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INCREASING THE NATURAL VALUES OF TREATED WASTEWATER ON THE ISLAND OF TEXEL, THE NETHERLANDS

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ABSTRACT

The “tourist island” Texel is interesting for testing new policy plans for integrated water management. In this policy plans treated wastewater is being considered as a commodity instead of a burden, a good source of fresh water and nutrients. Moreover, it is demonstrated that a constructed wetland can be beneficial, when combined with the surroundings it can function as a recreation area, increase natural values and be used for recycling nutrients. It can also function as a “water harmonica” between a sewage treatment plant and the surface water, be a part of closing water and nutrient cycles. The full-scale Everstekoog constructed wetland has already proven that a clever combination of an oxidation ditch and a constructed wetland is a cost-effective way to change sewage into ”living" water suitable for various purposes. High numbers of *Daphnia* in a basin, despite low algae concentrations, led to the idea to grow *Daphnia*, which appeared to live on small sludge particles from the sewage treatment plant, incorporated in the so called “kwekelbaarsjessysteem”. It comprises a step-wise ‘food-chain type’ system to increase the ecological value of effluents from oxidation ditches to enhance the natural values on the island, to "produce food" to improve the food situation on Texel of fish and subsequently birds like Spoonbills, which feed on small planktivorous fish, to change the effluent of the sewage treatment plant in a “living water” and to use this improved effluent as a lure flow for a fish trap to siphon fish from the sea across a high Dutch dike. The work on Texel has led to a renewed interest in various types of constructed wetlands in The Netherlands.

KEYWORDS

constructed wetland, food chains, Daphnia, Spoonbills, water management, ecological engineering, effluent

INTRODUCTION

The island of Texel, The Netherlands, is facing many problems and opportunities in water management. It is quite different from the mainland, it has very high natural values, and it is a well-known tourist resort and is still an agricultural stronghold. The island is enclosed by the North Sea and the Wadden Sea. Apart from a drinkingwater line from the mainland, there is no external fresh water supply. Basically it forms its own watershed, it is a small version of the water system on the main land and thus interesting for testing new policy and plans. Until recently many measures in the water system on the island were taken without taking “all” aspects into consideration. The agriculture requires lower ground water tables, leading to intrusion of brackish water and diminishing of the fresh groundwater water lens below the surface of the island. Contrary, nature conservation prefers higher groundwater levels and restoration of saline ground water at several natural areas. These high dikes, a safeguard against the seawater, also form a huge barrier for fish. The De Cocksdorp siphon fish ladder has been an important step towards a more sustainable water system with more opportunities for fish to migrate from the sea to the island water system (Wintermans, 1998).

Integrated water management learned that the way the water system on the island of Texel is managed is not wise. The idea appeared that “all water problems” should be tackled jointly with an integrated approach of “all the aspects of water affairs”. Therefore the project Water for Texel Master Plan (Projectgroep Masterplan, 2000) has been started, in which all parties on the island who have interest in water management are taking their share. It directly appeared that such a plan makes sense and is worth the effort. The Water for Texel Master Plan aims on gaining knowledge on the very complex Texel water system (surface water, groundwater, treated wastewater (effluents)), on the enhancement of the natural values of the surface waters on Texel by separating the different flows and qualities, combining the different interests on Texel. In the meantime the water-related organisations (agriculture, nature, recreation) have accepted the Master Plan, and agreed with a whole array of measures. The total estimated cost of the Master Plan are about € 25 million, the implementation started in September 2001. Several pilot projects, focusing on improvement of diverse natural habitats have been initiated ((Projectgroep Masterplan, 2001)).

During dry periods the wastewater effluent from wastewater treatment plant is considered to be a valuable source of water on the island, but even after treatment in a low-loaded activated sludge plant the quality is not good enough. Although the water is very clear, as it originates from drinking water (plus precipitation), from a biological point of view it is still "dead water", without treatment or dilution it is not suitable for fish. The main sewage treatment plant on Texel, STP Everstekoog is located in the centre of the island. The effluent from Everstekoog flowed to the north in the direction of a brackish area, with high natural values, before being pumped into the Wadden Sea. It was pointed out that it is much more favourable to use the effluent in an area with high agricultural values south of the Everstekoog treatment plant. For this purpose a diversion channel has been constructed.

