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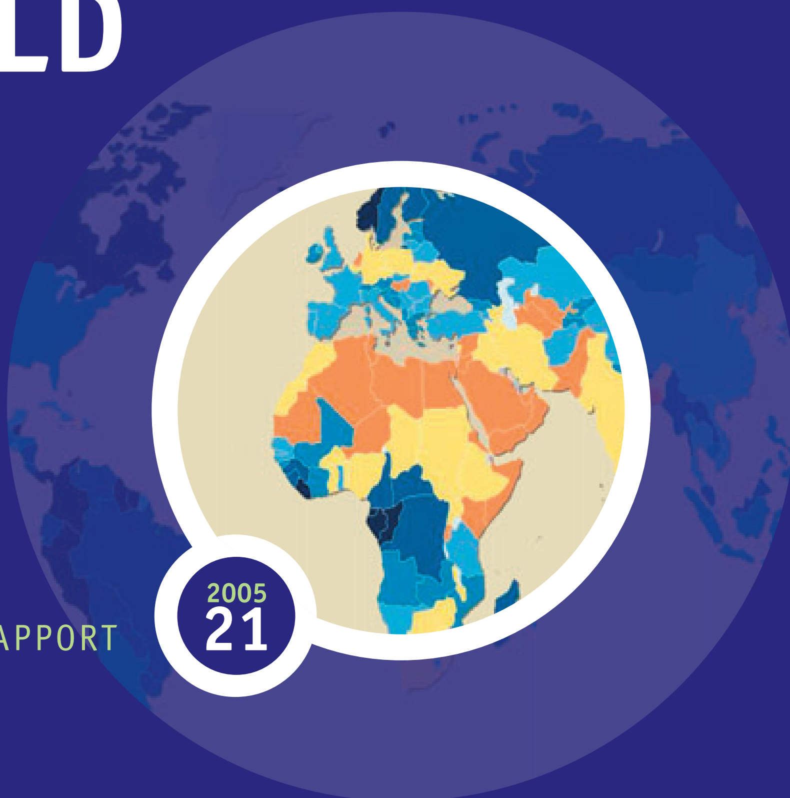
WETTERSKIP FRYSLÂN

‘WATERHARMONICA’ IN THE DEVELOPING WORLD



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WATERHARMONICA PROOF

'WATERHARMONICA' IN THE DEVELOPING WORLD

RAPPORT

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stowa@stowa.nl WWW.stowa.nl
TEL 030 232 11 99 FAX 030 232 17 66
Arthur van Schendelstraat 816
POSTBUS 8090 3503 RB UTRECHT

Publicaties en het publicatie overzicht van de STOWA kunt u uitsluitend bestellen bij:
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AUTEURS

Adriaan Mels (Lettinga Associates Foundation)
Ernst-Jan Martijn (Lettinga Associates Foundation)
Ruud Kampf (Hoogheemraadschap Hollands Noorderkwartier)
Theo Claassen (Friesland Water Authority)

DRUK Kruyt Grafisch Advies Bureau

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PREFACE

The Waterharmonica was conceptualised by Claassen (Claassen, 1996) as part of a contest on innovative aspects of future management strategies, set out by the Dutch Foundation for Applied Water Research (STOWA). STOWA considered the Waterharmonica concept as a very promising approach for improved management of wastewaters and awarded it a prize.
The Waterharmonica aims at implementing eco-engineered water treatment systems such as constructed wetlands subsequent to current wastewater treatment plants. These eco-engineered systems could form a natural post treatment system of the effluent, bridging the quality gap between effluents and surface water.
The intermediary results of the programme are described in two reports in 2005. The first report, entitled *Waterharmonica - the natural link between water chain and water systems*, elaborates the application potential of the Waterharmonica in The Netherlands and reviews current Dutch experiences of the Waterharmonica at full scale treatment plants. The other report lies before you and is compiled by LeAF (Lettinga Associates Foundation), The Netherlands.

Tijdens het 25-jarig jubileum van STOWA in 1996 mocht Theo Claassen (Wetterskip Fryslân), een prijs in ontvangst nemen voor zijn visie over waterbeheer in de toekomst. Hij kreeg de prijs voor zijn schets van ecotechnologische toepassingen als schakel tussen effluent van RWZI's en oppervlaktewater, als tegenhanger van hoogtechnologische (en dure) systemen zoals membraanfiltratietechnieken. Dit idee heeft Ruud Kampf (Hoogheemraadschap Hollands Noorderkwartier) de Waterharmonica genoemd. In het concept van de Waterharmonica wordt met de natuur samengewerkt om de gewenste waterkwaliteit te bereiken. Aan de prijs van STOWA was een geldbedrag verbonden, te besteden aan onderzoek om het concept van de Waterharmonica operationeel toepasbaar te maken. In dit kader heeft STOWA aan Royal Haskoning de opdracht gegeven om te inventariseren welke systemen momenteel in Nederland bestaan en wat de ervaringen met deze systemen zijn en wat de toepasbaarheid van het Waterharmonica concept in Nederland is. Het tweede onderdeel van de opdracht was het concept van de Waterharmonica en de toepasbaarheid ervan in ontwikkelingslanden verder uit te werken. Dit rapport getiteld "Waterharmonica in the developing world" is opgesteld door door LeAF, (Lettinga Associates Foundation).

The authors of this report are; Adriaan Mels, Ernst-Jan Martijn LeAF (Lettinga Associates Foundation), Ruud Kampf (Hoogheemraadschap Hollands Noorderkwartier), Theo Claassen (Friesland Water Authority). Members of the project stearing group were: Jannes Graansma (Hoogheemraadschap Hollands Noorderkwartier), Bert Moonen (Waterschap Groot Salland), Gerard Rijs (RIZA), Wim van der Hulst (Waterschap Aa en Maas), Sjef Ernes (Aqua for All) en Bert Palsma (STOWA).
The investigations described in this report aimed at exploring and mapping the potential of eco-engineered wastewater treatment in developing countries. Analogously to the Waterharmonica concept as proposed for The Netherlands and Europe eco-engineered treatment could form a potential 'link' between (primary) wastewater treatment and potential reuse of water and nutrients.

Juni 2005
Ir. J.M.J. Leenen.
Director of STOWA (Dutch Foundation for applied water research)

SUMMARY

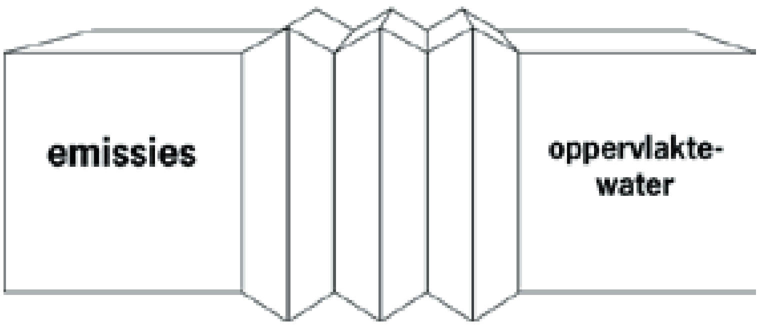
THE WATERHARMONICA

Although the effluent quality of wastewater treatment plants in The Netherlands is generally of a very high quality, the water is still more toxic than is to be expected based on its chemical and physical composition. It lacks a natural daily oxygen rhythm, which makes it hostile to higher aquatic organisms. Moreover, in many cases it still contains too many microorganisms from the activated sludge process and of human origin. As such, the effluent is not yet suitable for use as swimming or recreational water or nature development. The quality is still a bottleneck for reaching the standards of the receiving surface waters according to Dutch standards or the goals of the EU Water Framework Directive.

The Waterharmonica (Figure 1) aims at implementing eco-engineered water treatment systems such as constructed wetlands subsequent to current wastewater treatment plants. These eco-engineered systems could form a natural post treatment system of the effluent, bridging the quality gap between effluents and surface water.

The Waterharmonica was conceptualised by Claassen (Claassen, 1996) as part of a contest on innovative aspects of future management strategies, set out by the Dutch Foundation for Applied Water Research (STOWA). STOWA considered the Waterharmonica concept as a very promising approach for improved management of wastewaters and awarded it a prize.

FIGURE 1 THE 'WATERHARMONICA' AS A BUFFER BETWEEN THE SEWAGE TREATMENT PLANT AND SURFACE WATER, BASED ON CLAASSEN, 1996



Based on the prize a broader programme was initiated by the waterboards Friesland Water Authority and Hoogheemraadschap Hollands Noorderkwartier and STOWA. The programme started in 2003 and aims at conceptual development and practical implementation of the Waterharmonica in The Netherlands and in developing countries.

The intermediary results of the programme are described in two reports in 2005. The first report, entitled *Waterharmonica - the natural link between water chain and water systems* (STOWA, 2005a), elaborates the application potential of the Waterharmonica in The Netherlands and reviews current Dutch experiences of the Waterharmonica at full scale treatment plants. Nowadays, various examples of this approach already exist, such as at wastewater treatment plants Everstekoog and Land van Cuijk. Royal Haskoning, The Netherlands, has compiled this report. The other report lies before you and is compiled by Lettinga Associates Foundation, The Netherlands.

WATERHARMONICA IN THE DEVELOPING WORLD

The investigations described in this report aimed at exploring and mapping the potential of eco-engineered wastewater treatment in developing countries. Analogously to the Waterharmonica concept as proposed for The Netherlands and Europe eco-engineered treatment could form a potential 'link' between (primary) wastewater treatment and potential reuse of water and nutrients.

Wastewater management in many developing countries is generally quite different compared to The Netherlands and Western Europe. In many cases a carefully planned wastewater infrastructure is not or only partially available, resulting in untreated wastewater discharge into water bodies and consequently severe public health risks.
This report highlights the fact that the Waterharmonica can actually function as a feasible treatment approach in cases with no or only partial wastewater treatment. This is motivated by the fact that the requirements for wastewater treatment systems at many locations in developing countries tend to match well with the principles of ecological engineering, such as:

- A low or absent energy (electricity) requirement which is in many places not (reliably) available;
- Easy operation with low skilled operators;
- Easy to construct with locally available material;
- Permanent and continuous operation without too much maintenance;
- More or less constant effluent quality (i.e. robust systems) when the design is adequately adapted to local climate and temperature conditions;
- Possibility to produce biomass (e.g. algae, duckweed, various grasses, fish) by making beneficial use of the available nutrients;
- Applicable at small and large scale and especially feasible in rural areas.

The Waterharmonica highlights the fact that wetlands are multifunctional and combine pollution control with biomass production and/or nature development and can make use of the fertilizing value of wastewater. Moreover, the approach also stresses the beneficial use of treated effluents. The starting point is to consider drinking water and rain water as a good source of water, only 'misused' to transport wastes. After a good treatment of this 'wasted water' it can be a good resource again, not just with respect to the water volumes, but also with respect to former pollutants, including valuable nutrients.

TREATED WASTEWATER AS A NATURAL RESOURCE

Chapter 2 of this report provides an overview of the global needs and constraints for wastewater treatment and the conversion of treated wastewater into a natural resource. The UN Millennium Water Goals that were formulated in Johannesburg, 2002, emphasize the fact that there is a general lack of safe water resources and sanitation facilities in the developing world. Moreover, the availability of fresh water resources per capita is decreasing due to the increasing world population and a strong increase the agricultural demand for irrigation water. The use of untreated or (partially) treated urban wastewater as an alternative source of water is becoming an increasingly important issue for the coming decades.

The number of options for the (re) use of treated effluents is large. Some important examples are agricultural irrigation, wastewater-fed aquaculture, landscaping / landscape restoration, water supply to natural habitats, such as bird sanctuaries, water supply to recreational areas, groundwater and aquifer recharge, reduction of salt water intrusion and various industrial uses. The paragraphs 2.4 and 2.5 provide a more extended description of wastewater reuse in agriculture and aquaculture, because of their global importance.

ECO-ENGINEERED WASTEWATER TREATMENT SYSTEMS

In order to present the various options for eco-engineered wastewater treatment system a review of systems and examples was made. Table 1 presents an overview, including the examples that are described in this report. They can be categorized into natural wetlands, constructed wetlands, aquatic plant production systems and wastewater-fed aquaculture systems. These are not strict systems definitions and many aquatic based applications consist of a mixture of various types of treatment and reuse principles and objectives.

TABLE 1 OVERVIEW OF ECO-ENGINEERED UNIT OPERATIONS

Type of treatment	Description / remarks	Example
Natural wetlands	Wetlands of natural origin in which wastewater is discharged; although these system are not deliberately 'engineered' they provide a good source of technical information	• Nakivubo wetland, Kampala, Uganda (§ 3.4) • East Calcutta Wetlands, India (§ 2.5)
Constructed wetlands (surface / subsurface flow; horizontal / vertical flow)	Man made wetlands, preferably planted with local plant species, with a large variety in system options. Vegetation: emerging vegetation such as common reed or cattail	• Constructed wetland with landscape design in Nairobi, Kenya (§ 4.1) • Constructed wetlands in Bandung, Indonesia (§ 4.4), Dhulikhel Nepal (§ 4.5) and in Khe Sanh, Quang Tri, Vietnam (§ 4.6)
Aquatic plant production systems	Free surface water systems planted or stocked with a large variety of floating and submerged species, such as water hyacinth, water lettuce, duck weed, algae and Vetiver grass. Sometimes combined with aquaculture (as a second step)	• Castor, Senegal (§ 3.6)
Wastewater-fed aquaculture systems	Fishponds fed with primary treated sewage	• Wastewater-fed fish farm in Kalyani township in West Bengal (§ 4.3)

For a good functioning of eco-engineered treatment systems some form of pre-treatment is generally necessary. The pre-treatment system aims at the removal of most of the suspended solids, a large fraction of the COD and of the pathogenic organisms, and (optionally) nutrients of the wastewater. Feasible unit operations for pre-treatment are sedimentation tanks, stabilisation ponds, UASB bioreactors and oxidation ditches.

THE NEED FOR STAKEHOLDER INVOLVEMENT AND INTEGRATED PLANNING

Wastewater management schemes aimed at treatment and use of wastewater such as the Water-harmonica are relatively complex because they incorporate treatment for both pollution control and the supply of effluent for various uses. Tackling this complexity is necessary if responsibilities for a sustainable and protection of the water cycle are to be acknowledged. In the ideal case the conceptual-, feasibility- and facilities planning processes would be an iterative planning process concerning the early involvement of all stakeholders.

An integrated planning process, involving all relevant stakeholders, can be facilitated by using decision-making tools. Examples of such as decision-making tools are SANEX™ or the conceptual framework that is provided in Figure 21 in paragraph 5.3.

PLACE AND FUTURE PROSPECTS OF THE WATERHARMONICA PROGRAMME

The Waterharmonica session during the 7th INTECOL Wetlands Conference on July 29th 2004 (http://www.iees.ch/EcoEng042/EcoEng042_kampf.html) elaborated on the place and future prospects of the Waterharmonica programme. It was stated that there is already worldwide a lot of knowledge about polishing and reuse of wastewater and of effluents of wastewater treatment plants. It is important to use that knowledge. The knowledge is widely available but fragmented and often misunderstood. Therefore the Waterharmonica is also about communication:

- Communicating the need for integrated water management. Wastewater managers should consider the effect of their activities on adjacent ecosystems–including humans;
- Communicating "integrated knowledge in a useable form".

The main future task for the Waterharmonica is therefore to disseminate knowledge about how to use a watershed and ecosystem approach when managing wastewater. This could be done by:

- Making examples of successful, and less successful cases of such management accessible;
- Providing technical and practical knowledge about design and management of eco-engineered treatment systems;
- Using the internet site of the programme, but also imbed the concept in other forums like the Ecological Engineering Society (www.iees.ch), the user groups of IWA, etc. This should lead to a contact network of scientists and practitioners to promote and discuss the Waterharmonica approach.

The ongoing progress of the Waterharmonica programme is documented at the Internet site www.waterharmonica.nl. This site also reviews specific case studies and reports on a special Waterharmonica session that was held at the 7th INTECOL International Wetlands Conference in Utrecht, The Netherlands 25 - 30 July 2004.

STOWA IN BRIEF

The Institute of Applied Water Research (in short, STOWA) is a research platform for Dutch water controllers. STOWA participants are ground and surface water managers in rural and urban areas, managers of domestic wastewater purification installations and dam inspectors. In 2002 that includes all the country's water boards, the provinces and the State.
These water controllers avail themselves of STOWA's facilities for the realisation of all kinds of applied technological, scientific, administrative-legal and social-scientific research activities that may be of communal importance. Research programmes are developed on the basis of requirement reports generated by the institute's participants. Research suggestions proposed by third parties such as centres of learning and consultancy bureaux, are more than welcome. After having received such suggestions STOWA then consults its participants in order to verify the need for such proposed research.

STOWA does not conduct any research itself, instead it commissions specialised bodies to do the required research. All the studies are supervised by supervisory boards composed of staff from the various participating organisations and, where necessary, experts are brought in.

All the money required for research, development, information and other services is raised by the various participating parties. At the moment, this amounts to an annual budget of some six million euro.

For telephone contact STOWA's number is: +31 (0)30-2321199.
The postal address is: STOWA, P.O. Box 8090, 3503 RB, Utrecht.
E-mail: stowa@stowa.nl.
Website: www.stowa.nl.

SAMENVATTING

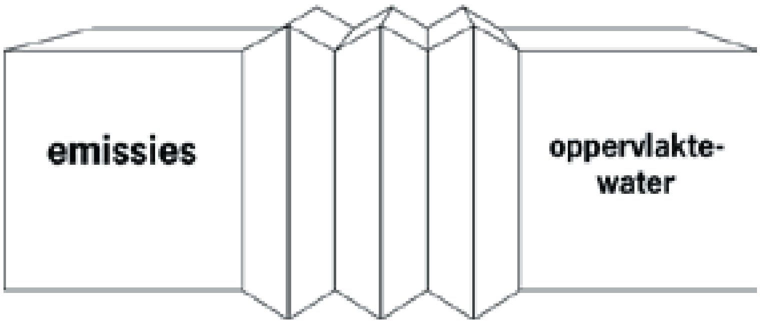
DE WATERHARMONICA

Hoewel de effluentkwaliteit van rioolwaterzuiveringsinstallaties (rwzi's) in Nederland over het algemeen van hoge kwaliteit is, is het gezuiverde water nog steeds giftiger dan verwacht mag worden op basis van de chemische en fysische samenstelling. Een natuurlijk dagelijks zuurstofritme ontbreekt, waardoor het water niet geschikt is voor hogere aquatische organismen. Bovendien bevat het in veel gevallen nog steeds hoge concentraties micro-organismen afkomstig van het actief-slibproces en van menselijke oorsprong. Als zodanig is het effluent nog niet geschikt voor gebruik als zwemwater, als recreatief water of voor natuurontwikkeling. De kwaliteit vormt daarom nog steeds een knelpunt voor het bereiken van de kwaliteitsdoelstellingen voor ontvangend oppervlaktewater volgens zowel Nederlandse standaarden evenals voor de doelstellingen van de EU Kaderrichtlijn Water.

De Waterharmonica (Figuur 1) richt zich op de toepassing van eco-technologische waterbehandelingssystemen zoals zuiveringsmoerassen als behandeling na bestaande rwzi's. Deze eco-technologische systemen vormen een natuurlijk zuiveringssysteem waarmee het kwaliteitsverschil tussen gezuiverde effluenten en oppervlaktewater overbrugd kan worden.

De Waterharmonica benadering is voorgesteld door Claassen (Claassen, 1996) als bijdrage aan een door de Stichting Toegepast Onderzoek Waterbeheer (STOWA) uitgeschreven prijsvraag naar vernieuwende ideeën voor waterbeheer. Het Waterharmonica concept werd door de jury erkend als veelbelovende benadering en kreeg een prijs toegekend.

FIGUUR 1 DE 'WATERHARMONICA' ALS BUFFER TUSSEN RIOOLWATERZUIVERINGSINSTALLATIE EN OPPERVLAKTEWATER. GEBASEERD OP CLAASSEN, 1996



Op basis van deze prijs is door STOWA en de waterschappen Wetterskip Fryslân en Hoogheemraadschap Hollands Noorderkwartier een breder programma opgezet rondom de Waterharmonica. Dit programma is gestart in 2003 en heeft de conceptuele ontwikkeling en praktische toepassing van de Waterharmonica in Nederland en in ontwikkelingslanden tot doel.

De tussentijdse resultaten van het programma zijn in 2005 in twee rapporten beschreven. Het eerste rapport, getiteld *Waterharmonica - de natuurlijke schakel tussen waterketting en watersystemen* (STOWA, 2005a) gaat in op het toepassingspotentieel van de Waterharmonica in Nederland en geeft een overzicht van de huidige Nederlandse ervaringen met toepassing van de Waterharmonica op praktijkschaal bij een aantal rwzi's. Er bestaan verschillende voorbeelden van praktijktoepassing van de Waterharmonica, zoals bij rwzi Everstekoog en rwzi

Land van Cuijk. Dit rapport is opgesteld door Royal Haskoning Nederland. Het andere rapport is opgesteld door LeAF (Lettinga Associates Foundation) en gaat in op de toepassing van de Waterharmonica in ontwikkelingslanden.

WATERHARMONICA IN ONTWIKKELINGSLANDEN

De in dit rapport beschreven studie richtte zich op het in kaart brengen van het potentieel van eco-technologische afvalwaterzuivering voor ontwikkelingslanden. Analoog aan de toepassing van de Waterharmonica als schakelsysteem zoals voorgesteld voor Nederland en Europa kunnen eco-technologische zuiveringssystemen in ontwikkelingslanden een 'schakel' vormen tussen (voor-) zuivering van afvalwater en potentieel hergebruik van water en de nutriënten in het afvalwater.

De afvalwatersituatie in veel ontwikkelingslanden verschilt over het algemeen sterk van de situatie in Nederland en andere landen in West Europa. In veel gevallen ontbreekt een zorgvuldig geplande waterinfrastructuur en wordt afvalwater niet of slecht gedeeltelijk gezuiverd. Vaak resulteert dit in de lozing van onvoldoende gezuiverd afvalwater op oppervlaktewater met de bijkomende risico's voor de volksgezondheid. Eco-technologische zuivering kan een geschikte aanvullende behandelingsmethode vormen in gevallen waar afvalwater niet of slechts gedeeltelijk wordt gezuiverd.

De eisen die op veel plaatsen in ontwikkelingslanden gesteld worden aan afvalwaterzuiveringsinstallaties sluiten goed aan bij de principes van eco-technologische zuiveringssystemen, zoals:

- Een laag (of afwezig) energie / elektriciteitsgebruik; op veel plaatsen in ontwikkelingslanden is een (betrouwbare) energievoorziening slechts beperkt beschikbaar;
- Gemakkelijk beheer waarbij weinig specialistische kennis nodig is;
- De systemen zijn gemakkelijk te bouwen met lokaal beschikbaar materiaal;
- Eco-technologische systemen kunnen door relatief weinig onderhoud continu functioneren;
- Bij een goed ontwerp van het systeem op basis van de lokale klimaats- en temperatuursomstandigheden is een relatief constante effluentkwaliteit mogelijk (dus robuuste systemen);
- Er kan waardevolle biomassa (zoals algen, eendekroos, verschillende soorten grassen en vis) worden geproduceerd waarbij nuttig gebruik gemaakt wordt van beschikbare nutriënten;
- Deze systemen zijn geschikt voor toepassing op kleine en grote schaal en in het bijzonder in rurale gebieden.

De benadering van de Waterharmonica benadrukt het feit dat zuiveringsmoerassen multifunctioneel zijn. De verwijdering van verontreinigingen kan gecombineerd worden met biomassaproductie en / of natuurontwikkeling waarbij gebruik gemaakt wordt van de bemestende waarde van afvalwater. Daarnaast benadrukt deze benadering het nuttig (her)gebruik van behandeld afvalwater. Als vertrekpunt wordt genomen dat drinkwater en regenwater van oorsprong een bron van goed water is, die in het gemengde rioleringssysteem wordt 'misbruikt' voor afvaltransport. Na een goede zuivering kan dit 'verspilde' water opnieuw als natuurlijke hulpbron worden gebruikt. Hierbij gaat het niet alleen om het water, maar ook om de aanwezige vervuilende stoffen, inclusief de nutriënten.

GEZUIVERD AFVALWATER ALS EEN NATUURLIJKE HULPBRON

Hoofdstuk 2 van dit rapport geeft een overzicht van de mondiale behoeften aan afvalwaterzuiveringssystemen en van de inzet van behandeld afvalwater als natuurlijke hulpbron. De VN Millenniumdoelen die in 2002 in Johannesburg zijn geformuleerd, benadrukken het feit dat er wereldwijd en vooral in ontwikkelingslanden een tekort is aan veilige watervoorraden en afvalzuiveringsfaciliteiten. De waterbeschikbaarheid per capita neemt wereldwijd af tengevolge van bevolkingsgroei en een sterk groeiende vraag naar irrigatiewater voor landbouw en voedselproductie. Het gebruik van (behandeld of onbehandeld) stedelijk afvalwater als een alternatieve bron van water wordt de komende decennia een steeds belangrijker onderwerp.

Het aantal (her)gebruiksmogelijkheden voor gezuiverd afvalwater is groot. Enkele belangrijke voorbeelden zijn gebruik als irrigatiewater in de landbouw, gebruik in de aquacultuur, gebruik voor landschapsirrigatie en -ontwikkeling, verschillende industriële gebruikstoepassingen, watervoorraadvorming voor natuurlijke habitats zoals vogelgebieden, watervoorraadvorming in recreatiegebieden, grondwateraanvulling en het tegengaan van zoutwaterinfiltratie in kustgebieden. De paragrafen 2.4 en 2.5 geven, vanwege hun wereldwijde belangrijkheid, een uitgebreide beschrijving van het gebruik van (gezuiverd) afvalwater in landbouw en aquacultuur.

ECO-TECHNOLOGISCHE AFVALWATERZUIVERINGSSYSTEMEN

Om de mogelijkheden van eco-technologische afvalwaterzuivering in beeld te brengen is in tabel 1 een overzicht van systemen en voorbeelden opgesteld. Hierbij worden ook de voorbeelden genoemd die in dit rapport beschreven worden. Er kan onderscheid gemaakt worden naar natuurlijke moeraslanden, aangelegde zuiveringsmoerassen, systemen voor productie van aquatische biomassa en aquacultuursystemen. De systeemdefinities zijn niet vastomlijnd. Er zijn veel toepassingen die bestaan uit een mengvorm van verschillende behandelingsstappen en hergebruiksdoelen.

TABEL 1 **OVERZICHT VAN ECO-TECHNOLOGISCHE WATERZUIVERINGSSYSTEMEN**

Typering	Beschrijving / opmerkingen	Voorbeeld
Natuurlijke moerassen	Er zijn veel voorbeelden van natuurlijke moerassen waarin afvalwater wordt geloosd; hoewel deze systemen over het algemeen niet bewust zijn ontworpen kunnen ze een waardevolle bron van technische informatie vormen.	• Nakivubo wetland, Kampala, Uganda (§ 3.4) • East Calcutta Wetlands, India (§ 2.5)
Aangelegde zuiveringsmoerassen	Aangelegde zuiveringsmoerassen worden bij voorkeur beplant met lokale plantensoorten. Beplanting: opschietende beplanting zoals riet of lisdodde. Er is een grote variëteit in systeemtypen, afhankelijk van het stromingsprofiel (horizontaal, verticaal) en de blootstelling aan het oppervlak (open water, ondergrondse filtratie.	• Zuiveringsmoeras gecombineerd met landschappelijk ontwerp in Nairobi, Kenya (§ 4.1) • Helofytenfilter in Bandung, Indonesia (§ 4.4), Dhulikhel Nepal (§ 4.5) en in Khe Sanh, Quang Tri, Vietnam (§ 4.6)
Systemen voor productie van aquatische biomassa	Aangelegde zuiveringsmoerassen beplant of geënt met plantensoorten, zoals waterhyacint, watersla, eendekroos, algen and Vetiver gras. Soms gecombineerd met aquacultuur (als tweede behandelingsstap).	• Castor, Senegal (§ 3.6)
Met afvalwater gevoede aquacultuur systemen	Visvijvers gevoed met primair gezuiverd afvalwater	• Viscultuur op basis van afvalwater in in Kalyani in West Bengalen, India (§ 4.3)

Over het algemeen is voor het goed functioneren van eco-technologische zuiveringssystemen een voorbehandelingssysteem noodzakelijk. De voorbehandeling heeft als doel de verwijdering van gesuspendeerd materiaal, van een groot deel van het CZV, van pathogene organismen en (facultatief) van nutriënten. Geschikte systemen voor voorbehandeling van afvalwater zijn voorbezinkervijvers, stabilisatievijvers, UASB bioreactoren en oxidatiesloten.

BETROKKENHEID VAN BELANGHEBBENDE PARTIJEN EN GEÏNTEGREERDE PLANNING

Afvalwaterconcepten gericht op zowel de zuivering als op het nuttig gebruik van gezuiverd afvalwater zoals voorzien in de Waterharmonica zijn betrekkelijk complex vanwege de combinatie van verschillende doelstellingen. Om met deze complexiteit om te gaan is het belangrijk de betrokkenheid en verantwoordelijkheden van de belanghebbende partijen voor bescherming en een duurzame sluiting van de waterketen te onderkennen. In de ideale situatie is het planningsproces met zijn verschillende fases (conceptvorming, haalbaarheidsstudies, technische uitwerking) een iteratief proces waarbij de belanghebbende partijen al in een vroeg stadium worden betrokken.

Een dergelijk geïntegreerd planningsproces, waarin de relevante belanghebbenden worden betrokken, kan vergemakkelijkt worden met beslissingsondersteunde middelen. Voorbeelden hiervan zijn SANEX™ of het conceptuele kaderwerk zoals is weergegeven in afbeelding 24 van paragraaf 5.3.

PLAATSBEPALING EN TOEKOMSTIGE ACTIVITEITEN VAN HET WATERHARMONICA PROGRAMMA

Tijdens de speciale Waterharmonica sessie van de 7e INTECOL International Wetlands Conference (juli 2004) werd ingegaan op de positie en toekomstige activiteiten van het Waterharmonicaprogramma. Duidelijk werd dat er wereldwijd veel kennis beschikbaar is over de nazuivering en het hergebruik van afvalwater. Het is van belang om die kennis te gebruiken. Deze kennis is echter vaak gefragmenteerd en wordt dikwijls niet correct geïnterpreteerd. Een belangrijk aandachtpunt voor de Waterharmonica is dan ook (het faciliteren van) communicatie:

- Het communiceren van het belang van integraal waterbeheer. Afvalwaterbeheerders zouden meer besef moeten hebben van het effect van hun activiteiten op aangrenzende ecosystemen – inclusief de effecten op de mens;
- Het communiceren van "geïntegreerde kennis in een bruikbare vorm".

Een belangrijke toekomstige taak voor de Waterharmonica is dan ook om kennis te verspreiden over hoe een water- en ecosysteembenadering gebruikt kan worden in het afvalwaterbeheer. Dit zou gedaan kunnen worden door:

- Het toegankelijk maken van succesvolle en minder succesvolle voorbeelden van integraal water- en ecosysteembeheer;
- Het voorzien in technische en praktische kennis over het ontwerp en beheer van eco-technologische zuiveringssystemen;
- Het gebruik maken van de website van het Waterharmonicaprogramma. Maar ook het inbedden van het Waterharmonica concept in andere fora zoals de Ecological Engineering Society (www.iees.ch), de gebruikersgroepen van de IWA, enz. Dit zou moeten leiden tot een netwerk aan contacten tussen onderzoekers en mensen uit de praktijk om daarmee de benadering van de Waterharmonica te bediscussiëren en te bevorderen.

De voortgang van het Waterharmonica programma zal worden gedocumenteerd op het Internetadres www.waterharmonica.nl. Op deze site is ook informatie over meerdere praktijkstudies beschikbaar, evenals de verslagen van de speciale Waterharmonicasessie die is gehouden tijdens 7e INTECOL International Wetlands Conference in Utrecht van 25 - 30 juli 2004.

DE STOWA IN HET KORT

De Stichting Toegepast Onderzoek Waterbeheer, kortweg STOWA, is het onderzoeksplatform van Nederlandse waterbeheerders. Deelnemers zijn alle beheerders van grondwater en oppervlaktewater in landelijk en stedelijk gebied, beheerders van installaties voor de zuivering van huishoudelijk afvalwater en beheerders van waterkeringen. Dat zijn alle waterschappen, hoogheemraadschappen en zuiveringsschappen, de provincies en het Rijk (i.c. het Rijksinstituut voor Zoetwaterbeheer en de Dienst Weg- en Waterbouw).

De waterbeheerders gebruiken de STOWA voor het realiseren van toegepast technisch, natuurwetenschappelijk, bestuurlijk juridisch en sociaal-wetenschappelijk onderzoek dat voor hen van gemeenschappelijk belang is. Onderzoeksprogramma's komen tot stand op basis van inventarisaties van de behoefte bij de deelnemers. Onderzoekssuggesties van derden, zoals kennisinstituten en adviesbureaus, zijn van harte welkom. Deze suggesties toetst de STOWA aan de behoeften van de deelnemers.

De STOWA verricht zelf geen onderzoek, maar laat dit uitvoeren door gespecialiseerde instanties. De onderzoeken worden begeleid door begeleidingscommissies. Deze zijn samengesteld uit medewerkers van de deelnemers, zonodig aangevuld met andere deskundigen.

Het geld voor onderzoek, ontwikkeling, informatie en diensten brengen de deelnemers samen bijeen. Momenteel bedraagt het jaarlijkse budget zo'n zes miljoen euro.

U kunt de STOWA bereiken op telefoonnummer: 030 -2321199.
Ons adres luidt: STOWA, Postbus 8090, 3503 RB Utrecht.
Email: stowa@stowa.nl.

Website: www.stowa.nl

'WATERHARMONICA' IN THE DEVELOPING WORLD

INHOUD

1

INTRODUCTION

1.1 THE WATERHARMONICA

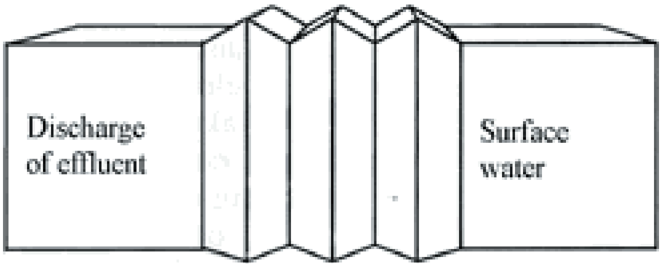
The latest policy on water management in The Netherlands and other European countries is aimed, amongst others, at stimulating further improvements in surface water quality by means of the EU Water Framework Directive (WFD). The WFD stimulates a combined approach by stimulating emission reduction at wastewater treatment plants, while at the same time setting water quality criteria for receiving surface waters. The initiative of implementation of the WFD for the inland waters in The Netherlands lies with the regional Water Boards.

The effluent quality of municipal wastewater treatment plants in The Netherlands has improved considerably during the last decades. The Pollution of Surface Waters Act (1970) states that all sewage wastewater has to be treated before discharging into surface water. At first, this Act basically required the removal of oxygen consuming material (BOD and ammonium) and pathogenic bacteria. Since the implementation of the EU Urban Wastewater Treatment Directive EC 91/271 the removal of nutrients is obligatory[1].
Although the effluent concentrations of nutrients and oxygen consuming compounds are nowadays relatively low, the treated wastewater is an important source of nutrients for the surface waters and is still more toxic than is to be expected based on its chemical and physical composition. It lacks a natural daily oxygen rhythm and, as such, is hostile to higher aquatic organisms. Moreover, in many cases it still contains too many microorganisms of the activated sludge process and of human origin. As such, the effluent is not yet suitable as swimming or recreational water and for nature development and not for reaching the WFD quality standards of the receiving surface waters.

The 'quality gap' between the actual effluent quality and the multiple use purposes of receiving surface waters both in The Netherlands and other European countries shows a need for 'extension' technologies that form a 'link' between the discharge of municipal wastewater treatment plants and receiving surface waters. The increasing demands can be met by further improvements of the effluent quality through the introduction of advanced treatment techniques, such as membranes, ozone, UV, and (denitrifying) sand filters. A drawback of these systems will be a higher consumption of fossil energy and resources, while on the other hand it is not yet sure that the treatment will be sufficient to comply with the earlier mentioned constraints put on receiving surface waters.

An alternative approach is found in the inclusion of eco-engineered treatment options as systems for post treatment. The Waterharmonica (Figure 2), conceptualised by Theo Claassen and Ruud Kampf (Claassen, 1996, Kampf et al., 2003), is the embodiment of the ambition to include ecologically engineered 'linking systems', such as constructed wetlands, as an integral part of the design and extension of wastewater treatment plants. In this approach, the linking system will act as natural post treatment of the effluent and might in the future be an integrated part of the overall treatment process.

