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Use of the Waterharmonica for conversion of treated waste water into a natural resource in the developing world

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Please visit our website at www.waterharmonica.nl

Abstract

In the Netherlands the need for treatment technologies that form a 'link' between municipal wastewater treatment plants and (re)use of treated wastewater is more and more acknowledged. A lot of experience has been gathered with the design and operation of wetland systems, however, the evaluation and spin-off of these experiences has been limited so far. As such, the 'Waterharmonica' is being developed as an instrument to include ecologically engineered 'linkage-systems' as an integral part of design for the renovation and extension of municipal wastewater treatment plants with the aim of using this water for nature and recreational development, and replenishing of ground water sources. The concept has resulted in a research and implementation programme named 'Waterharmonica' (2003-2004) which is financed by the Dutch Foundation for Applied Water Research (STOWA) and the Dutch Water Board Hollands Noorderkwartier. Part of the Waterharmonica programme focuses on exchanging knowledge and experiences with developing countries. A short survey concludes that the latter countries have practically no cases similar to the Waterharmonica. Municipal wastewater treatment facilities are either lacking or at least do not have an engineered, planned and controlled, ecological system for biological reanimation of the treated wastewater prior to disposal or (re)use. However, unless disposal is in an affluent body of water like the sea, direct or indirect use of raw or partially treated wastewater is generally, more or less controlled or uncontrolled, a daily practice in many developing countries. Each case has its own contextual dynamics, such as land and water rights issues, governing the fate of water, nutrients and pollutants. Each case requires a 'life-cycle' approach to facilitate stakeholder negotiation processes, indicating mutual benefits and responsibilities that can or must be shared. Hence, a flexible framework is developed for sustainable and integrated development of sanitation, wastewater collection, -treatment and (re)use of water and nutrients, with emphasis on the role of natural treatment processes.

Introduction

The latest policy on water management in the Netherlands is aimed amongst others at stimulating further improvements in water quality by means of a water directive ('Kaderrichtlijn Water'). Improvements in sanitation and wastewater treatment are good examples of required developments, the initiative of which lies with the district Water Boards (Kampf et al., 2003). The quality of effluent from municipal wastewater treatment plants in the Netherlands has improved considerably during the last couple of years. However, although the effluent is often of a better quality than the receiving surface water (in terms of nutrients and oxygen-binding substances), it's still more toxic than is to be expected based on it is chemical and physical composition. It lacks a natural daily oxygen-rhythm, as a "dead water" it is hostile for higher organisms and it contains too many microorganisms of human nature and from the activated sludge process. As such, the effluent isn't suitable for humans (swimming or recreational water) and nature. The solution can be sought in sophisticated technologies, like the membrane-bioreactor as alternative to the existing activated sludge systems, or, membrane technologies and ozone for effluent post-treatment. However, such systems consume more energy and resources, whilst the quality of the effluent still doesn't comply with the existing or desired quality of receiving surface water. In other words, in the Netherlands there is a need for more sustainable technologies to form a 'link' between discharge of municipal wastewater treatment plants and receiving surface water. Progress has been made on this issue in the last couple of years. Many wetland systems have been constructed 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. As such, the combination of wet-nature and wetland systems is easy to make, but also the integration of active biological management or storage can be combined with this method of effluent treatment.

The Waterharmonica

The Waterharmonica, conceptualised by Theo Claassen and Ruud Kampf (Claassen, 1996, Kampf, Claassen, et al 2003), is the embodiment of STOWA's ambition (Applied Research Foundation of the Dutch Water Boards) to include ecologically engineered 'linkage-systems', such as constructed wetlands, as an integral part of design for the renovation and extension of municipal wastewater treatment plants (Figure 1).

