SEWAGE MANAGEMENT IN BONAIRE

Evaluation of Proposed and Alternative Solutions for Reduction of Nitrogen Pollution to Coastal Waters

Report by

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Delft, 17 November, 2004

SUMMARY

This report is the expert opinion of staff from the UNESCO-IHE Institute for Water Education on the proposed Sewerage and Sanitation System for Bonaire Island. The expert opinion is based on a study of the available project documents and interviews during a short visit to the island. The study was carried out on the request of the WWF. Its aim was to evaluate the existing plan and to provide information on possible other, more effective solutions.

Problem description
The problem that is to be addressed by the proposed Sewerage and Sanitation System is the nitrogen contamination in coastal waters around Bonaire, which results in declining reef quality. In this report special attention is therefore paid to nitrogen in wastewater and its management.

The proposed solution
The existing plan includes collection of household and hotel wastewater in a vacuum sewer in the sensitive zone, a stretch of 10 km along the coastline in and near Kralendijk. The wastewater from this zone is to be pumped to a central wastewater treatment plant of the activated sludge type that is combined with effluent filtration and UV disinfection. Considerable amounts of septage are also to be treated in this plant. The effluent is to be returned via an irrigation scheme to the hotel area and used for irrigation.

Evaluation
The calculations in the Feasibility Study on the proposed project did not convince the experts that the amount of nitrogen that is percolating from the coastal zone to the sea is reduced by implementation of the proposed project. In fact, it is likely that the amount of nitrogen applied to the most sensitive zone (the hotels at the shore) is going to be increased by the project and the percolation of nitrogen to the sea may therefore increase as well. A preliminary mass balances over the hotel gardens showed that significant percolation of nitrogen can be expected.

The cost of the proposed solution is high, especially for the wastewater collection system. Moreover, a substantial part of the operation and maintenance cost is to be covered from the marketing of irrigation water to the hotels. The willingness of the hotel owners to buy back the effluent at the proposed price is questionable, and therefore the financial sustainability of the project as well.

Recommendations
It is recommended to replace the proposed project by an alternative option. The alternative option described in this report follows a decentralized approach, in which existing infrastructure (package plants at a number of hotels, tanks at households) is as much as possible used in combination with new infrastructure.

For the hotels (or a cluster of hotels) the wastewater collected in the existing local sewer systems is to be treated in upgraded or new package plants for wastewater treatment. The package plants should remove nutrients and include disinfection for local reuse in irrigation. Commercially available package plants are able to provide effluent with better quality than is expected from the plant in the proposed project. Therefore, and because the septage will be kept separate from the wastewater, the nitrogen load to the gardens will be much less than in the proposed project.

For the households the existing storage tanks and infiltration pits are to be upgraded to septic tanks. The septic tank effluent is to be collected in a small diameter gravity sewer system. This sewer type is less costly than the proposed vacuum sewer. The small diameter gravity sewer systems are to be connected to package plants in a similar way as for the hotels.

This alternative option scores better than the project design proposed by the consultant, in terms of: reduction of nutrient flux to the sea, cost-effectiveness and complexity of technology. Crucial for a successful implementation of the alternative option is a dedicated and well-trained organisation for operation and maintenance of the infrastructure. This provides employment and business opportunities.

Final recommendations

We recommend that the alternative option is worked out in further detail and implemented. This report indicates that this option has a better feasibility than the project proposed by the consultant.

We strongly recommend that the EU, as an important party in the wastewater project on Bonaire, enters in open and constructive consultations with all stakeholders to review the situation and to jointly decide on (new) directions to be taken.

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Sewage Management in Bonaire

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Abbreviations

BHG	Bonaire Hospitality Group
BMG	Bonaire Management Group
BNMP	Bonaire National Marine Park
BNR	Biological nutrient removal
BOD	biological oxygen demand
BONHATA	Bonaire Hotel and Tourism Association
CBS	Central Bureau of Statistics
COD	chemical oxygen demand
CURO	Counsel of Underwater Operators
DROB	Dienst Ruimtelijk Ordening en Beheer
GDP	Gross Domestic Product
N	Nitrogen
PE	population equivalent
SBR	Sequencing Batch Reactor
STINAPA	Stichting Nationale Parken
TCB	Tourism Corporation Bonaire
UNESCO	United Nations Educational Scientific and Cultural Organisation
WEB	Water en Electriciteits Bedrijf
WWTP	wastewater treatment plant

Exchange rates used in this report

1 € = 2 ANG
1 € = 1.2 US$

1. Background

1.1 Bonaire – a Diver's Paradise

Bonaire is a small island in the South-East Caribbean sea, about 80 km north of the Venezuelan Coast. Together with 4 other islands in the Caribbean Sea it forms part of the Netherlands Antilles. With a total surface area of about 285 km^2 and only around 10,000 inhabitants, the island Bonaire is not densely populated (CBS, 2004). The majority of population is concentrated in and around the capital Kralendijk, the rest lives rather dispersed over the island.

Box. 1. Key data on Bonaire (source: CBS 2004; DEZA, 2004)

Location:	80 km north of Venezuela, 50 km east of Curacao, 130 km east of Aruba
Population:	10,000
Religion:	Roman Catholic, Protestant, Jewish
Languages:	Dutch, Papiamento, English, Spanish
Area:	285 km^2, 38 km long, 11.5 km across at widest point
Government:	Part of Netherlands Antilles, an autonomous State within the Kingdom of The Netherlands
GDP:	US$ 2.4 – 2.8 billion (for Netherlands Antilles) US$ 115 million
GDP per capita:	US$ 11,500
Gross-revenue diving industry	US$ 23.2 million (1992)
Inflation:	3.3%
Major industries:	Tourism, related activities (e.g. real estate), shipping, salt production
Stay-over tourists:	64,176 (year 2003)
Cruise tourists:	44,601 (year 2003)
'Discovered':	1499 by the Spanish

Bonaire is one of the least tourist developed and least visited of the larger islands in the Caribbean. Yet it is often referred to as a divers paradise. The Island indeed has earned a reputation as a prime diving and snorkeling destination, and is consistently ranked in the World's top ten diving locations. This is because the island is surrounded by fringing reefs, clear waters, and beautiful spots for reef diving that are accessible few feet from the shore. With about 50 to 60,000 stay-over arrivals per year (DEZA, 2004), the tourist and diving industry presents a major source of income to the resident population. In addition to the stay-over tourism, also some 40-45,000 cruise boat tourists visit the island on an annual basis. The value of marine tourism to Bonaire Marine Park (BMP) was estimated by Dixon *et al.*(2000) at $US23.2 million in 1991. The government generated an additional $US340,000 through taxes levied directly on visiting divers. The BMP also generates substantial employment with up to 755 local workers and 238 foreign workers employed in Park-associated activities. By 1994 annual visitor numbers to BMP had increased to 65,820, of whom 24,081 were divers, and 57 cruise boats visited the BMP. Protection of the rich marine environment is therefore of key importance for the island's economic development. Bonaire indeed has gone to great lengths to preserve its natural resource. In 1979 the Bonaire National Marine Park was established, and subsequently it obtained legal protection as a National Reserve. In the year 2002, on the initiative of UNESCO, a group of experts declared the Southern Caribbean group of islands as an area of 'Outstanding Universal Value'. This status forms an important step towards recognition by UNESCO on its 'World Heritage List'. Some key data on Bonaire are summarized in Box 1.

1.2 Concerns about Coastal Pollution

Already for over a decade concerns have been voiced over an observed trend of declining reef quality (Callum, 1994). There are indications that this trend is caused (in part) by sewage contamination of coastal waters. Bonaire has no sewage collection and treatment system. Most households and commercial establishments use septic tanks, cesspits, and leach holes, while only few hotels have an on-site wastewater treatment plant installed (the efficiency of which is unclear). As a result, nutrients dissolved in the sewage may reach the coastal water via infiltration through the porous limestone underground or via run-off. The fringing reef surrounding Bonaire represents a delicate natural resource, which is particularly sensitive to even low levels of nutrients in the water. It is generally assumed that the damaging effect of nutrients on coral reefs is caused by the stimulation of algal growth, which subsequently covers and 'suffocates' the coral. Nutrients may also reduce the vitality of coral reef in other ways. Callum (1994) refers to the case of Barbados to stress the rapid and dramatic effects eutrophication may have on coral reefs. Within a period of merely 30 years, the thriving coral communities around Barbados have been reduced to lumps of algal covered rock. Secondary effects included loss of fisheries, and beach erosion problems on the island, threatening much of the resort infrastructure along the South Coast. For Bonaire, a similar event would have severe consequences in terms of significant decreases in diving tourism, thereby destroying the island's economic base. In addition, the resort infrastructure would likely be threatened by coastal erosion, while fisheries around the island might also decrease substantially. The predicted direct consequences for the local economy indeed call for immediate action.