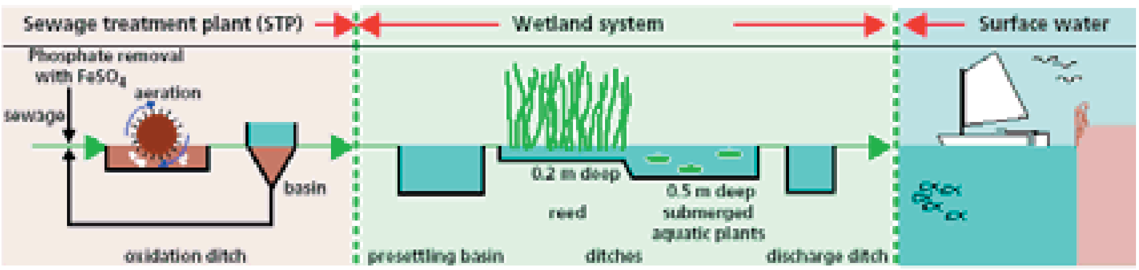
FIGURE 2 THE 'WATERHARMONICA' AS A BUFFER BETWEEN THE SEWAGE PLANT AND SURFACE WATER, BASED ON CLAASSEN, 1996



Constructed wetlands are widely researched and applied for tertiary treatment of domestic wastewater and storm water run-offs in Europe, Unites States and Australia (Denny, 1997). In The Netherlands also a number of interesting applications of eco-engineered post treatment systems have been developed and implemented during the last ten years applying (STOWA, 2001) to form the latter mentioned 'link' for biological reanimation of effluent. It is interesting to see the combinations of functions that are possible within these systems (e.g. food chains involving *Daphnia*, fishes and birds), through which several environmental and nature goals can be pursued. These combinations do not only refer to the combination of wet nature and wetland systems, but also to e.g. the integration of effluent treatment with active biological management or water storage.

The Waterharmonica approach acknowledges that the boundary conditions of wastewater treatment plants are increasingly set by the characteristics and demands of receiving surface water systems (see Figure 3 as an illustration of demands set by recreation). Examples of constructed wetland systems as intermediate systems before discharge to surface water are also known for other applications like e.g. storm water treatment. As such, the approach of the Waterharmonica is in fact a basis for an eco-engineered application of integrated water management. It introduces a framework and set of tools for the design of appropriate ecological solutions depending on local situations.

FIGURE 3 EXAMPLE OF 'WETLAND SYSTEM' AS BUFFER BETWEEN SEWAGE TREATMENT PLANT AND 'RECREATIONAL' WATER AT THE ISLAND OF TEXEL, THE NETHERLANDS (KAMPF ET AL., 2003)



[1] The effluent concentrations of total N and total P of new treatment plants larger than 20,000 population equivalents have to be lower than 1 mg P/l and 10 mg N/l, respectively.

1.2 POTENTIAL OF THE WATERHARMONICA CONCEPT FOR DEVELOPING COUNTRIES

Needs for both sanitation and reuse of water and nutrients in the developing world
The volumes of urban wastewater flows are increasing sharply around the world. This is more specifically so for cities in developing and transition countries[2], because of the relatively high population growth figures, high urbanization rate, progress in sanitation facilities and rapid economic development.

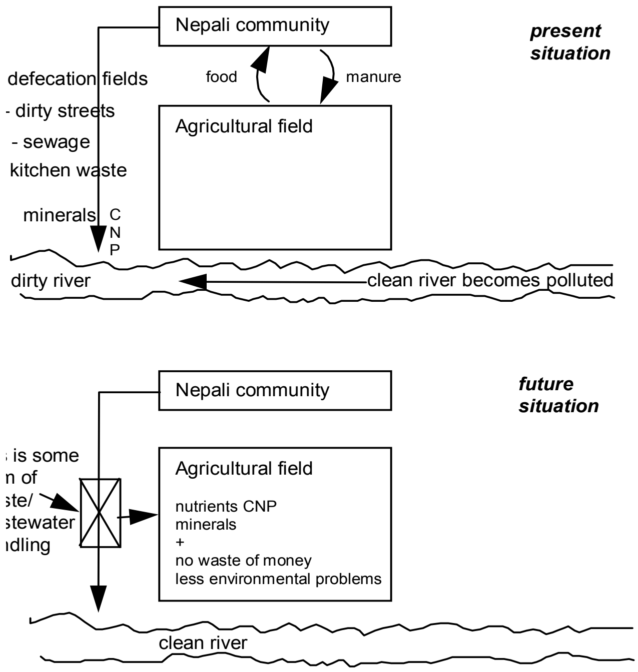
Lack of environmental awareness in combination with processes of industrialisation, modernisation and increases in standards of living (e.g. piped water supply) in general lead to an increase in water-use and wastewater-produce per capita. The latter becomes a problem when at the same time the financial and organisational requirements for widespread sanitation are lacking. Unfortunately this occurs frequently because developing countries are typically forced to prioritise basic issues such as drinking water supply versus sanitation, or at least, provisions for segments of the population versus provisions for all, rather than being aided in more sustainable integrated approaches.

Bolt et al. (1999) and Claassen & Kampf (1999) acknowledge that many of these countries are facing a dual problem. Due to inadequate or inexistent sanitary provisions, wastewater disposals are the cause of major health and environmental problems, whilst at the same time agro-fertilizers are scarce and expensive. The reuse of water and nutrients through beneficial use of treated wastewater is therefore an excellent component of a much needed and far more sustainable integrated approach. Even Western countries are picking up on this approach (after Tchobanoglous et al., 1998; Zeeman & Lettinga, 1999; Van Lier & Lettinga, 1999, and Mels et al., 2002).

An example of such an integrated approach in a rural Nepali community is depicted in Figure 4. The shown schemes are the result of a workshop organised by IRC in several rural communities in Nepal (Bolt et al., 1999; Claassen & Kampf, 1999). In the present situation wastes and wastewater are disposed off in a local river, leading to downstream water pollution and potential health risks related to water borne diseases. At the same time valuable nutrients and clean water are lost. By considering wastes and wastewater as a potential resource that – after proper treatment – can be used for irrigation and fertilization a double benefit can be achieved.

[2] We refer here to the list of 36 partner countries as formulated by the Dutch Ministry of Foreign Affairs in the policy document Mutual Interests, Mutual Responsibilities - Dutch Development Co-operation en route to 2015 (Ministry of Foreign Affairs, 2003)

FIGURE 4 CLOSING THE NUTRIENT CYCLE, AS AN EXAMPLE OF USEFUL (RE)USE OF WATER AND NUTRIENTS IN A NEPALI COMMUNITY (BOLT ET AL., 1999, CLAASSEN & KAMPF, 1999)



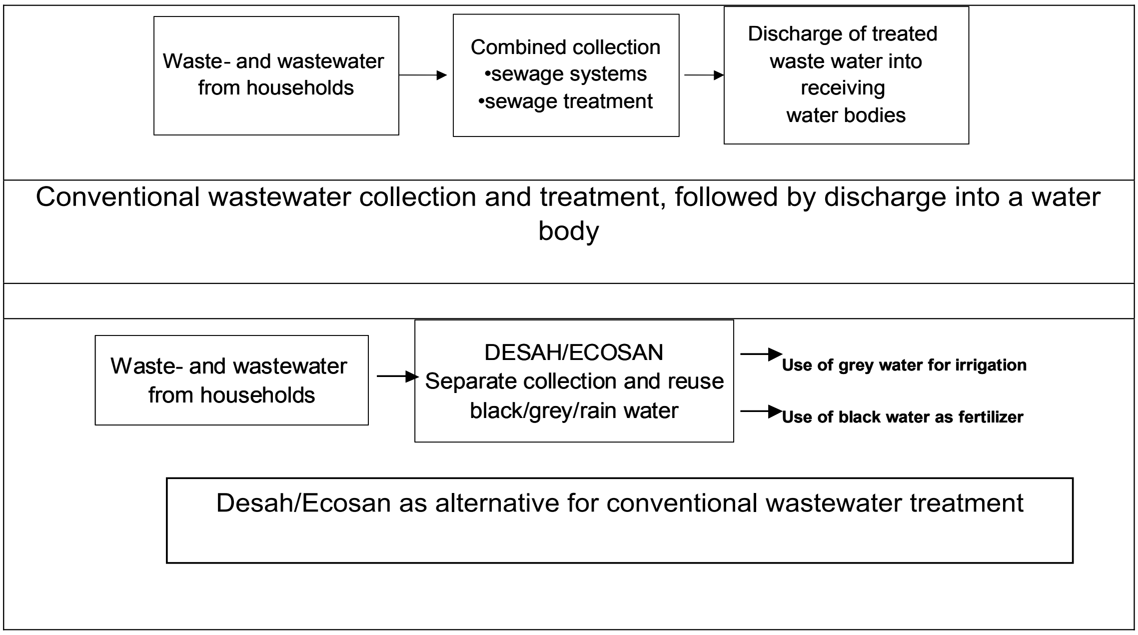
ECO-ENGINEERED TREATMENT AS A LINK BETWEEN WASTEWATER DISCHARGE AND REUSE

This report explores and maps the potential of eco-engineered treatment systems as a 'link' between wastewater discharge and reuse of water and nutrients in the developing world. Analogously to the Waterharmonica concept as proposed for The Netherlands and Europe eco-engineered treatment forms a potential 'link' between wastewater discharge and potential reuse of water and nutrients.

As depicted in Figure 5 two principally different systems are existent in practice. In the first system – which is the most widely applied – all the wastewater is collected and is transported to some form of treatment facility or, as is the case in many countries, is discharged directly into surface waters. The other system starts with the separate collection of black and grey wastewater and sometimes urine at the household level (the 'Decentralised Sanitation and Reuse (DESAR)' or 'Ecological Sanitation (EcoSan)' approach; STOWA, 2004). Because of the diversion in concentrated and less concentrated flows this will in many cases lead to more efficient treatment and reuse options.

In many practical cases the departure point for wastewater reuse will be combined collection because the sewer and treatment infrastructures already exist. Although the current gravity sewer systems require large quantities of water to transport relatively small amounts of concentrated wastes, the 'wrong' can be turned into a 'good' by making beneficial use of the treated wastewater.

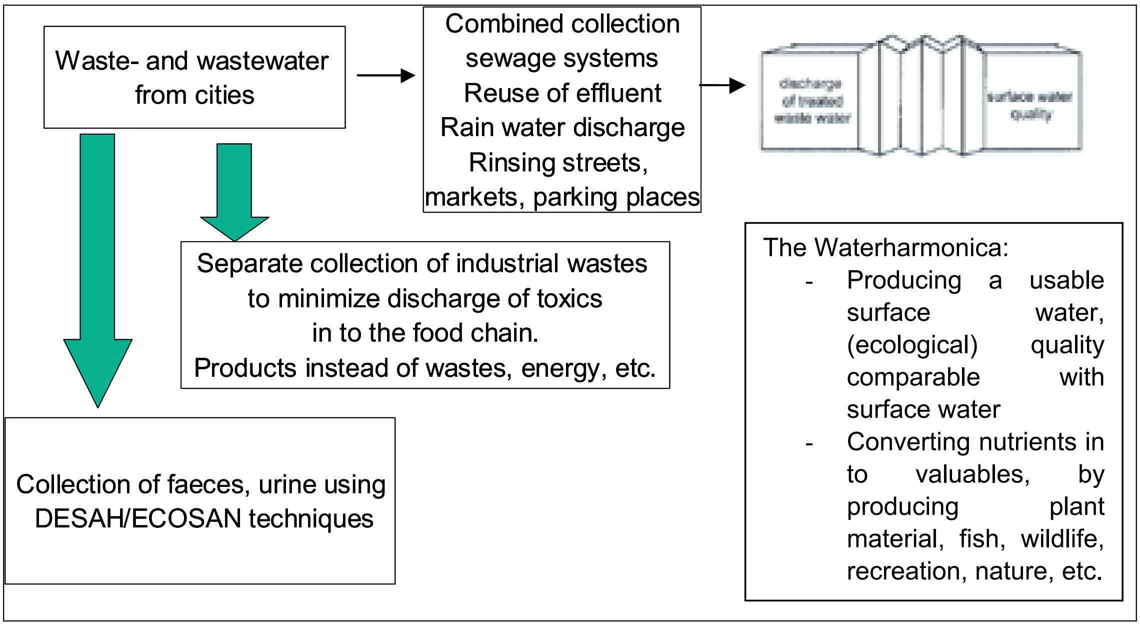
FIGURE 5 CONVENTIONAL WASTEWATER DISPOSAL (UPPER FIGURE) AND DESAH / ECOSAN AS ALTERNATIVE (LOWER FIGURE)



The combined sewage system is common practice in the western world, though the disadvantages, like sewage outlets and increased costs during rainy periods due to treatment of rainwater in the sewage treatment plants are making the system expensive and vulnerable. Currently the policy of most water authorities is to prevent rain water coming in the sewage system by making separate rain water sewers and disconnecting rainwater from paved surfaces from the sewer system to discharge on surface water. These discharges can contain all kind of pollutants from roads, parking places, including feces of pet animals. Above that, in many build up areas sewers are used and needed for rainwater discharge.

This report highlights the fact that the Waterharmonica can actually function as an alternative between the two systems depicted in Figure 5 by making use of the existing transport and treatment systems, but adding an additional unit operation in the form an eco-engineered system. This is depicted in Figure 6. The starting point is to consider drinking water and rain water as a good source of water, only 'misused' to transport wastes. After a good treatment of this 'wasted water' it can be a good resource, not just with respect to the water volumes, but also with respect to former pollutants, including valuable nutrients (Claassen & Kampf, 1999; Kampf et al., 2003). Another important issue is that the western sewer system is -though costly in investment - relatively cheap and effective in operation. Moreover, it brings huge amounts of water (carrying relatively small amounts of wastes) from a large service area together to one spot. This is actually the place were the 'wrong' could be turned into a good by making beneficial use of the treated wastewater.

FIGURE 6 THE PLACE OF THE WATERHARMONICA BETWEEN THE WATER CHAIN AND THE WATERSYSTEM, IN CONNECTION WITH DESAH/ECOSAN



Integrated Water Management, promoted in Agenda 21 (Rio 1992) and again during World Water Forums (The Hague 2000 and Kyoto 2003), is meant as a concept to link, amongst others, various water supply issues with wastewater management, at local, national and international levels, because of direct responsibilities or because of global concern for the environment. The Waterharmonica aims to elaborate on eco-engineered approaches within this vision.

Exploring and mapping the potential of eco-engineered wastewater treatment in the developing world has a dual motivation. First of all, eco-engineered wastewater treatment integrated with the use of effluent is generally cheaper than conventional treatment and can be implemented and managed more easily. Secondly, eco-engineered treatment with direct or indirect use of effluent is generally, more or less controlled or uncontrolled a daily practice in many developing countries (Martijn & Huibers 2001b).

The requirements for sanitation systems at many locations of transition countries tend to match quite well with the principles of ecological engineering, such as:

- A low or absent energy (electricity) requirement which is in many places not (reliably) available;
- Easy operation with low skilled operators;
- Easy to construct with locally available material;
- Permanent and continuous operation without too much maintenance;
- More or less constant effluent quality (i.e. robust systems) when the design is adequately adapted to local climate and temperature conditions;
- Possibility to produce biomass (e.g. algae, duckweed, various grasses, fish) by making beneficial use of the available nutrients;
- Applicable at small and large scale and especially feasible in rural areas.

The further development of eco-engineered treatment and reuse options is a feasible way to ascertain widespread wastewater management because it builds on existing experiences and capacities. For the sustainability of the latter it is crucial that eco-engineered solutions can be copied, operated and managed according to locally available capacity, conditions and needs. A systematic approach for the mobilisation and evaluation of knowledge on eco-engineered applications in the developing world within the Waterharmonica programme is therefore considered important. Southern countries will benefit by sharing knowledge and experiences and Western countries can learn from existing systems and concepts in the 'South'.

1.3 CONTEXT, OBJECTIVES AND OUTLINE OF THIS REPORT

The investigation that is described in this report is the partial result of a research and implementation programme, initiated by two water boards (Wetterskip Fryslân and Hoogheemraadschap Hollands Noorderkwartier) and is financed by STOWA, the Dutch Foundation for Applied Water Research. The programme was started in 2003 and aims at conceptual development and practical implementation of the Waterharmonica.

This part of the STOWA programme 'Waterharmonica' is aimed at exploring and mapping the potential of eco-engineered wastewater treatment in the Developing World (see paragraph 1.2) as a 'link' between wastewater discharge and the beneficial use of water and nutrients. A second report, entitled *Waterharmonica - the natural link between water chain and water systems* (STOWA, 2005a, elaborates the application potential of the Waterharmonica in The Netherlands and reviews current Dutch experiences of the Waterharmonica at full scale treatment plants. This report has been compiled by Royal Haskoning, The Netherlands.

The ongoing progress of the Waterharmonica programme is documented at the Internet site www.waterharmonica.nl. This site also reviews specific case studies and reports on a special Waterharmonica session that was held at the 7th INTECOL International Wetlands Conference in Utrecht, The Netherlands 25 - 30 July 2004.

Chapter 2 of this report provides an overview of the global needs and constraints for sanitation, wastewater treatment and the conversion of treated wastewater into a natural resource. It especially focuses on the reuse of wastewater in aquaculture and irrigated agriculture. Chapter 3 contains a review of eco-engineered treatment options. Chapter 4 contains a number of illustrative practical examples of eco-engineered treatment systems. Chapter 5 summarizes the most important findings of this study and discusses the potential and constraints of ecological engineering in developing countries.

Part II, which is added as a separate report, describes the preparation of a demonstration project in Matagalpa, Nicaragua.

2

REATED WASTEWATER AS A NATURAL RESOURCE

2.1 INTRODUCTION

This chapter provides an overview of the global needs and constraints for sanitation, wastewater treatment and the conversion of treated wastewater into a natural resource. It lists the potential water reuse options and especially focuses on the reuse of wastewater in aquaculture and irrigated agriculture.

2.2 GLOBAL WATER SCARCITY AND LACK OF SANITATION

THE MILLENNIUM DEVELOPMENT GOALS

A large part of the world's population has no access to safe drinking water and lacks appropriate sanitation services. Poor sanitary conditions remain one of the greatest health threats for poor people. Despite the intensive efforts of many national and international organizations, 1.1 billion people (approximately 18% of the world's population) still remain without access to safe sources of water and 2.4 billion (almost 40% of the world's population) are lacking appropriate wastewater handling facilities.

Water scarcity, unsafe and unsustainable use of water resources and lack of sanitation are therefore currently high on the international political agenda. At the World Summit on Sustainable Development (WSSD) in South Africa, September 2002 and the Third World Water Forum in Japan, March 2003, world leaders have pledged themselves to cut poverty in half by 2015. Access to safe water and sanitation services are essential to reach this millennium development goal. An agreement was reached to increase worldwide access tot sanitation services to 50% by 2015.

The Millennium Development Goal regarding poverty

- To cut poverty in half by 2015 (compared to 2002)

The specific Millennium Development Goal related to water and sanitation:

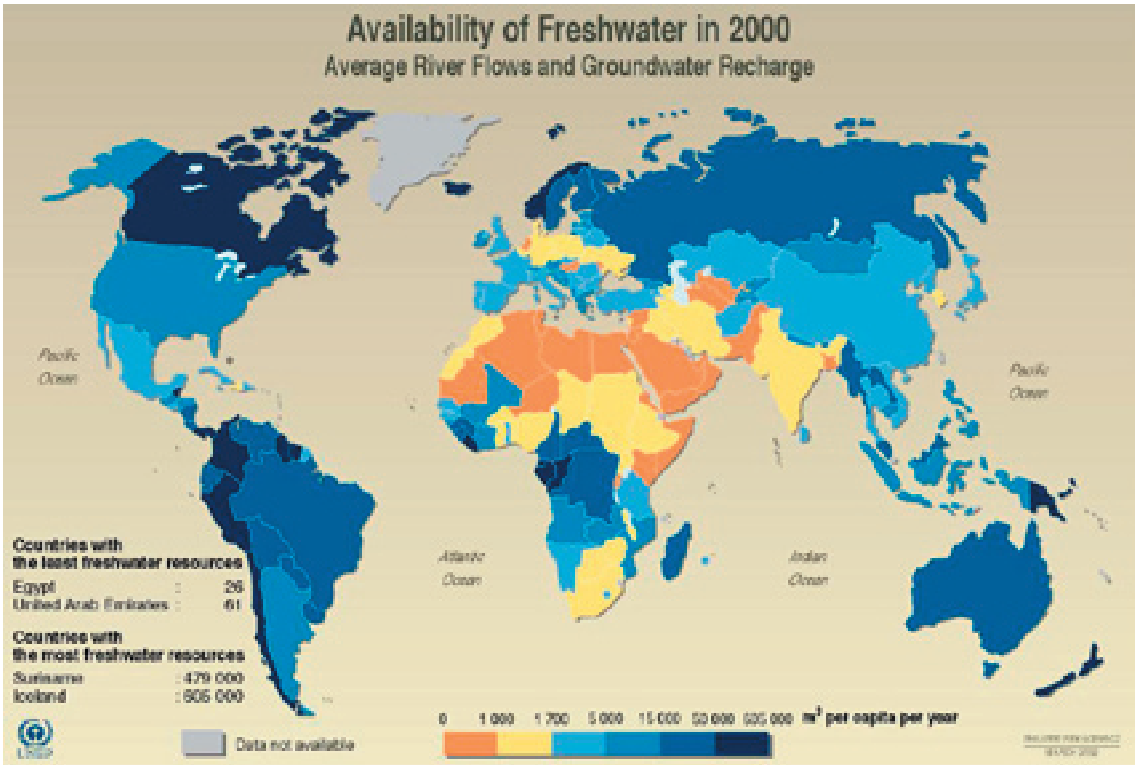
- To halve the number of people without access to safe drinking water and basic sanitation by 2015 (compared to 2002)

Source: World Summit on Sustainable Development, Johannesburg, 2002

WATER SCARCITY

Figure 7 below shows the global availability of freshwater in 2000 in m^3 per capita per year. The graph shows a relatively high water stress in the Middle East, Northern Africa, West Asia and parts of Australia. Surprisingly, also parts of Europe with high population densities have relative low fresh water availability per capita.

FIGURE 7 **AVAILABILITY OF FRESHWATER IN 2000 (WRI, 2000)**



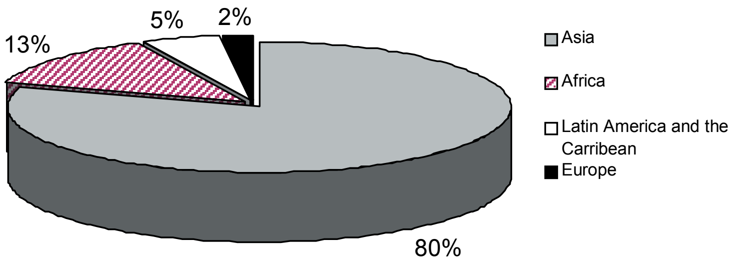
It is expected that fresh water will be become increasingly scarce: by 2025 fresh water use is expected to increase by 40%. More water, 17%, will be needed to grow food for growing populations and 23% in other uses. In addition, shallow groundwater, which is the main source of accessible water for poor people, is increasingly becoming polluted and depleted (Andersson, 2003). In addition, climate change is expected to cause more severe droughts. The number of people living in water scarce regions, internationally defined as an availability of less than 1,000 cubic meters of renewable water per person per year, is expected to increase with a factor 6 to 8 between 1990 and 2025 to about 1 billion (Gardner-Outlaow and Engelman, 1997). In fact the only source of water that will be increasing significantly in the coming decades is urban wastewater.

LACK OF SANITATION

Population growth, urbanization, improved sanitation and economic development in general lead to rapidly increasing volumes of fresh water required and wastewater to be disposed of. In most countries of the world an important part of the urban domestic wastewater is being discharged into surface water or natural drains, often with none or only partial treatment.

Over the period 1990-2000, access to improved sanitation increased globally from 51 to 61 per cent, resulting in 1 billion additional people with access to sanitation (http://www.developmentgoals.org). Despite these gains, in 2000 about 2.4 billion people still lacked access, especially in Asia (Figure 8). The gap between rural and urban areas remains extremely wide, especially in Eastern and South-central Asia, where coverage in rural areas is only about one quarter of the population, while urban coverage is 70 per cent. Halving the proportion of the world's population without improved sanitation by 2015 will require reaching an additional 1.7 billion people, a challenge for greater financing and more effective sanitation programs.

FIGURE 8 GEOGRAPHICAL DISTRIBUTION OF PEOPLE LACKING IMPROVED SANITATION FACILITIES IN 2000; (TOTAL NUMBER AMOUNTED 2.4 BILLION PEOPLE) (SOURCE: WHO, UNICEF AND WORLD BANK ESTIMATES)



2.3 TREATED WASTEWATER AS SOURCE OF WATER AND NUTRIENTS

Wastewater reuse options

The number of options for the (re) use of treated effluents is large. Some important examples are:

- Agricultural irrigation
- Wastewater-fed aquaculture
- Landscaping / landscape restoration
- Water supply to natural habitats, such as bird sanctuaries
- Water supply to recreational areas
- Groundwater and aquifer recharge
- Reduction of salt water intrusion
- Various industrial uses
- Household water

Because of their global importance, especially in developing countries, the following paragraphs give a more extended description of the wastewater reuse in agriculture and aquaculture.

2.4 WASTEWATER USE IN IRRIGATED AGRICULTURE

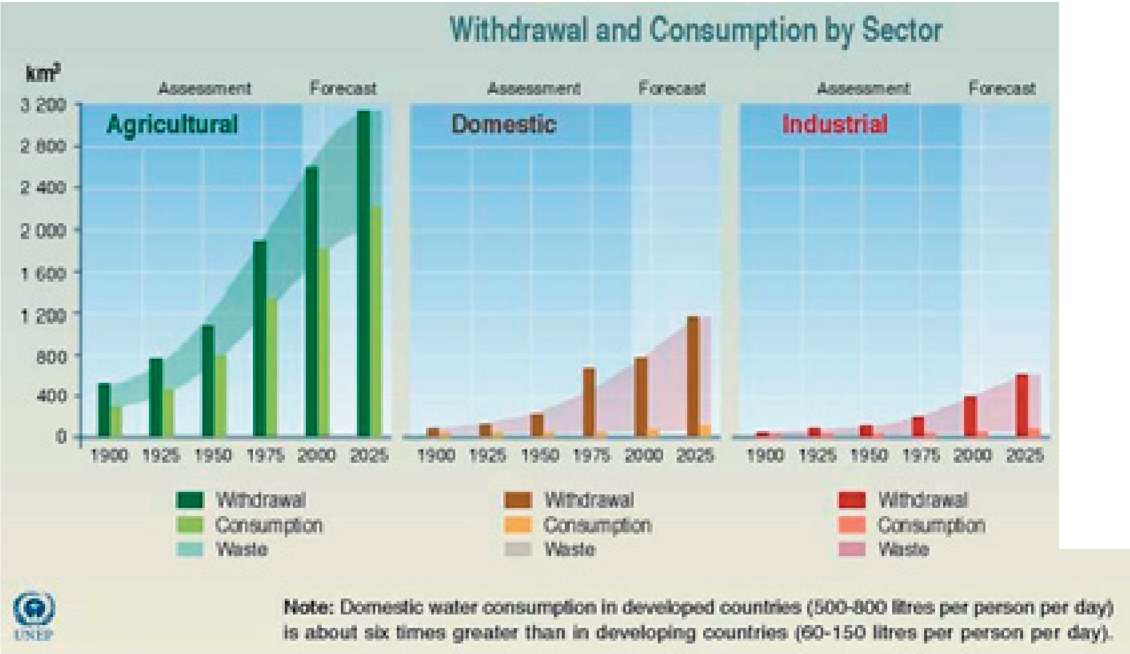
Domestic wastewater is an ideal potential resource for water and nutrients in agriculture. The World Health Organization states that 'where possible reuse of wastewater should be the preferred method of wastewater disposal to minimize treatment costs and obtain maximum agricultural benefits from the nutrients contained in the wastewater' (WHO, 1989).

Some major points advocating the use of treated wastewater in irrigated agriculture are (Martijn & Huibers, 2001a):

- Treatment and biomass production are combined and may form an attractive economic activity and a potential source of food or green energy;
- Alleviation of higher quality water scarcity: treated wastewater can replace current employed higher quality water resources used for irrigation and aquaculture;
- Reduced need for fertilization: treated wastewater provides crops and fish or fish feed with nutrients.

Agriculture is an enormous water consuming sector, simultaneously affecting and being affected by water scarcity and pollution hazards. According to UNEP approximately 70% of the total fresh water resources worldwide are used in agriculture. Forecasts predict an even higher share due to increasing agricultural demand related to population growth (Figure 9) and global climate change.

FIGURE 9 WATER WITHDRAWAL AND CONSUMPTION BY SECTOR, INCLUDING PROJECTIONS FOR 2025. SOURCE: IGOR A. SHILOMANOV, STAGE HYDROLOGICAL INSTITUTE (SHI, ST. PETERSBURG) AND UNESCO - PARIS, 1999



The water situation in Jordan illustrates the potential quantitative significance of using treated wastewater. Jordan is a semi-desert country with a total population of 4.9 million in the year 1999. Table 2 shows the available water resources and the projected values for the years 2010 and 2020 (Halalsheh, 2002). Due to the very limited water resources, all treated wastewater is – as a legal constraint - used in irrigation. The wastewater discharged from the existing treatment plants is considered as an important water resource, especially in the future as the amount of wastewater is predicted to increase from 75^*10^6 m^3/year in the year 2000 to 265^*10^6 m^3/year in the year 2020; by then contributing to 20% of the available water.

TABLE 2 ROJECTED AVAILABLE WATER SUPPLY ($*10^6$ M^3/YEAR) IN JORDAN

	2000	2010	2020
Surface Water	375	505	505
Renewable ground water	407	325	285
Fossil ground water	61	143	143
Reclaimed wastewater	**75**	**178**	**265**
Brackish water	0	15	50
Peace treaty water	30	50	50
Lower Jordan water	0	30	30

TREATED WASTEWATER AS A SOURCE OF NUTRIENTS

As an illustrative example the nutrient balance of the production of Wheat by secondary treated wastewater was calculated (Table 3). The case shows that domestic wastewater contains more than sufficient N and P to suffice the demand, while there might be a shortage on potassium (K) that might be added through a fertilizer. In fact there is a risk of overdosing of nitrogen (N) and phosphorous (P) and the (treated) wastewater should therefore be supplemented with other water sources or part of the nutrients should be removed.

TABLE 3 ILLUSTRATIVE EXAMPLE OF NUTRIENT UPTAKE OF WHEAT AND NUTRIENT ADDITION THROUGH IRRIGATION WITH (UNTREATED) WASTEWATER (SOURCE: HUIBERS, 2003)

	N	P	K
Removal from field in harvested product	112 kg/ha	8 kg/ha	141 kg/ha
Applied Treated Wastewater			
500 mm	40 mg/l	8 mg/l	25 mg/l
5.000 m^3/ha	200 kg/ha	40 kg/ha	125 kg/ha
Balance	+ 88 kg/ha	+ 32 kg/ha	- 16 kg/ha

EFFLUENT CHARACTERISTICS THAT ARE RELEVANT TO AGRICULTURAL REUSE

Appropriate use of treated or untreated wastewater can be defined in many ways (e.g. safe, sustainable, productive) and depends on many variables: type of wastewater, type of treatment, seasonal fluctuations in effluent quality and quantity, type of crops, cropping patterns, soil and soil management, climate, ground water, irrigation method, water requirements, social-cultural norms and values, etc. Wastewater reclamation involves the treatment or processing of wastewater to make it reusable.

The link between wastewater treatment and the use of effluent in irrigated agriculture is thus (or should be) based on negotiable effluent characteristics. A review of recent literature (Martijn & Huibers, 2001a) produced a list of wastewater characteristics that directly or implicitly relate to the design and management of wastewater reclamation and agricultural systems. The characteristics are shown in Table 4.

TABLE 4 **TREATED WASTEWATER CHARACTERISTICS THAT DIRECTLY OR IMPLICITLY RELATE TO THE DESIGN AND MANAGEMENT OF WASTEWATER RECLAMATION IN COMBINATION WITH AGRICULTURAL SYSTEMS (MARTIJN & HUIBERS 2001A)**

Characteristic	Effects
Plant macro nutrients	• The principal benefit is a reduced need for fertilization • A major point of attention is that nutrients should be balanced; nitrogen overdose may result in nitrate contamination of ground and surface water and in algae bloom in adjacent surface waters • Excessive N&P may lead to micro nutrients deficiency (Cu, Zn, Fe); excessive N may affect crop quality (e.g. enhanced vegetative growth or delays in fruit ripening)
Pathogenic micro-organisms	• Pathogenic organisms in wastewater may include a health risk to farm workers, nearby residents, crop handlers and consumers. Principal categories of pathogenic organisms are bacteria, viruses, protozoa and helminths • Pathogens do not penetrate the roots of most crops (one well-known exception is water melon) • The most widely adopted and somewhat conflicting guidelines for wastewater reuse in agriculture are from the WHO and the US-EPA
Inorganic soluble salts (Ca, Mg, Na, K, B, Cl, Carbonates and Sulphates/Sulphides)	• Long term application may lead to degradation of agricultural land (soil salinisation and sodification) • Ion specific plant-toxicity, mainly associated B, Na and Cl • Leaf-burn and staining of product (sprinkler-irrigation) • Corrosion or clogging of irrigation water distribution and filter systems
Biodegradable organic matter and suspended solids	• Too high concentrations (e.g. in raw wastewater) may result in clogging of water distribution systems and / or soil pores. Clogging due to algae (related to nutrient levels) is a serious problem with water-use-efficient localised irrigation systems such as drip-irrigation • Under septic conditions in the field there may also be malodour that may affect public perception and acceptance
Trace elements	• Trace elements include heavy metals and trace organic toxic or carcinogenic substances (e.g. pesticides, insecticides, drug residuals and endocrine disrupting compounds) • The concentration of most trace elements is generally lowered by 70-90% during secondary treatment • When using municipal wastewater the risks of food-chain-accumulation and plant toxicity hazards by trace elements are generally low • Uncontrolled industrial discharges of micro pollutants may pose risks and should be critically evaluated
Effluent flow-rate	• Reuse frequently requires water conveyance facilities for delivering the reclaimed water • Matching demand and supply; the irrigation water requirements are in most cases not continuous, while the effluent production is (although it may vary) • Need for construction of effluent storage tanks / basins which could be combined with tertiary treatment (e .g. ponds)

An agricultural system must deal with the characteristics mentioned in Table 4 as well as with the implications, in addition to other considerations that apply to all types of irrigation water. On the other hand, a wastewater reclamation system can be tailored to change these characteristics up to a level desired from both the agricultural system and the general environmental point of view. The general environment in this case relates to the environment beyond the agricultural system and refers to issues such as public health and groundwater, for example in the case of nitrate leaching. It is made implicit that an agricultural system has the potential, responsibility, and is often mandated, to incorporate concerns for these general environmental aspects.

PATHOGENIC MICRO-ORGANISMS AND PUBLIC HEALTH

The World Health Organisation has established guidelines for wastewater use in irrigated agriculture, as shown in Table 6 (WHO, 1989). Although these guidelines are toughly debated – Western countries tend to argue that the guidelines are not strict enough, while developing countries put forward that the measures to be taken to comply with the standards for unrestricted irrigation are unaffordable – they generally serve as the main standard that is considered in agricultural reuse nowadays.

TABLE 5 HEALTH GUIDELINES REGARDING REUSE OF TREATED WASTEWATER IN AGRICULTURE (WHO, 1989)

Reuse Condition[a]	Exposed Group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre)[c]	Faecal coliforms (geometric mean no. per 100 ml)[c]
Unrestricted irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	≤ 1000
Restricted irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended
Restricted irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e] if exposure of workers and the public does not occur	None	Not applicable	Not applicable

a) In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly; b) Ascaris and Trichuris species and hookworms; c) During the irrigation period; d) A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact; e) In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used

CURRENT STATUS OF WASTEWATER USE IN AGRICULTURE

In the urban and peri-urban areas of many developing countries, in many cases wastewater is used for agriculture. In some situations this is a typical activity of the urban poor who grow crops to supplement household income. In other cases, the traditional peri-urban farmer is confronted with increasing pollution of this originally fresh water source (Duran et al., 2003).

Israel and the USA are some of the most advanced countries in terms of regulated and researched experience on the use of wastewater in agriculture. Feigin et al. (1991) have edited a good portion of technical agronomical and irrigation information. The issues are complex and this is reflected in the rules and regulations that these countries use for governing reuse. Developing countries need to develop their own knowledge base, especially since many of the pre-requisites in Israel and the USA (e.g. tertiary treatment) is practically not achievable within the foreseeable future. Moreover, the types of farming systems in developing countries are often quite different; e.g. in terms of land and water rights, money to invest in drip-irrigation and level of education.

Urban and peri-urban agriculture for food production is very important in many cities in the developing world and the contribution of direct or indirect use of wastewater[3] is significant. E.g. Accra, the capital and biggest city of Ghana, has a well-developed urban agriculture and it is estimated that 70% of the vegetables consumed in Accra are grown in plots in and around the city. Only 8% of the wastewater of the city is treated, while 92% is discharged into open drains. The water used for irrigation of the vegetable plots is taken from the city drains, which in many cases contains untreated wastewater.

2.5 WASTEWATER USE IN AQUACULTURE

INTRODUCTION[4]

Wastewater use in aquaculture is aimed at growth of fish and other aquatic organisms or biomass for the production of food sources. Wastewater treatment is not the primary objective. Research has led to a scientific understanding that fertilization by wastewater provides natural food for fish in the form of phytoplankton, zooplankton, benthic organisms and aquatic plants.

Wastewater-fed aquaculture is used in a variety of unit operations around the world, especially in developing countries. The vast majority of wastewater reuse systems in aquaculture are traditional in the sense that they have been developed by farmers and local communities. There is a great diversity of systems when all forms in which human excreta are reused in aquaculture are considered (Edwards, 2000).
The direct use of sewage has also been an age-old practice in many places in especially Asia. Wastewater-fed aquaculture is situated in the peri-urban areas and is using the city wastewater as a source of water and nutrients.