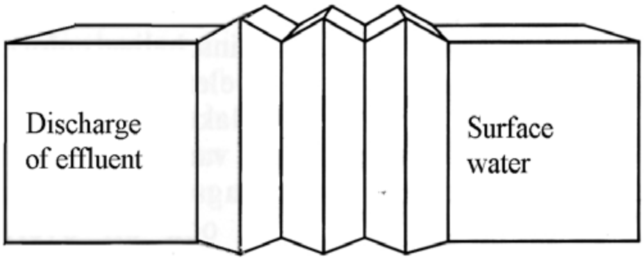

Figure 1. The "Waterharmonica" as a buffer between the sewage plant and surface water, based on Claassen, 1996

In such a design, the 'linkage-system' will take over part of the municipal wastewater treatment plant and the boundary conditions are increasingly set by characteristics and demands from receiving surface water systems. As such, the Waterharmonica is a sustainable eco-technological application of integrated water management. It does not provide a blueprint for planning but rather introduces a framework and set of tools for the design of appropriate ecological solutions according to local situations. The goals of the Waterharmonica project are:

- Redefinition in the light of ecological engineering;
- Inventory of practical knowledge and experience with the Waterharmonica;
- Promotion of demonstration of Waterharmonica projects in Holland;
- Exploration of the concept in developing countries.

In the Netherlands, as elsewhere in the western world the departure point for most local situations is effluent from municipal wastewater treatment plants. This is because the sewer infrastructure already exists and because alternatives, such as black/grey-water separation at household level as practised in the old "honey bucket system" of our ancestors, are still not possible at large. However, despite the fact that current systems abuse bulk (good quality) water to transport relatively small amounts of concentrated wastes, if the wastewater is treated adequately, the wrong can be turned into a good by making beneficial use of the effluent (Figure 2).

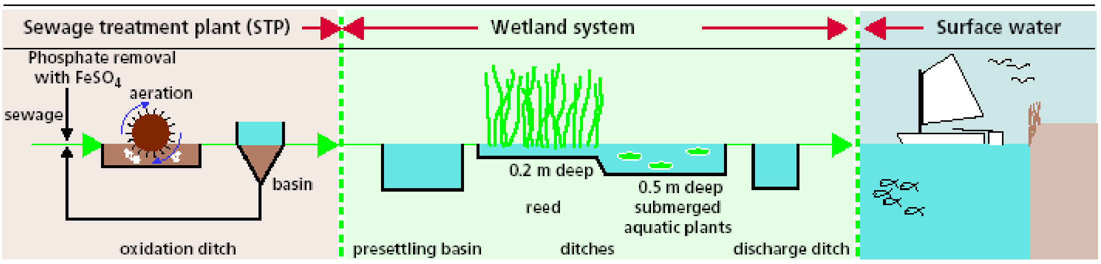

Figure 2. Example of 'wetland system' as buffer between sewage treatment plant and surface water (Kampf, 2003)

The ideas fit well in recent developments of ecological engineering. A good entrance is the web site of the International Ecological Engineering Society (www.iees.ch), but also Jana (Jana, Banerje, et al., 2000) is a good source of information. Integrated water management opens nice perspectives in using technical processes in "nature" and more natural processes in "engineering", see Winblad, 1998. The principles of re-using not only the water (volume), but also the nutrients still present in the wastewater will help to bring the nutrient cycles in balance, as stated by Gijzen & Mulder, 2001: "while the world population doubled between 1960 and 2000, the production of fertiliser nitrogen increased almost tenfold from 1 to 9×10^{10} kg/year. Current production is equivalent to about 37 % of the total amount of nitrogen input achieved via terrestrial and marine biological N_2 fixation (about 24 $\times 10^{10}$ kg/year)". To say the least it is an encouragement for re-use of nutrients, separation of wastes at the source, etc.

An Introduction of the Waterharmonica in Developing Countries

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 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.

Claassen and Kampf (1999) acknowledge that many developing countries are facing a dual problem: due to inadequate or inexistent sanitary provisions, wastewater disposals are the cause of major environmental problems, whilst at the same time agro-fertilizers re 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, and even developed countries are picking up on this (after Tchobanoglous et al. (1998); Zeeman et al. (1999); Van Lier et al. (1999) and Mels et al. (2002)). The basic principles for possible application in a rural Nepali community are depicted in Figure 3.