Even low levels of nutrients may lead to substantial increases in algal growth, and nitrogen (N) levels are of particular concern, since this element is usually considered to be the 'growth limiting' nutrient in the coastal marine environment. Although the sewage problem on Bonaire needs to be addressed as a general pollution problem, particular attention has been given to <u>Nitrogen</u> in discussions about possible solutions.

1.3 Proposed solution

The Government of The Netherlands Antilles has requested the European Commission to assist Bonaire with the financing, development and implementation of a sound sewage management system. The EC has agreed to provide funding for the proposed construction of a sewerage and wastewater treatment system, with a view to protect the sensitive coral reefs around Bonaire from eutrophication. In July 2002 the German company Dorsch Consult was awarded a contract for the development of a Masterplan and a Feasibility Study for a sewage management scheme on Bonaire.

Dorsch Consult implemented a feasibility study in 2002, in which they propose to collect and treat the sewage of Kralendijk and an adjacent 10 km stretch along the coastline (the so-called sensitive zone). The main characteristics of the proposed sewage management scheme are summarized in Box 2.

As can be derived from Box 2, the proposed activated sludge system is not designed to include biological nutrient removal (including Nitrogen), while a substantial part of the effluent is proposed to be reused for irrigation for the green zones of hotels in the 'sensitive zone'. This has raised concern with a number of parties and stakeholders on Bonaire, since nutrients, including nitrogen, will be brought back to the coastline (be it in a controlled manner).

1.4 ToR and scope of this study

The EC has approved the sewage collection, treatment and reuse plan proposed by Dorsch Consult, and has meanwhile awarded a contract for implementation to the same consultant. The Department of Development cooperation of The Netherlands Antilles (DROB), has formed a Steering Group to accompany the project in all its stages of planning and implementation (Steering Group Sewer Project Bonaire). Several environmental NGOs (a.o. Aliansa Naturalesa Boneiru, STINAPA - Foundation of National Parcs of Bonaire), hotel and tourist associations, and other stakeholders have expressed reservations with respect to the effectiveness of the proposed solution in terms of managing Nitrogen. In addition, reservations have been made about the cost-effectiveness of the proposed solution.

Box. 2. Main characteristics of proposed sewage management scheme (Feasibility Study, 2003).

The approach taken in the feasibility study is to collect and treat the generated sewage of Kralendijk and surroundings. The main characteristics of the proposed technology are listed below.

- The selected drainage system is a vacuum system
- The sewage from the sensitive zone is collected and treated in a centralized treatment plant in the centre of the island.
- The treatment system will be activated sludge (SBR), without biological nutrient removal; UV disinfection is planned to achieve pathogen removal
- Part of the treated effluent will be conveyed back to the hotel area for irrigation and landscaping purposes.
- The investment costs amount to ANG 24.5 million, the total contribution of the EC amounts to 14 million Euro

The price of effluent for irrigation is set at 2.5 ANG/m^3 (€1.25 /m^3)

- Cost of connection for residential plots are 2300 ANG (€ 1150)
- Cost of connection for commercial establishments are 3600 ANG(€ 1800)
- Cost of connection for hotels are 12000 ANG (€6000)
- Legislation will need to be changed in order to make the reuse of effluent feasible

UNESCO-IHE Institute for water Education was approached by WWF in July 2004 with a request to provide an independent expert opinion on the proposed sewage management plan. In addition The WWF requested UNESCO-IHE to provide information on possible other, more effective solutions. The detailed ToR for this assignment is presented in Annex 1. The experts made available for this study include Prof. dr. H.J. Gijzen (Head of Pollution Prevention and Control), and Dr. P. van der Steen (wastewater treatment engineer), both staff members of UNESCO-IHE. Considering the time and budget restrictions for the assignment these experts have taken an approach in which:

- The relative contribution of sewage production on Bonaire to nitrogen contamination in coastal waters is considered (Chapter 2),

- the proposed collection, treatment and reuse plan was reviewed in terms of effectiveness in addressing the prime source of the problem: nitrogen (Chapter 3), and,
- possible alternatives for achieving substantial reductions in coastal nitrogen discharge were identified and briefly described (Chapter 4).

In addition, the experts have considered the cost effectiveness of the proposed solution. The report will end with a series of conclusions and recommendations (Chapter 5). The approach consisted of studying the reports prepared by Dorsch Consult, by interviews with various stakeholders and project partners (including staff of Dorsch Consult), and by site visits (a.o. landfill, LVV site, hotels and their WWT infrastructure). The agenda for the 4 day visit is presented in Annex 2.

2. Origin of Nutrient Pollution

The feasibility study by Dorsch Consult (further referred to as 'the Consultant') points at sewage from households and commercial establishments (including hotels) as the main source of the identified nutrient problem affecting the coastal waters around Bonaire. Although we concur with the conclusion, that sewage is likely to present an important source of nutrient pollution, we believe that two essential steps are missing in the feasibility study:

1. An assessment or preliminary inventory of important sources of nitrogen pollution within the wider region (southern part of the Caribbean Sea).

2. Development of a mass balance for Nitrogen (imports, flows and transformations) on Bonaire island.

2.1 Possible sources and impacts

Eutrophication problems affecting coastal waters of small islands like Bonaire should be considered within the broader context of potential sources of nutrient discharge in the wider region. This is important considering the fact that the population on Bonaire is rather small (about 10,000 P.E.) and tourism is limited (<2000 P.E.). One would expect that a feasibility study would first consider all possible sources of nutrient pollution (especially Nitrogen), before zooming in on the technical options for sewage management on the island.

Bonaire and its coastal zones could be subject to influences of nutrient pollution far outside its own territory. Caracas, the capital of Venezuela with a total population of about 5 million people is located at about 230 km from Bonaire. Caracas has currently no sewage treatment system and most of the wastewater from domestic and industrial sources is discharged into the coastal waters. The same is in fact true for the entire coastline between Caracas and Maracaibo. Depending on the flow patterns and morphology of the Carribean Sea between the Venezuela coast and Bonaire, nutrients present in sewage discharges from Venezuela might affect the water quality around Bonaire. In fact, a preliminary assessment of flow patterns in this region suggests that the water flow direction indeed is from Caracas to Bonaire. Besides Venezuela, there may be other sources of pollution from neighbouring islands (Curacao), and from yachts and (cruise)ships in the Caribbean Sea.

We recommend that some attention will be given to this, by making an inventory of possible sources of eutrophication in the wider region. It is further recommended that simple modeling and flow simulation tools are used to predict the possible influence of sewage discharges in the region on the quality of coastal waters around Bonaire. Whatever the outcome of these studies, we wish to stress that local sources of pollution need to be tackled anyway. Sewage management on Bonaire needs to be addressed!

2.2 Nitrogen mass balance for Bonaire

Besides sewage, there may be other important sources of nitrogen pollution on Bonaire island. The establishment of a nitrogen mass balance for the island will help to visualize the relative contribution of sewage to the total nitrogen balance. Below a preliminary N mass balance is presented.

Major components for the N mass balance include:

- Import and subsequent application of N-fertilizer
- Municipal solid waste (which eventually ends up on the landfill)
- Food imports for human consumption (this will be accounted for under solid waste and sewage N)
- Sewage from households and commercial establishments (incl. Hotels)
- Sewage from airport (from airplanes, visitors and staff)
- Acceptance of sewage from boats and (cruise) ships
- Import of animal feed (e.g. chicken farm, other animals)
- Slaughterhouse waste

Table 1 presents a rough estimate of the amount of nitrogen contributed by each of above mentioned N-sources. Details on calculation of the values presented can be found in Annex 3.

Table 1. Main sources of nitrogen contributing to the total N mass balance on Bonaire.