CURRENT STATUS OF WASTEWATER USE IN AQUACULTURE

Most wastewater-reuse in aquaculture in the world today continues to take place in Asia where it is a traditional practice in a number of countries (Edwards, 2000). In contrast there is an almost insignificant current level of practice on other continents. Wastewater-fed aquaculture is a traditional activity in countries like Vietnam, China and India, although it appears to be on the decline.

Hanoi in Vietnam has a large wastewater-fed system of fishponds and rice fields, which depends on wastewater flowing out of the city. Ho Chi Minh has a unique system of tilapia seed production fed with faecally contaminated surface waters but it is declining in area due to rapid urban expansion. Although the Hanoi city master plan retains the aquaculture-agriculture land use pattern of the district, the wastewater-fed pond and pond/rice field area has declined by 35% to under 500 ha.

The world's single, largest wastewater-fed, fishpond complex is in Calcutta, India (see the paragraph below). Similar but smaller systems have been constructed in three municipalities within the Calcutta metropolitan area under the Ganga Action Plan. Wastewater-fed aquaculture systems are used to protect the Ganges from pollution. West Bengal appears to be the pioneering state with 130 sewage-fed fish farms covering an area of 4000 ha and supplying more than 8000 ton of fish per year to consumers (Jana, 1998; Jana, 2004).

[3] 'Direct use' is defined here as the use of treated wastewater where there is a direct link between the wastewater treatment system and the use application (e.g. irrigation); 'indirect use' includes mixing, dilution, and dispersion of treated wastewater after discharge into an impoundment, receiving water or groundwater aquifer prior to use. 'Indirect use' normally, but not necessarily constitutes unplanned use (after Asano and Levine 1998; in Asano T., 1998).
[4] For this paragraph we quoted parts of the excellent article 'Wastewater-fed aquaculture: state-of-the-art' of P. Edwards, published in: Waste Recycling and Resource Management in the Developing World. (pp. 37-49).

EXAMPLE: THE EAST CALCUTTA WETLANDS

East of the city of Calcutta (India) a city with approximately 5 million inhabitants, lies the world's largest natural wetland system used for wastewater treatment combined with agricultural production, covering originally 12,500 ha. A large part of the wastewater and urban run-off of the city enters this wetland and is used for a combination of fish farming and agriculture, while at the same time it is being treated. It is estimated that the entire wetland provides employment for about 17,000 people and that 20 tonnes of fish and 150 tonnes of vegetables are produced daily. The wastewater-based agricultural activities developed autonomously and are completely based on local initiatives.

There are three major sub-regions of economic activity using city wastewater and garbage, the fishponds (*bheris*), rice cultivation using effluent from the fishponds and vegetable farming on organic garbage substrate. The fishponds are central to the entire waste-recycling region. They cover a total area of about 3,000 hectares (Ghosh, 1999). In the fishponds algae and fish are grown simultaneously, with the algae providing a protein rich fish feed. A variety of fish species are produced, of which the most significant are the Indian Major Carp - Rahu (*Labeo rohita*), Catla (*Catla catla*), Mrigal *(Cirrihinus Mrigala*), Indian Minor Carp - Bata - (*Labeo bata*), Exotic Variety - Silver Carp (*Hypophthalmichthys molitrix*), Common Carp (*Cyprinus carpio*), Grass Carp (*Tenopharyngodon idella*), Tilapia - Nilotica (*Oreochromis nilotica*) and Mosambica (*Tilapia mosambica*).

The farmers use a careful procedure to grow the fish. In brief this procedure consists of pond preparation and subsequent filling of the pond with sewage water. After a certain period of facultative stabilisation of the wastewater the ponds are stocked. To ascertain the quality of water for fish growth, the farmers use a process of stocking test fish in which a small number of fish are stocked as probe species to test water quality. Secondary fertilization consists of periodic introduction of wastewater into the ponds throughout the growth cycle. The wastewater inflow may be continuous in ponds larger than 40 ha. The treated effluent of the fisheries is used to irrigate surrounding farms (two harvests a year) via a grid of drainage channels (after Calmanac, 2003).

Unfortunately, the untreated discharge of industrial wastewater streams has led to the presence of heavy metals in Calcutta wastewater and appears to be a significant health risk to Calcutta consumers. A survey by Biswas and Santra of fish (and vegetables) raised on wastewater from markets in the Calcutta metropolitan area indicated high levels of lead, cadmium and chromium compared to those from relatively pollution – free rural areas.

The East Calcutta Wetlands are declining in area due to increasing urbanisation. Edwards (2000) states that they are likely to disappear unless there is a significant increase in pond productivity to provide an incentive for landowners to maintain current land use; and/or local government recognizes the considerable environmental and social benefits.

3

ECO-ENGINEERED WASTEWATER TREATMENT SYSTEMS

3.1 INTRODUCTION

As stated in chapter 1, the Waterharmonica approach is based on the inclusion of ecologically engineered 'linkage-systems', such as constructed wetlands, as an integral part of the design or the renovation and extension of municipal wastewater treatment plants. This chapter contains an overview of eco-engineered wastewater treatment options including some design features. Illustrative examples of eco-engineered systems are provided in chapter 5.

3.2 ECOLOGICAL ENGINEERING

The term 'ecological engineering' was introduced by Howard T. Odum in 1962 to indicate 'those cases where the energy supplied by man is small, relative to the natural sources but sufficient to produce large effects in the resulting patterns and processes' (Ecological Engineering Group (EEG)-website, 2003). A definition stated by the Center for Wetlands University of Florida (www.cfw.ufl.edu) is very close to that of the Waterharmonica:

> *'Ecological engineering is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both. It involves the design, construction and management of ecosystems that have value to both humans and the environment. Ecological engineering combines basic and applied science from engineering, ecology, economics, and natural sciences for the restoration and construction of aquatic and terrestrial ecosystems. The field is increasing in breadth and depth as more opportunities to design and use ecosystems as interfaces between technology and environment are explored.'*

The goal of ecological engineering is to attain high environmental quality; high yields in food and fibre, low consumption, good quality, high efficiency production and full utilisation of wastes. This is in clear contrast to the mono-objectives of 'environmental engineering' where mitigation or remediation are the goals and merchandised components, such as scrubbers, filters, settling tanks and precipitators, are used (Yan and Ma, 1991; Mitsch, 1991; Chan, 1993; in Rose, 1999).

3.3 UNIT OPERATIONS FOR ECO-ENGINEERED WASTEWATER TREATMENT

In the natural environment, physical, chemical, and biological processes occur when water, soil, plants, microorganisms, and the atmosphere interact. Eco-engineered treatment systems are designed to take advantage of these processes to provide wastewater treatment. The processes involved in these systems include many of those used in mechanical or in-plant treatment systems—sedimentation, filtration, gas transfer, adsorption, ion exchange, chemical precipitation, chemical oxidation and reduction, and biological conversion and degradation—plus others unique to natural systems such as photosynthesis, photo oxidation, and plant uptake. In eco-engineered systems, the processes occur at 'natural' rates and tend to occur simultaneously in a single 'ecosystem reactor,' as opposed to mechanical systems in which processes occur sequentially in separate reactors or tanks at accelerated rates as a result of energy input.

Table 6 presents various types of eco-engineered unit operations. They can be categorized into natural wetlands, constructed wetlands, aquatic plant production systems and wastewater-fed aquaculture systems. These are not strict systems definitions and many aquatic based applications consist of a mixture of various types of treatment and reuse principles and objectives. The general physical features, design objectives and treatment capabilities of systems presented in the table are well documented by various authors and will not be repeated extensively in this report. The following paragraphs will present short descriptions and sub-divisions. A number of examples is provided in chapter 4.

TABLE 6 OVERVIEW OF ECO-ENGINEERED WASTEWATER TREATMENT SYSTEMS

Type of treatment	Description / remarks
Natural wetlands	Wetlands (fresh, brackish, salty) of natural origin in which, in a controlled or uncontrolled way, wastewater is discharged
Constructed wetlands (surface / subsurface flow; horizontal / vertical flow)	Man made wetlands, preferably planted with local plant species, with a large variety in system options. Vegetation: emerged plants such as common reed and cattail
Aquatic plant production systems	Free surface water systems planted with a large variety of floating and submerged species, such as water hyacinth, water lettuce, duck weed, algae and vetiver grass; sometimes combined with aquaculture (as a second step)
Wastewater-fed aquaculture	Fishponds fed with primary treated sewage

3.4 WASTEWATER RECLAMATION IN NATURAL WETLANDS

Strictly spoken, natural wetlands or swamps do not fall within the definition of eco-engineered systems. As the name indicates these types of wetlands are of natural origin. They are mostly located in or connected to river basins and / or large deltas. Natural wetlands are generally acknowledged as ecosystems of primary importance with very special functions and values including biodiversity conservation and water quality functions.

In developing countries especially, natural wetlands are often used for domestic wastewater treatment (Denny, 1997). Sewage from villages and small towns are frequently discharged directly or indirectly into existing wetlands and sometimes have drop latrines placed directly over them. Some of these wetlands have developed gradually into areas with agricultural and aquaculture activities, such as the East Calcutta Wetlands in India.

The efficiency of natural wetlands for wastewater purification depends on many variables, such as hydraulic and hydrological patters (hydraulic loading, flow patterns), biological characteristics (macrophyte species, root mat structure, etc.) and soil characteristics. In most cases the wetland is considered more or less as a 'black box' in which polluted waters are cleansed (Denny, 1997). The net result is that the wetland may not always function as supposed.

The discharge of domestic wastewater into natural wetlands is often very disruptive to the ecosystem. Nutrient enrichment changes the ecosystems and prime biodiversity sites are damaged. Modification of existing wetlands to improve treatment capability can be very disruptive to the natural ecosystem. It is questionable whether such an unintended pollution of natural wetlands is desirable and can still be classified as a case of ecological engineering.

EXAMPLE: THE NAKIVUBO WETLAND, KAMPALA, UGANDA

A well-known example of a natural wetland treating urban wastewater is the Nakivubo wetland (5.29 km^2) in Uganda, located at the northern shores of Lake Victoria. It is considered a green lung for the city and, as many wetlands located near urban areas, it is under thread because of increasing urbanisation.

The wetland is dominated by papyrus (*Cyperus papyrus*) grading to dry land through cattail (*Typha* sp.) and common reeds (*Phragmites* sp.), with a large area on the northeast side covered by grass (*Miscanthidium*). The neighbouring communities have converted the upper part of the Nakivubo wetland into agriculture and the vegetation here is dominated by cocoyam (Kansiime et al., 2003).

The Nakivubo wetland has been receiving sewage and urban runoff of Kampala city for more than 40 years. The Nakivubo river and its tributaries, which flow into the wetland, provide the main drainage channel for Kampala. They carry wastewater from the city centre, industrial area and residential zones. Up to 90% of Kampala's residents are not connected to a piped sewerage supply. Together the pollutant load is equivalent to the raw sewage produced by almost half a million people – or 40% of the population of Kampala.

It has been assumed for several decades that the water was sufficiently purified before entering Lake Victoria. However, several studies (Malubega & Kansiime, 1994; in: Denny, 1997; Kansiime & Van Bruggen, 2003) pointed out that the nutrient removal of the swamp was relatively low. Kansiime & Van Bruggen (2003) measured the removal of faecal coli in several parts of the wetlands as a function of the vegetation and calculated that only 91% of the faecal coli entering the wetland are removed.

FIGURE 10 **NAKIVUBO NATURAL WETLAND, KAMPALA, UGANDA (PICTURE: HANS VAN BRUGGEN, UNESCO-IHE)**

3.5 CONSTRUCTED WETLANDS

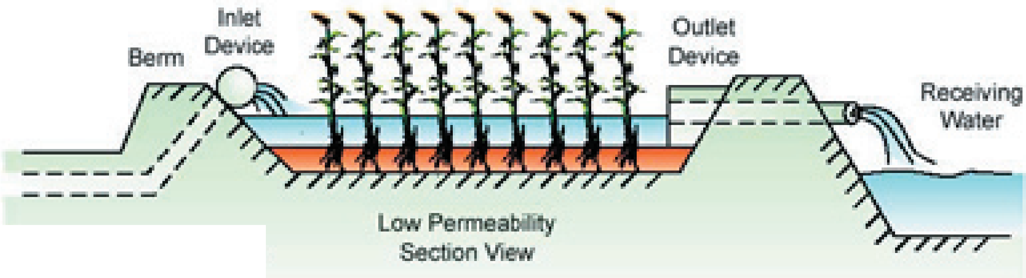
Constructed wetlands are 'man made' wetlands and are widely researched and applied in Europe, Unites States and Australia for tertiary treatment of domestic wastewater, storm water run-offs and local treatment of grey water (STOWA, 2001; Mels & Zeeman, 2003). The application of artificial constructed wetlands in the developing world is relatively new and not yet wide spread (at least, when stabilization ponds are not considered), although – as already argued in chapter 1 – the application potential appears to be large. Constructed wetlands are, in contrast to stabilization ponds, always equipped with higher plants such as reed.

There is a wide variety of design features regarding constructed wetland systems with differences in flow pattern, type of wastewater to be treated, the objective of treatment (primary, secondary or tertiary treatment), the type of substrate (soil, sand, gravel), one-stage, multi-stage and hybrid systems, used wetland vegetation, etc. Haberl (1999) concludes based on the large variation in design features that 'the one and only constructed wetland does not exist'.

FREE SURFACE WATER AND SUB SURFACE WATER FLOW SYSTEMS

With respect to flow patterns an important difference lies between free water surface and sub surface water flow wetland systems. Free water surface wetlands have a similarity with natural wetlands and may be designed to enhance nearby existing natural wetlands and to create new wildlife habitats. This type of systems is somewhat similar to aquatic plant treatment and may be combined with aquaculture.

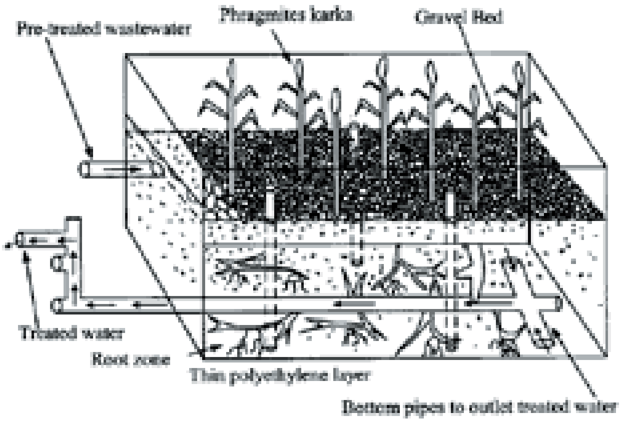
FIGURE 11 LAY-OUT OF A FREE WATER SURFACE WETLAND (KADLEC & KNIGHT, 1996)



Sub surface flow systems, also referred to as 'root zone systems' 'reed bed filter systems' or 'rock reed filters' are channels or trenches designed with the objective of secondary or advanced levels of treatment. Primary treated wastewater (primary clarification or e.g. a UASB) is distributed over the wetland through surface or sub surface flow drainage pipes and is filtered through the sandy or rocky medium. The effluent is removed through sub surface drains.

A principle difference in sub surface flow wetlands is found in the flow direction: both horizontal flow and vertical flow systems are applied. The influent dose might also be continuous or intermittent. Vertical flow filters are in most cases operated with intermittent loading in order to enhance oxygen supply to the root zone of the bed thus enhancing aerobic degradation and nitrification.

FIGURE 12 EXAMPLE OF A SUB SURFACE CONSTRUCTED WETLAND, PLANTED WITH PHRAGMITES KARKA (SOURCE: BILLORE ET AL., 1999)



CONSTRUCTED WETLAND VEGETATION

There is a wide variety of vegetation that is suitable for planting a constructed wetland. Most experts advise to choose species that are adapted to the local climate conditions. Some important and well-known example wetland plants are listed in Table 7.

TABLE 7 LIST OF EMERGENT WETLAND PLANTS USED IN CONSTRUCTED WETLAND TREATMENT SYSTEMS (LIM ET AL., 1998 IN SIM, 2002).

Planting zones	Common name	Scientific name
Marsh and deep marsh (0.3-1.0 m)	Common Reed	Phragmites australis Phragmites karka Phragmites mauritianus
	Spike Rush	Eleocharis dulcis
	Greater Club Rush	Scirpus grossus
	Bog Bulrush	Scirpus mucronatus
	Tube Sedge	Lepironia articulata
	Fan Grass	Phylidrium lanuginosum
	Cattail	Typha latifolia Typha angustifolia
	Papyrus	Cyperus papyrus
		Cyperus alternifolius
		Cyperus latifolius
Shallow marsh (0-0.3 m)	Golden Beak Sedge	Rhynchospora corymbosa
	Spike Rush	Eleocharis variegata
	Sumatran Scleria	Scleria sumatrana
	Globular Fimbristylis	Fimbristylis globulosa
	Knot Grass	Polygonum barbatum
	Asiatic Pipewort	Eriocaulon longifolium

Mostly it is advised to chose local species for planting the constructed wetland. The choice of wetland plants might also be considered from the point of view of exploitation of the products. Tropical wetland plants have a high productivity and continuous growing season. The annual production of e.g. naturally grown papyrus can be more than 100 tonnes per hectare per year. In constructed wetlands where nutrients are not limiting, it may be even higher (Denny, 1997).

EXAMPLE:

EXPERIMENTS WITH FREE SURFACE CONSTRUCTED WETLANDS IN JINJA, UGANDA

In a collaborative work between the National Water and Sewerage Corporation in Uganda, IHE Delft and RIZA of The Netherlands the viability of the use of constructed wetlands planted with indigenous *Cyperus papyrus* and *Phragmites mauritianus* plants for the purification of pre-settled municipal wastewater in tropical environments was investigated in free surface flow constructed wetlands in Jinja, Uganda (Okurut et al., 1999).

The constructed wetland pilot unit comprised four main units each divided into duplicate parallel sub units separated with a brick wall. The units were fed in batch flow feed from an anaerobic lagoon that received wastewater from a nearby municipality. The sub units were operated with varying hydraulic retention time (7 or 12 days) during a period of 11 months. Table 8 shows the mean results of the study.

TABLE 8 MEAN INFLUENT AND EFFLUENT CONCENTRATIONS OF A CONSTRUCTED WETLAND IN AN EXPERIMENTAL CONSTRUCTED WETLAND IN UGANDA[1]

	Influent	Cyperus papyrus (effluent)	Phragmites mauritianus (effluent)
COD (mg/l)	155.2 ± 50.9	57.0 ± 20.7	88.5 ± 30.5
BOD_5 (mg/l)	48.4 ± 19.5	15.5 ± 12.8	23.6 ± 17.6
NH_4-N (mg/l)	54.1 ± 17.8	33 ± 15.5	24.3 ± 13.7
NO_3-N (mg/l)	0.08 ± 0.09	0.16 ± 0.08	0.42 ± 0.2
o-PO_4-P (mg/l)	3.71 ± 0.8	3.1 ± 0.95	2.34 ± 1.1

[1] Note: These are the average values of various periods with different hydraulic retention times

The study demonstrated that the experimental constructed wetlands were effective in reducing BOD and COD to lower levels than that prescribed in Uganda standards. BOD and total suspended solids concentrations in the effluents from both systems were below 20 mg/l and 25 mg/l, respectively. A high degree of faecal coliform removal was attained at longer retention times in the two systems.

FIGURE 13 EXPERIMENTAL CONSTRUCTED WETLANDS IN JINJA, UGANDA. LEFT: CONSTRUCTION; RIGHT: IN OPERATION. (PICTURES: HANS VAN BRUGGEN, UNESCO-IHE)

3.6 AQUATIC PLANT PRODUCTION SYSTEMS

Aquatic plant treatment uses floating or submerged aquatic plants, which can be used with the objective to provide secondary or enhanced levels of treatment and beneficial use of the produced biomass. Treatment is usually done in parallel basins or channels. Floating aquatic plant systems are similar in concept to free water surface wetland systems except that the plants are floating species such as water hyacinth (*Eichornia crassipes*), water lettuce (*Pistia stratiotes*), algae and duckweed. Another plant with growing attention is Vetiver grass (*Vetiveria zizanioides*).

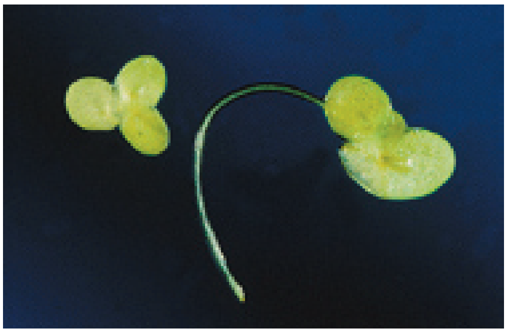
DUCKWEED PRODUCTION IN COMBINATION WITH FISH CULTURE

One of the mostly investigated types of aquatic plants for wastewater treatment is duckweed. It is mostly used in the purification of (primary treated) wastewater in combination with fish farming on the effluent of the duckweed ponds. Duckweed grows fast in sewage water and is very protein rich. As such it can be used as an additive protein source for fish or animal feed. Harvested duckweed contains up to 45% protein by weight and may be used without further processing as a complete feed for fish.

There are various duckweed species; examples are *Spirodela polyrhiza, Lemna minor*, *Lemna gibba* and *Wollfia ahrriza*, with typical temperature optima. *Spirodela polyrhiza* works best in temperature ranges of 30 to 40 °C whereas *Lemna minor* and *Wollfia ahrriza* perform best in temperature ranges of 25 to 30 °C and 5 to 25 °C, respectively. Subsequently to the duckweed ponds usually ponds with a variety of fishes such as Tilapia are planned that are fed on the effluent of the duckweed ponds.

Duckweed harvesting should be done every two-three days and it is important to leave a minimum number of duckweed plants to keep the entire surface of the water covered so that algae growth continues to be suppressed. If algae gain the upper hand the pH will be shifted upward. If the pH of the wastewater exceeds 7.4 or thereabout, free ammonia will poison the duckweed plants.

FIGURE 14 LEMNA MINOR (LEFT) AND A MIX OF S. POLYRHIZA AND LEMNA SP. (RIGHT)



PRODUCTION OF VETIVER GRASS

Vetiver grass (*Vetiveria zizanioides*; see also www.vetiver.org) is a sterile tropical grass that grows rapidly. The use of Vetiver grass for wastewater treatment is emerging from research that has been done in Australia, China and Thailand.

Vetiver grass cultivation is reported to be robust for several reasons. The first is that the physiology of Vetiver grass enables it to withstand elevated levels of ammonia, toxic metals and a pH range from 4.5 - 11.5. The dominant growth factor is temperature. Vetiver grass will

go dormant when the temperature around the root zone drops below 15°C, while optimal growth will occur at 25 degrees celcius.
The figure shows vetiver grass that was grown hydroponically on a wastewater effluent in tropical Australia in an experiment to assess nutrient removal ability. Vetiver grass has the potential to produce up to 132 tonnes per hectare per year of dry matter (Ash & Truong, 2003).

FIGURE 15 VETIVER GRASS

EXAMPLE: AQUACULTURAL WASTEWATER PURIFICATION SYSTEMS AND REUSE, SENEGAL

The use of water hyacinth in wastewater treatment is an age-old technique utilised over 1,000 years ago in Sudan and is being re-visited today (Gaye & Diallo, 1997 in: Rose, 1999). In Castor, Senegal, the local NGO, ENDA-Tiers Monde, has built a wastewater collection and treatment system serving most of the community's inhabitants. The project has been successful in gaining support from community members, creating employment opportunities and treating wastewater to a standard high enough to use it directly for the production of food.

The system consists of a grease trap, two septic tanks, followed by a small-bore sewage system. The sewage enters a large decanting tank/sedimentation basin, which gets covered by a sludge blanket where most of the sludge is retained. From this point, the secondary effluent flows to a series of four aerobic concrete tanks. The tanks are approximately 1 metre deep and are narrowly designed to prevent wind from layering the plants to one side of the ponds. Water hyacinth and water lettuce (*Pistia stratiotes*) comprise the active wastewater treatment at this point in the process. As water passes from tank to tank, the effluent quality is progressively increased. Effluents recovered from the process are being used to irrigate bananas, apples, papaya, peppers, corn, zucchini, okra and a variety of other vegetables. Additionally, a number of tree species are raised on treated effluents recovered from this system. The water hyacinth biomass produced through the treatment process is harvested regularly. This biomass is formed into compost for use in local market gardens (Gaye & Diallo, 1997 in Rose, 1999).

Dissemination of this locally-managed and low-cost sanitation technology has stimulated a growth sector of the local economy while increasing public awareness of the issue and improving the environmental health of the community (Rose, 1999).

3.7 WASTEWATER-FED FISH FARMING

Wastewater-fed fish farming is aimed at fish production in pre-treated sewage. This type of wastewater-fed aquaculture is strongly developed, especially in the state Bengal in India with 130 sewage-fed fish farms covering an area of 4000 ha and supplying more than 8000 ton of fish per year to consumers (Jana, 1998; Jana, 2004). In the absence of a supply of fresh surface fresh water, farmers fill up ponds with untreated wastewater that is then left for 2-3 weeks for natural purification before stocking fish. Subsequently, ponds may be topped up with wastewater continuously or periodically depending on the pond area, the availability of wastewater and the season with regard to low temperatures in winter in temperate climates and dilution of pond water due to monsoons rains in the tropics.

Farmers have learned by experience how to culture mainly herbivorous and omnivorous fish such as Chinese carps, Indian major carps and Tilapias. They assess water quality in wastewater-fed ponds by observing watercolour, light penetration in water and fish surface behaviour after dawn when pond dissolved oxygen concentrations have declined to their lowest level during the night. 'Good' water quality is indicated by green colouration and low light penetration which reflect adequate levels of protein-rich plankton for fish to feed on, and minimal surfacing of fish at dawn to gulp air which indicates sufficient dissolved oxygen in the water for the fish during the light when photosynthesis, the main oxygen providing mechanism, does not operate.

Research has provided a scientific basis for the key parameters in wastewater-fed aquaculture practice developed earlier by farmers. The most important key parameters are the organic loading rate (10-30 kg BOD_5/ha/day), nutrient loading rate (4 kg N and 1 kg P/ha/day), minimal night time dissolved oxygen of 2-3 mg/l and permissible maximal ammonia concentrations in fishpond water of 0.5 mg/l of un-ionised ammonia. Furthermore it is recommended to grow herbivorous and omnivorous carps and tilapias.

Recent insights recommend pre-treatment before municipal wastewater is fed to fishponds. It conforms to the recommendation of no human nematode eggs flowing into the ponds and a maximal concentration of 10^3 faecal coliforms per 100 ml in accordance with the tentative guidelines established by the World Health Organisation for wastewater-fed aquaculture[5] (WHO, 1989). One key recommendation is also to achieve this by the use of stabilization ponds prior to the treated effluent flowing into the fishponds.

An improved design provides minimal treatment of wastewater and maximal production of microbiologically safe fish (Mara et al., 1993). There is 1-day retention in an anaerobic pond followed by four days retention in a facultative pond before the partially treated effluent enters the fishpond. The design criterion for the fishpond is a surface loading of 4 kg total N/ha/day and the number of faecal coliforms is then estimated and should be less than 1×10^3 /100 ml in the pond water. The design takes a rapid die-off of faecal coliforms into consideration as has been found in fertile wastewater-fed fishponds.

It was developed following a recommendation from a symposium in Calcutta in 1988 that sanitary engineers and aquaculturists should unify their approaches to wastewater-fed aquaculture design, as there is a discrepancy in the use of the term "optimal organic loading rate by about 1 order of magnitude" (Table 9).

[5] These guidelines are currently being reviewed and will probably be less strict in the future.

TABLE 9 THE DIFFERENT AIMS AND LOADING RATES OF STABILIZATION PONDS AND FISHPONDS (EDWARDS, 2000)

Parameter	Stabilization ponds	Fish ponds
Aim	Maximum wastewater treatment	Maximum fish production
BOD_5 loading rate (kg/ha/d)	200 - 300	10 - 30

PUBLIC HEALTH ASPECTS

Based on recommendations by WHO (1989) and bacterial quality standards and threshold concentrations for fish muscle, Pullin et al. (1992 in: Edwards, 2000) published guidelines for domestic wastewater reuse in aquaculture:

- a tentative maximum critical density of 10^3 total bacteria/100 ml in wastewater-fed fish pond water;
- absence of viable nematode eggs in fishponds;
- suspension of wastewater loading for two weeks prior to fish harvest;
- holding fish for a few hours to facilitate evacuation of gut contents;
- < 50 total bacteria /g of fish muscle and no Salmonella;
- good hygiene in handling and processing, including evisceration, washing and cooking well;
- use as high-protein animal feed, if direct consumption of fish is socially unacceptable.

Anecdotal evidence does not indicate that there is high risk for public health from consumption of fish raised in most reuse systems. However, scientifically based data are almost entirely lacking to support this. It was recognized from the beginning (WHO, 1989) that public health standards should be based on epidemiological rather than microbiological guidelines i.e., on actual rather than on potential risk. There is evidence from India and Egypt that the microbiological quality of fish cultured in wastewater-fed ponds is better than that of freshwater fish from many other water bodies and surface waters which have been polluted unintentionally (Edwards, 2000). It can be argued that it is safer to consume fish cultured in a well managed and monitored, wastewater-fed system than to rely on wild fish caught from increasingly polluted and unregulated surface waters.

The 1988 Calcutta seminar recommend that domestic wastewater should not be reused in aquaculture if it contains hazardous industrial wastewater (Edwards and Pullin, 1990 in: Edwards, 2000). Unfortunately, this is usually the case in rapidly industrializing developing countries with mixed domestic and industrial wastewater streams. Edwards (2000) states that an anaerobic pre-treatment process is required to precipitate heavy metals as insoluble metallic sulphides.
Hydrocarbons in industrial effluents might accumulate more readily in fish than heavy metals and warrant careful monitoring but they were within accepted standards in wastewater-fed fishponds in Egypt (Shereif and Mancey, 1995 in: Edwards, 2000) and in Peru (Cavallini, 1996 in: Edwards, 2000) that incorporated prior treatment in anaerobic, facultative and maturation ponds.

3.8 REQUIREMENTS FOR PRE-TREATMENT

INTRODUCTION

As already discussed in chapters 1 and 2, the Waterharmonica concept considers eco-technological treatment as a chain between partial treatment and beneficial use of effluents. For eco-engineered treatment systems some form of pre-treatment will be required. The pre-treatment system is aimed at the removal of most of the suspended solids, a large fraction of the COD and of the pathogenic organisms, and (optionally) nutrients of the wastewater. The following paragraphs discuss a number of pre-treatment systems.

SEDIMENTATION TANKS AND SEPTIC TANKS

Sedimentation tanks are the most rudimentary form of pre-treatment. Suspended solids and related pollutants are removed by gravity forces in settling tanks with hydraulic retention times of 1 to 24 h. The settled sludge will have to be removed regularly. It is not yet stabilised and will need further treatment by e.g. digestion of composting.

The performance of the system in case of treating sewage with a general composition is as follows:

- BOD removal 20-30%
- Suspended solids removal 30-40%
- Nitrogen removal 5-10%

Septic tanks are a modification of sedimentation tanks. They are basically designed for small wastewater flows at single or multiple households. Septic tanks are designed to retain the settled sludge for a period of 6 – 24 months. Due to this long sludge retention time the sludge is largely stable when it is discharged. Due to the long sludge retention also anaerobic bacteria can play a role is the removal of dissolved organic material. There are special configurations such as the UASB-Septic tank that are designed to optimise the treatment performance of septic tanks.

STABILISATION PONDS

Waste stabilization ponds were advocated by the WHO (1989) as suitable and affordable wastewater treatment systems for developing countries, intended to induce at least some form of treatment rather than direct disposal or use of raw wastewater. The required retention times in stabilization ponds are rather long: for municipal wastewater they usually range from 20-50 days.

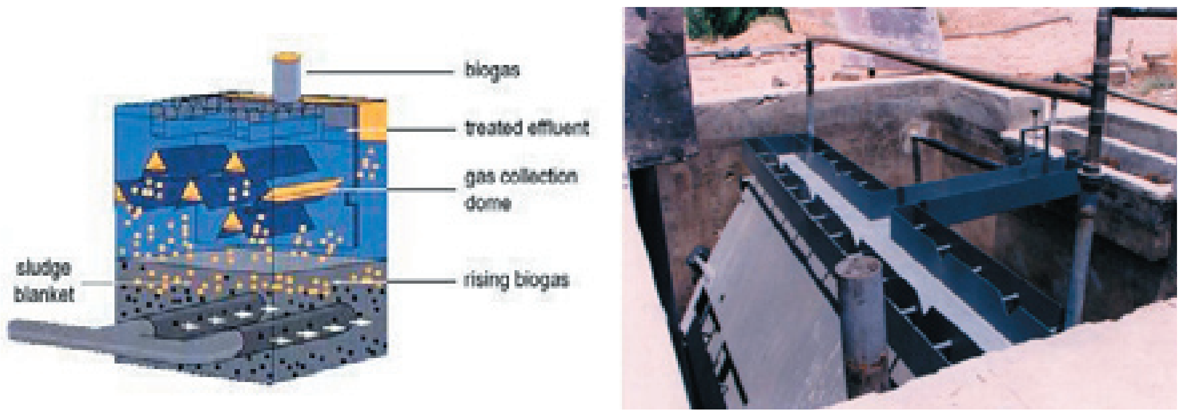
Stabilisation ponds are probably the most applied systems for municipal wastewater treatment in the developing world. They appear to be most cost effective for locations where land is inexpensive (about $ 3-8 per m^2 according to Alaerts et al., 1993). Many large cities in South America and Africa, and even the Middle East employ these systems (e.g. the wastewater of Amman in Jordan is treated in 200 h stabilization ponds).

Stabilisation ponds generally consist of a series of *anaerobic*, *facultative* or *fully aerobic* ponds. In the anaerobic pond the organic load is high and oxygen can only be detected in a very thin layer near the water surface. Organic pollutants are removed by a combination of sedimentation and anaerobic conversions. This pond should frequently be emptied, because of accumulation of suspended solids. Facultative ponds are usually aerobic during daytime due to photosynthesis of algae, while they are anaerobic during nighttime. Aerobic or maturation ponds receive a relatively low load of organic material and consequently the environment in the pond is pre-dominantly aerobic both during daytime and at night. The main objective of a maturation pond is the removal of remaining BOD and of pathogens. The nutrient removal in stabilisation ponds is generally low. The qualifications of anaerobic, facultative or maturation ponds can be directly related to the influent organic load: if the volumetric loading rate is higher than 100 g BOD/(m^3.d) the pond will be anaerobic and at superficial loads less than 5 to 15 g BOD/(m^3.d) the pond will have the characteristics of a maturation pond. The depths of stabilization ponds are usually around 1.5 m.

UASB BIOREACTOR

The UASB (Upflow Anaerobic Sludge Blanket) bioreactor was developed in the 1980s in The Netherlands by G. Lettinga and his research group (Figure 16). In its basic design this reactor consists of one compartment. Sewage enters at the bottom of the system through an influent distribution system and flows through a blanket of anaerobic bacteria. This anaerobic bacterial sludge degrades the organic material and converts it into biogas (methane and carbon dioxide) and new bacterial mass. The system has a specially designed biogas collection system. The removal of nutrients (nitrogen and phosphate) is low and is mainly due to physical retention of particle bound nitrogen.

FIGURE 16 DESIGN AND APPLICATION OF AN EXPERIMENTAL UASB BIOREACTOR IN JORDAN (PHOTO: WAGENINGEN UNIVERSITY 2003)



The UASB is especially feasible for the treatment of wastewater in the (sub) tropics within a water temperature range of 18-35 °C. Its first demonstration was in Cali, Colombia. Worldwide more than 1500 installations are in operation for the treatment of both industrial and municipal wastewater. For domestic wastewater the applied hydraulic retention times are 6 to 24 h. The system is relatively easy to construct and has several strong features. The energy consumption is very low, because there is no need for aeration. In fact energy is produced in the form of biogas. Because of the absence of electro-mechanical parts and the fact that it is a single-stage system is relatively robust and cheap to construct. The sludge production of the system is low, because of the relatively low bacterial growth yield. The excess sludge is stabilized.

The performance of the system in case of treating sewage with a general composition is as follows (average results from Latin America and India):

- BOD removal 75 - 85%
- Suspended solids removal 70 - 80%
- Nitrogen removal 5-10%
- Pathogen removal:
  - Coliforms: 70 - 90%
  - Helminth eggs: up to 100%

OXIDATION DITCH

The oxidation ditch was developed in The Netherlands by A. Pasveer (1909 – 2001), a pioneer in wastewater treatment. The system consists of a closed-loop ditch with a combined aerator / recirculating device (Pasveer, 1958). The aerator is installed at a water depth of 1.0-3.0 m and recirculates the sewage. The driving force for the air that is put in the system is the negative pressure that is generated in the water by the rotation of the screw. Removal of suspended solids, BOD and a part of the nutrients is performed by bacterial degradation and sludge growth. The so-called activated sludge that is formed during the process is removed by settling in a part of the ditch with a relatively low water speed.