To improve the effluent quality a full scale constructed wetland was added to the STP in 1994. To monitor the efficiency a joint 4-year research project has been started in 1995 by the Waterboard Hollands Noorderkwartier (until 2003: Waterboard Uitwaterende Sluizen) and the Utrecht University. The first results have been presented at the 5th International Conference on Wetland Systems for Waterpollution Control IAWQ, Vienna (Schreijer, Kampf, et al., 1996; Kampf, Toet, et al., 1996)

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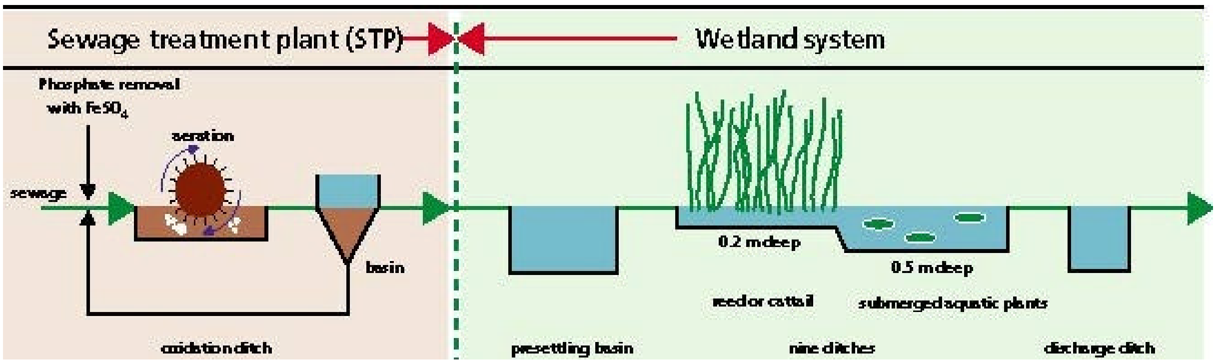

Figure 1. Everstekoog: Scheme of the sewage treatment plant and the constructed wetland.

THE EVERSTEKOOG CONSTRUCTED WETLAND

The STP Everstekoog is an oxidation ditch with a load of 45.000 P.E. (Population Equivalents) in summer and only 10.000 P.E. in winter. Dry weather flow in summer is 3000-4000 m³/day; the maximum flow is 10.000 m³/day. Phosphorus removal takes place simultaneously by dosing ironchloride to the aerationbasin. The full flow of the STP is treated in the surface-flow constructed wetland since 1994. The system consists of a presettling basin, nine parallel ditches with a length of 150 m and a discharge ditch. The first part of each ditch is only 0.2 m deep and has vegetation of reed (*Phragmites australis*) or cattail (*Typha latifolia*). The deeper (0.5 m) part has been planted with submerged aquatic plants. One ditch is a control without macrophytes (Figure 1). Total water surface is 13,000 m^2, total volume is 7,140 m³. The mean total hydraulic retention time (HRT) in the constructed wetland was just over 2 days at dry weather flow in summer. In the first research period (1995-1996) all ditches received the same flow, in 1997/1998 different flow regimes through the ditches resulted in HRT´s of 1.6 up to 11.3 days (resulting in retention times in separate ditches of 0.3, 1, 3 and 10 days).

The investment costs of the constructed wetland alone were less than € 250,000, excluding the extensive instrumentation for the research project. This leads to capital cost of € 25,000 annually. Maintenance and supervision costs are also about € 25,000 per year. At a flow of 1.200,000 m³/year the specific cost is about per € 0.05 per m^3 at an HRT of 2 days and € 0.10 at a HRT of 4 days. To put this in perspective the costs for transport of the wastewater to the STP are estimated at € 0.10 per m³ and for the treatment of the wastewater in the oxidation ditch, including sludge treatment, € 0.50 per m³.

For monitoring and research purposes an extensive instrumentation was fitted in the wetland (pressure sensors for flow measurements, oxygen probes with thermometers, redox sensors and a weather station). The data have been stored in data loggers and transferred automatically to the waterboard office at Edam (Kampf, Schreijer, et al., 1999; Schreijer, Kampf, et al., 2000).

The quality of the effluent of the STP Everstekoog was typical for a well functioning oxidation ditch (very low loaded activated sludge plant). Results of 1997 - 1998 are summarised in Table 1. The effluent has become clear water, but still with an odour. Despite the removal of particles in the settling tank, the effluent still contained fine activated sludge particles, with a variety of bacteria.