N-source	**Annual imports/prod.**	**Kg N per year**	**% of total**	**Comments**
Fertiliser	2400 kg	840	1	Import is not restricted
MSW	7.1 million kg	43000	37	0.6% N (dry wt)
Sewage: • Domestic/hotels • Airport • Cruise ships	 12000 P.E. 500 P.E. 500 P.E.	47000	41	
Animal feed	1 million kg	21600	19	90t/months
Slaughterhouse waste	20500 kg	1640	2	25% waste 50% protein
Total	N.A.	114080	100	

From the data in Table 1 it becomes clear that sewage contributes about 40% of the total nitrogen balance on the island. Important other sources of nitrogen include animal feed imports (19%) and MSW (37%). The nitrogen in waste dumped in the landfill, may become mobilized via leachate, which might penetrate in the porous underground (there is no lining applied in bottom part of the landfill on Bonaire). The N present in imported animal feed, may find its way to the coastline in case animal excreta are transported via run-off.

We recommend that possible ways to improve the N balance on the island are considered by minimizing N-influx and introduction of N-sinks. Options include:

- The banning or control of fertilizer imports
- The banning of sewage discharges from cruise ships to the island
- The banning of sewage discharges from airplanes
- Establishment of a sanitary landfill, ensuring no leachate infiltration occurs
- Reconsider the animal production system on the island (e.g. produce own animal feed and control animal feed imports, reuse of animal excreta)
- Stimulate agricultural production and pasture production based on waste(water) reuse.
- Consider organic-N (sewage effluent and manure) application to sport fields
- Consider the development of a golf course on the island (N-sink and source of income).

Paragraph 2.1 has pointed at the possibility of other important sources of N contamination in the southern part of the Caribbean Sea. These sources might significantly contribute to raising background levels of N in the coastal waters of Bonaire, thereby posing a threat to the reef. Paragraph 2.2 has underlined the fact that besides sewage, there are other important sources of N pollution. Sewage contributes to about 40% of the total N-balance on the island.

3. Evaluation of Proposed Solution

3.1 Design and planning process

Page 12 of the Feasibility Study by Dorsch Consult states that the objective of the project is *"..to establish a centralized sewer system and a wastewater treatment plant to establish modern standards of sewage treatment on the island of Bonaire in order to protect the marine environment."* The consultant has prepared a masterplan for the project and subsequently has implemented a feasibility study for the provision of sewerage and wastewater treatment for the more densely populated coastal strip of Kralendijk.

The objective is formulated in such a way that the provision of a *centralized* sewer system and a *centralized* treatment plant forms an integral part of the objective. The feasibility Study report also states that "The project will contribute to a significant reduction of the input of land borne nutrients and nutrients from ships into the coastal waters." Indeed, the contamination of coastal water with nutrients, particularly nitrogen (N) is generally considered to be THE central cause of the observed problem of reef deterioration. Since all parties generally accept this, one must assume that the purpose of any intervention should be to reduce N discharges into coastal waters. Therefore, the main objective could be phrased as "the protection of the reef by achieving substantial reductions of the nutrient flux (particularly nitrogen) into the sea". Subsequently, the selection of the strategy and best available technology to achieve this could have been the subject of the feasibility study. As it is formulated now, it seems that from the start of the feasibility study the centralized option was perceived as the favoured one.

The selected sewage management scheme collects and transports Nitrogen and subsequently divides it into fractions (sludge/filtered, effluent). The proposed scheme, however, does not remove nitrogen (removal is defined as a process that causes N to leave the island, e.g. in form of N_2). In terms of sustainability, one needs to consider ways to compensate the current net import of N to the island. It is surprising that the consultant has not considered BNR in the technological design, which could yield true N-removal. We recommend that the effectiveness of the proposed solution is expressed in terms of kg N removed, while cost effectiveness could be expressed in Euro/kg N removed.

3.2 Critical review of important assumptions

The consultant has made a number of assumptions which are essential to the success of the project as well as assumptions directly related to the design of the infrastructure, especially the treatment plant. A number of important assumptions are fundamentally flawed. In addition, a number of weaknesses were observed in the technical design. The critical assumptions discussed below are grouped into two categories, according to how these affect: a) the effectiveness of reducing N discharges, and b) cost effectiveness.

3.2.1 *Effectiveness in reducing N discharges*

<u>N mass balance</u>
The consultant has made no attempt to make a nitrogen mass balance, which could demonstrate that sewage indeed is the main contributor to the nitrogen pressure on the reef (see par. 2.2). Implicitly this suggests that the consultant assumes that sewage from Bonaire is the main source of N contamination in the coastal water. Par. 2.1 points at other important sources of N-contamination from the wider region, while par. 2.2 suggests that sewage contributes to about 40% of all nitrogen on the island.

<u>N removal efficiency</u>
The consultant assumes that 75% N removal can be achieved in the wastewater treatment plant (from 114 mg/l in the raw wastewater to 28 mg/l in the effluent). First of all we would like to point out that this would yield an effluent level of N which is close to N levels of raw sewage from the hotels. It is therefore questionable that irrigation with such effluent could provide an improvement compared to the current situation. Besides, a 75% N-removal efficiency is not likely considering the proposed technical design (40% would be more realistic). Further details are presented in par. 3.3. It is therefore likely that the N level in the irrigation water will be substantially higher than 28 mg/l (about 68 mg/l).

<u>Organic N hydrolysis</u>
The direct treatment of sewage and septage without pre-settling and solids removal stimulates hydrolysis of organic-N and release of ammonia in the SBR. Once N is present in mineralized form (NH_4, NO_3, NO_2), it can no longer be removed from the treatment plant via (suspended) solids removal. This fact will contribute to effluent N-values substantially higher than the reported 28 mg/l.

N dosage via irrigation of hotel gardens
The consultant argues that 28 mg/l N in the effluent provides an appropriate N-dosage for irrigation of the hotel gardens which provides sustainable protection of the reef. The underlying assumption is that the N-dosage is less than the European Union guideline for N application in drinking water protection areas (40 kg N/ha/year).

However:

a. Drinking water resources in the EU are allowed to have up to 10 mg/l of NO_3, while the coastal waters in Bonaire must keep N levels at virtually undetectable concentration. In combination with the porous underground of Bonaire, dosage of 40 kg/ha.y might yield significant nutrient fluxes to the coastal waters.

b. The type of vegetation used in the hotel gardens is not expected to have a high nutrient requirement.

c. Re-calculation of the proposed irrigation scheme suggests that at least 77, and more likely even over 186 kg N will be added per ha hotel garden per year in stead of the assumed <40 kg/ha.y (see below).

Nitrification
The Feasibility Study assumes that nitrification will not occur in the SBR treatment plant. At the reported temperatures and sludge retention times, however, nitrification will most likely occur (Gray, 1990). As a consequence, the assumed oxygen requirement of the SBR will increase almost 5-fold (higher O&M costs). Besides, bulking sludge phenomena are likely to occur, and these might negatively affect the N-removal efficiency.

3.2.2 *Cost effectiveness*

High per capita investment costs
The proposed sewage management system is expensive by any standards. The WHO quoted in 1990 typical sewerage investment cost for Latin America and the Caribbean of US$ 120 per capita (WHO, 1990). Assuming a 5% increase in cost per year, todays cost would be US$ 240 per capita. The investment cost for sewerage in the proposed project is 2161 ANG or US$ 1294 per capita (12.3 mio ANG/5692 PE hydraulic). Though the conditions in Kralendijk (high excavation cost due to rocky soil, no natural slope) may cause higher cost, the sewerage cost in the proposed project are high and the per capita investment costs are amoung the highest values reported in the world. Besides, household and hotels are required to pay for their connections, while hotels will be charged additionally for irrigation water. It is therefore not surprising that the Feasibility Study states that a full cost recovery scheme (including O&M costs and depreciation of investments) is not feasible. Instead the report suggests to operate at "…wastewater charges, which adequately cover just O&M cost in combination with the medium irrigation water price of 2.5 ANG/m^3.

Higher O&M costs
The O&M costs for the sewerage, treatment and reuse system are calculated by the consultant as 113 ANG or US$ 65 per P.E. per year (1.03 mio ANG/ 9083 PE). In reality the O&M costs are higher, since the O&M cost for the SBR system are likely to be higher than assumed in the Feasibility Study. The SBR reactor will require

substantially higher aeration levels, considering the fact that nitrification is likely to occur.