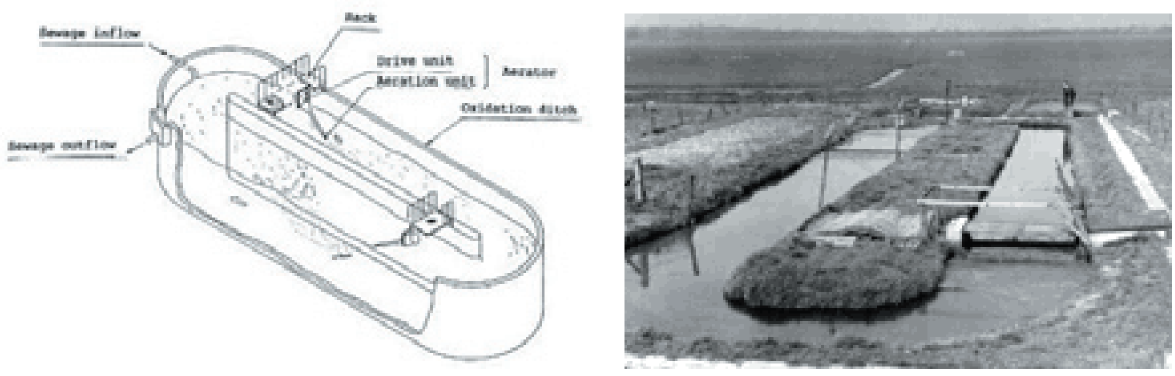
The oxidation ditch formed the starting point of the development of numerous advanced activated sludge systems. In it original basic form the system is relatively simple and easy to construct (see Figure 17).

The system has a design sludge loading that varies between 0.05 and 0.20 kg BOD per population equivalent (p.e.) per day, depending on the wastewater temperature and an approximate volume of 250 – 300 l per p.e. It is possible to perform nitrification and denitrification treatment by controlling the oxygen concentration in the system. Some advantages of the system are that it is relatively stable in case of fluctuating flow conditions and that it generates stabilized sludge. The energy consumption is approximately 20-25 kWh per population equivalent per year.

The performance of the system in case of treating sewage with a general composition is as follows:

- BOD removal 85-99%
- Suspended solids removal 80-95%
- Nitrogen removal approximately 70% (almost complete nitrification)

FIGURE 17 DESIGN AND APPLICATION OF AN EXPERIMENTAL OXIDATION DITCH IN THE NETHERLANDS



4

ILLUSTRATIVE EXAMPLES OF THE WATERHARMONICA APPROACH

4.1 INTRODUCTION

This chapter presents a number of illustrative cases of wastewater treatment systems that are based on ecological engineering. Several other examples have already been highlighted earlier in this report in between the text.

The described cases are selected because they are relatively well documented. The review that was conducted in the framework of this project showed that well-documented wastewater treatment cases are rather scarce in developing countries, especially when it comes to the design and performance of treatment system. Another argument of including these examples (and especially the ones described in the paragraphs 4.2 and 4.3) is that they illustrate that wastewater treatment systems based on ecological engineering can have multiple functions, i.e. they serve for wastewater treatment but also for e.g. landscape design or fish farming.

More practical examples of wastewater systems reflecting the Waterharmonica principle can be found at the site www.waterharmonica.nl. This site also documents the presentations that were held at the 7th INTECOL International Wetlands Conference in Utrecht, The Netherlands, 25 - 30 July 2004.

4.2 COMBINATION OF A CONSTRUCTED WETLAND WITH LANDSCAPE DESIGN IN NAIROBI, KENYA

Nyakang'O & Van Bruggen (1999) describe a multi-stage wetland system, located in the outskirts of Nairobi adjacent to the Nairobi National Park. The wetland was constructed to treat the wastewater of a restaurant and a swimming pool resort. On-site wetland treatment was chosen because of difficulties connecting to the Nairobi City Council Sewer.

The system was commissioned in 1994 and consists of a septic tank, a subsurface horizontal flow constructed wetland (area = 1800 m^2) followed by three ponds in series, with a total area of about 5400 m^2 (see Figure 16). The constructed wetland is filled with 1 m of gravel covered with 10 cm of soil to support growth of bulrush (*Typha* spp). The three ponds are shallow near the shore (< 60 cm) and have a deep section in the centre (1.5 m). The shallow shores have been landscaped with harmonious curved features to enhance beauty as well as to facilitate growth of macrophytes. The ponds were planted with indigenous papyrus species, like *Cyperus alternifolius* and *Cyperus latifolius,* ornamental plants and wild flowers.

The system was designed for 1200 population equivalents and has a theoretical retention time of 32 days. It receives secondary wastewater from a swimming pool resort (30%) and a restaurant (70%).

FIGURE 18 LAYOUT OF THE MULTI-STAGE WETLAND SYSTEM IN NAIROBI, KENYA

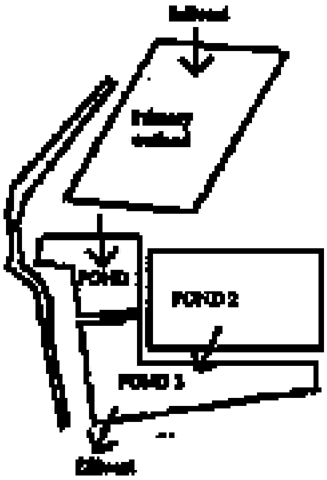


Table 10 shows the mean influent concentrations and the removal efficiencies of the wetland. The removal efficiencies were corrected for evapotranspiration (approximately 20-25% of water evaporated). An attempt was made to make a nutrient balance for the whole wetland. The balance showed that most of the N and P was retained in the soil with limited amounts being removed by harvesting of the plants.

Faecal coliforms in the septic tank effluent amounted 8.10^6 MPN/100 ml. These dropped to 3.10^3 after pond 1. The final effluent contained only 500 faecal coliforms/100 ml.

TABLE 10 MEAN INFLUENT LOAD AND CORRECTED REMOVAL EFFICIENCIES OF THE MULTI-STAGE WETLAND SYSTEM IN NAIROBI, KENYA

	Influent	Removal efficiency (%)
COD (mg/l)	146 ± 17.5	96.5 ± 1.0
BOD_5 (mg/l)	103 ± 10.6	98.4 ± 0.3
Kj-N	13± 1.5	90.4 ± 2.4
NH_4-N (mg/l)	11 ± 1.4	92.4 ± 1.4
o-PO_4-P (mg/l)	9.4 ± 0.9	88.2 ± 1.4

According to the authors, the wetland fulfils the requirements for wastewater purification and combines this function with the creation of a pleasing environment for man and wildlife. Next to plants all life forms were encouraged, resulting in an abundant presence of birds, frogs and aquatic vertebrates. In total 128 bird species have been recorded at the wetland. Two fish species have been successfully introduced: *Tilapia nilotica* and *Poecilia reticulata*.

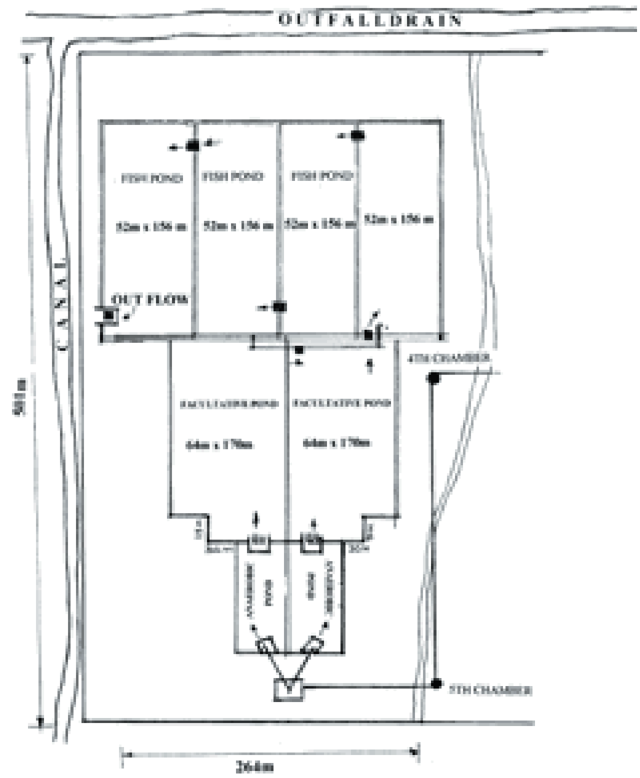
FIGURE 19 SIGHT ON THE MULTI-STAGE WETLAND SYSTEM IN NAIROBI, KENYA (PICTURE: HANS VAN BRUGGEN, UNESCO-IHE)

4.3 SEWAGE-FED FISH FARMING IN KALYANI

Jana (1998) describes a wastewater-fed fish farm in Kalyani township in West Bengal that was constructed in the beginning of the 1990s. The system incorporates pre-treatment by anaerobic and facultative ponds. It receives approximately 17.000 m^3 per day, which is 15% of the sewage of Kalyani town. The other 85% is treated by using a trickling filter and then discharged through a connecting canal to the Ganges River.

The system consists of two anaerobic, two facultative and four fish-growing ponds (Figure 20). The total system covers approximately 6 ha and has an average hydraulic residence time of 12-14 days. The approximate retention times in the anaerobic, facultative and fish-growing ponds are 1, 4 and 7 days, respectively. No supplementary feeding or fishpond fertilization is done during the culture period and no aeration device is installed.

FIGURE 20 LAYOUT OF THE SEWAGE-FED FISH FARM IN KALYANI, CONSISTING OF TWO ANAEROBIC, TWO FACULTATIVE AND FOUR FISH-GROWING PONDS (JANA, 1998)



The fish-culturing practice is basically a composite system using different species of fish that utilize different ecological niches of the pond system. The polyculture at Kalyani fish farm contains ten species, among which various types of Karps and Tilapia. A stocking density of 30,000 – 50,000 fingerlings per ha is used. The monthly catch varies by with values ranging from 49 to 73 kg /per ha in the period June 1995 to May 1996. The monthly catch was lower during the post-monsoon and winter months.

TABLE 11 FISH SPECIES AT THE KALYANI FISH FARM

•	Five species of Indian major carps (Labeo rohita, Catla catla, Cirrhinus mrigala, Labeo bata, Labeo calbasu)
•	Carp (Cyprinus carpio)
•	Silver carp (Hypophthalmichthys molitrix)
•	Grass carp (Ctenopharyngodon idella)
•	One exotic carp (Hypophthalmichthys nobilis)
•	Tilapia (Oreochromis niloticus, O. mossambicus)

4.4 WASTEWATER TREATMENT IN SUBSURFACE CONSTRUCTED WETLANDS IN BANDUNG, INDONESIA

Environmental pollution in Indonesia, especially at rivers, lakes and other public water bodies, has been increasing considerably over the past few years (Kurniadie & Kunze, 2000). Only around 25% of wastewater is being treated mostly at the primary level prior to disposal, and the remaining 75% of untreated wastewater is discharged into the rivers or other public waters. This has created severe environmental pollution problems such as eutrophication and transmission of waterborne diseases (cholera, typhoid, dysentery and hepatitis). Conventional systems of sewage treatment have limitations in Indonesia. Lack of local technical ability combined with high repair and maintenance costs often requires expensive

foreign currency and can cause system failures. In recent years there has been increased interest in alternative technologies with aimed at developing low cost, low maintenance and energy efficient treatment methods.
The objective of a study reported by Kurniadie & Kunze (2000) was to investigate a constructed wetland with vertical flow system to treat sewage from a private household. A constructed subsurface flow wetland (5 m long, 3 m wide and 1.1 m deep) to treat sewage from a family house was constructed in Bandung, Indonesia in February 1999. The wetland served for 6 p.e. (2.50 m^2 surface/p.e.) and was operated in vertical flow with discontinuous feeding by a timing device and drainage system spread over the whole bed area. The wetland was planted with *Phragmites karka* at a density of seven plants per m^2. The wastewater was mechanically pre-treated in a sedimentation tank (3 m^3) and pumped onto the sand filter bed once a day. The filter bed was built from a multi-layer with sand as the main media. Small size gravel (8-16 mm) was used in the first top layer (10 cm), followed by 15 cm of bigger size gravel (16-32 mm) and another 5 cm of small size of gravel (8-16 mm). Sand with a hydraulic conductivity (K_f value) of 6.2×10^{-4} m/s, d_{10} (0.25 mm) and uniformity (U) 4.0 was used as the main layer (60 cm deep), followed by 5 cm of small size gravel (8-16 mm) and finally, at the bottom, 15 cm larger sized gravel (16-32 mm). The treated water was collected in a drain at the bottom of the filter bed and used again as irrigation water for gardening or directed to the nearest public waters.

The treatment efficiency of the constructed wetland is shown in Table 12. The average concentration of fecal coliforms bacteria in the influent of this wetland was 6.2×10^8 fecal coliforms bacteria per 100 ml. The final concentration of fecal coliform bacteria in the effluent was 9.3×10^3 counts. These effluent concentrations are still below the WHO (1989) guideline values (1000 fecal coliforms per 100 ml) for unrestricted irrigation.

TABLE 12 AVERAGE INFLUENT AND EFFLUENT CHARACTERISTICS OF AN EXPERIMENTAL CONSTRUCTED WETLAND IN BANDUNG IN THE PERIOD MARCH 1999 TO JANUARY 2000.

Parameter	Influent	Effluent
Settleable Solids (ml/l)	0.2	0.0
COD (mg/l)	461	69
BOD_5 (mg/l)	230	29
Total-N (mg/l)	94	67
NH_4-N (mg/l)	37	6.7
NO_2-N + NO_3-N (mg/l)	11.8	24.6
PO_4-P (mg/l)	18.7	5.9
Temperature (°C)	22.6	22.6
Oxygen (mg/l)	1.1	6.6
Fecal Coliform (MPN/100 ml)	6.2×10^8	9.3×10^3

4.5 TWO-STAGE CONSTRUCTED WETLAND FOR TREATING HOSPITAL WASTEWATER IN DHULIKHEL, NEPAL

The application of wastewater treatment in Nepal is limited. Untreated domestic and industrial wastewater and solid waste are mainly discharged directly into rivers without any prior treatment. They are the major sources of river water pollution in the Kathmandu Valley. Constructed wetland technology was introduced to Nepal in 1999 (Claassen, 2002).

Dhulikhel is the first application of this system in Nepal. The wastewater of the hospital of Dhulikhel (40 beds, 10 staff members), near Kathmandu, Nepal, is treated in a two-stage constructed wetland (CW). Besides the treatment task of the plant, this constructed wetland system has become a national demonstration site of constructed wetland technology (Figure 21). It caught national attention of almost all national media. The site is nowadays used for student trips and for workshops/trainings in the field of water and sanitation sector (Shresta et al., 2001).

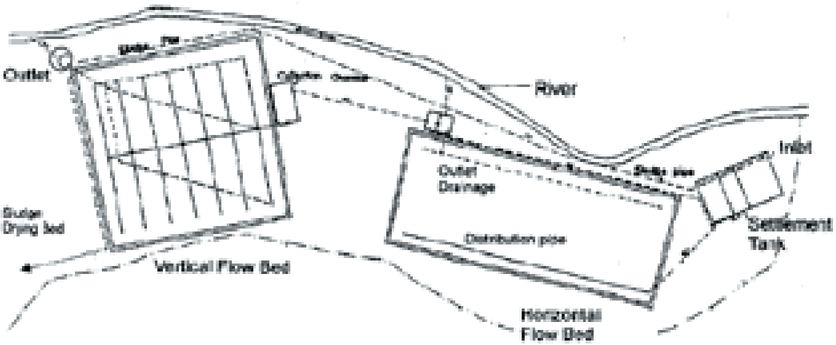
FIGURE 21 PICTURE OF THE TWO-STAGE CONSTRUCTED WETLAND TREATING HOSPITAL WASTEWATER IN DHULIKHEL, NEPAL (PICTURE: MAARTEN CLAASSEN)

The treatment system (Figure6 19) consists of a three-chambered settlement tank followed by a horizontal flow bed and a vertical flow bed (Laber et al., 1999). The sludge of the settlement tank is dried in a sludge drying bed. Both beds are fed intermittently with a specially constructed mechanical feeding unit, which needs no electricity. The design parameters of the constructed wetland are as follows:

- Design flow rate: 20 m^3 /d;
- Bed area: 140 m^2 (20 m x 7 m) horizontal bed, 120 m^2 (11 m x 11 m) vertical bed;
- Main layer horizontal bed: 60 cm of coarse broken gravel (pore volume: 39%);
- Main layer vertical bed: 90 cm of sand (pore volume: 30%, k_f-value: 10^{-3} m/s);
- Vegetation: both beds are planted with *Phragmites karka*.

The plant is operated without electric power. The aim was the elimination of organic compounds, nitrification and a significant reduction of pathogenic indicator bacteria. Different phases of operation (high and low water level within the soil profile, serial operation, one stage operation) were investigated during trials in 1997-1998. Serial operation with a high water level in the horizontal flow bed and low water level in the vertical flow bed showed the best treatment performance.

FIGURE 22 SITE PLAN OF THE CONSTRUCTED WETLAND AT DHULIKHEL HOSPITAL / NEPAL (LABER ET AL., 1999)



The discharge into the system was two to three times higher as the design assumed. However, treatment performed remained well and close to the expected concentrations and efficiencies of the original design with a very stable effluent quality despite influent fluctuations (Table 13). The removal of pathogens by the systems is nearly 100%, but because of bad maintenance of the system, the quality may vary (Claassen, 2002).

TABLE 13 INFLUENT AND EFFLUENT CHARACTERISTICS OF THE DHULIKHEL CONSTRUCTED WETLAND SYSTEM (LABER ET AL., 1999)

	loading rates (l/m²/day)		COD		BOD_5		NH_4-N		NO_3-N		TSS	
	VFB[1]	HFB[1]	in	out	in	out	in	out	in	out	in	out
Average	130	110	349	16	164	3	37.9	3.03	0.18	35.2	216	2
St.dev.	36	31	216	11	94	4	17.1	5.3	0.2	16.9	158	1
Removal (%)				95%		98%		92%		-169%		99%

[1] HF – horizontal flow bed; VFB – vertical flow bed

Due to the successful experiences at Dhulikhel hospital, about ten constructed wetlands have been implemented in Nepal.

4.6 TREATMENT OF COFFEE WASTEWATERS IN A UASB AND A SERIES OF CONSTRUCTED WETLANDS IN KHE SANH, QUANG TRI, VIETNAM

Wet processing of Arabica coffee produces a higher quality and receives higher prices on the world market compared to coffee prepared via dry processing. Wet coffee processing produces large amounts of concentrated and acidic wastewater with BOD and COD values up to 20,000 mg /l and 50,000 mg/l, respectively. Another problem is the high acidity of this wastewater, with a pH generally below 4. The discharge of untreated coffee wastewater may have a large effect on surface waters and down stream water use as is illustrated by the study on the effect of discharge of coffee wastewaters on the water quality in the watersheds of the city Matagalpa, Nicaragua, in the second part of this report.

An example of coffee wastewater treatment with the aid of a constructed wetland is a pilot project in Khe Sanh, Quang Tri, Vietnam described by Von Enden & Calvert (2002). At this pilot project site the wastewater of a wet coffee process is treated. At the site around 100 tonnes fresh cherry are processed during the peak of production. The total effluent reaches

400 m³ per day at peak times. The average water consumption has been decreased from over 10 m³/tonnes cherry down to around 4 m³/tonnes processed cherry through recycling and reuse of processing waters.

The wastewater treatment system (Figure 20 below) consists of an acidification pond (200 m³), followed by a neutralisation tank (25 m³) filled with ground limestone. After neutralisation of the wastewater to a pH of ca. 6, water is treated in an Upflow Anaerobic Sludge Blanket (UASB) bioreactor before entering a series of two constructed wetlands planted with macrophytes for secondary treatment. The water levels in the wetlands may be artificially raised and lowered to assist the oxygen flow. The constructed wetland is able to remove up to between 49 and 81% BOD loadings and lower the amount of suspended solids between 36 and 70% depending on initial BOD loadings and retention time (Biddlestone et al., 1991). In addition, macrophytes remove nutrients and salts from biogas digester effluents. For tertiary treatment, the wastewater runs through a water hyacinth (*Eichornia crassipes*) pond for water polishing before entering the open waterway.

FIGURE 23 LAY-OUT OF THE KHE SANH, QUANG TRI PILOT PLAN FOR TREATMENT OF COFFEE WASTEWATER

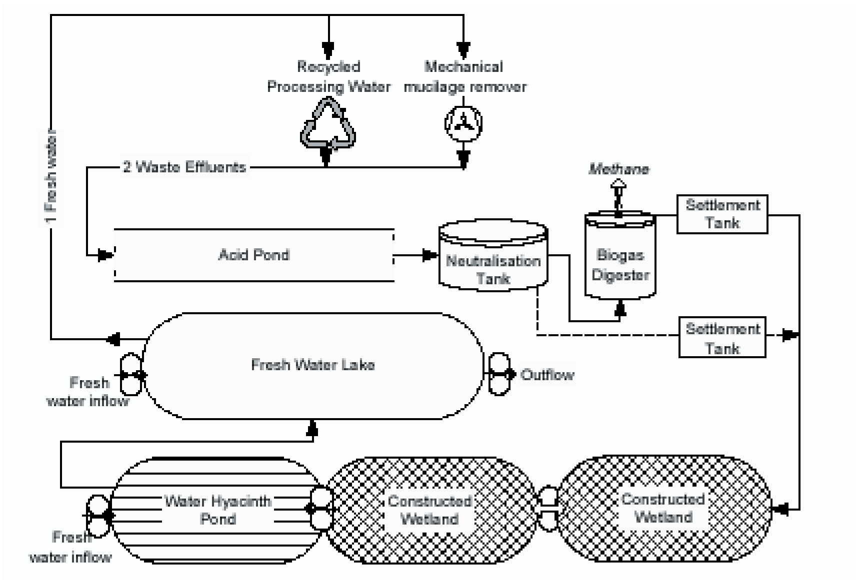


Table 14 shows the indicative values for the efficiency of the Khen Sanh Pilot coffee wastewater plant.

TABLE 14 INDICATIVE EFFICIENCIES OF THE KHEN SANH PILOT COFFEE WASTEWATER PLANT

	Influent (Acid pond)	**Neutralisation pond**	**UASB**	**Settling tank**	**Wetland**	**Hyacinth Pond**	**Effluent**
pH	3.8	6.1	6.1	6.5	6.5	7	7
BOD (mg/l)	20,000	10,000	1,000	800	< 400	200	<200
BOD reduction	50%	Minor	90%	20%	50%	50%	

5

EVALUATION AND CONCLUSIONS

5.1 TYPES OF ECO-ENGINEERED SYSTEMS

As is illustrated in chapters 3 and 4, there is a large variety in eco-engineered treatment systems. A rough classification can be made in natural wetlands, constructed wetlands, aquatic plant production systems and wastewater-fed aquaculture.

NATURAL WETLANDS

The discharge of wastewater into natural wetlands is common practice in many places around the world with as a famous example the Nakivubo wetlands of Kampala in Uganda. Although natural processes will ultimately result in the degradation of most of the pollutants it is questionable whether such an unplanned pollution of natural wetlands is desirable since it cannot be assured if the treatment complies with its primary objectives.

In quite a number of cases the discharge of wastewater into wetlands has resulted in interesting forms of informal use of wastewater in aquaculture and agriculture (e.g. in the East Calcutta Wetlands). These cases are very interesting since they provide a large amount of 'hands on' experience on how to use the fertilizing potential of wastewater and how to deal with public health risks. Moreover, they show that wastewater treatment is not necessarily something that has to be paid for, but may even provide a certain economic return.

CONSTRUCTED WETLANDS / AQUATIC PLANT PRODUCTION SYSTEMS

Constructed (man-made) wetlands can be considered as an emerging technology in developing countries. Although constructed wetlands are not the only types of ecological engineering to be considered, they are often forwarded as one of the most promising. Aquatic plant production systems explicitly make use of the bioproductive potential constructed wetlands. These systems make use of the fertilizing value of sewage to produce various types of biomass, such as duckweed, Water hyacinth or Vetiver grass. The spread of well-engineered constructed wetlands that are based on multi-functionality is still limited.
Despite their apparent potential, the spread of constructed wetlands has been slow. Denny (1997; in Haberl 1999) has mentioned two reasons for this relatively slow spread of constructed wetlands to developing countries:

- Aid programmes from developed countries tend to favour technologies which have commercial spin-off for the donors;
- Developed world advisors are often unable to transfer their conceptual thinking to the realities and cultures of the third world; rather than assisting developing countries to develop their own technologies the tendency has been to translocate northern designs to tropical areas.

WASTEWATER-FED AQUACULTURE

Wastewater-fed aquaculture is used in a variety of unit operations around the world, especially in developing countries. Well-engineered systems generally consist of pre-treatment to remove BOD and pathogens. The effluents are subsequently applied to fish ponds. The vast majority of wastewater-fed aquaculture systems are traditional in the sense that they have been developed by farmers and local communities. Illustrative is the practice in the state Bengal in India with 130 sewage-fed fish farms covering an area of 4000 ha and supplying more than 8000 ton of fish per year to consumers. The Kalyani case that is described in paragraph 4.3 is illustrative for the design of these systems.

5.2 PLACE AND POTENTIAL OF THE WATERHARMONICA CONCEPT IN A DEVELOPING WORLD CONTEXT

WIDENING OF THE SCOPE

As described in chapter 1, the Waterharmonica is originally proposed for the Dutch / European situation as an ecological buffer between secondary or tertiary wastewater treatment at the one side and discharge to surface water at the other side (Claassen, 1996). An important consideration in this definition is that the effluents of advanced treatment plants are still containing considerable quantities of nutrients and are more toxic than is to be expected based on its chemical and physical composition and that the effluent is not yet suitable to meet the quality standards for swimming or recreational water and for nature development. Moreover, it does not have the 'ecological potential' that is aimed for in the EU Water Framework Directive.

One of the questions that can be asked is how this approach links up with the situation in developing countries. The sanitation situation in many developing countries is completely different compared to The Netherlands and Western Europe. In many cases a carefully planned wastewater infrastructure is not or only partially available. Western-style engineered wastewater treatment facilities that treat wastewater to a secondary or tertiary level are often not existent or do not function. In many cases wastewater is discharged into water bodies without treatment. The (waste) water problems in many countries are related to public health risks caused by the absence of basic sanitation and to decreasing water availability (Chapter 2). As such, the aim of reaching the very stringent EU Water Framework Directive quality standards does not have the highest priority, to say the least.

Therefore, in order to translate the Waterharmonica concept to developing countries and to underline the value of this approach, a broadening of the scope is proposed, based on several key elements:

1 The first Waterharmonica element that translates well to developing countries is that wetlands (natural or constructed) can have a very important function as a buffer zone between wastewater discharge and a range of options to use effluent: agriculture, aquaculture, landscaping/recreation, household/garden, industry, groundwater recharge, and environmental protection. More philosophically, wetlands have a function as a transition zone between society and nature or agriculture. If the system has well-defined system boundaries it provides a very good tool for pollutants' control.

2 A second key element is the recognition that eco-engineered treatment systems in themselves are multifunctional. They should not only be considered as wastewater treatment systems

alone but also as bioproductive ecosystems that use the fertilizing value of wastewater and can be 'engineered' for this goal. Various examples show that wetlands have a large potential in producing biomass, such as reed, willow trees, duckweed, water hyacinth, grasses and fish. The biomass productivity can be high due to an often continuous growing season in (sub) tropical countries. In such a multi-functional approach, wastewater treatment might even become an economic activity that creates income and reduces or covers the cost of wastewater treatment. Several examples, such as the Kalyani sewage-fed fish farms (paragraph 4.3), illustrate this.

3 A third key feature is the fact that eco-engineered treatment systems need a form of pre-treatment in order to function. If not, they will easily be overloaded with suspended solids and organic matter. Various pre-treatment systems are available (paragraph 3.8) such a sedimentation tanks, stabilization ponds, UASB Bioreactors and oxidation ditches. The pretreatment certainly does not have to comply to tertiary treatment standards.
The three key elements can be used to widen the scope of the Waterharmonica when it is to be applied in developing countries. In fact, following the described principles, the Waterharmonica approach is also a way of thinking, and not only a technical system.

Summarizing the above:
When the Waterharmonica approach is translated into a developing world context its scope is widened compared to the European definition where it – in first instance – focuses on the implementation of eco-engineered systems after tertiary wastewater treatment in order to increase the ecological potential of the wastewater. When applied to a developing world context, eco-engineered systems will often form the core treatment of the wastewater chain. Eco-engineered systems should always include some form of pre-treatment.
The Waterharmonica stresses the fact that wetlands are multifunctional and combine pollution control with biomass production and / or nature development and can make use of the fertilizing value of wastewater. The total treatment aims at beneficial use of effluents. Finally, it reduces the problems with (sometimes severe) surface water pollution.

5.3 THE NEED FOR AN INTEGRATED PLANNING AND STAKEHOLDER INVOLVEMENT

Wastewater management schemes aimed at treatment and use of wastewater such as the Water-harmonica are relatively complex because they incorporate treatment for both pollution control and the supply of effluent for various uses. Tackling this complexity is necessary if responsibilities for a sustainable closing/protection of the water cycle are to be acknowledged. In the ideal case the conceptual-, feasibility- and facilities planning processes would be an iterative planning process concerning the early involvement of all stakeholders.

An advantage of involving all relevant stakeholders in an early planning stage is that, once the multiple benefits and beneficiaries of wastewater reuse are recognised, additional options may be available for sharing project responsibilities and costs among project sponsors (after Asano and Mills 1990, in Metcalf & Eddy 1995). Water users, for example, could be involved through the 'polluter pays' principle. On the other hand, contributions from effluent users (such as fish farms) and the government can be negotiated, such as making land available for wastewater treatment facilities.

An integrated planning process, involving all relevant stakeholders, can be facilitated by using decision-making tools. An example of such as decision-making tool is SANEX™ (see the box below).

SANEX™
SANEX is a tool that could assist in the planning of Waterharmonica cases in developing countries. It has shown to be a good communication tool during various sessions in Nepal (Bolt et al., 1999). The author, Thomas Loetscher, states that:

"SANEX™ has been developed to facilitate sanitation planning. It is currently used by around 250 planners, practitioners and trainers in over 60 countries, who want to learn more about the various types of sanitation, who would like to find out whether certain technologies are suitable for their communities, or who need a comprehensive tool for education and training purposes. SANEX™ features a sophisticated costing module that can estimate community-specific construction and recurrent costs of many sanitation technologies.

The purpose of SANEX™ is to support beneficiaries, planners and other stakeholder groups during the early stages of sanitation planning by helping them identify suitable sanitation alternatives and by facilitating the assessment of these alternatives with regards to their preferences. Its key benefit is its ability to remind users of potential sanitation alternatives and the issues affecting their suitability. Being interactive, SANEX™ gives easy access to concise information, including a cost estimate, and it provides immediate feedback to user input, thus aiding sensitivity analysis and stimulating discussions.
Decision-making is a dynamic process, during which perceptions and preferences normally change. Often, these changes are many and profound. It is, therefore, not uncommon that the steps and the reasoning leading to a decision are inadequately documented. To avoid this problem, the 'Comment' feature of SANEX™ allows users to record their reasoning and to justify their input. Extensive use of this feature is recommended."

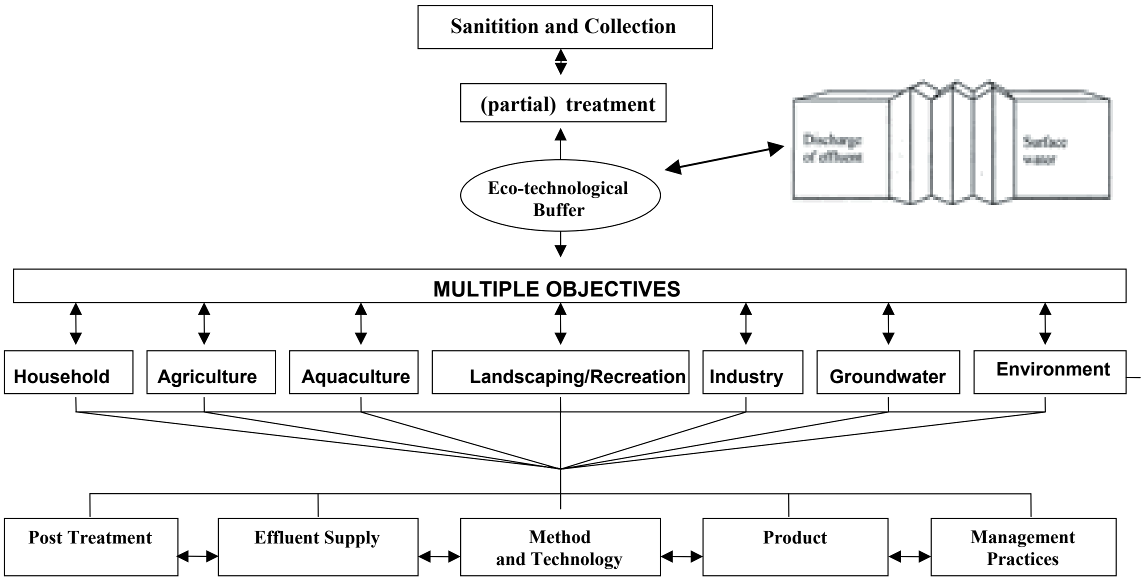
The SANEX™ tool is downloadable without cost at http://www.thomasl.info/tools.htm

Another decision-support tool could be the framework shown in Figure 21. This framework is based on an earlier framework that has been designed at Wageningen University (Martijn & Huibers, 2001b) specifically for the use of treated wastewater in irrigated agriculture and with an emphasis on developing countries. This framework has been used successfully over the last couple of years for the training of students and professionals.

The framework shown in Figure 21 stresses the need for an integrated approach providing a picture of the whole wastewater chain (collection, treatment and effluent use). It includes eco-engineered treatment as an important part of the treatment and stresses the use of effluents for various purposes such as agricultural use, use in household/garden, industry, aquaculture, land-scaping/recreation, groundwater recharge, and, environmental protection. The items 'post treatment, 'effluent supply', 'method and technology', 'product' and 'management practices' highlight several issues that should be discussed and decided upon during the planning process.

The various stakeholders (farmers, households, municipalities, health workers, etc.) may have different entry points into the presented framework. The framework is considered as a *primary decision making tool* because it shows that there are relations between various issues, which is intended to facilitate a negotiation process. Once these relations are acknowledged, then so-called *secondary decision making tools* can be employed (if available) to facilitate actual decision-making. Such secondary tools may consist of technical feasibility design studies, reviews, investigating legal and institutional constraints, commitments of stakeholders, etc. Adequate technical background information could, for example, give more insight into the feasibility of using various types of eco-engineered systems, using case studies for comparison and demonstration.

FIGURE 24 CONCEPTUAL FRAMEWORK OF THE WASTEWATER CHAIN, FACILITATING FOR INTEGRATED PLANNING AND DESIGN OF COLLECTION, TREATMENT, AND EFFLUENTS USE



5.4 FUTURE PROSPECTS OF THE WATERHARMONICA PROGRAMME

The Waterharmonica session during the 7th INTECOL Wetlands Conference on July 29th 2004 (http://www.iees.ch/EcoEng042/EcoEng042_kampf.html) also elaborated on the key elements of the general Waterharmonica concept. At this session it was concluded that the Waterharmonica focuses on the following:

- polishing and reuse of wastewater;
- integrating Water Chain and Water System;
- using ecological engineering concepts.

In the Waterharmonica approach, wetland creation and restoration are possible using wastewater. To promote the Waterharmonica, economic, recreational, and environmental benefits of the Waterharmonica should be spread beyond the wastewater managers, the city managers, the water boards, and the immediate landowners.

In the European Union, as in other developed countries, wastewater has to be managed using a watershed and ecosystem approach. The Waterharmonica forms, from a holistic point of view, a good tool to obtain wise management of wastewater to promote hygienically safe surface water (for use and reuse) and to promote biodiversity and create recreational values.

In tropical and developing countries, wise use of water and nutrient resources in wastewater to alleviate poverty and achieve sustainable development is the key factor, while maintaining vital ecosystem functions is also important. As in the western world, wastewater in developing countries has to be managed and this could be done using a watershed and eco-engineering approach, with some major advantages:

- Low external energy requirement;
- Easy operation;
- Low maintenance requirements while maintaining acceptable effluent quality;
- Safe biomass production (building material, energy source, food production or stocking wild populations);
- Feasibility (using different systems) for urban, peri-urban, and rural areas;
- Reduction in surface water pollution.

The UN Millennium Water Goals that were formulated in Johannesburg, 2002, highlight the fact that there is a general lack of safe water resources and sanitation facilities in the developing world. Moreover, the availability of fresh water resources per capita is decreasing due to the increasing world population and a strong increase the agricultural demand for irrigation water. The use of untreated or treated urban wastewater as an alternative source of water, will become an increasingly important issue for the coming decades.

It was stated that there is already worldwide a lot of knowledge about polishing and reuse of wastewater and of treated effluents. It is important to use that knowledge. The knowledge is widely available but fragmented and often misunderstood. Therefore the Waterharmonica is also about communication:

- Communicating the need for integrated water management. Wastewater managers should consider the effect of their activities on adjacent ecosystems–including humans;
- Communicating 'integrated knowledge in a useable form'.

The main task for the Waterharmonica is to disseminate knowledge about how to use a watershed and ecosystem approach when managing wastewater. This could be done by:

- Making examples of successful, and less successful cases of such management accessible.
- Providing technical and practical knowledge about design and management of e.g. constructed wetlands and aquaculture systems.
- Using the internet site of the programme (www.waterharmonica.nl), but also imbed the concept in other forums like the Ecological Engineering Society (www.iees.ch), the user groups of IWA, etc. This should lead to a contact network of scientists and practioners to extend and promote the Waterharmonica approach.