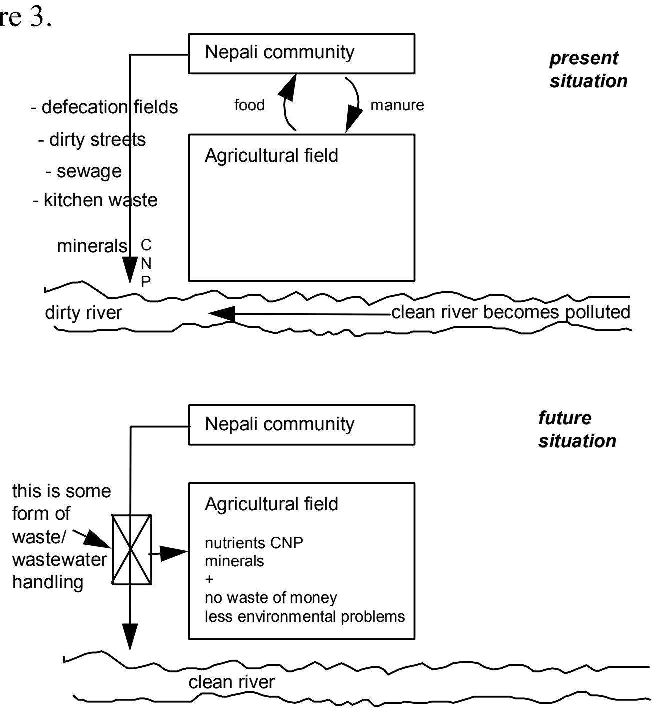

Figure 3. Closing the nutrient cycle, as an example of useful (re)use of water and nutrients in a Nepali community (Bolt, Claassen, et al., 1999, Claassen & Kampf, 1999) .
More information on the de website: www.rekel.nl/closethenutrientcycle

Integrated Water Management (IWM), as promoted in Agenda 21 (Rio 1992) and again during World Water Forums (the Hague 2000; 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-technological approaches within this vision.

Exploring and mapping the potential of eco-technological wastewater treatment in developing countries has a dual motivation. First of all, eco-technological wastewater treatment integrated with the use of effluent is generally cheaper than conventional treatment and can be implemented and managed more easily by the developing countries themselves. Secondly, eco-technological wastewater treatment with direct or indirect use of effluent is generally, more or less controlled (sewage collection systems and wastewater treatment) or uncontrolled (illegal, unguided, or unplanned direct and indirect use of raw, partially treated or diluted wastewater has been practised for years without professional concern for the hazards (Martijn and Huibers 2001b), a daily practice in developing countries.

> *Direct versus indirect use:*
> '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).

As such, the further development of these practices is the most 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 developing countries themselves can copy, operate and manage systems according to their own capacity and needs. The requirements for sanitation systems in developing countries tend to match quite well with the principles of ecological engineering, such as (after G. Rose 1999):

- Low to no use of electricity (or energy) because it isn't (reliably) available;
- Permanent and continuous operation without too much interference and with more or less constant efficiency/effluent quality (i.e. robust systems);
- Easy to operate without high skilled operators.

As stated earlier, the Waterharmonica-concept developed primarily from the use of constructed wetlands in the Netherlands. Although this type of ecological engineering is not the only eco-technology to be considered in developing countries, it is often forwarded as one of the most promising. Denny (1997; in Haberl 1999) has mentioned three reasons for the relatively slow spread of constructed wetlands to developing countries, which may actually be applicable to the slow spread of ecological technologies in general:

- 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 environments.

These facts are generally well known today, although the practical application is often not in coincidence with the theoretical viewpoint (Denny 1997; in Haberl 1999). A systematic approach for the mobilisation and evaluation of knowledge on eco-technological applications is therefore important for three reasons:

1. Western countries can learn from existing systems and concepts. In the West there is a growing consciousness that sanitation technologies based on centralised collection and treatment of domestic wastewater are not always rational
2. Developing countries will benefit by sharing knowledge and experiences between themselves
3. The capacity of well organised and financed Western institutions can be directed towards this type of international development cooperation (i.e. no blue-print)

Need for an Integrated Approach

It should be stressed that per definition no isolated technology is ecological or 'green'. Brix (1999) warns that the term 'green' is nowadays widely used (and misused) in connection with many types of technologies. In order to evaluate in more detail the 'greenness' of different wastewater treatment technologies, the life-cycle approach might be applied. However, because constructed wetlands, besides the water quality improvement function, perform a multitude of other functions such as biodiversity, habitat, climatic, hydrological and public use functions, methodologies need to be developed to evaluate these functions and to weigh them in relation to the water quality issues (Brix 1999). The same can be argued to apply to land-based treatment technologies, such as slow-rate applications in irrigated agriculture, which in certain cases could be more acknowledged in its dual performance of both wastewater treatment and beneficial use of water and nutrients.