High connection fees

The consultant assumed that both households and hotels are willing to connect to the sewer system and are willing and able to pay for the connection fee. However, the proposed connection fee for households is ANG 2300,- (US$ 1377,-), which is about 1.2 times the average income per capita per month (http://www.minbzk.nl/aruba_en_de/armoedebestrijding). The consultant has based the affordability analysis on two example-households with a monthly income of ANG 750 and ANG 2000, respectively. For these example-households the connection fee is 3 and 1.1 times the monthly income. For the poorer segments of the Bonairean population, this is not affordable. These figures suggest that the willingness to connect and pay the connection fee is rather uncertain. Moreover, it will be difficult to force people to connect, since about 80% of the island population will continue to use septic tanks or infiltration pits anyway. Considering the costs, many households may prefer to continue to rely on septic tanks or similar systems.

The feasibility Study suggests that hotels will pay an average connection fee of 12000 ANG. Although this investment may be quite affordable for most hotels, it is not likely that hotels with on site sewage treatment systems would go for this (thereby losing their investment in WWT, and losing their currently ‘free’ irrigation water).

Investment losses

The proposal by the consultant suggests that the existing infrastructure of septic tanks in the target region will be dismantled. This will represent a substantial loss of capital investment. Similarly, the existing infrastructure for wastewater treatment at various hotels will be lost.

Price irrigation water

The consultant assumes that the hotel owners will buy the treated effluent for landscaping of their gardens, at a price of 2-3 ANG per m^3. However, some hotel owners indicated that they are able to produce irrigation water at almost similar cost. It is questionable whether the hotel owners are actually willing to buy the effluent at these prices. To force the hotel owners to buy the effluent irrigation water by prohibiting on-site production of drinking water may prove to be legally difficult. The income from effluent sale to the hotels (240000 – 360000 ANG per year; Table 6.1, Feasibility Study) amounts to some 30% of the total operation and maintenance cost for the sewer, the treatment plant and the irrigation system (1.0 million ANG per year; Table 6.6, Feasibility Study). The income from effluent sales seems therefore crucial for the financial feasibility of the project. If the effluent cannot be marketed, the feasibility of the entire operation will be endangered. From meetings with hotel owners and representatives of tourist- and hotel associations on Bonaire, it became clear that there is very little support for the proposed scheme. The assumption of the Feasibility Study that 2/3 of hotel owners will buy the effluent at 2.5 ANG/m^3, therefore, is doubtful.

Institutional arrangements

The institutional arrangements for the proposed sewage management system form a crucial factor, which will directly affect the effectiveness of the system i.t.o. N reduction and cost. The Feasibility Study states, “…the facilities shall be operated by WEB” (p17). However, in a meeting with the Director of WEB this position was denied. The Director of WEB explained that under the current technical proposal he would not be interested to take up the wastewater scheme in his company.

3.3 Evaluation of the technical project design

3.3.1 *Summary of technical project design*

The proposed project includes the connection of households, restaurants and shops to a sewer system, for the collection of a total of 2239 person equivalents (P.E.) of waste load. In addition, also hotels and resorts will connected. The hydraulic load from the hotels is estimated to be equal to 3560 P.E., while the waste load is estimated to be 1780 P.E. The wastewater collected in the Kralendijk sewer system will be pumped to the wastewater treatment plant, located near the center of the island. The proposed sewer system is a vacuum sewer, which is divided in 5 zones. Each zone has its own pumping station.

At the site of the wastewater treatment plant, the wastewater will be mixed with septage, originating from the households that are not connected to the sewer and the cruise ships. The sludge is transported to the site by tankers (similar to the current situation, where the sludge is disposed in drying beds near the proposed WWTP site). The unsewered population is estimated to be 10156 in 2017 (85% of the population). It is further assumed that 50% of the septage is actually collected and treated. The septage volume is assumed to be 600 l/capita/year with a BOD load of 200 PE/m^3. The volume of septage from the ships is reported as 10 m3/day. The combined BOD load of domestic septage and cruise-ship septage to the wastewater treatment in 2017 is expected to be 5171 PE, that is 57% of the total load (9083PE). The wastewater treatment plant consists of:

1. a screen
2. a parshall flume (for flow measurements)
3. an aerated grit and grease removal
4. a pumping station
5. a blower/generator station
6. an activated sludge biological treatment of the Sequencing Batch Reactor type
7. a sand filter
8. a UV disinfection unit
9. a Magnetic Inductive Flow meter
10. a sludge thickener
11. sludge drying beds
12. sludge composting site

Part of the treated effluent is to be returned with a pipeline to the hotels located in the 'sensitive zone' (330 m^3/day, 42% of total wastewater inflow; Table 6.1). It is assumed that at least 2/3 of all hotels will be connected to this system and will use the effluent for irrigation.

3.3.2 *Comments on the proposed technical design*

<u>Low coverage</u>

The proposal only covers a small part of the wastewater generated in households, restaurants and shops in Bonaire (only 3912 pe, so less than 1/3 of the total number of PE of the entire island. This leaves 67% of the island's wasteload under the current scheme of septic tanks or pits, with potential subsequent leakages of N via overflow and infiltration. Of course, the proposed project is only a first step towards full coverage, but the poor cost-effectiveness of the proposed project (3.2.2) would probably preclude the development of any future second phase. This justifies the search for an alternative solution, which could deal with a larger share of the total population.

Combining septage and sewage

The consultant has proposed to mix the septage with the raw wastewater, treat this mixture in the SBR reactor and subsequently bring part of the effluent back to the hotel area. It is not clear from the study why the septage is introduced in the SBR reactor. Septage from septic tanks is commonly kept separate from (relatively diluted) wastewater and disposed off by thickening, drying and/or composting. Keeping the septage separated from the wastewater could reduce the waste load to the SBR reactor with 57%! This would require a much smaller reactor and much less aeration during the treatment process. Addition of the septage requires a lot of oxygen for oxidation of the organic matter present in the septage and also of ammonium-nitrogen present in the septage. It is therefore highly recommended to keep the septage separate and treat it separately by improving the system of drying beds, which is already in place.

By adding septage the influent nitrogen concentration is substantially increased (to about 114 mg/l). Consequently, the effluent N concentration will be higher and therefore also the amount of nitrogen transported back to the hotel gardens (and possible via runoff/infiltration to the reef) is increased.

Besides, the hydrolysis of organically bound N in the SBR will make the removal of nitrogen via solids separation impossible (only via sludge generated in SBR; see par. 3.2.1) Also this will contribute to high effluent N-levels. The fact that the proposed sewage management scheme does not a) separate organically bound N first, b) introduces septage in the SBR, and c) does not include BNR suggests that the consultant is not considering N reduction as a prime objective.

Irrigation scheme and N mass balance

The following analysis shows that the proposed project most probably will not reduce the nutrient flux from the sensitive zone to the sea:

In order to assess whether the proposed solution will prevent or reduce a flux of nutrients from the project area into the sea, a preliminary mass balance was made over the area to be irrigated with treated sewage. The following areas are defined (par. 3.5.1, p45 in Feasibility Study):

- Project area, i.e. the area serviced by the sewer system: 550 ha.
- Area serviced by the irrigation system (from Plaza Hotel to Hato): 247 ha
- Total area of hotel gardens within the area serviced by the irrigation system: 67 ha
- Area of hotel gardens to be irrigated with treated sewage: 2/3 x 67 = 44.7 ha

The consultant has calculated that the nitrogen addition to the hotel gardens is below the EU guideline for drinking water protection areas. However, the calculation was based on the assumption that the treated effluent would be spread over 247 ha (i.e. the gross area covered by the irrigation system). This includes paved and build-up areas. Obviously a realistic approach would be to calculate N addition based on the area of the irrigated gardens, since this represents the actually irrigated area.

Re-calculation of actual nitrogen addition to the irrigated hotel gardens is therefore as follows: 335 m^3/day * 0.028 kg/m^3 * 1/44.7 ha * 365 day/year = 77 kg/ha/year. This is far above the EU guideline (which already is a doubtful guideline for Bonaire; see par. 3.2.1). In fact the nitrogen addition to the hotel gardens will likely be even higher because:

a) The 28 mg/l nitrogen concentration in the effluent is unrealistic since it is based on 75% nitrogen removal in the wastewater treatment plant. A more realistic N concentration is about 68 mg/l (40% N removal), and
b) The nitrogen load is based on an unrealistically low water addition of 273 mm/year. More realistic is 1800 mm/year (see par. 3.5.3 of Feasibility Study), which would result in an even higher nitrogen addition (if similar effluent or water plus fertilizer would be used).
c) Finally, we suspect that the proposed 67 ha for hotel garden, in fact represent the total hotel plot area. If this was done, then per ha N-loads go up further by approximately a factor 3.