6

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'WATERHARMONICA' IN THE DEVELOPING WORLD

PART II

THE POTENTIAL OF ECO-ENGINEERED WASTEWATER TREATMENT FOR PROTECTING THE DRINKING WATER SOURCES OF MATAGALPA, NICARAGUA

INHOUD

SUMMARY

Agricultural activities are polluting the water streams in the region of the city Matagalpa, Nicaragua. This forms a serious threat to a reliable drinking water supply (Wijbrandi, 2002). The main pollutant is the processing of coffee beans that produces wastewater of high acidity and high concentrations of organic material and nutrients, depleting life-supporting oxygen from the water. Apart from this quality problem, there is a serious problem with regard to the quantity of the water. The discharge from the rivers that feed the basins downstream is almost halved in the last decade.

This research entails a study of the situation of the watershed in past, present and future concerning water quantity, water quality and the various water demanding stakeholders involved. This should pave the way to answer the question whether the approach of the Waterharmonica (eco-engineered wastewater treatment) to solve the described problem. The results of this study will contribute to an ongoing programme *Proyecto Cuencas Matagalpa* (PCM). PCM is an initiative of different governmental institutions and NGOs in the Matagalpa region with the goal to contribute to the improvement of the living conditions of the population of the province Matagalpa, whereby special attention is given to the watersheds in the region.

This study was conducted by Joost Jacobi, student of Wageningen University within the Water-harmonica programme. It was supported by STOWA, NOVIB, Aqua for All and Lettinga Associates Foundation, The Netherlands.

SITUATION ANALYSIS

Matagalpa (with an estimated 160,000 inhabitants) is situated in the vulnerable watersheds of the *Molino Norte* and *San Francisco*. The river basins have surface areas of 22.3 and 30.0 km² before they reach the city (a total of 5.230 ha) and have lengths of 8 and 7 km respectively. An important part of the drinking water supply of Matagalpa is coming from these rivers. With a rapidly increasing human population of the city of approximately 4% per year, the water demand is steadily rising and it is increasingly difficult to respond with an adequate drinking water supply. On the other hand - although there is a lack of figures - most stakeholders in the region acknowledge that the river discharges of Molino Norte and San Francisco have decreased in the last ten years. Since 2003, extra water is pumped from a watershed (river Aranjuez) situated 20 kilometres southeast of the city into the river Molino Norte during the dry season (December until April).

Coffee production in the area is of great economic importance. In the two watersheds 15 large plantations are responsible for more than 90% of the total coffee production. After harvest of the coffee berries, river water is used for the wet process, which takes place at the farm. After de-pulping the coffee berries, the coffee bean undergoes a fermentation process and is being washed afterwards. The (polluting) by-products of the process are: coffee pulp, mucilage (slimy layer surrounding the beans) and the wash water. The usual coffee wastewater consists of mucilage and wash water. The pH of the coffee wastewater drops to 4-5 and the concentration of organic material is very high (BOD of 2-3 g/l; COD of 5-8 g/l). Also the nitrogen concentration is high (approximately 200 mg/l). When stored, the pH decreases further due to acidification. Coffee production is a seasonal activity (November – February), for a large part taking place during the dry season when the river discharges are at their lowest.

Besides the coffee wastewater, human and animal excrements are affecting the quality of the river water and result in pollution with human pathogens. During the coffee harvest season, labourers come to the rural areas and live at the various plantations. The rural population in the two watersheds is then increased by fifty percent. Although 'latrine-projects' have been set up, most excrements end up in the fields. At the beginning of the rainy season, the drinking water company reports high concentrations of coliform bacteria and suspended solids, when heavy rains wash away soils, including the excrements.

When extra water is pumped from Aranjuez into the river Molino Norte, another source of pollution affects the river water quality. Nearby the pumping station, water intensive fern-nurseries are located. The ferns are exported and are an attractive business from an economic point of view. Besides the high water demand of the ferns, a lot of pesticides are used. N 2004 the quality of the water was poor and MARENA (ministry of environment and natural resources) doubted whether to pump this water from Aranjuez into the river Molino Norte.

CURRENT MEASURES FOR POLLUTION PREVENTION AT COFFEE FARMS

At a number of coffee farms, pollution preventive actions have been taken. Coffee pulp is no longer dumped into the river but turned into organic fertilizer after composting. At most farms, infiltration pits (*pilas*) can be found in which the wastewater can infiltrate and evaporate. As valuable land is needed for the installation of such *pilas*, they often have insufficient capacity. Moreover, due to the soil properties, the infiltration capacity is limited. At eight larger farms anaerobic bioreactors (UASB) are installed to reduce the organic pollution of the wastewater of which six are in operation. There is one example at coffee farm *La Hammonia* where a UASB is used in combination with aerobic treatment and the use of a constructed wetland and which treated water is used for (sprinkler) irrigation.

Calculations on the COD load of the rivers caused by the discharge of coffee wastewater were made with data found in literature and up to date coffee production figures. Based on data of the river discharges during the dry season and the coffee production data it is estimated that coffee wastewater constitutes up to 8-10% of the total river water volume. Based on mass balances it can be shown that the wastewater load of coffee farms results in very high COD load of the river, despite the current pollution prevention measures that have already been taken[1]. The self-purification capacity of the rivers has not been taken into account in this calculation.

Considering the COD loads it is very unlikely that the (physical-chemical) drinking water treatment plant that is used to treat the river water before supply to the city can completely remove the organic pollution also discharged during the coffee campaign (not taking into account the high loads of nutrients that are discharged). The organic material that remains in the drinking water forms a hygienic risk because of growth of bacteria in the piping network. Chlorine is used to minimize the risk, but may result in the formation of chlorinated hydrocarbons.

The decreased drinking water quality during the coffee season is confirmed by a survey among inhabitants of Matagalpa. Frequent complaints about the bad odour of the drinking water during the coffee season and irritated skin after washing were encountered. Many people add

[1] The exact percentage of coffee wastewater that receives treatment is not known; based on field vists it is estimated to be around 50%

extra chlorine at home or use some kind of filtration technique to minimize this nuisance. Those who can afford it buy bottled water.

During the last years the legislation regarding coffee wastewater discharge has sharpened. Legislation set by MARENA requires treatment up to < 200 mg COD/l. The implementation of more adequate treatment facilities is however problematic, as most farmers lack the finances to invest in treatment systems because of the decreased world market prices for coffee. The prices have decreased by more than 50% compared to the price level of 1999. Another bottleneck is that MARENA lacks the capacity to do sufficient controls.

WASTEWATER TREATMENT BY WETLANDS?

A part of the investigation focused on the question whether eco-engineered wetland systems can form a (partial) solution of the above-described water quality problem. The background of this idea forms the *Waterharmonica* programme, which is initiated by the Dutch Foundation for Applied Water Research (STOWA) and the waterboards Friesland Water Authority and Hoogheemraadschap Hollands Noorderkwartier. The Waterharmonica deals with the implementation of wetland systems as an integral part of wastewater treatment. The basic idea is that eco-engineered treatment systems may form an important link between a basic wastewater treatment system and safe discharge in surface water or reuse of effluent.

The conclusion is that wetlands may form an interesting option for the improvement of the river water quality and thus the drinking water quality. Considering the size of their activities, implementing (improved) treatment systems at the fifteen larger coffee plantations is an important measure to take. Especially implementing treatment at the five or six coffee farms that are located near the Molino Norte is of major interest, because of it is the main source of drinking water.
Another option is a more centralised constructed wetland system that treats the wastewater of a number of coffee farms. In this case constructed wetlands will form a treatment as well as a zone for temporary water storage and (possibly) nature development.

The advantages of wetland systems are the relatively low capital investment and low maintenance. A disadvantage might be the land requirement. Pre-treatment with a bioreactor will be necessary, considering the very high COD and the low pH of the wastewater water. The bioreactors can be followed by eco-technological systems in the form of e.g. constructed wetlands or aquatic plant treatment systems. The production of wood or reed in or after the wetland can make these systems more attractive and integrate them with other agricultural activities.

RECOMMENDATIONS

These are technical recommendations to Proyecto Cuencas Matagalpa, NOVIB and Aqua for All based on this study:

Despite the preventive measures that have already been taken it is clear that coffee production is still a major river polluter during the dry season and is seriously affecting the quality of the drinking water of Matagalpa during the coffee season. The government of Nicaragua has clear-cut goals to decrease the pollution load by the coffee farmers.

Reduction of pollution can be achieved by the introduction or further improvement of the wastewater treatment systems at the fifteen larger coffee farms. Especially implementing treatment at the five or six coffee farms that are located near the Molino Norte is of major interest, because of its importance for the drinking water supply (main source). The following two strategies for pollution prevention were formulated in the scope of this study:

1 Introduction of constructed wetlands systems at the larger farms, especially the five or six farms near Moline Norte. The advantages are the relatively low capital investment and low maintenance. A disadvantage might be the land requirement. Pre-treatment with a bioreactor such as a UASB will be necessary, considering the very high COD and the low pH of the wastewater. The bioreactors can be followed by eco-technological systems in the form of e.g. constructed wetlands or aquatic plant treatment systems. Wood or reed production in or after the constructed wetland can make these systems economically more attractive, integrate them with other agricultural activities and can contribute to reforestation.

2 Introduction of a (semi-) centralised treatment wetland system. This could be done by connecting the larger farms (especially the ones near Moline Norte) to a piping network and have centralised wastewater treatment consisting of a combination of a UASB bioreactor and constructed wetlands. The advantage is that farms need less operational and management capacity to treat the wastewater.

In principle one could also think about treatment of the river water (e.g. by a constructed wetland) just before the drinking water intake or improving the drinking water treatment plant, e.g. by introduction of an aerated reactor and an activated carbon filter.

It is not possible at this moment to assess the most cost-effective solution. However strategies 1 and 2 are preferable from the point of view of pollution prevention.

'VALUATION OF WATER'

A major bottleneck is the low world market price for coffee; most of the farmers lack investment potential to fund their own treatment facilities. It is interesting to develop of different financing mechanisms to support the farmers. The wastewater of coffee farms is affecting the drinking water quality. The inhabitants of Matagalpa pay for the drinking water. Further improvement of the quality by measures at the drinking water treatment plant is probably more costly than pollution prevention measures on the farms. Why not use part of the drinking water fees to help the farmers to finance their treatment?

CHANGE OF PRODUCTION

Due to the low coffee prices 60% of the farmers (especially the ones that own the smaller plantations) consider changing their activities. What might be needed for these farmers is a programme addressing alternatives / challenging changes into other forms of agricultural production.

OTHER POINT OF INTEREST: THE SEWAGE TREATMENT PLANT OF MATAGALPA

The Mayor of Matagalpa has asked if the wastewater treatment system of the city of Matagalpa can be improved. This sewage treatment consists of a set of stabilization ponds after which the water is released to the *Rio Grande de Matagalpa*. An extension of its capacity is planned for the year 2010. Till now only about 20% of the sewage water from the city Matagalpa is treated which is causing problems more downstream the *Rio Grande*. Here people use the water again for domestic purposes and in some cases as irrigation water of vegetables. Also some fisheries are affected by the contamination of the water and it is causing health risk for the local population.

Two recommendations are made:

- The installation of a UASB reactor before the current stabilization ponds would improve the capacity of the ponds by a factor 2.
- The stabilization ponds could be turned into constructed wetlands in which biomass like reed or trees are grown. This would be a source of fuel for the area

FOLLOW UP

The study will have a follow-up, starting in spring 2005. This follow-up is supported by Aqua for All and Novib and by a group of volunteers of the Dutch water sector. The aim of the follow-up is to support *Projecto Cuencas Matagalpa* in stimulating pollution prevention measures by expertise and funding. The follow-up will link up with the Waterharmonica programme.

RESUMEN

El potencial del tratamiento eco-tecnológico de desagües para el mejoramiento de la calidad del agua potable de Matagalpa, Nicaragua

ANTECEDENTES DE LA INVESTIGACIÓN

La disminución de la disponibilidad y la contaminación de las aguas superficiales es un tema de gran preocupación mundial. La situación en la ciudad de Matagalpa (aprox. 160,000 habitantes) en Nicaragua es un buen ejemplo. Esta ciudad esta situada en las vulnerables cuencas de los ríos *Molino Norte* y *San Francisco*. Las cuencas tienen áreas superficiales de 22.3 y 30.0 km^2 (un total de 5.230 ha) y miden 8 y 7 km de largo respectivamente. Una parte importante del suministro de agua potable para la ciudad de Matagalpa viene de estos dos ríos de los cuales han dicho que las descargas han disminuido en los últimos diez años. Con un rápido aumento de la población de la ciudad de alrededor de 4% anual, la demanda de agua sube constantemente y cada vez es más difícil responder con un suministro adecuado de agua potable.

Además, la baja calidad del agua de río es un problema provocado por varias actividades en el área montañosa río arriba en las cuencas. Parte del agua de las cuencas del Molino Norte y San Francisco es empleada por granjas cafetaleras de la región para el procesamiento de sus granos. Después, el agua contaminada por tal proceso corre hacia la ciudad de Matagalpa. También el uso intensivo de agua de los criaderos de helecho es un fuente de contaminación por la variedad de químicos usados en su cultivo. Otras fuentes de contaminación son los excrementos animales y humanos que, cuando entran en los ríos, provocan concentraciones elevadas de bacterias coliformes en el agua representando riesgos potenciales a la salud.

OBJETIVOS Y ENFOQUE DE LA INVESTIGACIÓN

El objetivo de esta investigación ha sido el de aumentar el conocimiento sobre las situaciones pasadas, presentes y futuras de las cuencas con respecto al uso y la contaminación de su agua. La situación del agua ha sido investigada con respecto a su cantidad y su calidad, y los incentivos influyendo a las actividades de su uso, a través de trabajos de campo, entrevistas con los interesados directos locales y búsquedas de documentación. Una segunda actividad de investigación fue explorar la potencial de la implementación de tecnologías de tratamiento (de eco-ingeniería[2]) para tratar el desagüe de café antes de su descarga en los ríos.

CANTIDAD Y CALIDAD DEL AGUA DE LAS CUENCAS

Aunque faltan las cifras, la mayor cantidad de los directamente interesados en la región reconoce que se están disminuyendo las descargas de los ríos de Molino Norte y San Francisco. Desde el año 2003, agua extra es bombeada de un valle situado 20 kilómetros al sureste de la ciudad. En la época de secas (diciembre a abril), cuando las descargas de los ríos están bastante bajas y la demanda de agua potable en la ciudad es mayor que lo normal, agua extra es bombeada desde una cuenca cercana (el río Aranjuez) en el río Molino Norte.
La producción de café es de gran importancia en el área. En las dos cuencas 15 plantaciones grandes son responsables de mas del 90% del total de la producción de café. Después de cosechar las cerezas de café, se usa agua de rió para el proceso mojado, que ocurre en la granja. Después de quitarles la cáscara y la pulpa a las cerezas, los granos pasan por un pro-

[2] Del inglés “eco-engineering”: el uso de sistemas naturales (como por ejemplo humedales construidos) para el tratamiento de agua y la producción de biomasa.

ceso de fermentación y después son lavados. Los productos secundarios (contaminantes) del proceso son: pulpa de café, mucílago (una baba que rodea al grano) y el agua de lavado. El pH del desagüe de café baja a 4-5 y la concentración de materia orgánica (DQO[3]) es muy alta (5-8 g/l). Cuando está almacenado, el pH del agua disminuye aun más por la acidificación. La producción de café es una actividad estacional (enero – abril) y toma lugar al final de la época de secas en un periodo cuando las descargas de río están en su nivel mas baja.

Además del desagüe de café, excrementos de origen animal y humano están afectando la calidad del agua de rió resultando en contaminación con microorganismos patógenos humanos. Durante la estación de la cosecha de café, los trabajadores vienen a las áreas rurales y viven en las diferentes fincas. La población rural en las dos cuencas aumenta entonces con un cincuenta por ciento. Aunque proyectos de implementación de letrinas han sido desarrollados, la mayoría del excremento termina en los campos. Durante la época de lluvias, la compañía de agua potable reporta altas concentraciones de bacterias coliformes y sólidos suspendidos en el principio de la época de lluvia, cuando lluvias fuertes se llevan tierra al río, incluyendo a los excrementos.

Cuando agua extra es bombeada del rió Aranjuez al Molino Norte, hay otra fuente de contaminación afectando la calidad del agua de rió. Cerca de la estación de bombeo, están localizados criaderos de helecho que usan grandes cantidades de agua. Los helechos son exportados y forman un negocio atractivo desde el punto de vista económico. Además de la alta demanda de agua de los criaderos, estos usan una gran cantidad de pesticidas. Este año la calidad del agua fue baja y MARENA (el ministerio de medio ambiente y recursos naturales) dudaba si debería o no bombear esta agua del río Aranjuez al Molino Norte.

MEDIDAS ACTUALES DE PREVENCIÓN DE CONTAMINACIÓN EN LAS GRANJAS DE CAFÉ

En cierto numero de granjas de café, fueron tomadas medidas preventivas para reducir el contenido de DQO en el desagüe. La pulpa de café, en lugar de ser descargada en el río, es convertida en fertilizante orgánico después de compostaje. En la mayoría de las granjas, se pueden encontrar *pilas* (fosos de infiltración) en las cuales el desagüe puede infiltrarse y evaporarse. Como se necesita tierra valiosa para la instalación de esas *pilas*, muchas veces tienen una capacidad insuficiente. Además, por la propiedades del suelo, la capacidad de infiltración es limitada. En 8 granjas más grandes, bioreactores anaerobios (UASB) fueron instaladas para reducir el contenido en DQO del desagüe, de los cuales 6 están en operación. Hay un ejemplo en granja de café *La Hammonia* donde un reactor UASB es usada en combinación con un sistema de tratamiento aerobio y el uso de un filtro biológico (un estanque con plantas acuáticas). Finalmente el agua es usada para el sistema de irrigación por aspersión.

Calculaciones de la carga de DQO del desagüe de café en los ríos fueron hechas con datos encontrados en la literatura y cifras actualizados de la producción de café. Basado en los datos de la descarga de río durante la estación seca y los datos de la producción de café, fue estimado que el desagüe de café constituye hasta el 8-10% del total de agua en el río. Basado en balances de masa se puede mostrar que la carga de desagüe de las granjas de café resulta en cargas muy altas de DQO en el río, a pesar de las medidas actuales de prevención de contaminación que ya han sido tomadas[4]. La capacidad de auto-purificación de los ríos no fue tomada en cuenta en estos cálculos.

[3] Demanda Química de Oxigeno, un parámetro usado para indicar la concentración de material orgánica

Considerando las cargas de DQO, es muy improbable que la planta de (física-química) de tratamiento de agua potable usada para tratar el agua de río antes de suministrarla a la ciudad, puede remover por completo la contaminación orgánica descargada en los ríos durante la campaña de café (no tomando en cuenta la altas cantidades de nutrientes descargadas). El material orgánico restante en el agua potable forma un riesgo higiénico por el crecimiento de bacterias en la red de tubería. Cloro es usado para minimizar el riesgo pero puede resultar en la formación de hidrocarburos clorados.

Que la calidad del agua potable disminuye durante la estación del café ha sido confirmado por media de una encuesta entre los habitantes de Matagalpa. Quejas frecuentes fueron encontradas sobre un mal aliento del agua potable y sobre irritaciones de la piel. Mucha gente agrega cloro extra en su casa o usa algún tipo de filtración para minimizar las molestias. Los que lo pueden pagar compran agua embotellada.

Durante los últimos años la legislación con respecto a la descarga de desagüe de café se ha puesto más estricto. La legislación puesta por MARENA requiere un tratamiento hasta < 200 mg DQO/l. Sin embargo, la implementación de instalaciones de tratamiento más adecuadas es problemática, porque en la mayoría de los casos a los granjeros les faltan los fondos para invertir en sistemas de tratamiento, debido a los bajos precios de café en el mercado internacional. Los precios han bajado con mas del 50% comparado con el nivel de los precios en el año 1999. Otro problema es que a MARENA le falta la capacidad de hacer controles suficientes.

TRATAMIENTO DE DESAGÜES POR MEDIO DE HUMEDALES CONSTRUIDOS

Una parte de la investigación se ha enfocado en la cuestión si los sistemas de humedales construidos pueden formar una solución (parcial) del problema de calidad de agua descrita en los capítulos anteriores. Este idea se basa en el proyecto *Waterharmonica (Harmónica de Agua),* un proyecto Neerlandés de investigación y de implementación patrocinado por los Consejos Regionales Neerlandeses de Agua sobre la implementación de sistemas de humedal como parte integral del tratamiento de desagües. La idea básica es que sistemas de tratamiento construidos según el principio de la eco-ingeniería pueden ser un enlace importante entre un sistema básico de tratamiento de desagüe y una descarga segura en aguas superficiales y el reuso de agua.

La conclusión es que los terrenos pantanosos pueden ser una opción interesante para el mejoramiento de la calidad del agua de río, resultando en una mejor calidad de agua potable. En el caso de sistemas operando de manera descentralizada en las granjas de café, implementando (mas) sistemas de tratamiento en las 15 plantaciones más grandes sería lo más eficiente. Especialmente la implementación de tratamiento en los cinco o seis granjas de café cerca del Molino Norte es de interés mayor, por su importancia en al suministro de agua potable (fuente principal). Las ventajas de los sistemas de humedales son la inversión de capital relativamente bajo y el mantenimiento bajo. Una desventaja puede ser el requisito de tierra. Pretratamiento con un bioreactor será necesario, considerando el valor alto de DQO y el pH bajo del desagüe. Los bioreactores pueden ser complementados por sistemas eco-tecnológicos en forma de (por ejemplo) humedales construidos o tratamiento por medio de plantas acuáticas. La producción de madera o junco localizada adentro o después del humedal puede hacer estos sistemas mas atractivos y integrarlos con otras actividades agrícolas.
Otra opción es construir un sistema mas centralizado en las orillas del río. Hay dos opcio-

[4] El porcentaje exacto del desagüe de café que recibe tratamiento no se sabe; basada en visitas de campo es estimado ser alrededor del 50%

nes: delante de donde se toma el agua de río, o delante de la planta de agua potable. En este caso los humedales construidos formarían una zona de tratamiento y de regulador de caudal así como un almacenamiento temporal de agua y posiblemente de desarrollo de naturaleza. Lo ultimo es deseable cuando las descargas de río fluctúan fuertemente durante el año y el suministro suficiente de agua potable es en peligro en la estación seca.. Plantaciones bien manejadas de especies de árboles apropiados pueden contribuir al aumento de la capacidad de capacidad de almacenamiento de agua y la prevención de erosión.

RECOMENDACIONES

Estos son recomendaciones técnicos a Proyecto Cuencas Matagalpa, NOVIB y Aqua for All basadas en este estudio:

A pesar de las medidas preventivas que ya han sido tomadas queda claro que la producción de café sigue contaminando el río durante la estación seca y esta afectando seriamente el ultimo agua potable del agua retirada de las cuencas. El gobierno tiene metas claramente definidas para disminuir la carga de contaminación causada por los granjeros de café.

La reducción de la contaminación se puede obtener por medio de la introducción o el mejoramiento de los tratamientos de desagüe de las 15 granjas más grandes de café. Especialmente la implementación de tratamiento en los cinco o seis granjas de café localizadas cerca de Molino Norte es de mayor interés, por su importancia en el suministro de agua (fuente principal). Estas son cuatro maneras técnicas para reducir la contaminación:

1 Introducción de sistemas descentralizadas de humedales construidos en las granjas mas grandes: Las ventajas son la inversión de capital relativamente bajo y el mantenimiento bajo. Una desventaja puede ser el requisito de tierra. Pretratamiento con un bioreactor como un UASB será necesario, considerando el valor alto de DQO y el pH bajo del desagüe. Los bioreactores pueden ser seguidas por sistemas eco-tecnológicos en forma de (por ejemplo) humedales construidos o tratamiento por medio de plantas acuáticas. La producción de madera o junco localizada adentro o después del humedal puede hacer estos sistemas mas atractivos, integrarlos con otras actividades agrícolas y puede contribuir a la reforestación.

2 Introducción de un tratamiento centralizado. Esto se puede realizar conectando las granjas mas grandes (especialmente los que están cerca de Molino Norte) a una red de tubería y tener un tratamiento centralizado de desagüe en forma de una combinación de un reactor UASB y humedales construidos. La ventaja sería que los granjeros necesitarían una menor capacidad de gestión y de operación para tratar el desagüe.

3 Tratamiento del agua de río en un humedal construido antes de la entrada de agua potable

4 Mejoramiento de la planta de tratamiento de agua potable, por ejemplo por la introducción de un reactor aireado y filtración por medio de carbón activado.

En este momento no es posible evaluar la solución más conveniente en cuanto a la relación costo-beneficio. Sin embargo, las soluciones 1 y 2 son las preferidas del punto de vista de prevención de contaminación.

‘VALORIZACIÓN DE AGUA’

Un gran problema es el bajo precio internacional de café; a la mayoría de los granjeros les falta la potencial de invertir para financiar sus propios facilidades de tratamiento. En nuestra opinión es interesante desarrollar diferentes mecanismos de financiamiento para apoyar a los granjeros. El desagüe de las granjas de café esta afectando la calidad del agua potable. Los habitantes de Matagalpa pagan por el agua potable. Mejoramientos adicionales de la calidad a través de medidas ‘centralizadas’ en la planta de tratamiento de agua potable son probablemente mas caros que medidas de prevención de contaminación en las granjas (tratamiento descentralizado o sistemas de tubería). ¿Por que no usar parte de las cuotas de agua potable para ayudar a los granjeros a financiar su tratamiento?

CAMBIO DE PRODUCCIÓN

Debido a los precios bajos del café, el 60% de los granjeros (especialmente aquellos que tienen plantaciones pequeñas) esta considerando cambiar sus actividades. Lo que podría beneficiar a los granjeros que se encuentran en esta situación seria el iniciar un programa que se enfoque en brindar alternativas / y cambios que representen nuevos retos en otras formas de producción agrícola.

OTROS PUNTOS DE INTERÉS

El alcalde de Matagalpa ha solicitado via Joost Jacobi si el sistema de tratamiento de desagüe puede ser mejorado. Nuestras sugerencias:

- La instalación de un reactor UASB ubicado antes de los estanques de estabilización actuales mejoraría la capacidad de los estanques con un factor de 2.
- Los estanques de estabilización podrían ser convertidos en pantanos construidos en los cuales biomasa como junco o árboles serian cultivados. Esto podría ser una fuente de combustible para el área.

1

BACKGROUND

1.1 INTRODUCTION

Agricultural activities are polluting the water streams in the region of the city Matagalpa, Nicaragua. This forms a serious threat to a reliable drinking water supply (Wijbrandi, 2002). The main pollutant is the processing of coffee beans that produces wastewater of high acidity and high concentrations of organic material and nutrients, depleting life-supporting oxygen from the water. Apart from this quality problem, there is a serious problem with regard to the quantity of the water. The discharge from the rivers that feed the basins downstream is almost halved in the last decade.

This research entails a study of the situation of the watershed in past, present and future concerning water quantity, water quality and the various water demanding stakeholders involved. This should pave the way to answer the question whether the approach of the Waterharmonica (eco-engineered wastewater treatment) to solve the described problem. The results of this study will contribute to an ongoing programme *Proyecto Cuencas Matagalpa* (PCM). PCM is an initiative of different governmental institutions and NGOs in the Matagalpa region with the goal to contribute to the improvement of the living conditions of the population of the province Matagalpa, whereby special attention is given to the watersheds in the region.

This study was conducted by Joost Jacobi, student of Wageningen University within the Water-harmonica programme. It was supported by STOWA, NOVIB, Aqua for All and Lettinga Associates Foundation, The Netherlands.

1.2 RESEARCH BACKGROUND

NICARAGUA

The surface of Nicaragua is approximately 129,500 km². Bordered in the north with Honduras and in the south with Costa Rica, in the west there is a coastal area of more than 300 km of the Pacific Ocean, and in the east a coastal line of 500 km of the Caribbean Sea. The climate varies in the different parts of the country, from a tropical one to the subtropical one, and the vegetation varies from rainforests to the subtropical vegetation of the highlands. In the populated regions of the country, located at the Pacific and in the western highlands, there is the dry season from December until April, and a rainy season from May until October.

The country can be classified in three main regions: the region of the Pacific, the central highlands and the coastal region of the Atlantic. The region of the Pacific is divided in the coastal plain and in the depression or the rift of Nicaragua, where there is a chain of the volcanoes. Nicaragua has five million inhabitants approximately, of which the most live in the coastal region of the Pacific, where also agricultural production cattleman are concentrated. The north of Nicaragua is dependent on coffee tillage. After tourism, coffee is the one of the most important export products. In 2001, 150 million dollars was generated in the coffee industry of Nicaragua. The decrease of the international coffee-price has major consequences for the profits.

According to the Pan American Health Organization (PAHO), approximately 37 percent of the estimated total Nicaraguan population of 5 million people has access to treated drinking water (distributed by piping systems). The urban population is estimated to be 63.7 percent of the total population, or approximately 3.2 million people (PAHO, 1999). Of that urban population, it is estimated that 93 percent has access to drinking water services, while only 12 percent of the rural population has similar access. Of the urban population, 87 percent has access to sanitary disposal services (including the use of latrines), but only 54 percent of the rural population benefit from such services. In 1990, 70 percent of the public water supply systems in Nicaragua used ground water, while the remaining 30 percent used surface water.

MATAGALPA AND ITS RIVERS

The municipality Matagalpa, capital of the equally named province, is located in the north of Nicaragua, in the mountain area Cordillera Dariense (Figure 1). The city itself is situated next to the Rio Grande de Matagalpa at 700 meters above sea level. More than half of the population of the province lives in the city Matagalpa, which counts an estimated 160,000 inhabitants; the other part lives in the rural areas. Shortage of water ration forces people to leave their villages. In some villages in the area around Matagalpa there is no water at all with the result that people move to the big city and end up in the slums. The city of Matagalpa obtains its drinking water from the rivers Molino Norte and San Francisco. The total extension of these basins is 32.2 km². Their degrees of latitude are N13°09'-12°53' and of longitude W85°59'-85°49'. Molino Norte is located in the north of the city Matagalpa and its river travels about 12 kilometres from the head until its outlet meets the river San Francisco, giving origin to the Rio Grande de Matagalpa.

The climate of the Matagalpa is subtropical, and has a temperature between 18-26°C. The average annual precipitation 1550 mm, and the annual evaporation is 1215 mm. The main agricultural activity is coffee production, but also elementary products are cultivated for own consumption such as corn and beans. For the export vegetable and ornamental ferns are grown in the area. Besides that, the area is covered with pastures and forest. The inclination of the slopes varies between the 4 and 75% and at some steep slopes mudflows occur, caused by the erosion.

FIGURE 1

COFFEE PRODUCTION AND OTHER AGRICULTURAL ACTIVITIES

Coffee production is of great importance for the economical development at both regional and national scale. Prior to coffee exportation, considerable processing takes place in order to prepare dried green coffee beans. This processing occurs in one of two basic approaches: dry or (semi-)[5]wet processing. In Matagalpa (as in whole Central America) wet processing is practiced with coffee wastewater as a source of important environmental problems.

Wet processing occurs in three stages. In the first step, the outer skin of the coffee fruit (known as 'pulp') is removed with the aid of water in a 'pulper'. This produces a pulp wastewater as well as a humid solid waste, which is the pulp. In the second step, mucilage (a slime layer which surrounds the coffee bean) is removed by a fermentation process. During fermentation, pectic substances are hydrolyzed which solubilizes the slime layer. The wastewater formed by draining off the spent liquor of the fermentation process is known as the fermentation water. Finally, the beans are rinsed in a channel forming the wash wastewater. The fermentation liquor is usually diluted with the wash water and together form the so-called *aguas mieles*. The washed beans are partially dried in the sun and then sent from the coffee farm to a larger processing unit where the coffee beans are dried further. Once completely dry, the beans are mechanically treated in order to remove the hull. The dehulled green coffee beans constitute the product that is finally exported.

Besides coffee production there is an increasing development of fern nurseries in the study

[5] The semi-wet process is similar to the wet process. During semi-wet processing, however, the time-consuming fermentation step is reduced as the mucilage layer is removed mechanically. After the mechanical removal of the mucilage, the wet coffee should ideally undergo a shortened 'finish' fermentation to fully remove remaining mucilage from the parchment followed by washing in order to produce an optimal quality (Becker 1999)

area. The ferns are exported and are very profitable. The fern is a water demanding crop and many pesticides are used to avoid diseases. Vegetables are grown for the export as well but also for own consumption. Furthermore, various types of cattle can be found in the watershed of which the cow is most common.

1.3 PROBLEM DEFINITION AND RESEARCH OBJECTIVES

Due to the increasing population, the water demand of the city Matagalpa is rising and it is getting more difficult to respond with an adequate water supply. Moreover, the quality has decreased due to increased (agricultural) activities in the two watersheds.

An important part of the drinking water supply is coming from the rivers Molino Norte and San Francisco of which it seems that discharges have decreased in the last ten years. Coffee plantations (*fincas*) located in the mountain area of the Molino Norte and San Francisco catch most of their process water from the water streams for processing the coffee beans. After this process, polluted water is running towards the city Matagalpa and is effecting the quality of the drinking water. Not only the coffee plantations but also the water intensive fern-nurseries are sources of pollution because of the many chemicals used for its cultivation. Furthermore, animal and human excrements, when washed down to the rivers, contribute to an increase of coliform bacteria concentrations in the water and form a serious health risk when in direct contact with human beings.

1.4 RESEARCH OBJECTIVES

The research objectives of this study were:

- to gain more knowledge about the past, present and future situation of the watersheds Molino Norte and San Francisco with respect to water quantity and quality;
- to investigate the sources and degree of river water pollution;
- to assess the effects of the river pollution on the drinking water quality of the city Matagalpa;
- to investigate the potential of installing eco-engineered treatment at coffee farms to improve the river water quality as such the drinking water quality.

1.5 OUTLINE OF THE REPORT

Chapter 2 contains the methodologies that were used to answer the research objectives of this study. Chapter 3 describes the trends in water availability in the Matagalpa region. Chapter 4 describes the facts and figures that were found on the river water pollution and the effects on the drinking water quality. Chapter 5 goes into the potential implementation of eco-technological wastewater treatment systems as a measure for pollution prevention. Chapter 6 gives the conclusions of the study and provides recommendations for a project follow-up.

2

METHODOLOGY

2.1 GENERAL

In order to answer the research questions of paragraph 1.4 a field research of four months was conducted in the two watersheds (Molino Norte and San Francisco) and in the city Matagalpa. The aim was to collect data on issues like types of pollution, existing wastewater treatment systems, agricultural activities, population growth, discharges, precipitation, and so on. Observations in the field and interviews with farmers were executed to see what type of contamination sources exist, where they are located and to find out what processes and which stakeholders are involved in the production of wastewater. Topographic maps of the watersheds were prepared as a technique to integrate information.

Furthermore, interviews were conducted with the various stakeholders; people at the drinking water company and at the treatment plant, local authorities, the Ministries of Agriculture and Environment, the University, inhabitants of Matagalpa and (coffee) farmers. Twenty-four inhabitants of Matagalpa were interviewed with the focus on frequency of drinking water supply, water quality and price (see Annex A for list of questions). During field visits, 21 farmers were questioned about subjects like land use, water use, applied treatment systems, future plans, etc. (see Annex B). The interviews with the farmers were executed with the assistance of a staff member of *Projecto Cuencas Matagalpa* (PCM) to bridge the gap of cultural differences and to create an open atmosphere in order to receive sincere answer.

The results of the interviews are presented in the various chapters with statistic accounts. The given numbers in the bars do not always correspondent with these figures (21 farmers and 24 citizens of Matagalpa). Sometimes, for some reasons that are not always known, people did not answer the question and in some cases more answers were possible. The expression 'no answer' means that the specific question has not been asked because e.g. people had little time or did not feel at ease.

To integrate all collected data the so-called DPSIR-framework (see paragraph 2.2) was used as a basis, starting with a description of the State-indicator concerning water quantity and quality of the watersheds. From here, the other indicators (Driving forces, Pressure, Impact and Responses) were further elaborated.

2.2 THE DPSIR INDICATOR FRAMEWORK

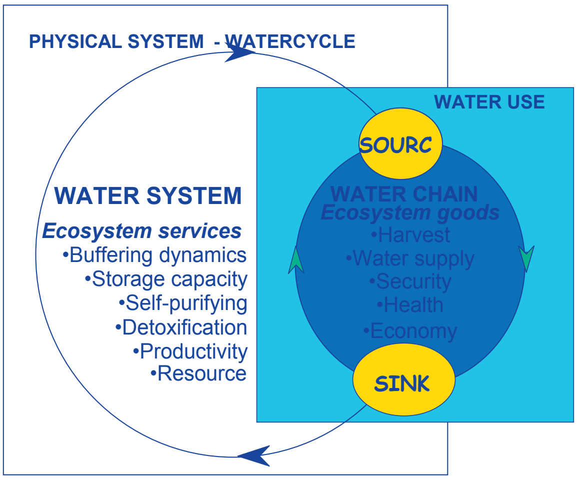
INTRODUCTION

There are different definitions of integrated water management (not limitative: Meire & Coenen, 2003; Verhallen et al, 2001; Savenije et al, 1998; Heathcote, 1997; Mitchell, 1991; Ministry of Transport, Public Works and Water Management, 1989/1998; all to find in Santbergen, 2003). Integrated water management is defined by (Santbergen 2003):

A participatory decision-making process (including governments, groups of interest, non governmental organizations, individual citizens and scientists from various α, β and γ disciplines), aiming at an identification, selection, implementation and evaluation of measures on a sustainable development and management of water systems on different spatial and temporal scales, based on their natural characteristics and interrelationships.

