAA will then make the necessary formal arrangements with those institutions.

On the basis of these points an institutional framework is proposed for the research project, as presented graphically in figure 4.1. In this figure it is tried to distinguish two levels:

- At the national level a Steering Committee will be established in which the Government of Nicaragua is represented by the (vice-) Minister of INAA, and the Dutch Government by the representative of the Embassy in Nicaragua (Cooperación Holanda). The project-directorate is present in the meetings of the Steering Committee as assessors to the Committee.

  The Steering Committee does have the following responsibilities:

  * evaluate and approve the annual Working Plan and annual Budget, as prepared by the project-directorate
  * initiate the (annual) bi-partite external evaluation(s) of the project, and prepare for both Governments, on the basis of such evaluation(s), a recommended policy towards the project.

  The Steering Committee will meet twice a year, or more often if required.

- At the project level a project-directorate will be established, consisting of a national project director (to be appointed by UNI as the executing institution) and a foreign project director, to be appointed by the Dutch Government. They will share the responsibility with respect to the day-to-day management of the project.

The project-directorate will:

* elaborate annual working plans and budgets;
* coordinate the various activities envisaged in those working plans;
* establish working relations with other institutions;
* prepare quarterly progress reports, to be submitted to both Governments, via the Steering Committee.

Apart from being the principal counterpart at the national level, INAA also will make available the project site in Masaya, and the basic infrastructure required by the project (as specified in 4.3.1.). Furthermore INAA will play a crucial role in the follow-up of the project in case the research results do point at the feasibility of full scale implementation, preferably in Masaya.

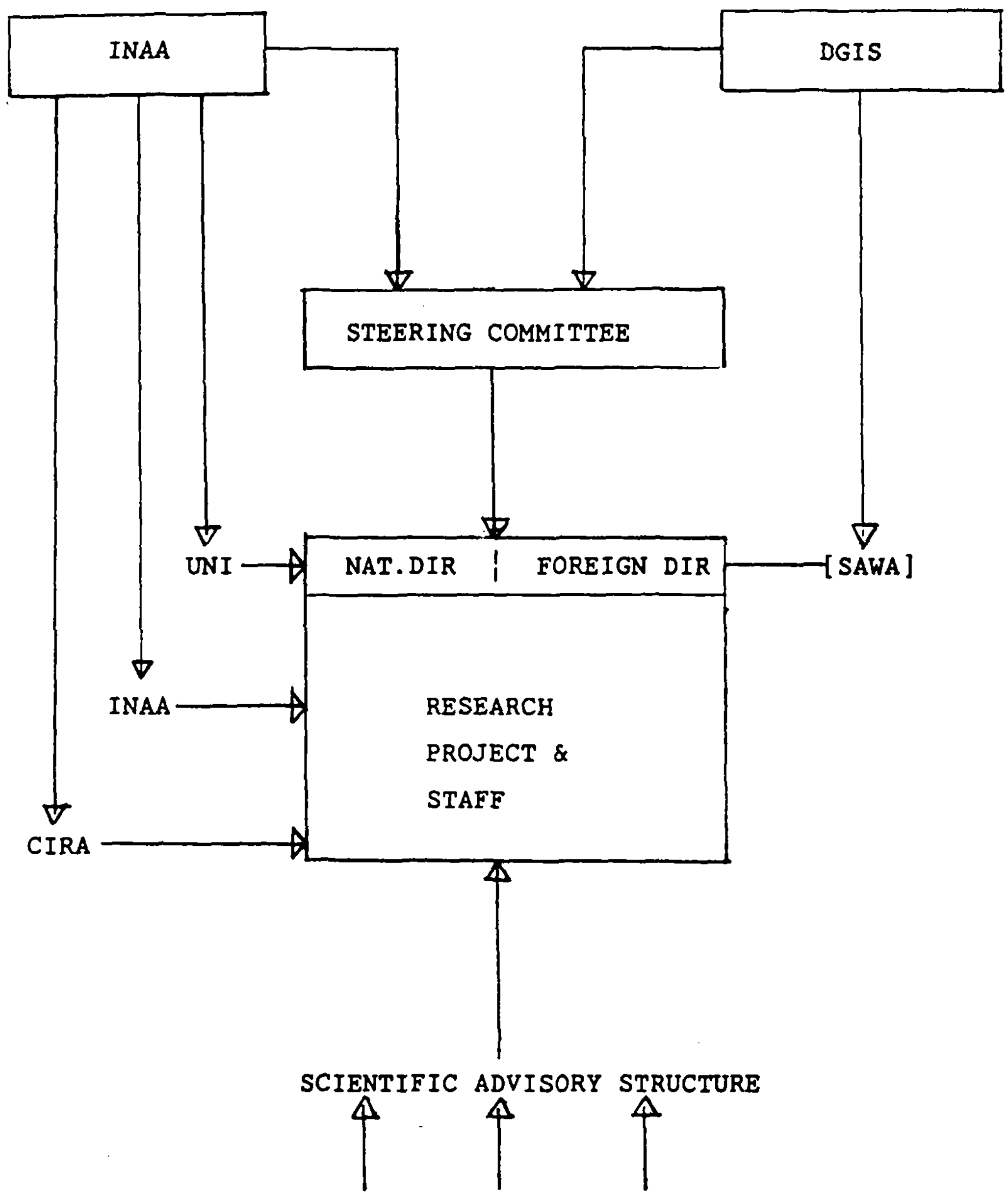
A scientific advisory structure is recommended for the project, which may perform a double function: advice the two Governments with respect to the progress of the project, and play an active role in the dissemination of the scientific results of the project.