Table 1. Effluent quality of STP Everstekoog (1997-1998)

Parameter	*Mean Concentration*	*Standard deviation N >=22*
NO_3-N (mg/l)	2.6	2.5
NH_4-N (mg/l)	1.1	1.6
Total N (mg/l)	6.2	4.3
Total P (mg/l)	1.1	0.7
COD (mg O_2/l)	32	6
E.coli (number per ml)	590	730

The hydraulic retention time had a profound effect on nitrogen removal (mostly due to denitrification) in the constructed wetland. Ammonia levels in the effluent of the constructed wetland varied, but were mostly well under 1 mg/l, nitrate concentrations went down to < 0.5 mg/l at the longer hydraulic retention times, even in winter. The load of N and P with the STP effluent to the Everstekoog constructed wetland is around 5,000 kg N/ha/year and 700 kg P/ha/year. Nitrogen removal was calculated as 1,250 kg N/ha/year. This means that a surface area of at least 5,000/1,250 = 4 ha (instead of 1.3 ha) is needed for a complete nitrogen removal in the system (HRT of 8 to 10 days). Phosphate removal in the Everstekoog constructed wetland was rather low, leading to the conclusion that when low P-concentrations in the effluent are preferred biological or chemical removal in the activated sludge plant is more attractive.

To our opinion the “classic” water quality parameters do not describe the changes in the water in the constructed wetland aptly. Already in the presettling basin of the constructed wetland the water started to "live", started to resemble eutrophic, but clear surface water. Regularly the water turned red through high numbers of zooplankton, mainly *Daphnia magna* (Figure 2).

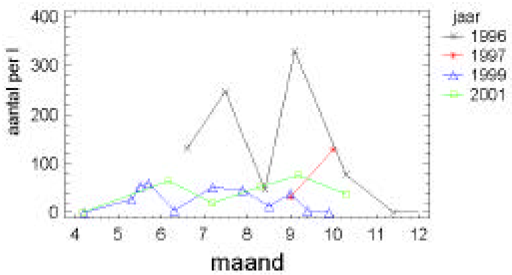

Figure 2. *Daphnia* in the presettling basin of the Everstekoog constructed wetland in four different years

The number of different species of plants and animals in the wetland has grown each year. Another good parameter to demonstrate the change in water quality is the diurnal oxygen pattern. The oxygen level in the effluent of the oxidation ditch was low, in the presettling basin it was only 2-3 mg/l. In the part of the ditches with submerged aquatic plants the daily oxygen pattern started to resemble the pattern of normal surface water. During daytime, the submerged aquatic plants and algae produced such an amount of oxygen that the level rose well above the saturation value (up to 20 – 30 mg/l). The high oxygen levels in the afternoon helped oxygen to penetrate deeper into the sediment. At the end of the day, the oxygen levels dropped

sharply. This "solar energy process" for production of “free” oxygen-supply was also stable during longer periods, and functioned even under ice in wintertime.
The effluent of the constructed wetland was even more turbid then the effluent of the STP, but it was a different kind of suspended solids. Instead of activated sludge flocs, the water contained algae, *Daphnia* and other small wildlife. An interesting observation was that the presettling basin, and the ditches with a short retention time did not contain any fish, despite the high numbers of *Daphnia*. The reason is probably that the high concentrations of free nitrogen at high loads during certain periods of the day, when nitrification in the STP is less than average, are toxic for fish.
Only after a hydraulic retention time of over 2 days in the ditches the water was suitable for fish such as Stickleback. On Texel both Threespine Stickleback (*Gastrosteus acculeatus)* and Ninespine Stickleback *(Pungitius pungitius)* occur, it is the main food of Spoonbills (*Platalea leucordia)*, breeding in good numbers on the island. In ditches with more then 3 days HRT the number of Stickleback could be high, up to 25 per m^2. Although the constructed wetland is situated in the agricultural part of the island, fishes attract quite high numbers of birds. Especially Spoonbills (*Platalea leucorodia*) come to feed on small fish. In 1997 40 birds of 11 species bred in the constructed wetland (Kampf, Schreijer, et al., 1999; Kampf, Eenkhoorn, et al., 2002). A general introduction of natural values of constructed wetlands can be found in Leonard, Kadlec, et al., 1995 and Knight, 1996.