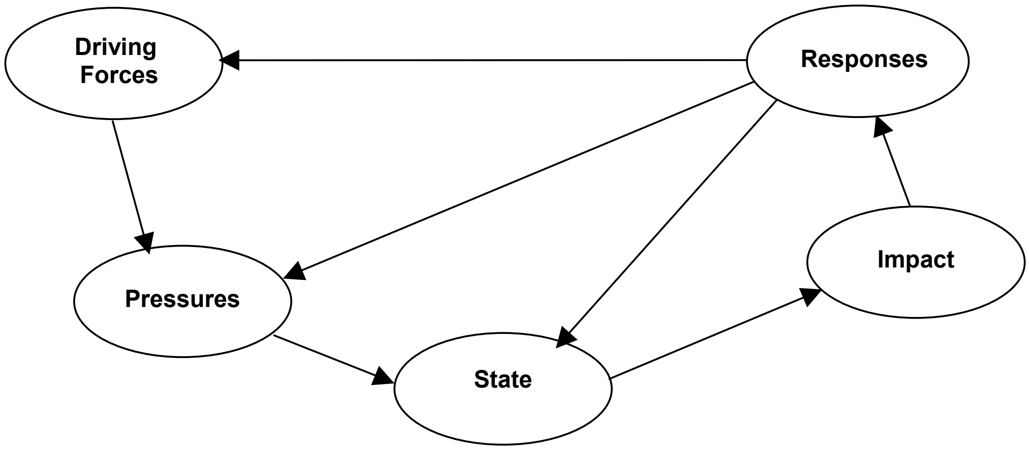
THIS DEFINITION IS BASED ON THE FOLLOWING RECOGNITIONS:
Figure 2 below provides a picture of the interrelated natural subsystem (physical system – water cycle) and the human subsystem (water use). A water system is defined as 'a geographically bordered, interrelated and functioning entity of surface waters, ground waters, sediments, banks and flood plains and technical infrastructure, including all intrinsic morphological, hydrodynamic, chemical and biological/ecological characteristics and processes'

FIGURE 2 THE WATER CYCLE AND WATER USE (SANTBERGEN, 2003)



DPSIR INDICATOR FRAMEWORK
The DPSIR indicator framework, as introduced by the European Environment Agency, will be applied for this research as a tool to access a water system inventory (see Figure 3 and Table 1). DPSIR stands for: Driving forces-Pressures-State-Impact-Responses. *Be aware: in the DSPIR framework, a water system inventory is more than a description of the state of a water system (quality and functioning) only*. According to Heathcote (1997; chapter 3): 'A watershed inventory (read: describing the state (S) of a water system) gives an overview of physical, chemical, and biological processes operating in a watershed ecosystem. It seldom, however, points the way to a clearly defined 'problem' to be solved by management actions. Yet disagreements about what problem is to be solved can create significant obstacles to effective watershed management, even if stakeholders agree on most issues and conditions in the system'. Thus; problem perceptions and visions on an 'ideal' water system will vary according to the specific water system/basin and the people living and working in it.

FIGURE 3 THE DPSIR (DRIVING FORCES-PRESSURES-STATE-IMPACTS-RESPONSES) INDICATOR FRAMEWORK OF THE EUROPEAN ENVIRONMENT AGENCY (1998)



With regard to the DPSIR indicator framework, it is essential to distinguish between internal and external driving forces. Internal driving forces are human activities and water uses, from within the boundaries of a water system, that causes pressures on, and therefore influences the quality and functioning of a water system, and that can directly or indirectly be influenced by decision-makers within the water system.

External driving forces are forces or developments that reach beyond the boundaries of the studied water system, which will influence (future) water demands (and therefore potential water use impairments) and which are beyond the direct control of the decision makers within a water system (Verhallen & Ruigh-van der Ploeg, 2001; Heathcote, 1997). Examples are: population size/growth, economic growth or decline, a more anthropocentric or eccentric philosophy in a society, climate change, etc.

In the table below, the different indicators of this framework are defined and some examples of the indicators are given.

TABLE 1 THE DPSIR INDICATOR FRAMEWORK (AFTER: EEA, 1998)

Indicator	Definition	Example(s)
D = Driving forces	Driving forces describe the human activities/functions/ uses, like urbanization and agriculture that are the main sources of problems or threats. Driving forces can be external (from outside the water system) or internal (from inside the water system).	Number of inhabitants, land use patterns, amounts of fertilizers per ha. Coffee price
P = Pressures	They describe the stress that a driving force puts on the quality and functioning and therefore indirectly on the related functions/ uses of the water system.	Nutrient loads, drinking water shortage, acidification
S = State	The state of the water system presents the historical and present quality and functioning of a water system, in terms of physical, chemical and biological/ecological characteristics.	Concentrations of BOD, phosphorus and nitrates and some historical trends in these concentrations.
I = Impact	The impact describes the changes in the quality and functioning of a water system and the related functions/uses as a consequence of the driving forces.	Polluted drinking water, algal blooms, fish kills, water shortage
R = Responses	Responses describe the policies that have been or are being developed to deal with the recognized problems.	Introduction of good farming practices, investments in treatment capacity of waste water treatment plants.

ASSESSING WATER DEMAND AND WATER QUALITY IN A RIVER BASIN

Most estimates of water demand require an estimation of population size and potential growth over the planning horizon. Population size is a key variable in determining not only water demand, but demand for other water-using activities such as electric power generation, manufacturing, agriculture, and recreation, and the intensity of these activities within the watershed. Forecasted population size is also a useful measure of the potential market for water-related goods and services (Heathcote, 1997).

Generally speaking, water demand is influenced by population size and density, annual per capita income, social forces and life-style expectations, quality of supply, and annual rainfall. These variables can be used to make reasonable accurate predictions of water demand for a given area. Estimating current water demand, like current population size, is a relatively straightforward task. The simplest approach is to estimate daily per-capita water demand and multiply per-capita use by the population served. This estimation can be extended into the future by using projected population figures and assuming the same usage rate as currently exists (Heathcote, 1997).

It is somewhat more difficult to estimate future water demand under circumstances of changing usage, especially under water conservation programs or, possibly, under an assumption of increased per-capita use. Like population forecasting, estimation of future water demand is an inexact science. Critical planning assumptions in demand forecasting are (Heathcote, 1997): estimated population growth rate over the planning horizon (1), estimated precipitation entering the area (2), estimated volume of surface and/or groundwater available for future extraction (3), nature of water-using industries, commercial establishments, and institutions in the basin (4), attitudes toward water use versus conservation in the basin (5).

Driving forces regarding the water quality aspects are mainly expressed as direct sources of water pollution. The external driving forces concerning water quality of a watershed can be e.g. the climatic conditions in the area and more specific the heavy rainfalls at the beginning of a wet season. Furthermore, factors that have its influences on type of land use in the region (e.g. international market) can be defined as an external driving forces. A description of the actual situation (state) concerning the water quality of a watershed can be done by calculations with figures derived from literature or by the execution of physical-chemical analyses of water samples. For the last case a longer period of time is needed in order to come up with reliable results. Furthermore a qualitative analysis can be conducted in the form of interviews at various levels.

3

TRENDS IN WATER AVAILABILITY

3.1 INTRODUCTION

This chapter will start with an overview of the study area and all relevant locations concerning the water system. Then the results on the water quantity of the two watersheds will be presented. Looking at the water quantity in the study area, there are two important issues that are linked which each other: the amount of available fresh water and the water demand. The availability of water will be discussed first whereby the focus will be on surface (river) water. Population size and population growth are seen as the most important factors that affect the water demand side.

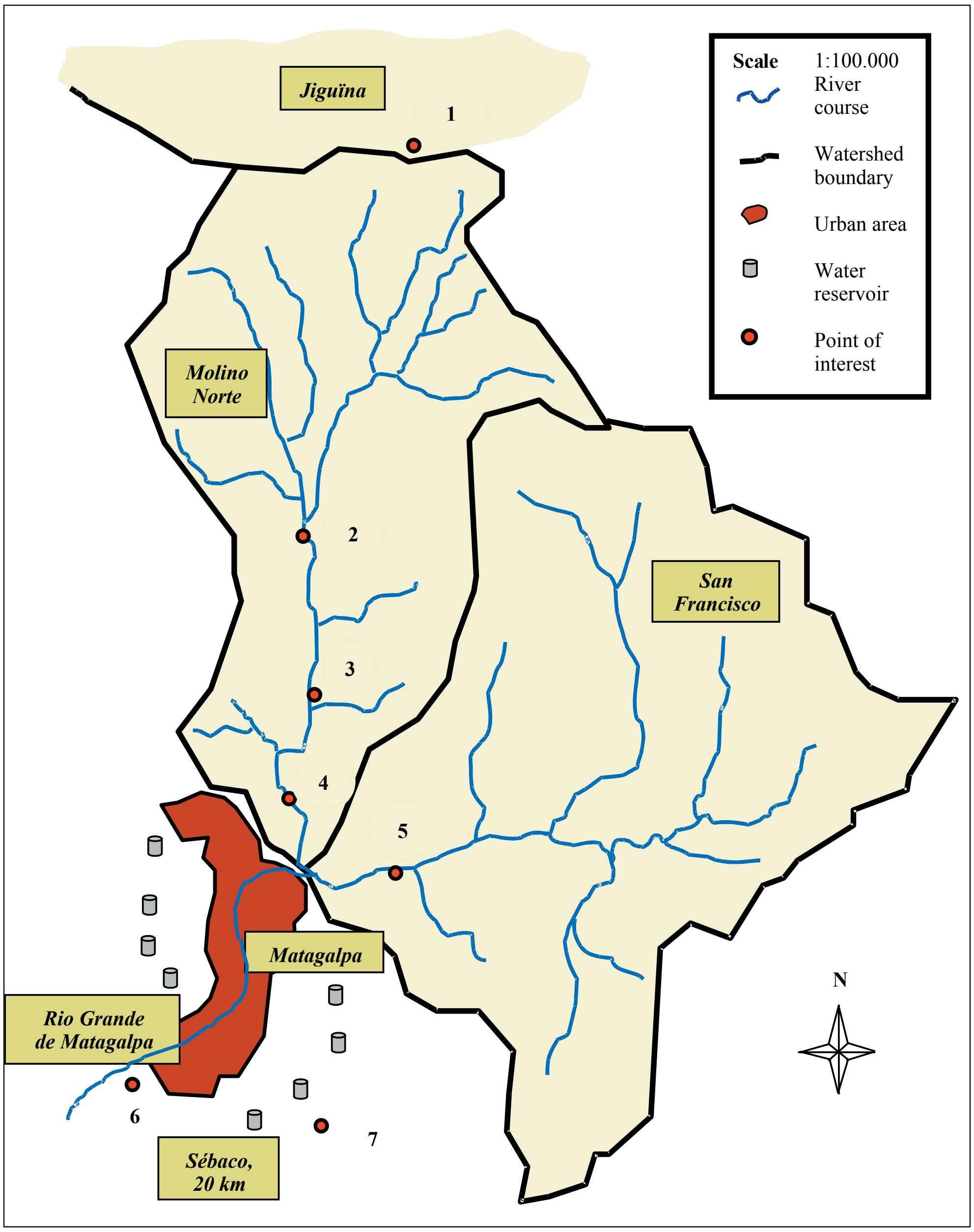
3.2 THE DRINKING WATER INTAKE

Figure 4 provides an overview of the two watersheds or the so called watersheds in which the sources of water supply and the main treatment plants are marked with red dots and indicated with numbers.

The various cuencas that supply water to the rivers Molino Norte and San Francisco are subcuencas of the Rio Grande de Matagalpa. The basins have surface areas of 22.3 and 30.0 km² (a total of 5.230 ha) and have longitudes of 8 and 7 km respectively. The area consists of slopes between 30-75% and is lying among peaks as high as 1.525 m above sea level; with the city Matagalpa lying at an altitude of 750 m above sea level.

The intake of the river Molino Norte (point 2 on map) for the supply towards the treatment plants is situated 3 km more upstream of the first, smaller treatment plant (point 3) and the water is distributed in a closed channel. The small treatment plant delivers drinking water for those houses lying above the level of the main treatment plant. Together with the main treatment plant (point 4) it accounts for 50 % of the drinking water supply of the city population. The water that is not channelled, lapses on its natural bed until arriving to the city of Matagalpa where it unites with the Rio Grande of Matagalpa.

FIGURE 4 OVERVIEW OF THE SOURCES AND TREATMENT PLANTS OF THE (DRINKING) WATER SUPPLY OF THE CITY MATAGALPA



1. Pumping station of Jiguina taking water from Aranjuez
2. Intake point in Molino Norte (main intake point)
3. Small treatment plant (for drinking water)
4. Main treatment plant (for drinking water)
5. Pumping station of San Francisco (currently out of order)
6. Wastewater Treatment Plant of the city
7. Distribution of pumped water from adjacent valley Sébaco

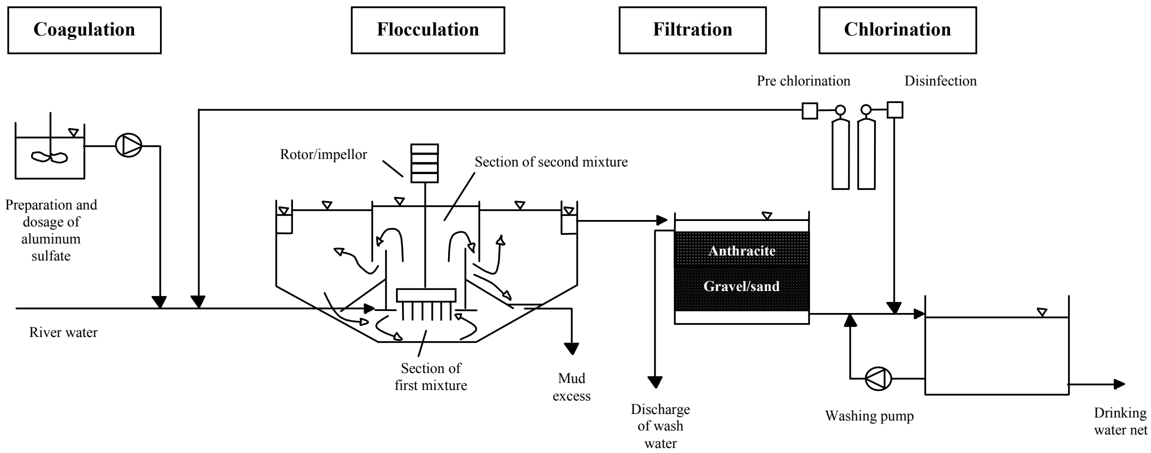
During the rainy season (May until November) the discharge of the river Molino Norte exceeds the capacity of the drinking water treatment plant of Matagalpa and it is not necessary to pump water from the river San Francisco. The pumping station in the river San Francisco (point 5) was built in 1966 to increase the water supply to the main treatment plant. It is out of order since 2 years now because of deteriorated materials. New materials are bought already but there is lack of money for the construction. It is expected that within 2 or 3 years water is pumped again from the river San Francisco to the treatment plant. In this way it contributes in the drinking water supply for about 20 to 30 % of the total of both rivers. Since September 2003 a Nicaraguan-German executed drinking water project is running which covers the other 50 % of the drinking water supply. From Sébaco, a town 20 kilometres southwest of Matagalpa, groundwater from wells is pumped and distributed the entire way to the edge of the city Matagalpa. Here the water is treated and pumped to 8 different storage tanks spread out around the city at a level of 800 m above sea level (point 7).

The dry season (December-April) is the most critical period with respect to drinking water supply due to low river discharges. During this period extra water is pumped from the river Aranjuez situated north of the Molino Norte (point 1).

3.3 DRINKING WATER TREATMENT PLANT

Figure 5 shows a process lay-out of the main drinking water treatment of Matagalpa. The water treatment is based on a combination of coagulation-flocculation with aluminium sulfate, settling, filtration and chlorination. Water from surface sources is filtered of sediments and organic matter prior to chlorination.

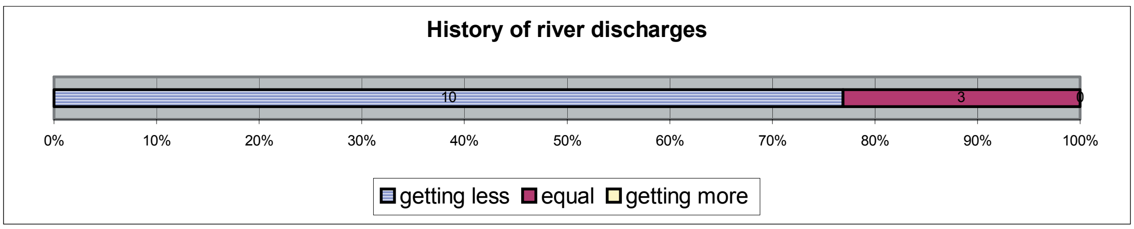
FIGURE 5 SCHEME OF THE (PHYSICAL-CHEMICAL) MAIN TREATMENT PLANT FOR THE DRINKING WATER SUPPLY OF THE CITY MATAGALPA



3.4 WATER DISCHARGES OF THE RIVERS MOLINO NORTE AND SAN FRANCISCO

Reports by Proyecto Cuencas Matagalpa (PCM) as well as some local NGO's and Novib (Dutch organisation) state that the discharges of the rivers Molino Norte and San Francisco have decreased substantially, especially during the last ten years. Also 77 % of the 13 interviewed farmers, when asked about the history of the rivers, mention a decrease of river discharges (Figure 6).

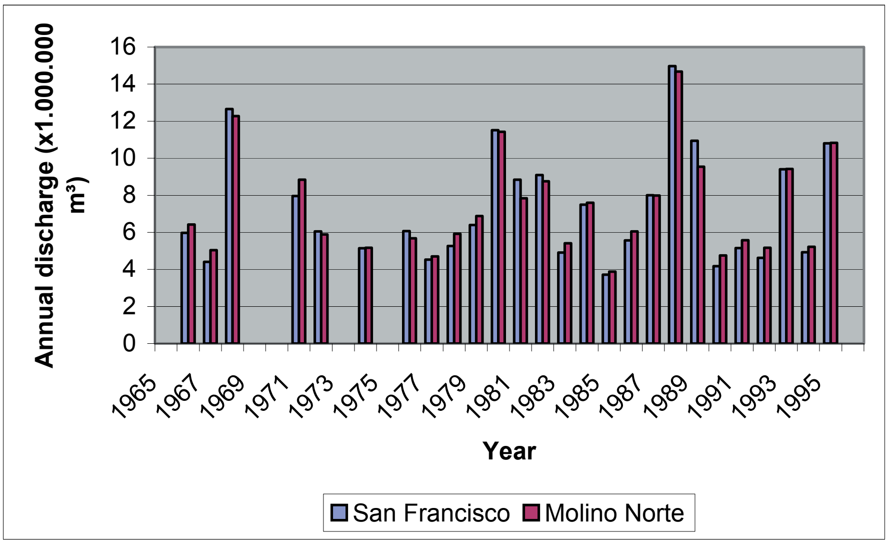
FIGURE 6 FARMERS' PERCEPTIONS ON THE HISTORY OF THE DISCHARGES OF MOLINO NORTE AND SAN FRANCISCO (INTERVIEWS CONDUCTED IN THE DRY SEASON)



There are little figures available to confirm this decrease of river discharges and the ones available do not directly implicate such a drastic decrease. Figure 7 shows a study carried out by the German GWK-consult. The study was conducted as preparatory work before the so-called ‘Sébaco-project’ that led to the transport of extra drinking water from the valley of Sébaco to the city Matagalpa during critical periods. No historical discharge measurements were available for the two watersheds. Therefore, a model was used in which storm rainfall and all other rainfall events, soil type, land use and wet/dry conditions were incorporated (SCS-method) to calculate the river discharges.

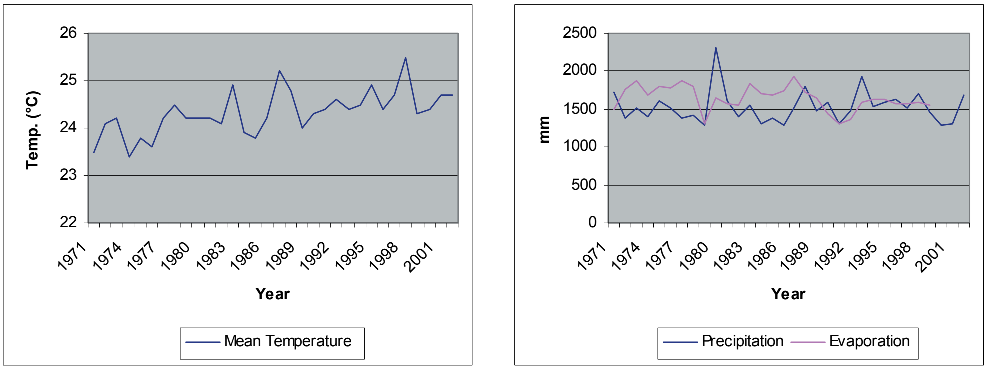
No sufficient data were available for the years ’65, ’69, ’70, ’73, ’75 and’96 and also the last eight years are missing. It is visible that the discharges of the two rivers are pretty much similar whereas in practice the river San Francisco has a higher discharge than the Moline Norte. This probably has to do with the shortcomings of the method used for the discharge calculations. But the conclusion to be drawn from this graph is that no clear trend of the river discharges over the period 1966-1995 can be identified.

FIGURE 7 ANNUAL DISCHARGES OF THE RIVERS SAN FRANCISCO AND MOLINO NORTE (GWK, 1997)



To get more insight in the river discharges over the last ten years meteorological data were collected from the Nicaraguan Institute of Territorial Research in Managua (INETER). The whether station in Muy Muy, 30 kilometres southeast of Matagalpa, is the only station that lies relatively close to the study area and has up-to-date figures. Although the microclimate determined by specific local conditions in this particular place can differ significantly from that in the two cuencas, trends in temperature, precipitation and evaporation will be used in this case.

FIGURE 8 MEAN TEMPERATURE (LEFT PICTURE) AND PRECIPITATION AND EVAPORATION IN MUY MUY (INETER, 2004)



After interpretation of the data, there is a trend of increase in the mean temperature in the period between 1971-2003 (Figure 8, left). This however did not lead to a change in the evaporation curve in Figure 8, right, that shows no in- or decrease. This is also the case for the precipitation curve that stays around an average of more than 1500 mm per year.

Although the various sources mention a decrease of river discharges in the study area, this cannot be verified by the available data on this subject. Questions can be asked on the reliability of the collected data, the method used for discharge calculation or on the operational whether station. But maybe the perception of the 'respondents' of diminishing discharges is wrong and that it actually fits in with the changeable character the river discharges have in this area. Another point related to the perception of decreasing water might be the decreasing water availability per capita that is due to the increasing population size of the city.

In many cases the vast deforestation of the last decade is indicated as the cause of the assumed decrease of river discharge. Theoretically, deforestation creates peak discharges (maximums as well as minimums) as it will results in a decrease of the water holding capacity of the soil. This means higher discharges during the rainy season (more run-off) and less discharge during the dry season (lower groundwater table). But also in this case, after the interpretation of the peak discharges (period 1966-1995), the figures cannot proof this phenomenon (see Annex C). Still, it cannot be denied that land use and especially forestry, plays a crucial role in respect to water quantity and water quality. As a response, reforestation programs (PCM, MAGFOR), working with more than 22 different tree species, are set up alongside projects working on the diminishing of tree cutting. Examples of the latter are the briquetadora, the production of fuel alternatives from rice or coffee chaffs, the improvement of efficiency of kitchen stoves and biogestores for the production of methane gas out of manure.

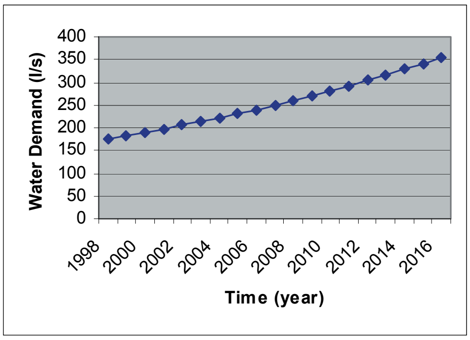
3.5 WATER AVAILABILITY

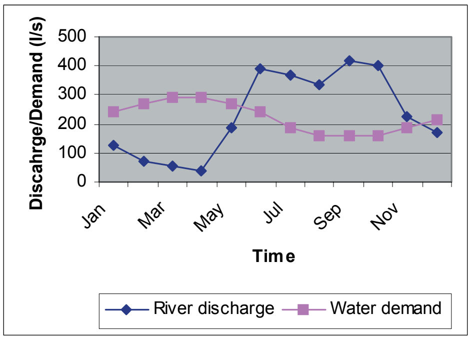
It is difficult to find the exact figures of the population size of the city Matagalpa. Very often official figure used for statistics by the government are not up to date. For this study the assumption is made that the city Matagalpa counts a population of 160,000, which is used by local authorities and is a mean value of all figures found.
Studies that have been carried out in the demographic field have the limitations that they are studies of big territorial and administrative clusters (economic regions, geographical regions and departments) and very few studies on the population at local level have been executed.

As mentioned earlier, population size and population growth are the driving forces determining water demand. Figure 9, left picture, is based on a population of 160,000 in the city Matagalpa and daily consumption of 120 litres (PCM, 2004) per person per day. This means that in the year 2004 a total water supply of 222 l/s was needed. The curve of the figure is caused by the population growth rate of 4 % (PCM, 2004).

Before the implementation of the 'Sébaco-project' in 2003, the people from the city Matagalpa were dependent on the river discharges of Molino Norte and San Francisco and the capacity of the drinking water treatment plant for their drinking water supply. As can be seen in the Figure 9, right picture, there was a shortage of drinking water during the months of January till May. The consequence for the population of Matagalpa was a drinking water supply of only two to three times per week. People were forced to collect water in e.g. barrels as means of reservoirs in order to have access to water during days without water supply.

FIGURE 9 DRINKING WATER DEMAND OF THE CITY MATAGALPA OVER TIME (LEFT) AND COMPARISON BETWEEN THE AVERAGE RIVER DISCHARGE OF MOLINO NORTE AND THE DRINKING WATER DEMAND OF MATAGALPA FOR 2003 (RIGHT)



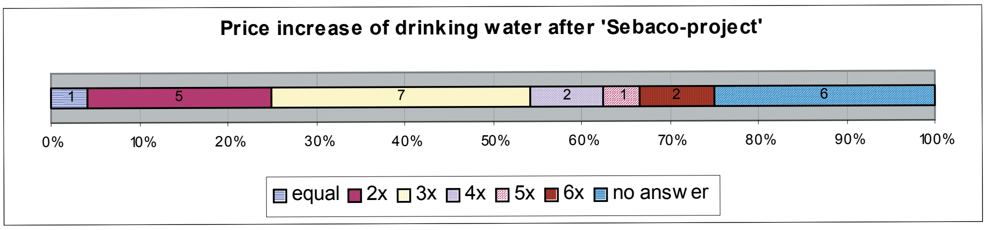


As a first response to this situation (shortage of drinking water and a still increasing population), a pumping station was constructed in the neighbouring water shed with a capacity to pump 50 l/s in the river Molino Norte of which 37 l/s reach the drinking water treatment plant. It only operates during the most critical months (January-May) and the amount of water pumped varies with the local climatic conditions (e.g. more rainfall, less water pumped). During the rainy season, the discharge of the river Molino Norte rises above the capacity of the drinking water treatment plant, and it is not necessary to pump extra water towards this plant.

A second response came in September 2003 as the Nicaraguan-German executed drinking water project (US $ 30 million) was implemented. Groundwater is pumped-up and transported over 20 kilometres to a distribution point just outside Matagalpa. In the dry season Sébaco accounts for almost 50% of the total drinking water supply of the city Matagalpa, namely 115 l/s. During the wet season the discharge from this pumping station is 70 l/s which is about 35%.

As a consequence of these supplementary drinking water supplies, the houses connected to drinking water system, have now access to drinking water during 7 days a week with some exceptions during the dry season. The measures have led to increasing costs. This price increase is also a result from the fact that the World Bank invested in this project under the precondition that there should be return of money. Before, the citizens of Matagalpa paid a fixed price per month for their drinking water whereas now they pay per volume consumed with a minimum sum per month. On average this resulted in an increase of the monthly costs of about 3 to 4 times (Figure 10).

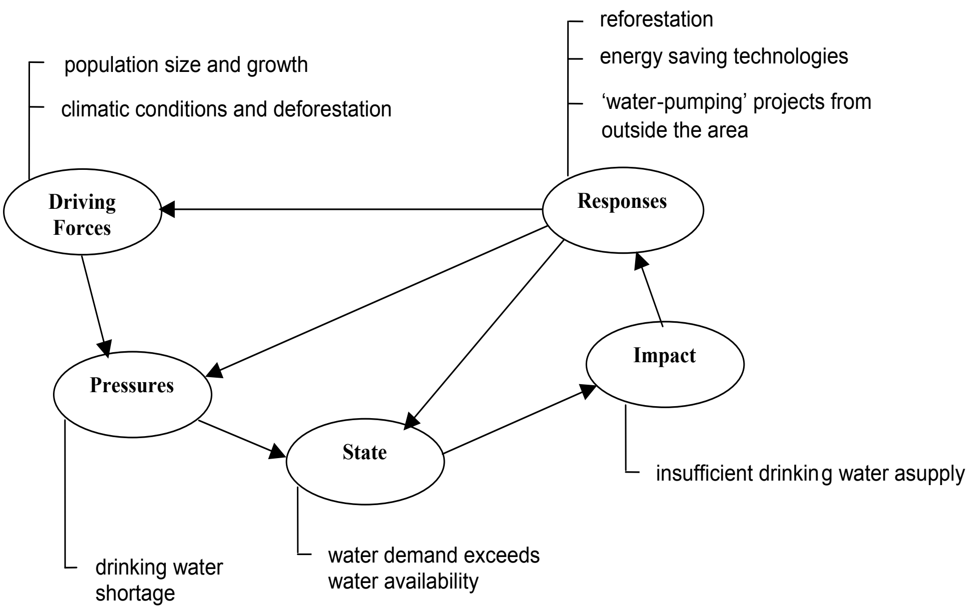
FIGURE 10 PRICE INCREASE OF DRINKING WATER AFTER THE IMPLEMENTATION OF THE 'SÉBACO-PROJECT' ACCORDING TO 24 INTERVIEWED RESIDENTS OF THE CITY MATAGALPA



3.6 DPSIR-ANALYSIS AND DISCUSSION

What can be concluded when using the DPSIR-analysis (Figure 11) on the water quantity aspect of the study area is that the supposed climatic conditions and deforestation (although hard proof is missing), together with the population size and growth, form the driving forces that create a pressure on the functions and uses of the water system. This becomes visible when the state of the water quantity issue is expressed in water availability and water demand (before the 'Sébaco-project'), which shows us a demand that exceeds the water availability of the river Molino Norte. The impact this has on the population of Matagalpa is a drinking water supply of only two days a week. Responses came in the form of projects which developed possibilities to pump water from outside areas towards the city Matagalpa to assure a sufficient drinking water supply.

FIGURE 11 SCHEMATIC OVERVIEW OF A DPSIR-ANALYSIS ON THE DRINKING WATER AVAILABILITY



In this way the actual situation is a new one where new driving forces will put a pressure on this actual state that will result in new impacts and responses can be expected. For the moment it appear that there is a sufficient drinking water supply with the new 'water pumping' projects expressed in a '7-days-per-week-service'. The discussion when talking about future scenarios is whether the responses in the form of these water quantity projects together with reforestation and energy saving technology programmes keep pace with the water demand of the growing city Matagalpa.

A critical question can be put here whether this 'Sébaco-project' is a long-term solution. It is a fact that from the valley of Sébaco already two other pumping stations are built for extraction of groundwater for other 'nearby' villages. Undoubtedly, this will have its impact on the groundwater table in the valley where in addition the water-demanding crop rice is grown as a main agricultural activity.

4

TRENDS IN THE RIVER AND DRINKING WATER QUALITY

4.1 INTRODUCTION

As stated in the problem definition, an important problem of the city Matagalpa is the bad quality of the river water, which has its impact on the drinking water quality. In this chapter a closer look will be taken on the water use activities that influence the river water quality. By uantifying the quality of the water system in terms of physical and chemical characteristics, the actual state of the water system becomes clear. It can be expected that poor quality water has its effect on (the biodiversity of) the ecosystem but the main focus in this study is on its impact on the quality of the drinking water supply of the city Matagalpa. Interviews conducted with residents of the city Matagalpa provide supplementary information on the drinking water quality.

4.2 WASTEWATER PRODUCTION AT COFFEE PLANTATIONS

COFFEE PLANTATIONS

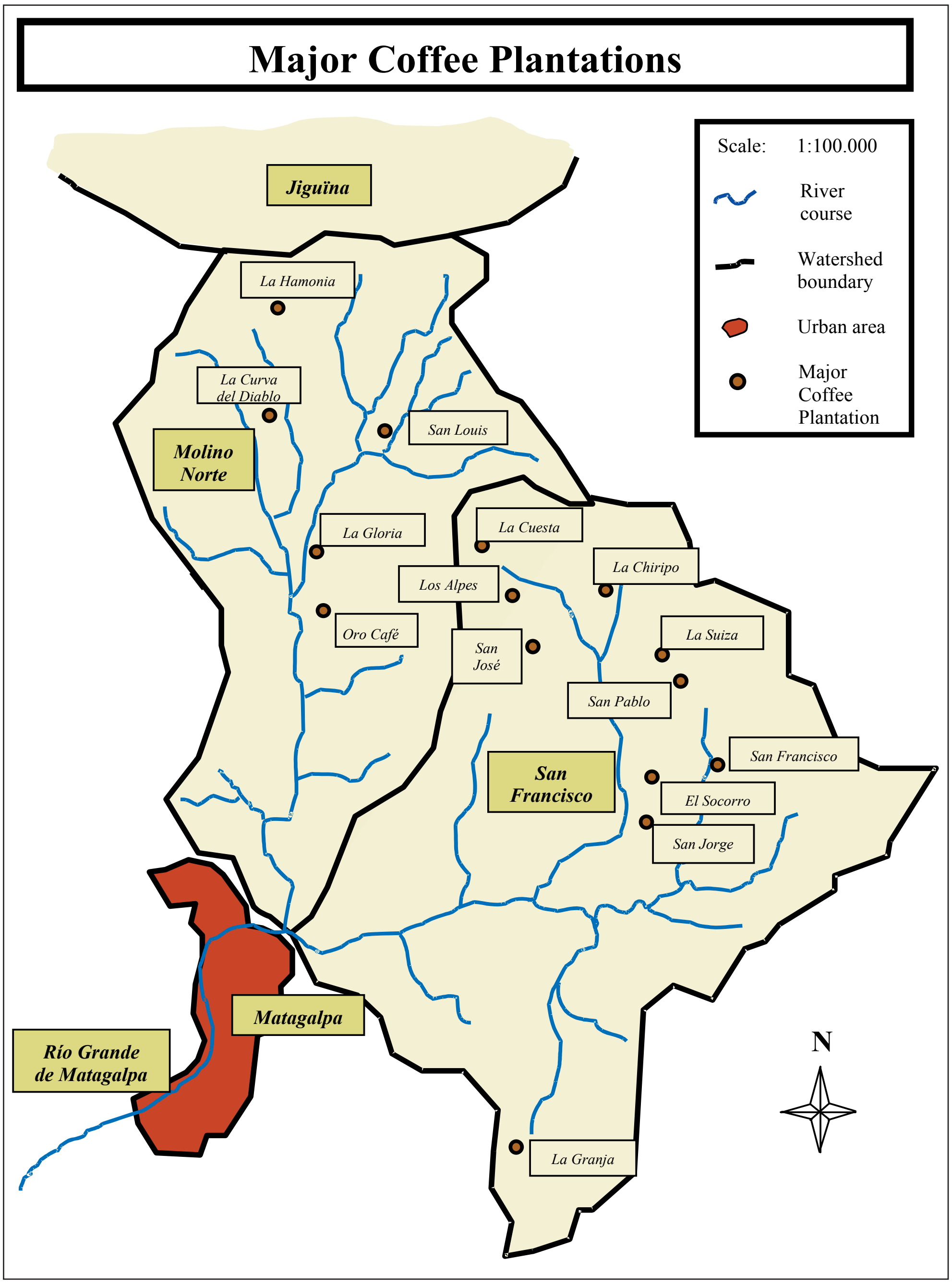
In the two watersheds Molino Norte and San Francisco there are a total of 138 farmers of which the cattle farmers together with the coffee farmers take the main position in terms of area. Table 2 provides an overview of the different land uses and their percentages of the total area. These figures are from a detailed research conducted by PCM in 1998. The area of coffee production has probably increased in the last years. Also pasture has increased, both at the cost of the forest area.