At the Dutch side it is recommended to form a small advisory committee for the regular monitoring of the project, consisting of people, knowledgeable in the field of waste water treatment in developing countries. Such people may be available from consultants actively involved in this field, from the University of Wageningen (Department of "Waterzuivering"), the Technnological University Delft (Dep. of Sanitary Engineering and Water Management) which is cooperating with UNI (Environmental Engineering) in the form of a "NUFFIC" project, etc.

At the Latin American side the following scientific institutions may be asked to play some form of advisory role with respect to the project:

- Universidad de los Andes, CVC, and Universidad del Valle (Colombia)
- CEPIS (Peru)
- CETESB (Brasil)
- the Pan-American Health Organization (PAHO)
- etc.

Figure 4.3 Institutional framework



4.5. <u>Staffing</u>

The project will be run by INAA and UNI on the Nicaraguan and by a consultant firm on the Dutch side. This consultant (possiblY SAWA) will organize the needed expertise.

A. Staffing in the phase of preparation

During this phase the following activities will take place:

- preparatory mission(s) to Nicaragua, USA and Latin American countries;
- training of Nicaraguan staff members;
- design of the pilot-plant;
- preparation of the site;
- ordering and supplying of equipment, chemicals,vehicles, etc.;
- construction of pilot plant.

The preparatory organizational work has to be undertaken by the consultant and INAA. The consultant will assist UNI in the design work and in the training of Nicaraguan staff.

Site preparation and construction of pilot plant installation will be carried out by INAA and a local contractor.

The staffing in this phase will be described in further detail in a final version of the project proposal.

B. Staffing during the research phase

Nicaragua (INAA/UNI)	The Netherlands (Consultant)
1 Director	1 Research coordinator
1 Wastewater engineer	1 (Nicarguan) administrator
1 Biologist for FAM research	student(s)
1 Biologist for FAM research	
1 Researcher for re-utilization of FAM (Agricultural engineer)	Short missions of experts in various fields for monitoring and evaluation
1 Economist	
1 Analist in Masaya	
1 Analist in Managua	
1 Maintenance worker(Masaya)	
2 students	

4.6. Monitoring and evaluation

Monitoring and evaluation will consist of the following activities:

- Preparation of 3 monthly progress reports by the project directorate.
- Scientific supervision visits by experts or delegates of the Scientific Advisory Committee.
- General supervision by the steering committee.
- One or two regional workshops where professionals discuss the field of the project and related subjects. These may be mainly professionals from Latin America, but also from other parts of the world.
- Publication of a final project report and presentation of the results at regional and international conferences.

Traducción del Neerlandés

APPENDIX 1. Terms of Reference of the Mission

ORIENTACION GENERAL respecto al ESTUDIO DE FACTIBILIDAD PRELIMIÑAR de la investigación propuesta "Depuración de las Aguas Residuales Domésticas en Nicaragua", por INAA/SAWA.

La misión se concentrará en dos aspectos de la presente proposición de investigación.

1. ¿Cuál es la perspectiva de aplicación práctica del método de depuración propuesto, en Nicaragua y, en términos más generales, en países en desarrollo trópicos: cómo hay que estimar la viabilidad técnica, así como económica del método, y cuáles son las condiciones que podrán o deberán ser puestas, en relación con el cuadro institucional y organizatorio y con la organización práctica, así como financiera de la realización?