Take for example the case of urban farmers using raw wastewater flowing in open drains for vegetable growing on squatted lands in Accra, Ghana, described by Obuobie (2003) and Agodzo et al. (2001). They constitute 'de facto' wastewater managers, without land and water rights, condoned but not acknowledged by authorities, and sometimes symbolically persecuted. The diffusion of institutional responsibilities, lack of finances and current priorities aimed at supplying safe drinking water (without integrating adequate sanitation) leaves farmers in a vacuum and their practices unaided with professional concerns for the hazards. Another example of endogenously developed wastewater management solutions is the well-known Calcutta Wetlands in India (Ghosh 2001). For an overview of the hazards and benefits associated with the use of wastewater in irrigated agriculture; see Martijn and Huibers (2001a).

Framework and Decision Making Tools

Studying different cases in developing countries (see Annex 1) leads to a clear conclusion: the need for decision making tools to facilitate the exchange of 'the third element of ecological systems' (after David Del Porto, EEG-website 2003), information:

1. *Framework* for integrated planning and design of sanitation, wastewater collection, treatment, and the use of water and nutrients for various uses, to induce stakeholders to explore relationships and negotiate responsibilities and shared benefits, and, to identify gaps in knowledge;
2. *Secondary decision making tools* that provide detailed information.

Multiple-objective wastewater management schemes are more complex than conventional mono-objective facilities because they incorporate treatment of wastewater 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. This becomes evident from the fact that, unless wastewater is discharged into an affluent body of water like the sea, any form of disposal may potentially lead to direct or indirect, planned or unplanned, use of the discharged effluent (Martijn and Huibers 2001; and see cases in Annex 1). The effectiveness or suitability of eco-technological solutions then depends on a number of system-specific boundaries. For example, land availability and mosquito plagues are well known potential bottlenecks in the case of wetland systems, and so are the local institutional capacity and public acceptance to work on alternative solutions. In short, an integrated eco-technological application also demands an integrated framework to help map these and other boundary conditions.

Such a type of framework has been designed at Wageningen University (Martijn and 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 by Wageningen University and LeAF for the training of students and professionals and is modified for use in the Waterharmonica. The modification basically entails a widening of the scope for options to use water and nutrients in: agriculture, aquaculture, landscaping, household, industry, groundwater, nature preservation and recreation. All based on a review of the case studies (Annex 1). The framework in itself (Figure 4) looks rather like a 'skeleton', which gets packed and clothed only during stakeholder negotiation processes; e.g. when discussing in a specific case how the relation between 'choice' of a sanitation system (type of toilet even) ultimately effects the type of crops a farmer can cultivate, regarding, for example, agronomical and epidemiological issues and public acceptance. As such, the framework is primarily intended to induce stakeholders to explore relationships and current information gaps.