A fundamental flaw in the technical project design is illustrated with the following: the nitrogen production by the tourists in the hotels is on average 17.8 kg/day (1780 pe). The amount of nitrogen transported back to the hotel gardens would be 22.8 kg N/day (at 40% N removal in the treatment plant). Therefore more N would be added to the hotel gardens than the total amount of nitrogen present in all wastewater currently generated by the hotels. Since most hotels are located right at the shore, this would actually implicate that the project would increase the nutrient load to the most sensitive part of the coastline, instead of reducing it.

With the data available at this point in time it is not possible to assess how much nitrogen will percolate to the groundwater and to the sea in case of irrigation as proposed by the project. However, we present the following preliminary analysis.

A nitrogen mass balance for irrigated fields has the following general description:

$$N_{input} = N_{denitrified} + N_{uptake\ by\ crops} + N_{runoff\ water} + N_{percolation\ water}$$

$N_{denitrified}$ is on average 20% of the nitrogen input for agricultural fields (Polprasert, 1990). For the conditions on Bonaire; a small layer of topsoil on porous limestone, this may actually be less.
N_{uptake} by crops is for instance for corn in the range of 175-200 kg N/ha/year (Polprasert, 1990). The consultant assumes 80 kg N/ha/year a reasonable value for hotel gardens. Whether this is indeed a realistic figure is unclear, a reference for the source of this data is not given in the Feasibility Study.

		40% N-removal	75% N-removal
N_{input}	(kgN/ha/year)	186	77
Irrigated area	(ha)	44.7	44.7
$N_{cropuptake}$	(kgN/ha/year)	80	80
$N_{denitrified}$	(kgN/ha/year)	37	15.3
N_{runoff}+$N_{percolation}$	(kgN/ha/year)	69	<0

The mass balance shows that for the (unrealistic high) 75% N removal efficiency and for the (unrealistic low) assumed water gift, no nitrogen runoff and percolation is expected. At 40% nitrogen removal in the treatment plant a considerable amount of nitrogen is expected to end up in the groundwater and the sea. In fact 69 *44.7 = 3084 kg N/year is expected to flush into the sea. In case the N uptake by plants would be lower (which again is likely) the sea contamination would go up further.

Conclusion: since the N input to the most sensitive area (the hotels at the shore-line) is likely to increase, it is unlikely that eutrophication is prevented. Eutrophication might actually increase.

The mass balance proposed by the consultant for the entire project area suggests that 59 kg N are removed from the area per day, while only about 10 kg N would be returned via irrigation (84% removal efficiency). This suggests a dramatic reduction in N contamination potential along the coast line, as a result of the proposed project. However, even today nitrogen is (partly) removed from the sensitive zone by septage collection from households and wastewater treatment at the hotels, amounting to an estimated removal of 40 kg/day (assumed a modest 65% collection/treatment efficiency). At best, the project will, therefore, increase the overall removal of nitrogen from the sensitive zone from 65% to 84%. However, the returned N in the consultants proposal is likely to be substantially higher than the proposed value, as was pointed out earlier (about 23 kg per day), which would reduce the removal efficiency to about 60%. In this case the net gain of the proposed sewage management scheme in terms of removing nitrogen from the project area would be nil or even negative.

Nitrification
The SBR reactor, where the biological part of the treatment takes place, is designed based on a sludge loading rate of 0.326 kgBOD/kg MLSS/day. The design wastewater temperature is 28 ^{0}C and the sludge age is 3 days. Under these conditions it is likely that nitrification will take place (Gray, 1990; Hellinga *et al.*, 1999) and a substantial part of the ammonium will be oxidised to nitrate. This has two consequences:

1. The aeration system should be designed on the extra oxygen demand caused by the nitrification process (about 4-5 times higher oxygen demand!). The present design has an aeration system aimed at satisfying only the oxygen demand from BOD oxidation. The aeration capacity may be too low.

2. Since nitrification will take place, it would be relatively easy to design the SBR operating cycle such that also denitrification occurs, and nitrogen could be removed from the water. This deserves to be worked out in detail, since it could reduce the nitrogen load to the hotel gardens and thus the nitrogen flux to the sea. Nitrogen removal may be more important than phosphor removal, since algae growth in marine environments are commonly nitrogen-limited. The implementation of only nitrogen removal (without P removal) may therefore be sufficient. A cost estimate for nutrient removal should therefore not be based on inclusion of P removal reactors (as in Annex 8 of the Feasibility Study).

3.4 Effectiveness of proposed scheme

Since N has been identified as the main problem in Bonaire’s coastal water, the (cost-) effective removal of Nitrogen should be the main objective of any sewage management scheme. The above evaluation demonstrates that the proposed scheme is fundamentally flawed, and is not likely to achieve a substantial reduction of N load to the sensitive zone.

3.4.1 *Effectiveness in removing N*

The proposed sewage management scheme is flawed since it is not likely to achieve a substantial reduction in the N load of the sensitive zone. This is attributed by:

- The actual removal efficiency of N in the SBR will probably not be higher than 40% (consultant proposed 75%).
- Organically bound N will become dissolved and can no longer be removed from the SBR sysem.
- The nitrogen load to the hotel gardens is (at 40% N removal by treatment) higer than the EU guideline for drinking water protection areas (40 kg/ha/year). The nitrogen load is most likely to be around 186 kg/ha/year.
- A preliminary mass balance on the hotel gardens showed that under the proposed project (but at 40% N removal by treatment) there is significant percolation of nitrogen from the hotel gardens to the groundwater and possibly to the sea.

3.4.2 *Cost Effectiveness*

The cost effectiveness of the proposed project is rather poor, since:

- The investment cost for the sewerage system are considerably higher than normally quoted for this type of infrastructure.
- The connection fees are high and for part of the population of Bonaire certainly not affordable. This may lead to households not connecting to the sewer system.
- The income from the sale of irrigation water to the hotels is about 30% of the operation and maintenance cost, and therefore crucial for the financial sustainability of the project. However, the assumption that 2/3 of the hotels will buy back the treated wastewater for the price of ANG 2.5 per m^3, is questionable since some of the hotels produce irrigation water at much lower cost.

4. Alternative Options

In this chapter the project and technical design prepared by the consultant is referred to as the 'proposed design' or the 'proposed project'.

4.1 Criteria for alternative options

Any alternative option should be aimed at:

- Preventing nutrient fluxes from Bonaire island to the sea

The alternative option should satisfy the following boundary conditions:

- The cost, especially the operation and maintenance cost, should be affordable (cost-effectiveness).
- The technology should be robust, such that disturbing conditions (power failures, temporary overload, temporary poor operational practice) do not lead to significant nutrient fluxes to the sea.
- The technology should be not too complicated, such that general operation and maintenance can be carried out by local (trained) personnel.
- The technology should not endanger public health.
- The technology should be acceptable to the community at large and the stakeholders specifically involved (authorities, hotel owners, environmental NGO's)

4.2 Preliminary design of alternative option

An alternative option is developed, based on the aim and boundary conditions formulated above and aimed at addressing the shortcomings in the proposed design. The design of the alternative option is based on a number of key principles, these are:

1. Manage concentrated waste streams separate from diluted waste, since in concentrated form it is easier to treat.
2. Try to avoid costly transport of waste over long distances.
3. Try to maximize the use of existing infrastructure in combination with new infrastructure.

<u>The alternative option</u>

Septage

The septage from households and restaurants is kept separate from the wastewater (design principle 1). The septage is treated on improved sludge treatment facilities at the LVV site, for example on drying beds. The small volume of percolate from the drying beds is treated in a simple waste stabilization pond system. The dried sludge contains considerable amounts of nutrients. It should therefore not be disposed of in a haphazard way, to prevent nutrient pollution of the groundwater. A possible solution could be co-composting with agricultural waste or woodchips and subsequent use in agriculture on Bonaire. The nutrients are then taken up by the crops. Consumption of these crops will reduce the import of crops to the island, i.e. reduce the nutrient imports. If no reuse option is available, the dried sludge could follow the solid waste management route (landfill).