TABLE 2 **LAND USE IN THE TWO WATERSHEDS (PCM, 1998)**

Land use	Area
Coffee production	19.7 %
New coffee plants	5.3 %
Vegetables	1.6 %
Corn	1.5 %
Beans	0.6 %
Pasture	30.6 %
Fruit trees	0.6 %
Forest	25.7 %
Reforestation	3.0 %
Total cultivated area	91.6 %
Total area	100 %

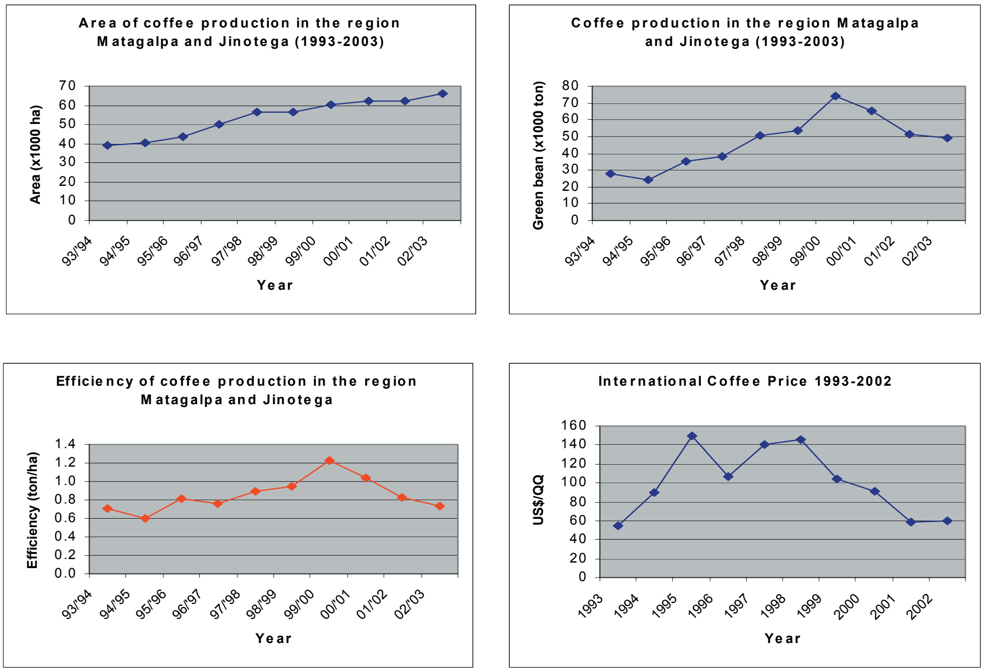
There are 63 coffee farmers in the study area of which most combine coffee cultivation with other land uses. Among the 63 coffee farms, 15 larger coffee plantations are responsible for 95 % percent of the total coffee production in this area. Their locations are shown in Figure 12.

FIGURE 12 THE 15 MAJOR COFFEE PLANTATIONS IN THE WATERSHEDS MOLINO NORTE AND SAN FRANCISCO



As is shown in Figure 13, the area of coffee production in the Matagalpa and Jinotega region increased from 1993 to 2003 onwards. In the same period, the coffee production has a maximum in the harvest period of 1999/2000 and decreases after this year.

FIGURE 13 CLOCKWISE: AREA OF COFFEE PRODUCTION, COFFEE PRODUCTION, EFFICIENCY AND INTERNATIONAL COFFEE PRICE



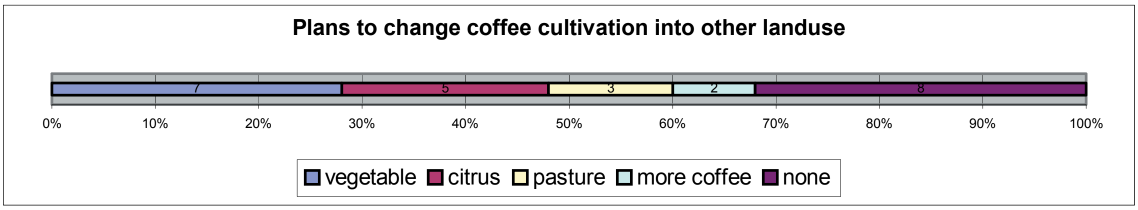
Based on the coffee production area and the total coffee production, the efficiency in ton green bean produced per hectare can be calculated. It is visible that the efficiency drops after the year 2000. This behaviour is consequence from the lack of maintenance works at the coffee plantations due to low coffee prices in the last years.

The present analysis considers a period of ten productive cycles, and it is observed that the behaviour of the coffee production curve can be subdivided in two segments: the first segment includes the agricultural cycles 1993/94 till 1999/00, in which we can see that the production behaves in an upward way, reaching its maximum of 70.000 ton green beans. In the second segment of the curve that includes the cycles 2000/01 till 2002/03, it is registered that the production diminishes in a sensitive way, until a production of 50,000 ton green beans in the last cycle. The above-mentioned is explained mainly by the quick descent observed in the international coffee prices starting from the year 1999; this in its turn resulted in difficulties for the farmers to meet in their bank obligations and at the same time they are not able to carry out the required maintenance works at a appropriate level.

During interviews with coffee farmers 60% of the farmers said, asking them about their future plans in terms of crop cultivation, that they have plans to change from coffee cultivation into growing either vegetables or citrus (or a combination) or to have cattle and thus change their land into pasture (Figure 14). 32 % is not thinking about changes and 8 % mention an increase of their coffee production area. This is, in the perspective of the declining international coffee price of the last of the last 5 years, somewhat surprising. Reasons behind these ideas can be the lack of investment capability to change their land use in combination of trust in the future and hoping for an increasing coffee price to come. Besides, being traditionally a coffee farmer for many generations, it is not an easy task to make a switch in your agricultural activity, or as stated by PCM: 'once a coffee farmer, always a coffee farmer'. It must be emphasized that these are just ideas and no concrete plans yet. Very much will depend on how the international coffee price will develop in the coming years.

[6] These two departments produce 80% of the coffee of Nicaragua.

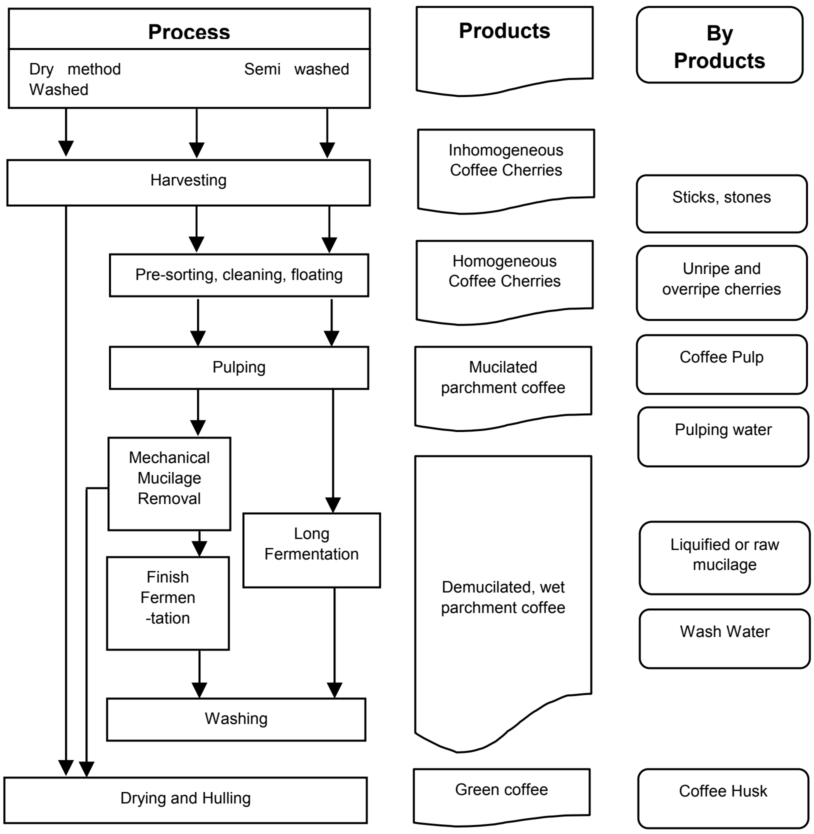
FIGURE 14 IDEAS OF THE INTERVIEWED FARMERS ABOUT THEIR FUTURE PLANS WITH REGARD TO THEIR LANDUSE



COMPOSITION OF COFFEE WASTEWATER

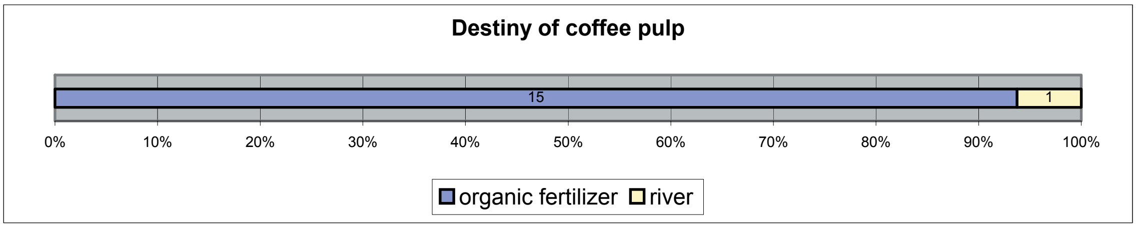
As already explained in chapter 1.2, the wet processing of coffee beans occurs in three stages. In the first step, the outer skin of the coffee fruit (known as 'pulp') is removed with the aid of water in a 'pulper'. This produces pulp wastewater as well as a humid solid waste, which is the pulp. In the second step, mucilage (a slime layer which surrounds the coffee bean) is removed by a fermentation process. The wastewater formed by draining off the spent liquor of the fermentation process is known as the fermentation water. Finally, the beans are rinsed in a channel forming the wash wastewater (Figure 15).

FIGURE 15 COFFEE PROCESSING METHODS (VON ENDEN, CALVERT, 2002)



The pulp that is produced at most of the coffee plantations near Matagalpa separated and used as organic fertilizer (Figure 16). This is a significant improvement compared the situation some years ago, when most of the pulp was dumped into the rivers.

FIGURE 16 DESTINY OF COFFEE PULP. DATA DERIVED FROM INTERVIEWED FARMERS



The coffee wastewater or so-called aguas mieles that is produced at the plantations consists of fermentation liquor diluted with wash water. It is currently the main environmental pollutant of the coffee plantations. The concentration of organic material in this stream is very high and it is very acidic (pH below 4). The values for BOD and COD that indicate the amount of oxygen needed to break down organic matter in coffee wastewater are high, and are usually in the range of 5,000 – 8,000 mg/l.

Nitrogen, phosphorus and potassium (N, P and K) are the most important (macro)nutrients which can be found in the coffee wastewater. De Matos (2000) reports concentrations of N, P and K in the range of 186 to 246; 5 to 7 and 44 to 346 mg/l respectively.

The main pollution in coffee wastewater consists of the organic matter that is released during the fermentation, particularly the mucilage layer surrounding the beans. The mucilage contains mainly proteins, sugars and pectins. A large part of the organic pollutants is present as suspended solids that can be settled and partially precipitate due to the low pH. If not separated from the wastewater, this crust will quickly clog up waterways and further contribute to anaerobic conditions in the waterways.

The remaining organic fraction contains a large fraction of biodegradable COD but also highly resistant compounds such as flavanoid color compounds from coffee cherries. At a pH of 7 and highter, flavanoids cause a dark green to black color staining rivers downstream from coffee factories. Flavanoids are not harmful to the environment. Other substances to be found in coffee wastewater are tannins, alkaloids (caffeine) and polyphenols.

It must be said that the given values of BOD and COD are not fixed. Different literature sources give a wide range of BOD and COD values of coffee wastewater as. This is also the case with the concentrations of the macronutrients Nitrogen (N), Phosphorus (P) and Potassium (K) that can be found in the wastewater. Very much depends on the management of the farmer for processing the coffee cherries. Also the amount of water used for the processing and whether or water is re-circulated play an important role in this case.

WASTEWATER TREATMENT SYSTEMS AT COFFEE FARMS

The combination of high acidity, high COD and high nutrient concentrations in coffee wastewater pose a large environmental pressure of the rivers when discharged untreated. The Ministry of Environment and Natural Resources (MARENA) has set an effluent standard for the discharge of coffee wastewater into the water streams, which has led to wastewater treatment measures at many farms. The COD should be reduced to less than 200 mg/l according to these laws.

So-called pilas, holes in the ground, are constructed at the majority of the coffee farms in which the aguas mieles are collected. This relatively cheap construction has the function to infiltrate and / or evaporate the wastewater. Lime is frequently added to increase the pH and to reduce smell. Although dissolved organic materials might still reach the groundwater and finally the river stream, it results in a reduction of COD that is discharged to the river. During field visits it became clear that many pilas have no sufficient capacity during the peak period of the coffee processing. Many systems are also clogged due to a combination of a poorly infiltrating soil and clogging soil pores due to the high organics concentration. This means that, although forbidden, still coffee wastewaters are discharged without treatment in the rivers. This is confirmed by Proyecto Cuencas Matagalpa that also indicates the lack of personnel at MARENA to carry out adequate controls as a major bottlenec.

In this area the Upflow Anaerobic Sludge Blanket (UASB) biogas reactor has been introduced at six larger coffee plantations of which four are currently functioning. The UASB is a very feasible option considering the higher temperatures and the ability of the system to deal with the irregular discharge of wastewater (only during the coffee campaign). There are many examples of UASBs treating coffee wastewater in other regions. In addition of an effective treatment of the wastewater (70-90% COD reduction, Annex F), biogas (methane) is produced, which by-product can be and is used as a fuel. During the harvest season, many laborers (at big farms up to 700 people) have their warm meals, heated with the help of this biogas.

Proper operation of the UASB bioreactor is needed in order to cultivate and maintain a healthy population of bacteria that are responsible for the wastewater treatment. Experience has shown that when left to the coffee farmers the reactors do not receive the proper attention. It is difficult for coffee farmers to monitor important parameters such as COD, VFA, alkalinity, pH and wastewater flow. Moreover, coffee production itself has the highest priority. A reported difficulty in operation is the rather high use of NaOH, which is a major cost factor. The replacement of NaOH by cheaper lime is not possible because of the formation of larger aggregates ('biobricks') that has a large effect on the bacterial activity and the performance of the system.

In order to overcome these various logistical problems PCM has a support organization that sends technicians out to the coffee farms to help with the operation of the reactors. The technicians collect samples from the anaerobic reactors and monitor the flow of the wastewater. The samples are processed in a central laboratory and wastewater engineers evaluate the results. Based on the lab test results, recommendations for the operation are made.

INSTALLATION OF UASB BIOREACTORS

In 1986 a project called 'Biogas and use of agricultural waste-products' was initiated with the goal to promote the use of wastes from agriculture and cattle as alternative energy sources to reduce the consumption of fuel woods and so six UASB-bioreactors were built. In 1987 the possibility to adapt this technology to treat wastewaters of the wet coffee process was explored. The technical feasibility to use an anaerobic treatment for the aguas mieles was tested in a laboratory and in a pilot project. This resulted in a proposal towards Novib with the goal to use bioreactors for the treatment of coffee wastewaters.The project consisted of the development of the UASB technology and in the period between 1988-94 four UAS's were constructed and installed at coffee plantation with a harvest from 16 to 184 tons of green beans per year. Since then two more coffee farmers have installed a UASB bioreactor (PCM, 1994; 2004).

'LA HAMMONIA'

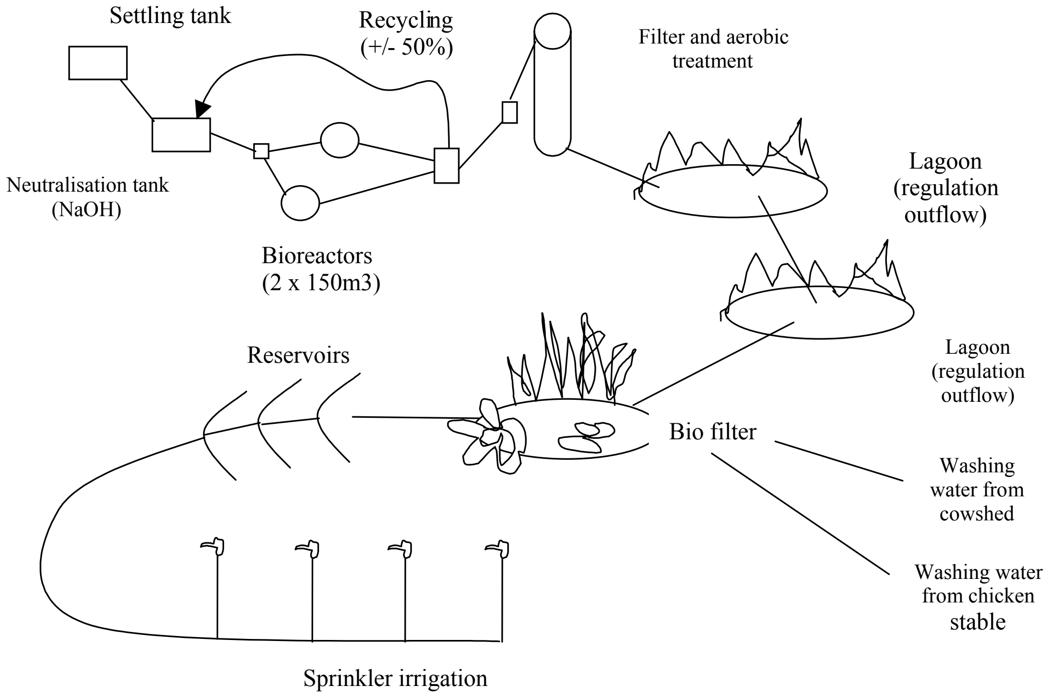
Figure 17 provides an overview of the water treatment and reuse system at the plantation 'La Hammonia'. it is an interesting example of an integrated treatment process.

At the beginning of the treatment chain, the suspended solids are removed by sedimen/ tation and used as organic fertilizer. In a second reservoir, NaOH is added to neutralise the wastewater to a pH of 6-7, which is necessary for an optimal operation of the bacteria inside the (anaerobic) bioreactors. A regulator determines the inflow of the two anaerobic reactors and varies between 5 to 10 l/s per reactor. After the two reactors a pump is installed that recycles the treated water partially back to the neutralisation tank. In this way, less NaOH is needed for lowering the pH and thus operation costs are reduced. The use of NaOH is the major operating cost of the whole chain. Around 50% of the water is recycled, depending on the pH of the incoming wastewaters.

After anaerobic treatment, filtering and an aerobic treatment take place. Subsequently, the water is led into two lagoons, which function is to regulate the outflow, depending on the discharge of the irrigation system at the end of the chain. Pasture (9 ha) is irrigated by a sprinkler system during the months December-April. Before the water is used for irrigation, it is once more treated by a bio-filter, a lagoon with shallow water plants where oxidation takes place. Also the washing water from the cowshed, from the chicken stable and wastewater of the slaughterhouse are led to this bio filter for treatment (an extra of approximately 1000 l/ d). From there the water is distributed by gravity again to three smaller reservoirs from where it leaves to three different sides by tubes for irrigation purposes. After three years of trials and errors, this is the first year (2004) the whole chain functions well. The water is treated in such a way that is can be used very well for irrigation and any discharge of wastewater to the river is avoided.

The exceptionality of the 'Hammonia-case' should be emphasized. The fifth generation German owners of this large plantation have expanded the location to what is more than just a coffee plantation. Besides coffee, cattle and chickens are held, as well as greenhouses where flowers are grown. La Hammonia lies in a beautiful natural setting close to a protected native forest and they have been able to set up hotel and a restaurant where among others their own products are served. This all means that they have more capital available for making investments. Besides treating wastewaters, their natural treatment system fits in their ecological philosophy of which the attraction of tourist is one of the spin-offs.

FIGURE 17 OVERVIEW OF THE WATER TREATMENTS AND REUSE SYSTEM AT THE PLANTATION 'LA HAMMONIA'



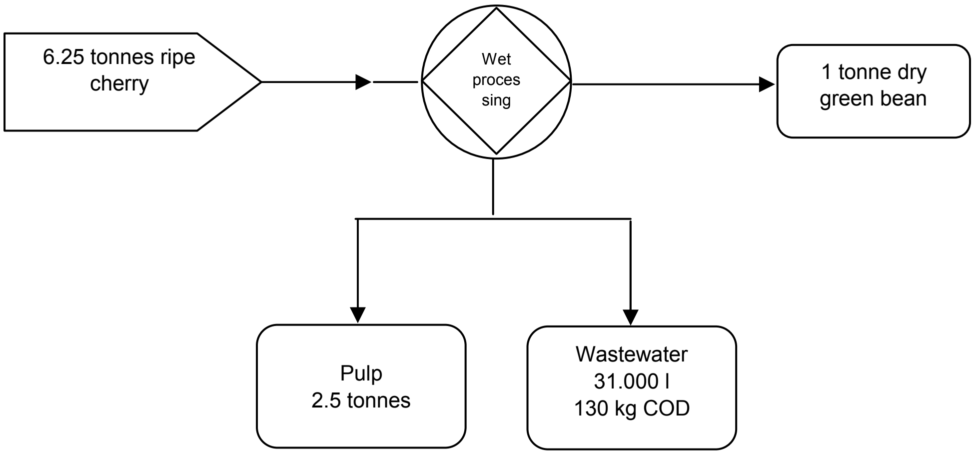
4.3 QUANTIFICATION OF WATER POLLUTION BY COFFEE WASTEWATERS

The discharge of coffee wastewater puts a large pressure on a water system. Due to the high concentrations, the loads of oxygen consuming compounds and nutrients might be high. Moreover, coffee wastewater is very acidic and contains various groups of recalcitrant components. Ultimately the pollution cause by coffee wastewater can affect the drinking water quality of the city Matagalpa.

In this paragraph a rough calculation is made to assess the effects of the coffee waste/water discharge on the river quality with respect to COD. The pulp produced during the coffee process (depulping) is left out of the calculations, because nowadays farmers are keeping it separate and use it as organic fertilizer.

The total coffee production in the watershed Molino Norte in 2004 (by extrapolating the production figures of 1998 (PCM)) is 640 ton green beans and in the water shed San Francisco 990 ton green beans per year. For the calculation of the COD load of the total wastewater, it is assumed that the depulping and washing process of 1 ton (= 1000 kg) green bean produces 31 m^3 wastewater (and 130 kg COD (Figure 18). This means a coffee wastewater production in these two watersheds of 19.840 and 30.690 m^3 respectively von Enden and Calvert, 2002 and Field, 1990). These figures should be seen as an indication, since the literature provides a wide range of wastewater production and concentrations values.

FIGURE 18 ASS BALANCE COFFEE PROCESSING (VON ENDEN AND CALVERT, 2002 AND FIELD, 1990)



The coffee-harvesting period coincides with the dry season when river discharges are lowest. This means that the wastewater discharge has a rather large impact on the quality of the river water. The two months of the highest production during the four months of harvesting are taken for the calculation of the water use per day.

Table 3 shows the calculated COD load to the water sheds Moline Norte and San Fransisco without treatment and with 50% of treatment. The (rough) assumption of 50% of treatment is based on the observations in the field. As described earlier most coffee plantations have some form of treatment through soil infiltration (pillas) or in some cases a UASB reactor. The self-purification effect of the rivers is not taken into account in this calculation and therefore the figures represent the estimated extra COD load at the discharge point. However, the main in-take point of the drinking water in the Moline Norte is lying rather close to a number of large coffee plantations.

This estimation in table 3 shows that the impact of wastewater discharge is high. Without treatment 300-400 g COD / m³ is added to the river water. With 50% treatment this is 150-300 g COD / m³.

TABLE 3 CALCULATED COD LOAD TO THE WATER SHEDS MOLINE NORTE AND SAN FRANSISCO CALCULATED WITHOUT TREATMENT AND WITH 50% OF TREATMENT

Water shed	Minimum discharge of river *	Coffee production	Water use for coffee processing	COD production	COD of coffee wastewater	Extra COD in river water without treatment	Extra COD in river water with 50% treatment
	(m³/day)	(ton green beans)	(m³/day)	(kg/d)	(g / m³)	(g / m³)	(g / m³)
Molino Norte	3200	640	332	1391	4200	395	195
San Francisco	6400	990	511	2140	4200	290	155

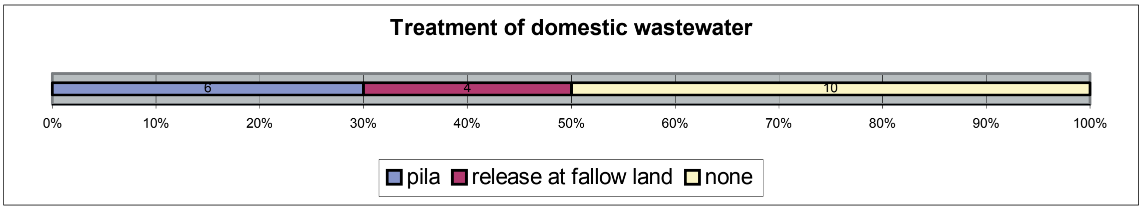
*Minimum discharge during harvesting season

4.4 OTHER SOURCES OF RIVER POLLUTION

DOMESTIC WASTEWATER IN THE RURAL AREA

The rural population along the watersheds Molino Norte and San Francisco counts 1550 and 2300 people, respectively. This number increases with 65 % during the coffee harvest season when labourers are attracted to these watersheds for employment in the coffee sector (calculation based on figures from Jarquin, 1997). Most houses in the rural area of the two water/sheds are not connected to a central sewer system. Domestic wastewaters in the rural area are mostly discharged without any kind of treatment (Figure 19).

FIGURE 19 TREATMENT OF DOMESTIC WASTEWATER ACCORDING TO INTERVIEWED FARMERS



Many latrine projects have been initiated in order to avoid a direct discharge of human excrement into the river streams. In practice it is noticed that not many people make use of these latrines. Since generations people have the custom to do their stool in the open field. Many people find it unhygienic to go to a toilet that is used by many others. Point here is that the concentration of rural people is highest around coffee plantations with a maximum during the harvest season when extra labour is needed and people settled near the coffee farms.

What can be expected and which also is the experience at the drinking water treatment plant, is a high concentration of coliform bacteria at the beginning of the rainy season (starting in May) when heavy rains wash away the human and animal excrements from the fields. Environmental specialists from Finland together with the local university (UNAN) have conducted several water quality analyses in January 2002. The contents of bacteria (see Table 4) indicate that the superficial waters of the river basins *Aranjuez*, *Molino Norte* and *San Francisco* are contaminated with domestic wastewater.

These samples are taken in the month January whereas the highest amounts of faecal bacteria in the river water can be expected at the start of the rainy season (May) when heavy rainstorms wash away all excrements into the rivers. According to WHO standards concerning pathogenic micro organisms, less then 1,000 faecal coliform/100 ml are allowed for irrigation practices (depending on type of crop grown (crops likely to be eaten uncooked versus e.g. cereal crops) and type of irrigation (e.g. less direct contact with drip irrigation)). For drinking water faecal coliforms should be absent in order to avoid health hazards.

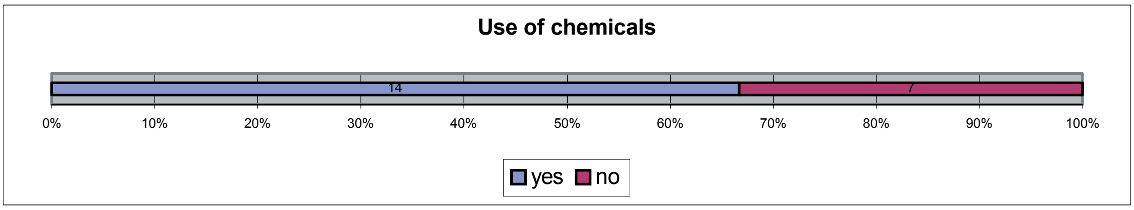
TABLE 4 QUANTITIES OF COLIFORM BACTERIA AND OF FAECAL COLIFORM BACTERIA OF TWO SAMPLES OF WELLS AND EIGHT SAMPLES OF RIVER BASINS IN MATAGALPA. SAMPLES TAKEN IN JANUARY 2002 (YKL-UNAN, 2002)

Sample Point	Quantity of coliform bacteria /100 ml	Quantity of faecal coliform bacteria /100 ml
1. Los Lipes, well	8	2
2. La Cortuja, well	<2.2	<2.2
3. Aranjuez, reservoir (supply source)	9,000	1,700
4. Rio San Fernando	390	90
7. Rio El Ocote	5,000	170
9. Rio San Francisco, lower course	700	60
10.Rio Molino Norte	30,000	20
12.Rio Selva Negra	16,000	20
13.Rio San Pablo, La Suiza	160,000	24,000
14.Rio San Francisco, upper course	3,000	20

PESTICIDES USE IN AGRICULTURE

In the cultivation area of Matagalpa high quantities of pesticides are used, among others in the coffee, fern and flower sector. By asking farmers about the use of chemicals, 66 % of them confirm the use of some sort of chemical at their farm (Figure 20). The main reason for those farmers who do not use chemicals is the lack of money to buy them.

FIGURE 20 RESPONSES OF INTERVIEWED FARMERS ON THE QUESTIONS WHETHER THEY USE CHEMICALS



An important diffuse source of pollution is the pesticide use in the cultivation of various crops. This is especially the case in the area near the river Aranjuez in the neighbouring *cuenca* from where extra water is pumped during the critical months. In this area ferns for the export are grown which crop requires a lot of pesticides. Although there are concerns on this source of pollution, and particularly the one coming from the fern sector, the fern production-area is still increasing. This has to do with the fact that the fern export is a very lucrative business and the largest farmer in this sector has political power and is protecting this business.

FIGURE 21 FERN NURSERY (PICTURE: JOOST JACOBI, 2004)

Pesticide residues like sulphates of metabolic endosulphate (a pesticide) were identified in a sample of sediments from a stream that runs through a cabbage field like as well as in the samples of the superficial soil and underground of the area where flowers are cultivated. In the superficial part of the cultivation of flowers there was also 0,09 mg/kg of indecomposable endosulphate. Near a coffee plantation in *Molino Norte* (point 10) DDT was found, something that indicates that it has been used recently. There were also endosulphate metabolites found in one of San Francisco's coffee plantations. The exact quantities of endosulphate could not be determined with the methods used, and therefore these quantities can vary a lot in those places where the residuals were found (YKL-UNAN, 2002).

OTHER SOURCES

Other point sources of pollutions in the area, besides the coffee pulp and the *aguas mieles*, are the wash waters from the milk houses and from livestock housing which contains excrements of the cattle and thus coliform bacteria.

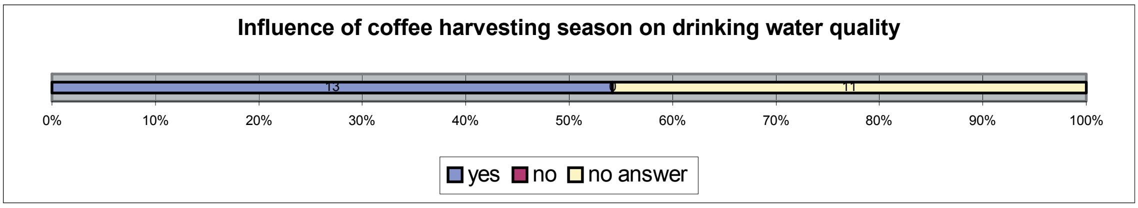
4.5 IMPACTS ON THE DRINKING WATER QUALITY

COFFEE WASTEWATERS

Considering the fact that the main drinking water treatment plant (Figure 5) is based on physical-chemical techniques it can be expected that the high COD that is present in the river water during the coffee season cannot completely be removed. As such the coffee wastewater is affecting the drinking water quality. Because of many uncertainties it is difficult to quantify, but the outcomes indicate a large effect. Especially dissolved BOD and COD will remain, including possibly inert dissolved compounds such as flavonoids, tannins, tannins, alkaloids and polyphenols. This poses risks for regrowth of bacteria in the drinking water net and the production of chlorinated hydrocarbons during the disinfection step.

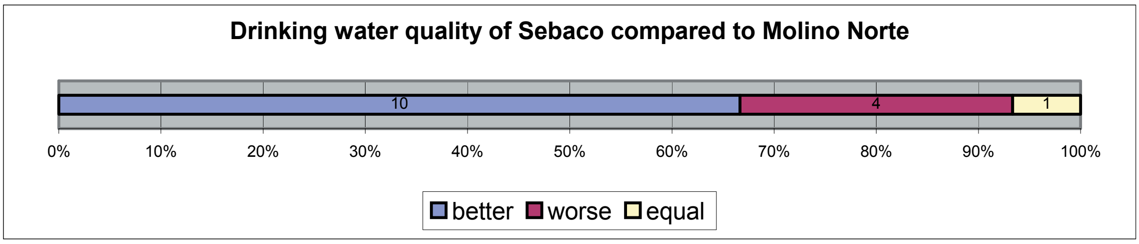
A qualitative analysis of the interviews held with the local population of Matagalpa about their experiences regarding the drinking water quality in the past and present, appears to confirm this. The most striking feature is that all interviewees refer to decrease of water quality during the coffee harvest season (see Figure 22). Complaints about bad odour and less taste are most common and in some cases skin irritation and a 'sticky feeling' after washing have been mentioned. Most people add the remark that the above features are of less magnitude in recent years which can be related to the fact that 90% of the coffee pulp is re-used as organic fertilizer and no longer thrown in the river streams as practiced before by all farmers (PCM, 2004).

FIGURE 22 INFLUENCE OF COFFEE HARVESTING SEASON IN DRINKING WATER QUALITY ACCORDING TO RESIDENTS OF THE CITY MATAGALPA



The people living in those parts of the city that are connected to the Sébaco groundwater supply are a good reference with respect to the differences of water quality between the drinking water that is taken from the cuenca *Molino Norte* and the ground water that is pumped from the adjacent valley Sébaco. As is shown in Figure 23 the respondents consider the Sébaco water of a better quality

FIGURE 23 DRINKING WATER QUALITY OF SÉBACO COMPARED TO MOLINO NORTE ACCORDING TO THE RESIDENTS OF THE CITY MATAGALPA



It should be mentioned that also the opinion about quality of the Sébaco-water is not always positive. Some respondents report initial stomach problems that might be due to a higher hardness (presence of $CaCO_3$) in this water. Furthermore it is said that the 'freshness' of the Sébaco water is less, which also is expressed literally in the water temperature. This has to do with the origin of the two types of water; Sébaco as groundwater and Molino Norte being formed by springs out of a mountainous area. As mentioned earlier, the respondents that are connected to the Sébaco water appreciate very positively that there is no longer any influence of coffee wastewaters during the harvesting season.

PESTICIDES

There is less information available and it is difficult to quantify the effect. However, the results of an investigation in the years 1994-1995 (Beck, 1996) revealed that pesticides were present in relatively high concentrations and that the drinking water quality of Matagalop occupied the second worst place of Nicaragua in this respect. The Ministry of Environment and Natural Resources, MARENA, had a discussion this year (2004) about the serious quality problems of the river Aranjuez (caused by pesticides used at fern plantations in that area) from where water is pumped in the dry season. The main issue was whether to pump water from this river into *Molino Norte* considering the high degree of pollution. After visiting the pumping station it was clear that also this year (spring 2004) water is pumped from this water source, probably a decision that is made in order to reply to the high drinking water demand of the city Matagalpa.

4.6 DPSIR-ANALYSIS AND DISCUSSION

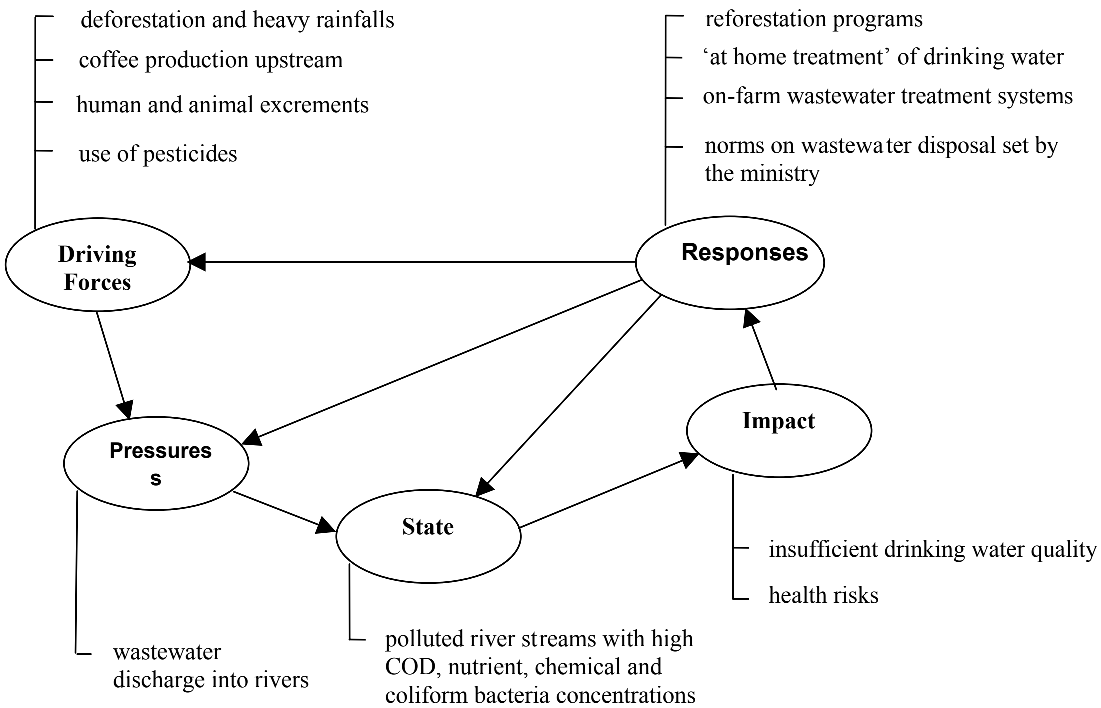
The results of the water quality aspects can be expressed by using the DPSIR-analysis. As *driving forces*, which are mainly expressed as direct sources of water pollution, three main factors are distinguished that influence the water system: coffee production, human and animal excrements and the use of pesticides. From these (land-based) activities there is a *pressure* on the water system in the form of wastewater production. The actual situation (*state*) concerning the water quality of the two *cuencas* is that water streams are polluted, resulting in high COD and nutrient concentrations that are mainly caused by the discharge of coffee wastewaters. Furthermore residuals of pesticides are found in the rivers and relatively high concentrations of coliform bacteria due to excrements, which are washed away from the field into the river courses. Heavy rainfalls at the beginning of the rainy season cause high sediment loads.