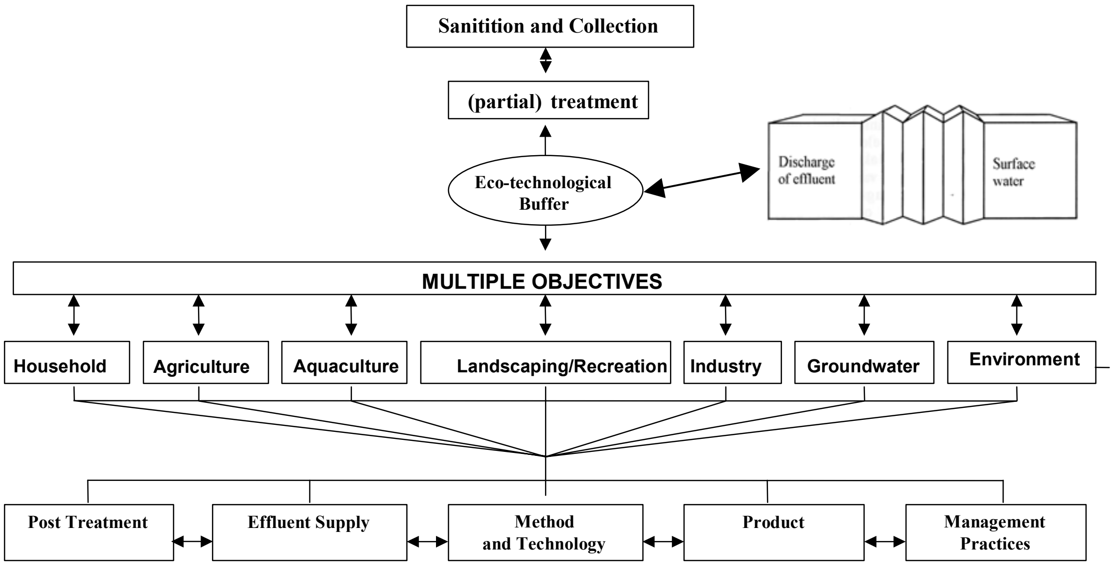

Figure 4. Framework for integrated planning and design of sanitation, wastewater collection, treatment, and the use of water and nutrients for various uses

Demonstration Projects

The Waterharmonica is still in a negotiation process with NGO's and mediator 'Aquaforall' (www.aquaforall.nl) concerning the establishment of two demonstration projects in developing countries. One of the projects entails the ecological rehabilitation of river basins in the city of Matagalpa, Nicaragua. The river basins, used to supply Matagalpa with drinking water, are severely polluted by upstream coffee industries. On-site anaerobic wastewater treatment facilities, integrated with the use of water, nutrients and biogas, may form part of the solution.

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ANNEX 1 Cases Waterharmonica in the developing world

Bolivia; River Pollution and Indirect Reuse

Place: arid Bolivia
Type: discharge of untreated wastewater into rivers or lakes and subsequent irrigation
Size: majority part of arid Bolivia
Author(s): Maledonado *et al.* (2003)
Institute(s): Centro de Aguas y Saneamento Ambiental, Bolivia, and, Wageningen University, the Netherlands

China; Purification Function of Wetlands in the Liaohe Delta

Place: Liaohe Delta, in Northeastern China
Type: natural wetlands
Size: 100,000 ha
Web-site(s): http://www.iees.ch/EcoEng001/EcoEng001_A.html
Author(s): Li Xiuzhen
Institute(s): Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, China and Wageningen University, the Netherlands (dissertation LI Xiuzhen, 2000)

Cuba; Incremental Ecological Wastewater Treatment: The Havana Prototype

Place: Havana, Cuba
Type: demonstration and proposed wetlands
Size: -
Web-site(s): http://online.caup.washington.edu/courses/udpsp00/udp508b/overview.html#havana
Institute(s): Center for Hydrologic Studies at the Instituto Superior Politécnico José A. Echevarría (ISPJAE), University of Washington, Canadian Urban Institute, Canadian International Development Agency (CIDA)

Eastern-Africa; Cost-Benefit of integrated wastewater and coastal management

Place(s): Mombasa (Kenya), Dar-es-Salaam (Tanzania) and Beau Vallon (Seychelles)
Type: systems integrated with coastal management
Size: -
Web-site(s): http://www.gpa.unep.org/documents/other/wgcar/WGCAR%204%20Case%20studies%20benefits.doc
Institute(s): UNEP

Ghana; Urban Agricultural Use of Wastewater

Place: Accra, Ghana
Type: wastewater use in urban agriculture for growing vegetables
Size: about 420 hectares and 3,500 people (farmers and family)
Author(s): Agodzo *et al.* (2001)
Institute(s): KNUST University, Kumasi, Ghana, and, Wageningen University, the Netherlands

India; Calcutta Wetlands

Place: East Calcutta, India
Type: natural wetlands; raw sewage and industrial wastewater used in garbage farms, fishponds and effluent from ponds in rice cultivation
Size: approximately 225,000 m^3/day wastewater enters the wetlands of about 3,000 ha
Web-site(s): http://www.changemakers.net/journal/98october/ghosh.cfm
http://www.changemakers.net/journal/98october/pye-smith.cfm
http://www.waste.nl/docpdf/OP_calc.pdf
http://www.ramsar.org/lib_wise_15.htm
http://www.calmanac.org/cmcnew/cal/numbers/geography.htm?showmenu=no
http://www.cepis.ops-oms.org/muwww/fulltext/repind53/calcutta/calcutta.html
Author(s): Dhrubajyoti Ghosh, Charlie Pye-Smith, Santosh Ghosh, Calmanac (City of Calcutta)