Part of the waste-stream described in the feasibility study as ‘septage from households’ is actually wastewater stored for several weeks or months in storage pits or tanks. In the alternative option this wastewater is dealt with in two ways (1) in the sensitive zone the storage facilities will be upgraded to septic tanks (see below) and the tank effluent will be collected in a sewer system (see below) (2) outside the sensitive zone the current practice of tanker collection is to be continued, until addressed in a later stage of the project.

Cruiseships and the airport
In principle the influx to the island of these waste flows should be avoided. It is therefore advised to evaluate the feasibility of ships and aircrafts to discharge at other, less sensitive destinations with a larger ‘carrying capacity’.
In case these waste flow need to be managed also in future, the pre-treated wastewater from the cruiseships and the airport is best treated in one of the decentralized wastewater treatment plants described below. Transport by tanker to the decentralized wastewater treatment plant is probably most practical. Collection through a pipeline may be considered in the future.

Stormwater system
The stormwater system is to be implemented as in the proposed project. The water from the First Flush Chambers should be treated in one of the decentralized wastewater treatment plants described below.

Wastewater collection, treatment and reuse
The alternative option is built on a decentralized approach (design principle 2). The main reason for choosing a decentralized approach are the high cost involved in the central sewer system. These high cost may endanger the sustainable operation of the system and therefore indirectly the protection of the reef (see § 3.2.2)

Hotel wastewater

The alternative option takes into account the existing infrastructure at the hotels, i.e. the local sewerage system to collect the wastewater from the hotels and the existing package treatment plants in operation at a number of hotels (Design principle 3).
During our visits to a number of existing plants we observed that the operators are very dedicated, but may need additional training for optimal plant operation. In addition the existing treatment plants are to be upgraded to state-of-the-art package plants. Also effective monitoring and evaluation schemes need to be developed and implemented. In short, the use of package plants by the hotels needs to be ‘professionalised’.
The other hotels or clusters of hotels are to be provided with package treatment plants. All package treatment plants should be able to produce effluent equal to municipal wastewater treatment plants, including nutrient removal. Nutrient removal in our view is absolutely essential, keeping in mind the main goal of the project. It is proposed to install package plants that are able to satisfy at least the Dutch IBA class IIIb requirements (i.e. BOD < 20 mg/l, COD < 100 mg/l, N-NH4 < 2 mg/l, Ntotal < 30 mg/l and Ptot < 2 mg/l). Currently hundreds of this type of plants are installed in the Netherlands to satisfy new EU criteria. Although the Ntotal criteria may not be sufficiently strict for the conditions of Bonaire, one must realize that the criteria take into account the low ambient temperatures in the Netherlands. Removal efficiencies at Bonaire will be substantially better. Some IBA systems commercial available in the NL are able to achieve effluent nitrogen concentrations between 15 and 20 mg/l

at Dutch summer temperatures (www.ibasinbeeld). The effluent from the package plants in Bonaire will therefore be of similar or better quality than the expected SBR effluent in the proposed project.

The above shows that decentralized wastewater treatment could provide satisfactory effluent quality. (Compare, in the present proposal the nitrogen concentration in the hotel wastewater is 49 mg/l (based on 70% wastewater generation rate, table 3.1 of Feasibility Study), in the wastewater from households 75 mg/l and in the irrigation water 28 mg/l. This shows that the package plants would need only 43 and 63 % nitrogen removal to improve on the situation (with regard to nitrogen concentration) of the current proposal for the household and hotel wastewater, respectively. The package plants commercially available will have no problem achieving this removal %.

The cost for this type of package plants is about € 700 per pe (http://www.wierden.nl/smartsite.html?id=10849; Dutch prices, 2004) at a plant capacity of 10 pe. In the alternative option the plant size will be larger (100-1000 pe), the average price per capita is estimated at euro 400 per P.E..
The treated wastewater from the hotels will need to be disinfected, stored and reused for irrigation in the hotel gardens. Disinfection is possible in UV systems (typically €60 investment cost per P.E. and € 10 O&M cost per year for domestic consumers. For hotel consumers a factor 2 applies. WAWTTAR, 1992).

The cost per capita for wastewater treatment in the alternative option is more than in the proposed project. This is due to economies of scale for central treatment. Important is that in the alternative option the total PE wasteload to be treated is significantly less (about 50%) because the septage is kept separate. Total investment cost for wastewater treatment in the current proposal is 5.0 million ANG (2.8 million euro), whereas in the alternative option it would be 460 euro/PE * 3912 PE = 1.8 million euro.

The hotel irrigation network in the alternative option will be simpler and cheaper than in the proposed project, since most of the irrigation infrastructure is in place already (Also the consultant calculated the irrigation system for the neighborhood system to be 30% cheaper than the centralized option). Treatment at the hotel sites allows easy effluent reuse. Effluent disposal into the sea should at all times be avoided, therefore sufficient area for irrigation should be available and sufficient storage capacity to overcome power failures (6 hours) should be provided.

By collecting, treating and reusing the hotel wastewater on-site, the amount of water to be handled in a sewer system for the domestic and commercial wastewater is reduced with 3560 PE's, out of a total of 5889 PE's to be handled in the sewer system in the proposed project.

Domestic and commercial wastewater

The domestic and commercial wastewater in the sensitive zone is currently stored in individual storage tanks and subsequently transported to the LVV site. Many of the storage tanks actually operate as either infiltration pits or as septic tanks. The alternative option is based on using this existing infrastructure as much as possible (Design principle 3).

The storage tanks and infiltration pits are to be upgraded to septic tanks, whose aim is to remove the solids from the wastewater and to provide preliminary treatment. By upgrading the infiltration pits, infiltration of nutrient rich wastewater into the groundwater is prevented. The effluent from the septic tanks is to be collected in a small diameter gravity sewer, also called settled-sewerage. The principle difference with conventional sewer systems is that the water to be transported is substantially reduced in solids contents. Therefore the slope of the sewer pipes can be reduced, resulting in lower excavation cost. The pipe diameter can also be smaller, further reducing costs. Some projects in the USA have shown that the cost of these systems can be as low as 50% of the conventional sewer systems (EPA, 2000). Essential for proper operation of the settled-sewerage system is timely desludging of the septic tanks (about once per year).

It is strongly recommended that an accurate calculation is carried out to compare the cost of this alternative option for the sewer system with the vacuum system proposed by the consultant. Apart from the high costs of the vacuum system, the complexity of the vacuum technology may also be a problem. Leaks in the sewer lines may disturb the operation and may be difficult to detect and repair.

The decentralized settled-sewerage systems may serve between 100 – 1000 PE's, depending on layout of the houses and optimal clustering.

Treatment of the wastewater is to be done in similar package plants as for the hotels. Treatment will be easier, since in the septic tanks some treatment has occurred already. A good functioning septic tank will remove 50-60% of the organic load.

Disinfection and storage is also to be provided, similar as for the hotels. The effluent is to be reused for landscaping purposes, for parks, sport fields etc, all located further away from the coastline. For larger clusters of homes, it may be considered to pump the effluent to agricultural fields in the center of the island. An economic analysis would be required to assess the feasibility of this option.

A modification of the alternative option could be: to collect the wastewater from hotels, households and restaurants in a settled sewerage system as described above, but to transport pre-treated and solids free wastewater to a central location for further treatment and reuse. The centralised treatment would not necessarily be of the activated sludge type, but could also be a natural system, like waste stabilisation ponds. This type of system is cheap in construction, operation and maintenance but needs a relatively large area. Effluent reuse could be partly in the hotel area and partly for agricultural purposes, for instance for chicken feed production for the chicken farm.

4.3 Institutional setting

The institutional setting should be designed to safeguard sustainable operation and maintenance of the infrastructure. For the alternative option, the following institutional arrangements need to be in place:

- An institute responsible for operation and maintenance of the collection system, the package treatment plants, the storage tanks and the irrigation water supply. The same institute would be allowed to collect fee's and is responsible for customer's relations. The institute could be public, private or a public-private-partnership. The technical staff would need to be trained in operation and maintenance of the infrastructure.

- A public institute to regulate the institute described above, performing all the tasks of a regular regulator. This would include checking plant performance.

- An environmental agency to monitor the effects of project implementation on either the nutrient flux into the sea, or the state of the reef close to the sensitive zone.

4.4 Comparison of proposed design and the alternative option

In this paragraph three options are compared:

1. the option proposed by the consultant
2. the option proposed by the consultant with some modifications
3. the alternative option

Option 2 would be: the same as option 1, but (1) nitrogen removal in SBR reactor by nitrification/denitrification is included, and (2) septage is kept separate and treated separately

The options are compared for the criteria listed in 4.1.