The drinking water quality *(impact)* is based on the results of calculations and partially on a qualitative analysis derived from interviews conducted with citizens of the city Matagalpa. The potential impact of the high COD of the untreated water of *Molino Norte* during the coffee harvest season (November-February) caused by wastewaters discharged in the river, is a high concentration of oxygen consuming organic material. This also means that dissolved organic material can be found in the drinking water networks and may cause the growth of bacteria in these networks. Moreover, during disinfection at the drinking water treatment plant carcinogenic chlorinated hydrocarbons can be formed. The interviews with citizens of Matagalpa show that most people experience an effect on the drinking water quality from the coffee wastewater during the harvest season in the shape of a bad taste and odour and skin irritations. Potential other health risks are posed by the presence of chemical pesticide residues, which are especially used at the fern plantations. In addition, at the beginning of the rainy season when human and animal excrements are washed into the rivers, high concentration of coliform bacteria may affect the drinking water quality. However, considering the good disinfection at this treatment plant the risk of infection of the drinking water appears to be neglible.

Responses came in the form of (small-scale) reforestation programs by *Proyecto Cuencas Matagalpa* in cooperation with the Ministry of Forestry (MAGFOR). Of the interviewed people, about 60 % treat their tap water (coming from both Sébaco and Molino Norte) in some way (mostly by adding chlorine) before drinking it. Those who can afford it buy bottled water. At farm level prevention of coffee pulp being discharged into the rivers is a major response. The introduction of UASB bioreactors for the treatment of coffee waters forms a second response. Four farmers are working with this technology. Most farmers have some form of treatment with the *pilas*, although in practice there are many problems with over loading due to clogging of soil pores. From political level there is a response by setting a norm for a maximal COD of 200 ml per liter of wastewater for legal discharge.

In Figure 24 the DPSIR-analysis is set out in a schematic overview. Questions coming forth from this outline about the actual situation of the water quality in the study area are in the direction of future trends. In the case of the new norms on wastewater disposal set by the Ministry of Environment and Natural Resources (MARENA), it is a fact that there is a lack of personnel to realize adequate controls on this aspect. Furthermore, long term changes in land use patters are difficult to predict but can be of great influence on wastewater discharges and thus on the water quality of the watersheds. And finally, most coffee farmers do have a simple form of coffee wastewater treatment (*pilas,* of which many are actually undersized), but how can these treatments be improved in the future? Or in other words, how can a coffee farmer, who is lacking capital for investments, be persuaded to install a good working wastewater treatment system? Or is this more a task of other stakeholders?

FIGURE 24 SCHEMATIC OVERVIEW OF THE DPSIR-ANALYSIS ON THE DRINKING WATER QUALITY



5

POTENTIAL OF ECO-TECHNOLOGICAL WASTEWATER TREATMENT SYSTEMS

5.1 POLLUTION PREVENTION STRATEGIES

As described in the previous chapter a significant number of measures has already been taken to reduce the pollution of the rivers Moline Norte and San Fransisco by coffee processing wastewater. Most of the coffee pulp is kept separate and is used as organic fertilizer at the plantations. Most of the plantations do have a basic wastewater treatment system in the form of *pilas*, although the performance of most of these systems is doubtful because of clogging of soil pores and in many cases insufficient capacity. At six larger coffee plantations UASB Bioreactors have been introduced. Four of them are in operation with technical assistance of Projecto Cuencas Matagalpa.

Despite the preventive measure that have already been taken it is clear that coffee production is still a major river polluter during the dry season and is seriously affecting the quality of the water that withdrawn form the watersheds. The government has clear-cut goals to decrease the pollution load by the coffee farmers. MARENA has set norms on wastewater disposal but there is a lack of staff members to carry out adequate controls resulting in the fact that restrictions on wastewater discharges are not (yet) complied with.

Reduction of pollution can be achieved by the introduction or further improvement of the wastewater treatment systems at especially the 15 larger coffee farms, since they are responsible for 95% of the coffee production in the area. Especially implementation of treatment at the five or six coffee farms that are located in the watershed of the Molino Norte is very strategic, because it serves as the main source for the drinking water supply of Matagalpa.

The following two strategies for pollution prevention were formulated in the scope of this study:

1 Introduction of decentralised constructed wetlands systems (including pre-treatment) at the larger farms, especially the five or six farms near Moline Norte.

2 Introduction of a (semi-) centralised treatment system. This could be done by connecting the larger farms (especially the ones near Moline Norte) to a piping network and have centralised wastewater treatment consisting of a combination of a UASB bioreactor and constructed wetlands. The advantage is that farms need less operational and management capacity to treat the wastewater.

In principle one could also think about ‘end-of-the-pipe’ measures that are aimed at the improvement of the river water quality before it reaches the drinking water intake, e.g. by treatment in a constructed wetland. Another option is to improve the drinking water treatment plant, e.g. by introduction of an aerated reactor and activated carbon filter.

5.2 POTENTIAL OF ECO-TECHNOLOGICAL WASTEWATER TREATMENT SYSTEMS

ECO-TECHNOLOGICAL TREATMENT OF COFFEE WASTEWATER

The advantages of eco-technological wastewater treatment systems are a relatively low capital investment and relatively easy operation and maintenance. A disadvantage might be the area of land that is required. Pre-treatment with a bioreactor will be necessary, considering the high COD and the low pH of the coffee wastewater. The pre-treatment could be followed by eco-technological systems in the form of e.g. constructed wetlands or aquatic plant treatment systems. Wood or reed production in or after the constructed wetland can make these systems economically more attractive, integrate them with other agricultural activities and can contribute to reforestation.

An example of the application of constructed wetlands for treatment of coffee wastewater is provided in the following text box:

PILOT PROJECT IN VIETNAM: TREATMENT OF COFFEE WASTEWATERS IN A UASB AND A CONSTRUCTED WETLAND

An example of coffee wastewater treatment with the aid of a constructed wetland is a pilot project in Khe Sanh, Quang Tri, Vietnam described by von Enden and Calvert (2002). It has much resemblance with the treatment system at coffee plantation ‘La Hammonia’ in Matagalpa. At the pilot project site the wastewater of a wet coffee process is treated. This wastewater includes fermentation and washing water. At the site around 100 tonnes fresh cherry are processed during the peak of production. The total effluent reaches 400 m^3 per day at peak times.

The average water consumption has been decreased from over 10 m^3/tonne cherry down to around 4 m^3/tonne processed cherry through recycling and reuse of processing waters (at ‘La Hammonia’ this recycling process has been stopped as it had a negative impact on the coffee quality).

The treatment system consists of an acidification pond (200 m^3), followed by a neutralisation tank (25 m^3) filled with ground limestone. After neutralisation of wastewater to pH 5.9 to 6.1, water is treated alternatively in an Upflow Anaerobic Sludge Blanket (UASB) biogas reactor before entering a constructed wetland planted with macrophytes for secondary treatment. In this treatment method, dissolved oxygen levels in the water are increased through diffusion of oxygen in the root zone of the macrophytes growing in the flooded gravel bed. The water levels in the wetlands may also be artificially raised and lowered to assist the oxygen flow. The constructed wetland is able to remove up to between 49 and 81% BOD loadings and lower the amount of suspended solids between 36 and 70% depending on initial BOD loadings and retention time (Biddlestone et al, 1991). In addition, macrophytes remove nutrients and salts from biogas digester effluents.

For tertiary treatment, the wastewater runs through a water hyacinth (Eichornia crassipes) pond for water polishing before entering the open waterway.

ROLE OF PRE-TREATMENT

Coffee wastewater is very concentrated and acidic. To avoid a too high load of suspended solids and COD to a constructed wetland system, adequate pre-treatment of wastewater will be a prerequisite. Also neutralisation of the low pH with NaOH or lime will be necessary to prevent inhibition of biomass in the pre-treatment reactor and to avoid long-term soil degradation in the constructed wetland.

Anaerobic pre-treatment with a UASB reactor may play a key role in the treatment scenario to be selected. This treatment system has many advantages such as minimal surface area required, relatively low investment costs and the potential of biogas consumption and is very feasible for the Nicaraguan climate. In addition, the produced biogas forms an additional fuel for the cooking activities that are needed to serve hot meals to the extra labourers during the harvest period. A strong point for the Matagalpa case is the fact that UASB technology has already been introduced in this area and that PCM has experience in giving technical assistance. The general experience is that these systems function very well and result in a reduction of COD of 70-90% (see Annex F).

OPTIONS FOR BIOMASS PRODUCTION

One of the key concepts of the Waterharmonica approach is that wastewater treatment and biomass production can be integrated and may provide a form of economic activity. This is important when realizing that farmers lack the money (now even more with a low international coffee price) to invest in wastewater treatment systems. Systems that produce biomass as a side product may reduce costs and stimulate farmers to implement treatment.

For the Matagalpa region the production of wood or reed in or after the constructed wetland could be very attractive since this would provide an alternative source of fuel and as such would reduce the pressure on existing forests. The produced reed can be converted into charcoal, a widespread practice. Moreover, such a practice could create more awareness with farmers with respect to reforestation. Textbox 4 below describes an example of the set-up of biomass production in the form of hardwood tree species with the aid of coffee wastewater in Australia.

EXAMPLE OF BIOMASS PRODUCTION IN THE FORM OF HARDWOOD TREE SPECIES WITH THE AID OF COFFEE WASTEWATER IN AUSTRALIA.

"The Queensland Department of Primary Industries and Fisheries (DPI&F) recently developed a drip-irrigated native hardwood tree plantation at the Nestlé Gympie coffee factory. This innovative approach, designed and managed by the DPI&F, has resulted in the implementation of an environmentally sustainable solution to managing industrial waste.

The Nestlé Gympie Factory, based in Queensland, is the largest coffee factory in Australia, producing nearly 10,000 tonnes of instant and roast & ground coffee per year. One of the by-products of coffee manufacture is coffee wastewater, which is similar in colour and consistency to a cup of very weak black coffee. Since 1987, Nestlé Gympie has been irrigating this coffee wastewater via travelling irrigator onto a 14ha pasture, which is grazed by cattle. This method is a convenient and effective means of wastewater disposal, but Nestlé Gympie Factory was concerned with the long-term sustainability of pasture irrigation.

A number of trials commenced in 2002, including determining the effectiveness of growing trees and wetland plants with coffee wastewater, various methods of solids removal, and water reuse within the factory. One of the first improvements made by Nestlé Gympie Factory was the installation of a triple effect wastewater evaporator. This allowed some of the highly coloured wastewater streams to be evaporated, resulting in a clear condensate stream. The removal of solids also contributed to a dramatic reduction in BOD, COD and nitrogen of the wastewater. Reuse initiatives of some clear streams within the factory helped contribute to reducing the total volume irrigated onto the paddock to approximately half of the previous volume.

In 2003, a full-scale irrigated forest project commenced, managed by the DPI&F. The area chosen for the purpose of growing drip irrigated native hardwood tree species was the vacant 9 ha of grassed land next to the irrigated site. Soil in this area consists of a shallow sandy loam with rocky surface horizon and clay subsoil. The climate is sub-tropical where the bulk of the annual rainfall (54 per cent) falls between December and March.

Fourteen native hardwood species were selected because of their capability to withstand conditions that they were likely to receive; the nature of their fast growth rates (which were a commercially economic consideration); and their ability to uptake both high levels of nutrients and water on a sustainable basis.

Measure plots within each species will record annually such things as tree diameter, height, leaf area, crown size and biomass. A key objective of this project is to confirm that irrigation of coffee effluent will not adversely affect tree growth performance. It is expected that thinning will be chipped at age three years and the total tree harvest will be at age 15-20 years.

Gypsum was applied over the undulating terrain followed by ripping and contour mounding at 4 meter intervals. Mounds created were sprayed with a knockdown herbicide just prior to planting in December 3003. Soil samples were collected prior to irrigation to have base data on the physical and chemical characteristics of the soil. Nine bores positioned within and outside the plantation site will be regularly inspected for changing water levels and sampled for chemical composition.

Dripper irrigation was chosen for the project, which allows wastewater to be irrigated over a greater area than the traveling irrigators, and also eliminates the issues associated with spray irrigation, notably odour from aerosols and spray-drift during windy days. Drip irrigation laterals were placed on mounds with emitters positioned every 60cm along the dripper line. The Netafim Uniram heavy-duty drip line selected has pressure-compensating emitters with a nominal flow rate of 2.3L/hr. This system was chosen for its reliability and low clogging hazard and provides significant control of effluent odour."

(http://www.onlineopinion.com.au/view.asp?article=2069)

IRRIGATION WITH TREATED EFFLUENT

The treated effluent could principally be used for irrigation. The larger coffee plantations have a wastewater production in the range of 50 to 400 m^3 per day. The use of this water for agricultural irrigation could be attractive and would also be an extra guarantee against pollution of the rivers. At this moment there are hardly any coffee plantations that use irrigation. This can be explained by several reasons. The coffee bush does not require irrigation, as the yearly rainfall is sufficient. Most coffee plantations are located very close to the beginnings of both rivers and as such have a high water availability. The higher parts of the two watersheds of the *Molino Norte* and the *San Francisco* cover an area with hill slopes ranging between 4-75 %. This makes the application of irrigation practices very complicated (see Annex G for slope, profundity and texture of the soil). Moreover, irrigation would require a plantation that is not only growing coffee plants but also growing other types of crops. However, the example of coffee plantation 'La Hammonia' (described in chapter 4) shows that effluent irrigation can be successfully applied and is not only theoretical.

5.3 STAKEHOLDER INVOLVEMENT AND FINANCING MECHANISMS

Local institutional capacity and willingness to work on solutions are important factors with respect to the implementation of decentralised or semi-centralised treatment systems. Annex H provides an overview of the relations between the stakeholders that are involved in water related issues within the study area.

The farmers are the first to take responsibility for the implementation of adequate wastewater treatment facilities. However, they lack investment potential due to the low world market price for coffee and also lack motivation. The Ministry of Environment and Natural Resources (MARENA) has set norms on wastewater disposal but there is a lack of staff members to carry out adequate controls. The result is that restrictions on wastewater discharges are not (yet) complied with.

It is clear that PCM with representatives of different institutions could play a central role. PCM maintains a good relationship with the various stakeholders like coffee farmers, the municipal executive of Matagalpa, (MARENA) and Dutch donors like NOVIB and Aqua for All. The organisation already has a technical staff that supports a number of farmers with their wastewater treatment.

Furthermore it is interesting to see whether the drinking water company (AMAT) can be stimulated to participate in a follow-up project. For them the improvement of the river water will mean a reduction of their operating costs and an improvement of the drinking water quality. Pollution prevention measures on the farms will certainly be less costly than centralised measures. In this respect it is interesting to develop different financing mechanisms to support the farmers. Why e.g. could a part of the drinking water fees not be used to help the farmers to finance their treatment?

5.4 OTHER POLLUTION PREVENTION OPTIONS

CHANGE OF LAND USE ACTIVITIES

Long-term changes in land use are difficult to predict but can be of great influence on wastewater discharges and thus on the water quality of the watersheds. Due to the low coffee prices 60% of the farmers (especially the ones that own the smaller plantations) consider changing their activities. What might be needed for these farmers is a programme addressing alternatives / challenging changes into other forms of agricultural production. This would indirectly contribute to the reduction of pollution.

COFFEE PROCESSING

There has been relatively little emphasis in this report on the prevention of wastewater production or on tackling the problem at its source. The issue, however, has had quite some attention at the coffee plantations near Matagalpa. In the case of coffee wastewater production various prevention methods have been introduced or tried. The use of pulp that was formerly dumped into the rivers as organic fertilizer has already been discussed. Also recycling of water within the processed has been tried and has shown to be successful. However, experience has shown that it affects the quality of the coffee and most farmers are reluctant to apply it. Moreover, although recycling decreases the water consumption, it is not decreasing the total COD and nutrient that are released during the process.

Another option is to change to dry processing of coffee beans, a technology with a lower water requirement. A drawback is a lower quality of the coffee and a lower world market price. Most of the farmers in Nicaragua have especially changed to wet processing in order to be able to provide a high quality product. This is therefore not considered as an option for the coffee plantations near Matagalpa.

6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

TRENDS IN WATER AVAILABILITY

It is clear that the water availability (the available water per capita) of the watersheds of Matalpa has decreased over the last ten years. The reason is not so much decreasing water discharges of the rivers, but the fast growing population of Matagalpa is putting an increasing pressure on the drinking water resources. The city is still growing rapidly and this process will continue.

In addition there is a feeling of decreasing river water discharges with various governmental and agricultural stakeholders. The decrease is supposed to be due to climatic conditions and deforestation. The decreasing water discharges could not be verified by facts since actual data over the last ten years are hardly available. Calculations and estimations of the river discharges based on rain and evaporation data show no significant changes. It is possible that the increasing deforestation is affecting the water holding capacity of the watersheds.

Various measures have been taken to ensure and increase the drinking water supply to the city of Matagalpa. As a first response, a pumping station was constructed in a the *San Fransisco* with a capacity to pump 50 l/s into the river *Molino Norte*. The system is currently not in operation but is designed to pump water during the most critical months (January-May). A second operational response is the pumping station of Jiguina that takes water from the river Aranjuez during the dry season, a water shed to the north of the water shed of Matagalpa. A third response came in September 2003 as the Nicaraguan-German executed drinking water project was implemented. During the entire year groundwater is pumped-up and transported over 20 kilometres to a distribution point just outside Matagalpa. In the dry season Sébaco accounts for almost 50% of the total drinking water supply of the city Matagalpa, namely 115 l/s. During the wet season the discharge from this pumping station is 70 l/s, which is about 35%. At this moment these three projects ensure a sufficient drinking water supply expressed in a ‘7-days-per-week-service’.
The questions on the sustainability of the present situation regarding the water quantity in this area and the expectations for the future are difficult to answer. The key question is whether the water supply measures will keep pace with the increasing water demand of the growing city Matagalpa. There is a lot of pressure on the groundwater of the Sébaco valley. Two other pumping stations are subtracting groundwater from this valley, which, together with the water demanding crop rice grown there, will probably have their impacts on the groundwater table. Independent research on this matter can be valuable. It also has been brought up that former mine activities in this valley have had their impact on the groundwater in the form of pollution with arsenic, but there is no official proof to verify this. The trends in the water discharges of the *Molino Norte* and the *San Francisco* are unsure. Reforestation and energy saving technology programmes (bio-reactors and technology which makes briquettes out of rice and coffee chaff, both technologies) will probably at have their

positive effect on the water holding capacity of the water shed and could diminish the water stress during the dry season.

TRENDS IN RIVER AND DRINKING WATER QUALITY

There are various sources of pollution that are affecting the river quality of the rivers *Molino Norte* and *San Francisco*. The coffee plantations appear to be the main contributor, at least during the coffee-harvesting season (November – February). Other sources are domestic wastewater and pesticides.

The coffee-harvesting period coincides with the dry season when river discharges are lowest. A part of the wastewater is treated before discharge (rough estimation 50% based on field observations). This still means that the wastewater discharge has a rather large impact on the quality of the river water in terms of oxygen consuming compounds and nutrients Moreover, coffee wastewater is very acidic and contains various groups of recalcitrant components. A rough calculation with respect to the COD loading to the water shed was made for the two months with the highest coffee production. Two situations were taken into account, a situation were wastewater treatment is completely absent and one with 50% of treatment. Without treatment 300-400 g COD / m^3 is added to the river water. With 50% treatment this is 150-300 g COD / m^3.

Considering the high COD and the type of drinking water treatment the coffee pollution it is clear that it is affecting the drinking water quality of the city Matagalpa. This is confirmed by interviews with residents of the city. Complaints about bad odour and less taste are most common and in some cases skin irritation and a 'sticky feeling' after washing have been mentioned. Most people add the remark that the above features have decreased in recent years which can be related to the fact that 90% of the coffee pulp is re-used as organic fertilizer and no longer thrown in the river streams as practiced before by all farmers (PCM, 2004).

The rural population along the watersheds Molino Norte and San Francisco counts 1550 and 2300 people, respectively. This number increases with 65 % during the coffee harvest season when labourers are attracted to these watersheds for employment in the coffee sector. Most houses in the rural area of the two watersheds are not connected to a central sewer system. Several projects have introduced latrines and provided for sanitation. However, E-coli measurements at several locations indicate that sewage wastewater is contributes to river pollution.

An important diffuse source of pollution is the pesticide use in the cultivation of various crops. This is especially the case in the area near the river Aranjuez, north of the Matagalpa water shed, from where extra water is pumped during the critical months. In this area ferns for the export are grown which growth requires a lot of pesticides.

POTENTIAL OF ECO-TECHNOLOGICAL WASTEWATER TREATMENT SYSTEMS

Reduction of pollution can be achieved by the introduction or further improvement of the wastewater treatment systems at especially the 15 larger coffee farms, since they are responsible for 95% of the coffee production in the area. Especially implementation of treatment at the five or six coffee farms that are located in the watershed of the Molino Norte is very strategic, because it serves as the main source for the drinking water supply of Matagalpa.

Constructed wetlands may form an interesting option for the treatment of coffee wastewater, thus contributing to improvement of the river water quality and indirectly the drinking water quality of Matagalpa. There are several examples of such an application, e.g. in Vietnam, but also one of the coffee plantations in the area has such a system. Pre-treatment with e.g. a UASB bioreactor will be necessary, considering the very high COD and the low pH of the wastewater water. The bioreactors can be followed by eco-technological systems in the form of e.g. constructed wetlands or aquatic plant treatment systems. Wood or reed production for charcoal in or after the wetland can make these systems more attractive and integrate them with other agricultural activities.

It can be concluded that technical measures for pollution prevention are available but that introduction of wastewater treatment at the coffee plantation is more dependant depending on the behaviour of the farmer (depending financial situation, awareness, motivation, future land-use, etc.) and governmental will and capacity to introduce the new wastewater standards.

6.2 RECOMMENDATIONS

These are technical recommendations to Proyecto Cuencas Matagalpa, NOVIB and Aqua for All based on this study:

Despite the preventive measures that have already been taken it is clear that coffee production is still a major river polluter during the dry season and is seriously affecting the quality of the drinking water of Matagalpa during the coffee season. The government of Nicaragua has clear-cut goals to decrease the pollution load by the coffee farmers.

Reduction of pollution can be achieved by the introduction or further improvement of the wastewater treatment systems at the fifteen larger coffee farms. Especially implementing treatment at the five or six coffee farms that are located near the Molino Norte is of major interest, because of its importance for the drinking water supply (main source). The following two strategies for pollution prevention were formulated in the scope of this study:

1 Introduction of constructed wetlands systems at the larger farms, especially the five or six farms near Moline Norte. The advantages are the relatively low capital investment and low maintenance. A disadvantage might be the land requirement. Pre-treatment with a bioreactor such as a UASB will be necessary, considering the very high COD and the low pH of the wastewater. The bioreactors can be followed by eco-technological systems in the form of e.g. constructed wetlands or aquatic plant treatment systems. Wood or reed production in or after the constructed wetland can make these systems economically more attractive, integrate them with other agricultural activities and can contribute to reforestation.

2 Introduction of a (semi-) centralised treatment wetland system. This could be done by connecting the larger farms (especially the ones near Moline Norte) to a piping network and have centralised wastewater treatment consisting of a combination of a UASB bioreactor and constructed wetlands. The advantage is that farms need less operational and management capacity to treat the waste-water.

In principle one could also think about treatment of the river water (e.g. by a constructed wetland) just before the drinking water intake or improving the drinking water treatment plant, e.g. by introduction of an aerated reactor and an activated carbon filter.

It is not possible at this moment to assess the most cost-effective solution. However strategies 1 and 2 are preferable from the point of view of pollution prevention.

'VALUATION OF WATER'

A major bottleneck is the low world market price for coffee; most of the farmers lack investment potential to fund their own treatment facilities. It is interesting to develop of different financing mechanisms to support the farmers. The wastewater of coffee farms is affecting the drinking water quality. The inhabitants of Matagalpa pay for the drinking water. Further improvement of the quality by measures at the drinking water treatment plant is probably more costly than pollution prevention measures on the farms. Why not use part of the drinking water fees to help the farmers to finance their treatment?

CHANGE OF PRODUCTION

Due to the low coffee prices 60% of the farmers (especially the ones that own the smaller plantations) consider changing their activities. What might be needed for these farmers is a programme addressing alternatives / challenging changes into other forms of agricultural production.

OTHER POINT OF INTEREST: THE SEWAGE TREATMENT PLANT OF MATAGALPA

The Mayor of Matagalpa has asked if the wastewater treatment system of the city of Matagalpa can be improved. This sewage treatment consists of a set of stabilization ponds after which the water is released to the *Rio Grande de Matagalpa*. An extension of its capacity is planned for the year 2010. Till now only about 20% of the sewage water from the city Matagalpa is treated which is causing problems more downstream the *Rio Grande.* Here people use the water again for domestic purposes and in some cases as irrigation water of vegetables. Also some fisheries are affected by the contamination of the water and it is causing health risk for the local population.

Two recommendations are made:

- The installation of a UASB reactor before the current stabilization ponds would improve the capacity of the ponds by a factor 2.
- The stabilization ponds could be turned into constructed wetlands in which biomass like reed or trees are grown. This would be a source of fuel for the area

FOLLOW UP

The study will have a follow-up, starting in spring 2005. This follow-up is supported by Aqua for All and by a group of volunteers of the Dutch water sector. The aim of the follow-up is to support *Projecto Cuencas Matagalpa* in stimulating pollution prevention measures by expertise and funding.

7

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8

LIST OF ANNEXES

Annex A	List of questions as part of the interviews conducted with (24) residents of the city Matagalpa
Annex B	List of questions as part of the interviews conducted with (21) farmers in the watersheds Molino Norte and San Francisco
Annex C	Composition of mucilage, coffee pulp, coffee pulping water and of washing water
Annex D	Chemical additions for treatment of drinking water in January 2004
Annex E	Effectiveness of COD reduction of two bioreactors at 'La Hammonia' and one at 'San Louis'
Annex F	Schematic overview of a stakeholder analysis of those parties related to the water system of the two Cuencas
Annex G	Schematic overview of a stakeholder analysis of those parties related to the water system of Matagalpa and its watersheds

ANNEX A
LIST OF QUESTIONS AS PART OF THE INTERVIEWS CONDUCTED WITH (24) RESIDENTS OF THE CITY MATAGALPA

Address *(Dirección):* Date *(Fecha)*:

1 What is the origen of your drinking water?
(¿Cuál es el origen de su Agua Potable?)
Molino Norte Sebaco Well (Pozo) River (Rió) Other (Otro)

2 For what activities do you use this water?
(¿Para cual cosas se usan este Agua?)

3 Do you treat this water in a certain way before using it? (chlorine, boiling, filter, ...)
(¿Se hacen un tipo de tratamiento con el agua? (cloro, hierva, filtrar,...))

4 How is the quality of the water? (taste, color, small animals, sediments,...)
(¿Come es la calidad del Agua Potable? (sabor, color, animalitos, sable,...))

5 How is the quantity of the drinking water? (sufficient, frequency,...)
(¿Cómo es la cantidad del Agua Potable? (suficiente, frecuencia, ...))

6 About the differences before and after the ‘Sébaco-project respectively:
(Sobre la diferencia antes y después el proyecto de Sébaco en respecto:)
Frequency *(frecuencia):*
Price *(del precio):*
Quality (if there is any) *(de la calidad (sí hay)):*

7 How was the quantity (frequency) of the drinking water 10 till 15 years ago?
(¿Cómo estaba la cantidad (frecuencia) del Agua Potable como 10 a 15 años atrás?)

Notes:
(Noticias):

ANNEX B
LIST OF QUESTIONS AS PART OF THE INTERVIEWS CONDUCTED WITH (21) FARMERS IN THE WATERSHEDS MOLINO NORTE AND SAN FRANCISCO

1. GENERAL DATA (DATOS GENERALES) Date: (Fecha:)

1.1 Name of farmer (Nombre del productor:)
1.2 Name of the farm/plantation: (Nombre de la granja / finca:)
1.3 Address (Dirección):

2. THE COFFEE FARM: (LA GRANJA / FINCA DE CAFÉ)

2.1 Cultivated land (Área cultivada:)

CULTIVO	MANZANAS*	QQ** (/MANAZANA)	OBSERVACIONES
Caffee (Café)			
Corn (Maíz)			
Beans (Fríjol)			
Banana (Plátanos)			
Pature (Pasto)			
Others (Otros)			
Total			

* 1 manzana (mz) = 0.7 hectare (ha)

** 1 quintal (QQ) = 46 kilogram (kg)

Animals (Animales)

Type of animal	Amount

2.2 Production of green ripe coffee cherries/green beans of the last three seasons:
(Café uva/oro: Producción de la finca en las ultimas tres cosechas:)

Años Agrícolas	QQ uva/oro
1.	
2.	
3.	

3. WATER (EL AGUA)

3.1 What do you use your water for? (drinking water, irrigation,....)
(Para que se usen el agua (agua potable, riego,...))

3.2 Origen of the water: River Well Municipality Other
(Origen del agua: Rió Pozo propio Municipal Otro)

3.3 How is the quality and auantity of the water you use?
(¿Cómo es la cualidad y cuantidad del agua se usa?)

3.4 What is the amount of water used for the processing of 46 kg *(1quintal)* ripe cherry/green bean?
(Consumen de agua en el beneficio por quintal de uva o otra unidad)

3.5 What do you do with the coffee wastewater?
(Que hace actualmente con las aguas mieles?)

3.6 What is the destination of the domestic wastewater?
(¿Que hace con las aguas domesticas?)

3.7 What is the destination of the coffee pulp?
(¿Que es el destino actual de la pulpa?)

3.8 What type of chemicals doe you use?
(¿Que tipos de químicos se usa?)

4. FUTURE/HISTORY (FUTURO/HISTORIA)

4.1 Have you been thinking of a change in land-use (explain the reason to change, e.g. change from coffee production to the production of other crop because of low coffee prices)
(¿Es pensando en cambiar el uso de suelo? (explica la razón de cambio por favor, por ejemplo: cambiar el cultivo de café por que el precio bajo del café?)

4.2 Have you been thinking of changing you farm/plantation into an organic farm/plantation? (what is the drive behind this?)
(¿Es pensando en cambiar la granja / finca en una orgánico? (y que es la razón para hacer eso?)

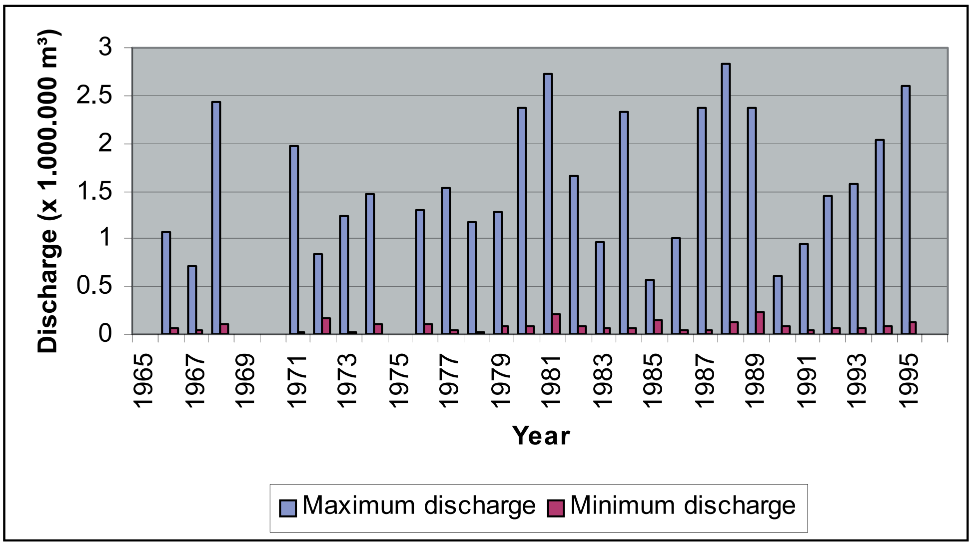
4.3 What do you think is the best type of treatment for the coffee wastewater?
(¿Que piensa es el mejor tipo de tratamiento por las aguas residuales?)

4.4 What do you consider as the main problem (in respect to cultivation activities) what would be the best solution for this problem?
(¿ Qué considera como el problema principal (con respecto a las prácticas de cultivo) y lo que sería la solución mejor para eso?)

4.5 How is the river discharge at the moment compared to few or many years (3-40) ago?
(Historia del caudal del rio)

Notes:
(Noticias:)

ANNEX C
MAXIMUM AND MINIMUM DISCHARGES OF THE RIVER SAN FRANCISCO DURING THE PERIOD 1966-1995



ANNEX D
COMPOSITION OF MUCILAGE, COFFEE PULP, COFFEE PULPING WATER AND OF WASHING WATER

TABLE. COMPOSITION OF MUCILAGE (CLIFFORD AND WILSON, 1985)

Water	84,2%
Protein	8,9%
Sugars	
- Glucose (reducing)	2,5%
- Sucrose (non reducing)	1,6%
Pectin	1,0%
Ash	0,7%

TABLE. COMPOSITION OF COFFEE PULP (GATHUO ET AL, 1991)

Ether extract	0,48%
Crude fibre	21,4%
Crude protein	10,1%
Ash	1,5%
Nitrogen free extract	31,3%
Tannins	7,8%
Pectic substances	6,5%
Non reducing sugars	2,0%
Reducing sugars	12,4%
Chlorogenic acid	2,6%

COMPOSITION OF COFFEE PULPING WATER (LOPEZ 1996)

Compound	Concentration of coffee pulp (% dry matter)	Extracted material (kg/tgcp)	Estimation of COD (kg COD/tgcp)	COD (%)
Proteins	12	3.5	5.4	8.9
Tannins	2.4	3.0	5.9	9.8
Chlorogenic acid	2.6	6.1	8.7	14.6
Caffeic acid	0.07	0.2	0.4	0.7
Caffeine	1.6	6.3	12.4	20.8
Sugars	8.3	24.6	27.0	45.3
Total			59.8	100

tgcp = tons green coffee produced

COMPOSITION OF WASHING WATER(LOPEZ 1996)

Compound	Compositionof mucilage (% dry matter)	Extracted material (kg/tgcp)	Estimation of COD (kg COD/tgcp)	COD (%)
Sust. Pecticas	35.8	31.5	26.1	29.4
Sugars	45.8	40.2	44.3	50.2
Cellulose	17.8	15.0	18.0	20.6
Total	98.6		88.4	100

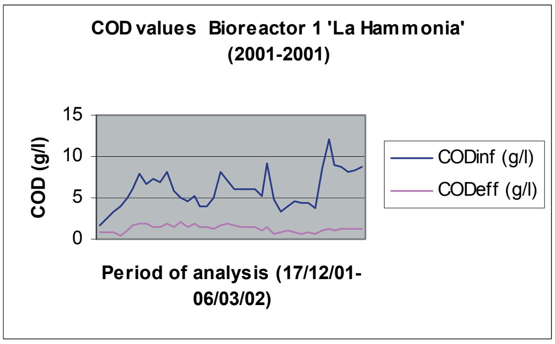
ANNEX E
CHEMICAL ADDITIONS FOR TREATMENT OF DRINKING WATER IN JANUARY 2004

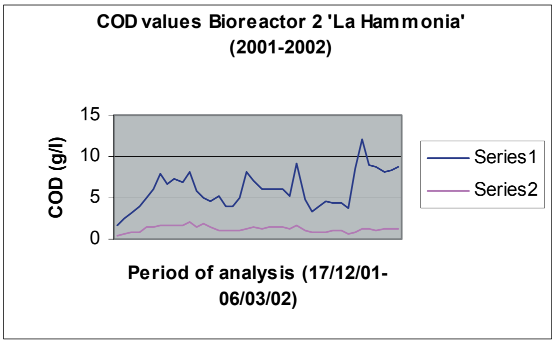
Chemical additions for treatment of drinking water in January 2004 (source: AMAT)

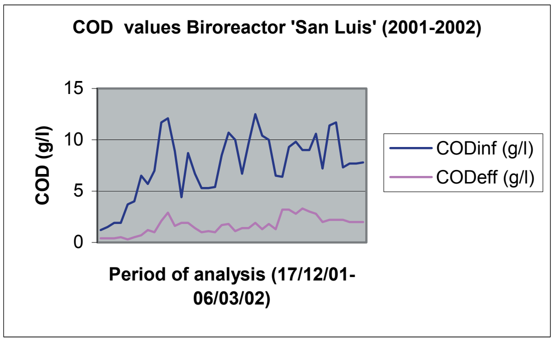
Place of treatment	Chlorine (gas) (kg)	Aluminium Sulphate (kg)	Cation Polymer (kg)	Lime (kg)	Sodium hypo chlorite (l)	Drinking Water (m^3)
Main plant	612	-	-	-	-	176.000
La Parrilla	68	-	-	-	5	55.000
Sebaco station	408	-	-	-	-	155.000

In December 2003, the main treatment plant consumed 476 kg Chlorine (g) and 640 l of Sodium hypo chlorite.

ANNEX F
EFFECTIVENESS OF COD REDUCTION OF TWO BIOREACTORS AT 'LA HAMMONIA' AND ONE AT 'SAN LOUIS'







ANNEX G
SCHEMATIC OVERVIEW OF A STAKEHOLDER ANALYSIS OF THOSE PARTIES RELATED TO THE WATER SYSTEM OF MATAGALPA AND ITS WATERSHEDS