India; Constructed wetlands pilot project in Punjab

Place: Punjab, India
Type: Surface Flow Treatment Wetlands System with (re)use of effluent
Size: two villages
Web-site(s): http://www.irc.nl/source/item.php/1762
Institutes/companies: Spatial Decisions (New Delhi), Punjab State Council for Science and Technology, CH2M Hill Canada Ltd., Industrial Cooperation-CIDA

India; Wastewater disposal through duckweed farming

Place: Vajirabad (Delhi), India
Type: duckweed ponds followed by pisciculture
Size: duckweed ponds of 152x60 meters area and 1.5 meter depth.
Author(s): Dwivedi A.K. (2001)

Indonesia; Constructed Wetlands to Treat House Wastewater in Bandung

Place: Bandung, Indonesia
Type: constructed wetlands
Size: household
Web-site(s): http://jurnal-kopertis4.tripod.com/1201.htm
Author(s): D. Kurniadie and Chr. Kunze
Institute(s): Padjadjaran University, Bandung, Indonesia and Justus Liebig Universität, Giessen, Germany

Kenya; Integrated Aquaculture System at the Baobab Farm

Place: Mombasa, Kenya
Type: integrated aquacultural system
Size: 0,12 ha rice fields, a rich habitat, 1000 crocodiles, a hippopotamus and a lot of fish
Web-site(s): http://www.baobabfarm.com/
http://www.urbanhorticulture.ch/tagungen/polykulturen03/index.htm
Author(s): Rene Haller and Sabine Baer
Company: Baobab Farm Ltd. P.O. Box 81995, Mombasa, Kenya

Mexico; The SUTRANE Integrated Wastewater Treatment System

Place: Xochicalli, Mexico
Type: Unit Treatment System for the Reuse of Water, Nutrients and Energy at the domestic level
Size: household and communities of up to 10,000 inhabitants
Author(s): Bruce Jank (1999)
Wbsite(s): http://www.unep.or.jp/ietc/publications/reportseries/ietcrep9/4.paper-C/4-C-jank5.asp
Institute(s): Xochicalli Eco-Development Foundation, A.C., Mexico D.F, University of Chapingo (Texcoco), Canadian Global Environmental Technologies

Mexico; Full Use of City Wastewater in Monterrey

Place: Monterrey, Mexico
Type: integrated industrial, domestic and agricultural use of treated wastewater
Size: city of 3.5 million people
Author(s): Bruce Jank (1999)
Website: http://www.unep.or.jp/ietc/publications/reportseries/ietcrep9/4.paper-C/4-C-jank5.asp
Institute(s): Canadian Global Environmental Technologies

Morocco; Groundwater Recharge and Wastewater Reuse, Greater Agadir

Place: Ben Sergao, Morocco
Type: groundwater infiltration and subsequent use for irrigation
Size: 1,000 m^3/d of highly concentrated effluents
Web-site(s): http://www.unep.or.jp/ietc/publications/reportseries/ietcrep9/4.paper-D/4-D-asan1.asp
Author(s): Bennani, *et al*., 1992

Pakistan; Wastewater Agriculture in Haroonabad

Place: Haroonabad, Southern-Punjab, Pakistan
Type: agricultural use of raw municipal wastewater
Size: 145 hectares; 4,600 m^3/day raw sewage
Web-site(s): http://www.ruaf.org/no7/29_pakistan.pdf
Author(s): Mehmood Ul Hassan (2002)
Institutes: RUAF and IWMI

Senegal; Aquacultural wastewater purification systems and Reuse

Place: Castor and Rufisque, Senegal
Type: duckweed, water hyacinth and irrigated agriculture
Website: http://network.idrc.ca/ev.php?URL_ID=5911&URL_DO=DO_TOPIC&URL_SECTION=201
Author(s): Gregory Rose (1999)

Tanzania; Constructed wetlands for wastewater treatment

Place: Tanzania (general)
Type: constructed wetlands and stabilization ponds
Size: -
Web-site(s): http://www.scienceinafrica.co.za/2001/september/wsp.htm
http://www.udsm.ac.tz/faculty/foe/wetlands/
Authors: Masudi, A.S, Mashauri, D.A, Mayo, A.W, and Mbwette, T.S.A.
Institute: University of Dar es Salaam, WSP & CW Research Project

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