Nutrient flux

Option 1 will probably not reduce the nutrient flux into the sea, as calculated in §3.3.2. Both option 2 and 3 will reduce the nutrient flux into the sea significantly.

Cost-effectiveness

We have serious doubts about the cost-effectiveness of option 1 (§ 3.2.2). Also the consultant concluded that only the operational costs can be recovered and not the investment costs. Another major problem is that households may not be willing/able to pay the connection fee. Similarly, many hotels may not be willing to buy back the effluent. Both situations would endanger the O&M due to lack of income.

For option 2 the SBR reactor can probably be smaller and the aeration cost will be lower because the septage is kept separate. At the other hand, the cost for the SBR reactor itself are a small part of the overall cost for the treatment plant. The affordability of option 2 is probably similar as for option 1.

The cost-effectiveness of option 3 is expected to be much better, because the collection systems and the irrigation systems are expected to be considerably cheaper than in option 1 and 2.

Robustness and complexity

Option 1 and 2 have storage capacity in the manholes for 6 hours of power cuts and since these happen seldom at Bonaire, this is not expected to be a problem. More likely is that problems are caused by the complexity of the technology, especially the vacuum installations and the process control of the SBR system. The risk of temporary system failure is therefore real. Expertise for repair and maintenance is not available on the island. Breakdown of the vacuum system in the vacuum and pumping stations would need to be repaired quickly otherwise the 6 hours storage volume is exceeded and the untreated wastewater is to be released to the environment in the sensitive zone. Another problem may come from improper operation of the SBR process. Highly skilled personnel is required to operate and maintain the process control (mechanical-electrical equipment)

and to deliver the required effluent quality. This personnel may not be available on the island and foreign assistance is very expensive.
Option 3 also has 6 hour storage capacity for power cuts. Just like breakdown of the vacuum system, complete breakdown for several days of the package plants would also result in release of wastewater into the environment. However, the complexity of the package plants is less than for the vacuum system and it may therefore be more easy to operate and maintain. Experience has shown that the hotels that have a package plant are able to operate these continuously without major breakdowns.

Public health aspects

Risk for people coming into contact with pathogens seems similar for the three options. If the central disinfection would not work properly, the irrigation water would not be pathogen free. Similarly for the decentralized plants. Advantage of the centralized plant is that it is cheaper to check the effluent quality, less samples required.

The evaluation of the 3 options are summarized in the table below:
(+ feasible, - not feasible, +/- intermediate)

	Nutrient flux reduction	Cost-effectiveness	Robustness and complexity	Public health
Option 1	-	-	-	+
Option 2	+	-	-	+
Option 3	+	+	+/-	+

5. Conclusions and Recommendations

5.1 The problem. An observed trend of declining reef quality has been attributed to nitrogen contamination in coastal waters around Bonaire. Although the sewage problem on Bonaire needs to be addressed as a general pollution problem, particular attention has, therefore, been given to Nitrogen in discussions about possible solutions.

5.2 Pollution sources from the wider region. Bonaire and its coastal zones could be subject to influences of nutrient pollution far outside its own territory (Caracas is at 230 km, other point source from the region, cruise ships).

We recommend that the proposed Nutrient Study will give some attention to this, by making an inventory of possible sources of eutrophication in the wider region. Also some preliminary flow simulation tools should be applied to predict the possible influence on Bonaire's coastal waters.

5.3 N-Balance. Besides sewage, there may be other important sources of nitrogen pollution on Bonaire island. Sewage contributes about 40% of the total nitrogen balance on the island.

The establishment of a nitrogen mass balance for the island should be made. This will help to visualize the relative contribution of sewage to the total nitrogen balance. We further recommend that possible ways to improve the N balance on the island are considered by minimizing N-influx and introduction of N-sinks.

Whatever the outcome of the studies recommended under 5.1 and 5.2, we wish to stress that local sources of pollution need to be tackled anyway. Sewage management on Bonaire needs to be addressed! In recognition of this, the following conclusions and recommendations relate to the focus of this report, i.e. the effectiveness of N removal and cost effectiveness of the present project compared to alternative solutions:

5.4 Effectivenes of N removal.

- The actual removal efficiency of N in the SBR will not be higher than 40% (consultant proposed 75%).
- Organically bound N will become dissolved in the SBR and can no longer be removed from the SBR system. This further reduces the N-removal efficiency in the system
- The nitrogen load to the hotel gardens is (at 40% N removal by treatment) higer than the EU guideline for drinking water protection areas (40 kg/ha/year). The nitrogen load is most likely to be around 186 kg/ha/year.
- A preliminary mass balance on the hotel gardens showed that under the proposed project (at 40% N removal by treatment) there is significant percolation of nitrogen from the hotel gardens to the groundwater and possibly to the sea.

We recommend to install treatment technology that is able to substantially reduce the nitrogen load to the irrigated hotel gardens. Moreover, the nitrogen contained in the septage should not be added to the wastewater.

5.5 Cost effectiveness of proposed solution.

The cost effectiveness of the proposed project is rather poor, since:

- The investment cost for the sewerage system are considerably higher than normally quoted for this type of infrastructure.
- The connection fees are high and for part of the population of Bonaire these will not be affordable. This may lead to households not connecting to the sewer system.
- The income from the sale of irrigation water to the hotels is about 30% of the operation and maintenance cost, and therefore crucial for the financial sustainability of the project. However, the assumption that 2/3 of the hotels will buy back the treated wastewater for the price of ANG 2.5 per m^3, is questionable since some of the hotels produce irrigation water at much lower cost.
- No acceptable institutional arrangement appears to be available at the moment. This seriously undermines both the treatment-effectiveness and the cost-effectiveness of the proposed project.

5.6 Alternative options

The alternative option developed consists of:

- Collection, treatment and reuse of the hotel wastewater per hotel or per cluster of hotels.
- Collection of the domestic and commercial wastewater in clusters of 100-1000 P.E.'s, in a small diameter gravity sewer, treatment in package plants with total nitrogen in the effluent < 20 mg/l, and reuse for landscaping as close as possible to the package treatment plant.

This alternative option scores better than the project design proposed by the consultant, in terms of: reduction of nutrient flux to the sea, cost-effectiveness and complexity of technology. Crucial for a successful implementation of the alternative option is a dedicated and well trained organisation for operation and maintenance of the infrastructure. This provides employment and business opportunities.

We recommend to further work out the alternative option, since this will more likely result in a reduced nitrogen flux to the sea than the project proposed by the consultant. Main advantages of this option are that it builds further on infrastructure that is in place already, and that it allows for gradual construction of the required new infrastructure. It also spreads the risk over a number of decentralized systems, wheras in the central option failure of the centralized treatment plant would cause a complete breakdown of the system.

Final recommendations

1. We recommend that option 3, as described and evaluated in chapter 4, is worked out in further detail and implemented. This report indicates that this option has a better feasibility than the project proposed by the consultant.

   We strongly recommend that the EU, as an important party in the wastewater project on Bonaire, enters in open and constructive consultations with all stakeholders to review the situation and to jointly decide on (new) directions to be taken.

2. We recommend a stakeholder workshop to discuss the alternative option as developed in this report and its advantages over the project proposed by the consultant. Necessary inputs to such a workshop would be:

- An accurate comparison (costs, operation) of a system of septic tanks connected to a small diameter gravity sewer and a system using vacuum sewers.
- A modified process design for the SBR reactor, including nitrogen removal through nitrification and denitrification. What would be the additonal costs involved in this modification? What will be the expected nitrogen effluent concentration?
- A new irrigation design is necessary. How much hotel garden is in reality available for irrigation? What would be the proper nitrogen dosage?
- The outcome of the planned ‘nutrient study’ will also give important information to be considered during the workshop.