2. Caso que la misión, por razón de sus resultados con referencia a 1, llegue a la conclusión que los elementos disponibles justificarán la realización de la investigación propuesta y si, además, considera una investigación de esta índole factible ante la situación actualmente reinante en Nicaragua, la misión presentará sus recomendaciones relativas a la organización y la materia de la investigación propuesta, a las autoridades nicaragüenses.

ad 1 La aplicabilidad

La preocupación principal de esta parte de la misión es: ¿existen indicios por los que se pueda garantizar un mejoramiento esencial resultando del método propuesto, respecto a aquellos métodos conocidos por la literatura y la práctica?
La misión intentará encontrar una solución de este asunto ante la situación nicaragüense, y eso, en primer lugar en cuanto a la depuración de las aguas residuales domésticas de Managua, y, si es posible, también de aquellas de Masaya (o de otras localidades nicaragüenses).

1.1 Con el fin de dar una idea de la importancia de la depuración, la misión trazará un plan global de los perjuicios al ambiente y a la salud, resultantes de la falta de depuración en la(s) localidad(es) correspondiente(s).

1.2 Además, la misión establecerá un inventario de la situación actual de la evacuación de las aguas residuales domésticas, en Managua y eventualmente en otras localidades de Nicaragua, lo que también tendrá que hacer con respecto a las exigencias, condiciones fundamentales, resp., necesarias para un método de depuración de las aguas residuales, centralmente alcantarilladas:
   * cantidad y calidad de las aguas residuales,
   * exigencias de calidad actuales, relativas al efluente,
   * el cuadro institucional de la depuración de las aguas, y
   * estrangulamientos financieros, organizatorios, técnicos, etc.

Como no existe modo alguno de expresar en dinero efectivo los beneficios de una buena depuración de las aguas residuales, no es posible llevar a cabo un análisis completo de los gastos y beneficios del método propuesto; por e se estimará la aplicabilidad o factibilidad práctica por medio de un análisis del rendimiento de los gastos : se establecerá un paralelo entre este método de depuración y otros que,en forma aproximada, dan los mismos resultados ('beneficios'), causando menos o todavía más gastos.
El paralelo arriba citado tendrá referencia no sólo al sistema propuesto de depuración previa (UASB), sino también a la depuración ulterior, por medio de un sistema de estanque, constituyendo una combinación de algas y plantas acuáticas.

1.3 En este respecto, la misión determinará, primero, las condiciones físicas, técnicas, institucionales y organizatorias que parecen ser necesarias para poder lograr una aplicación práctica y conveniente del método de depuración que forma parte de la investigación.

1.4 Después, la misión indicará aproximadamente el rendimiento de los gastos del sistema de depuración previa -UASB-, aplicado bajo las condiciones precitadas, en comparación con un simple estanque anaerobio, a base de una evaluación de los gastos económicos de ambos sistemas.

1.5 El sistema propuesto de depuración ulterior será también globalmente determinado por la misión, por razón de un paralelo entre (1) la depuración ulterior por medio de estanques que sólo contienen algas y (2) la depuración por estanques que solamente disponen de plantas más altas.

La aplicabilidad y la viabilidad económica del método de depuración propuesto estarán también sujetas a las posibilidades y los efectos de la reutilización de productos de recuperación, potencialmente valiosos (agua, biogas, plantas acuáticas, etc.), del proceso de depuración.

1.6 La misión establecerá un inventario cualitativo de las posibildades de reutilizar los productos de recuperación resultantes del proceso de depuración; si posible, se presentará una estimación más bien económica y cuantitativa,' en pro del análisis del rendimiento de los gastos, tratado bajo los puntos 1.4 y 1.5.

1.7 A ser posible, se hará mención de la susceptibilidad de los resultados del análisis del rendimiento de los gastos, respecto de variaciones relativas a las condiciones fijadas para la aplicación (véase 1.3). Es preciso tomar en cuenta la extensión de la aplicación, las condiciones físicas y técnicas, el cuadro institucional y organizatorio, la organización de la economía industrial (financiera), etc.

Además, se examinará la susceptibilidad de variaciones en los gastos (corrientes, así como aquellos destinados a inversiones).

Finalmente, el análisis de susceptibilidad abarcará también el riesgo de la discontinuidad de la depuración de las aguas residuales, originada por la susceptibilidad de(l) (los) método(s) de depuración, lo que se refiere, en primer lugar, parte biológica.

Quizás, algunos puntos de la aplicabilidad del método propuesto no puedan ser tratados por la misión sin previo aviso, pero necesiten un examen más puntualizado, dentro del proyecto de investigación propuesto.

1.8 Respecto a aquellos aspectos de la aplicabilidad práctica del método de depuración propuesto,debiendo ser examinados más de cerca, la misión redactará algunos puntos de investigación, los cuales podrán ser integrados, o no, en el programa de investigación del proyecto propuesto.

ad 2 La investigación propuesta

a. En vista de la importancia de la investigación propuesta, la misión compondrá un comentario, basándose, en primer lugar, en sus resultados relativos a la aplicabilidad del método de depuración propuesto. En ello, recomendará posibles suplementos o modificaciones, susceptibles de emanar de los resultados de la misión, con respecto a las perspectivas y condiciones de la aplicación.

b. Con respecto a la disposición de la investigación propuesta, la distribución de las tareas entre las diferentes organizaciones (nicaragüenses y holandesas), así como a otros aspectos prácticos de la proposición, la misión se entrevistará con las diferentes organizaciones respectivas de Nicaragua. En ello, someterá a discusión, sobre todo, todos los puntos subrayados en los diferentes comentarios a la proposición hecha por INAA/SAWA. Sin embargo, en su informe, la misión hará también mención de todo ello.

APPENDIX 2. Itinerary of the Mission

DATE	ACTIVITY
20-9	Departure Amsterdam, Arrival Gainesville, Fla., USA
21-9	Visit to the site of the research project of IFAS in Orlando, EPCOT-Center, regarding wastewater treatment based on waterplants and digestion of this biomass
22-9	Visit to IFAS, Univ.of Florida, discussions with Dr. Chynoweth and staff IFAS Departure Gainesville, Arrival Managua
23-9	Reception of the mission by Mr. Otoniel Argüello, Minister of INAA, Mr. Carlos Espinosa, Vice-Minister INAA, and counterpart staff to the mission of INAA, UNI and CIRA Visit to UNI, Dep.of Environmental Engineering, Head Dr. Sergio Vado + staff Visit to CIRA, Mr. Montenegro Guillen and Mr. Mauricio Lacayo
24-9	Discussions at UNI with departmental staff and Mr. Reining, seconded to the Department of Environmental Engineering by the TU-Delft via NUFFIC Departure to Matagalpa
25-9	Matagalpa: visit to the project-site of anaerobic treatment of the wastewater of coffee processing plants (SNV, Mr. R. Wasser) Visit to Matagalpa drinking water treatment plant (JvB)
26-9	Return to Managua Working session at INAA, visit to drinkingwater plant INAA, to the wastewater disposal system in the city, and to the city's refuse dump Visit to Alcaldia of Managua, Mr. Juan Carvajal Zamora, Director General de Calidad Ambiental
27-9	Visit to the wastewater facilities of Masaya and Granada, with staff UNI
28-9	Visit to bio-gasification installation near Managua (ENPRA) Discussion at IRENA, Mr. Caceres

29-9	Visit to 'Cooperación Holanda' [HS]
	Visit to Ministry of Health (MINSA), [JvB]
	Working session at UNI, with Mr. Vado and staff
	Second Visit to Alcaldia of Managua.
30-9	Visit to Lake Managua with boat of CIRA
	Discussions with Mr. Espinosa, INAA, with respect to the institutional aspect of the proposed project
1-10	Working session at UNI, discussions with respect to project design, contents, timing, etc.
	Visit to Los Brasiles [JvB]
2-10	Second visit to Masaya project site
3-10	Reunion with INAA, UNI, CIRA; presentation and discussion of provisional conclusions by the mission
4-10	Discussions at UNI regarding the project proposal
	Informal meeting of mission with 'Cooperación Holanda', Vice-minister INAA, Head Dep.of Env.Eng. of UNI, Dep.head CIRA: presentation of mission's findings
	Meeting with Arq. Edgard Herrera Zuniga, Rector of UNI
5-10	Final Meeting at INAA, debriefing.
	Departure Managua
	Unforeseen stop San Salvador because of technical problems plane
6-10	Departure San Salvador
7-10	Arrival Amsterdam.

APPENDIX 3. References

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