3. We recommend that, in addition to the wastewater project, additional actions are identified and prioritized, with a view to reduce the N flux to the coastal zones. Possible actions include:

   a. A programme to replace infiltration pits by sealed septic tanks in the areas not covered by the project. This should be complemented with an effective septage management scheme (institutional and technical).
   b. Studying the possible leaching of N from the landfill; if this takes place, ways to prevent leachate to reach the sea need to be considered. On the long term a sanitary landfill will need to be installed.
   c. Reduce N-imports (e.g. fertilizer, cruise ships, airport etc.).
   d. Substitute animal feed imports by local production via the effective reuse of wastewater effluent and (co-)composted septage (e.g. maize for chicken farm)

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Annex 1

Terms of Reference

Water Management en Sanitation Bonaire

Zeist 20/06/04

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PoBox 3007
6802 DA Arnhem

I herewith confirm the TOR for your consultancy 'Water Management and Sanitation Bonaire' for the Wereld Natuur Fonds, Boulevard 12 at Zeist. Mr. Carel Drijver, hoofd "Oceanen en Kusten" at the WNF, will be your contact point and the execution will take place between 25/06/2004and 01/10/2004.

We expect from you a report (10 pages max.) in which you deliver the following outputs:
a) inventory of alternatives for present Water Management and Sanitation Project developed for Bonaire with EU funding (hereafter referred to as *the present project*), as well as the selection and preliminary design of an *alternative solution* that saves costs, reefs, is robust, fits in the context of Bonaire and its importance as demonstration site for other islands and island states in the world
b) description and evaluation of the design and planning process of the present project over the past years and advice for improvement in the light of creating understanding and support for the *alternative* solution
c) comparative assessment of technical and managerial strengths and weaknesses of the present design against the *alternative* solution
d) comparative assessment of the effectiveness of the present design against the *alternative* solution in terms of preventing seepage of nutrients to the coastal reef ecosystem of Bonaire
e) comparative preliminary cost benefit analysis of present design against the proposed *alternative* solution (project level and socio-economic level)

For this consultancy the WNF agrees to pay your invoices up to a maximum of 12 days of work of which 7 in the Antilles (max. 760.- euro per day incl local costs) and 5 days in the Netherlands (max 630.- euro per day) as well as 1500.- travel costs and 500,- euro admin fee for Cesar Economics. Thus the grand total amounts up to a maximum of 10,470.- euro's. incl VAT. The number of days and fee per day will be reviewed in the light of the Partnership agreement between WNF and IHE-Unesco for Education and Capacity building in Water and the Environment.

Payment will be effectuated in three parts on the basis of your written invoices. Fourty % advancement after signing of the contract. Another 40% after receipt of the draft outputs and 20% after finalizing the entire assignment. We expect your first invoice by July 5th and your second invoice by October 01 2004.

We are looking forward to a fruitful cooperation and invite you to co-sign this letter in order to confirm you agreement with the TOR for this consultancy.

Zeist, 20/06/2004	Delft, 20/06/2004	Arhem, 20/06/2004
Het Wereld Natuur Fonds	UNESCO-IHE	Cesar Economics
(Carel Drijver)	(Erik de Ruyter van Steveninck)	(Herman Cesar)
……………………..	………………	………………….

Annex 2

PROGRAM
VISIT OF PROF. Dr. HUUB GIJZEN EN Dr. PETER VAN DER STEEN

Sunday September 19, 2004

14:50 Arrival at the Flamingo Airport

16:00 Briefing with Elsmarie Beukenboom (STINAPA)

Monday, September 20, 2004

9:00 Meet with Elsmarie Beukenboom (STINAPA), Ramon de Leon (STINAPA/BNMP), Kalli de Meyer (Aliansa), George de Salvo (Aliansa) @ STINAPA headquarters

14:00 Meet Jopi Giskus (Director of the Water and Power company) @ BMG office

16:00 Meet with Jack Chalk and Robert de Klut (Bonhata), Martin van de Valk (BHG), Steve Jevon (CURO) @ STINAPA headquarters

Tuesday, September 21, 2004

8:30 Meet @ LVV for site inspection of liquid wastewater deposit

9:30 Visit to the land fill

11:30 Meet with Jopi Abraham (leader political party in opposition) @ Staten gebouw

14:00 Site inspection at Plaza Resort

15:15 Site inspection at Harbour Village Resort

4:45 Site inspection at Cap't Don's Habitat

19:30 Diner discussions with Elsmarie Beukenboom

Wednesday, September 22, 2004

8:30 Meeting with Ramoncito Booij, leader Political party in Government

14:00 Meet with Ged. Dortalina, Reno Pieters (Project Leider) and the Steering members. Also present at the meeting: Chârmi Middelhof from DOS, Frederich Lansberg from Dorsch Consult

18:00 Report writing

23:00 Departure P. van der Steen

Thursday, September

08:30 Preparation de-briefing report by H. Gijzen

12:00 De-briefing with Elsmarie Beukenboom (STINAPA), Ramon de Leon (STINAPA/BNMP), Kalli de Meyer (Aliansa)

16:00 Departure H. Gijzen

Annex 3

Calculations of main N-components in N mass balance for Bonaire

Fertilizer:
Data obtained from two sources indicated an annual import of fertilizer of 800 kg. Via interviews we discovered that there are other parties that import and apply fertilizer (e.g. several hotels, LVV, import companies). We estimate that the total fertilizer imports are about 3 times the value above, so 2400 kg/year.
At an estimated N content of 35%, the total N imports via fertilizer is estimated at **840** kg/year. It is assumed that a substantial portion of this fertilizer is used within the sensitive zone (a.o. hotel gardens).

Municipal Solid Waste:
The per capita production of Municipal Solid Waste (MSW) on Bonaire is estimated at 1.5 kg/day (dry wt basis). The total population is estimated at 13,000 (10,000 resident plus 2000 tourist and 1000 transit; transit consists of 500 P.E airport transfers and 500 P.E. cruise ship transfer passengers). Therefore the annual MSW production amounts to about 7.1 million kg. At an estimated N-content of 0.6% (Sokka et al, 2004), this translates into a total N-load of **43000 kg** for the island. The landfill is located in the centre of the island. The type of landfill is a simple dumpsite, without lining or sealing at the bottom. Nutrients might infiltrate easily into the porous underground via the leachate.

Sewage:
The total sewage production on Bonaire is generated via 3 sources:

- Households
- Hotels
- Transit passangers (airport and cruise ships)

The total P.E. is calculated as follows:

10,000 P.E. resident population + 2000 P.E. tourists + 500 P.E. airport transit passengers + 500 P.E. cruise ship passengers = 13,000 P.E
With an average production of 10 g N/ per person per day, the annual N load is calculated as: 13000 x 0.010 kg/d = 130 kg N per day = **47000 kg N/y**

Animal feed imports:
The following numbers of animals are found on the island: 100 cows, 9000 goats, 10,000+ poultry, few hundred donkeys, and about 20 horses. In addition there are an undetermined number of cats and dogs. Many of the animals listed above feed by grazing or from kitchen leftovers. For the calculation of the N balance for the island, only the animal feed imports to Bonaire are relevant. The feed eaten via natural grazing does not affect the N mass balance, since this only contributes to the internal cycling of N. To some extend natural N-fixation may present a N-influx to the island.

The total amount of animal feed imports are estimated as follows:
The chicken farm imports 30 t maize per month = 360 t/y @ 12.5 % protein = 45 t protein = 7200 kg N. Additional imports for the donkey sanctuary and domestic animals (chicken, goats, cats, dogs) and horses are estimated at twice the above value. This would bring the total N imports via animal feed to **21600 kg** N per year.

Slaughterhouse:

The slaughterhouse is located at the LVV location in the centre of the island. Only some 35 goats are slaughtered per week. Assuming 45 kg weight per animal, waste production of 25%, and a protein content of 50%, the total nitrogen flux via the waste can be calculated as follows: 35 x 52 weeks x 45kg x 0.25 waste fraction x 0.5 protein content x 0.16 N-fraction = **1640 kg N/y**. One might argue that this N should not be included in the mass balance, as it is likely that the meat production has been established via natural grazing.

Proposed measures to improve the N balance:

- Banning or control of fertilizer imports
- Banning of sewage discharges from cruise ships to the island
- Banning of sewage discharges from airplanes
- Establishment of a sanitary landfill, ensuring no leachate infiltration occurs
- Identify N-sinks and stimulate their use

Possible (future) N-sinks:

- Denitrification and long-term storage in Landfill
- Land application of (animal) excreta, and partial plant/animal uptake and denitrification in subsoil.
- Collection of septage and long-term storage and partial denitrification.
- Development of a golf course with (treated) sewage irrigation
- Controlled irrigation of sport fields using (treated) sewage
- Centralised (treated) wastewater irrigated farming (e.g. chicken farm could produce its own maize for use as chicken feed.