The high numbers of *Daphnia* in the constructed wetland effected also the disinfection capacity of the system. For disinfection to a level of 10 E.coli per ml, a HRT of 2 days will be sufficient. Possibly, due to wildlife in the system, the E.coli numbers were rarely below 1 per ml. For E.coli values of less then 10 per ml throughout the year, the HRT must be at least 4 days. To minimise the influence of storm water flows it is important to buffer as much water in the system as possible. For a surface flow system this can be done by means of an appropriate design of the weirs.

More information can be found in the Dutch report on the project (Schreijer & Kampf, 2000), several conference papers (see the reference list), the PhD-thesis on the project (Toet, 2003) and through the website www.rekel.nl/water.

A surface flow constructed wetland, like the Everstekoog system, is a simple and attractive system. It is also cheap as long as land costs are not too high. It looks like a Dutch polder landscape; the maintenance of the system resembles the maintenance of ditches and canals the waterboard is accustomed to already for centuries.

SPIN-OFF: THE KWEKELBAARSJES SYSTEM – A FOOD-CHAIN BASED CONSTRUCTED WETLAND

The massive development of *Daphnia* and other zooplankton in the presettling basin of the Everstekoog constructed wetland in summertime, as depicted in Figure 2, had puzzled us first, but also led to some innovative ideas. The first question that arose was: how can all these *Daphnia* (only *Daphnia magna*) survive? The numbers of algae in this basin (<10 μg/l chlorophyll-a) were very low, not enough to maintain this population (most aquaculture systems have an algae module involved (See for instance (Borowitzka & Borowitzka, 1988; Proulx & La 1985; Staudenmann, Schönborn, et al., 1996). This led to the hypothesis that the zooplankton lived mainly on bacteria, the so called “pin-point flocs” in the effluent. The waterboard asked the Netherlands Organisation for Applied Scientific Research TNO for help. To test this hypothesis experiments were conducted using 80 l microcosms (one set was kept in the dark to prevent algae growth, another set in light to stimulate algae growth) it could be shown that the occurrence of *Daphnia* in the pond was determined by the availability of activated sludge flocs and loose bacteria, thus proofing that *Daphnia* indeed consumed activated sludge flocs. The observation was be stated with microscopic determination of the guts contents. Also on a practical scale in the Everstekoog constructed wetland the consumption of sludge particles contributed in a sizeable reduction of suspended solids in effluent from STP's (Groot, 1998; Hoogstrate, 2001; Rosenkranz, 2001). The effect of *Daphnia* in a pond with well-treated wastewater can also be described by the filtration capacity. McMahon & Rigler and Lampert give values of up to 4 ml/*Daphnia* per hour (McMahon & Rigler, 1965; Lampert, 1987). This means that a population of 100 per litre will filtrate 400 ml/l/h. This means that “every drop of water” in the presettling basin will pass the body of a *Daphnia* 10 times per day. Thus during the 1.3 days hydraulic retention time in the presettling basin the treated wastewater will be filtrated 13 times by *Daphnia* on an average, when 100 *Daphnia* per litre are available.

It was concluded that growing *Daphnia* in a surface flow constructed wetland could be an interesting process. In principle it is possible to lower the amount of sludge discharged to the surface water, but it could also be a contribution to disinfection of the effluent of a STP by consumption of pathogen bacteria, as could also be derived from the results with the Everstekoog constructed wetland (Schreijer, Kampf, et al., 2000).

The ideas and knowledge described above and the knowledge obtained during the “Everstekoog project” led to plan a combined “natural constructed wetland” system:

- to enhance the natural values on the island of Texel;
- to "produce food" for fish and subsequently for birds such as Spoonbills, which feed on small zooplanktivorous fish;
- to change the effluent of the sewage treatment plant into a “living water”.

For the sewage treatment plant De Cocksdorp there can be another benefit. The improved effluent could be used as a lure flow for a fish trap to siphon fish from the sea across a high Dutch dike.
One of the problems on the island is that for defence against the sea high dikes have been built. This makes the island much more difficult to reach for fish migrating from the sea to the island. Three Spined Stickleback (*Gasterosteus acculeatus*) grow up at sea and migrate back to inland waters to spawn, like salmon. It is hardly a problem to migrate back to the sea. The fish is easily pumped or flushed out with superfluous water. The new and higher dikes resulted thus in lower number of fish on the island. Together with other changes in landscape and land use, this has resulted in a worsening of the food supply for fish eating birds on the island. Not only the number of Three Spined Stickleback had decreased, but most of the fish remained smaller indicating a part of the population does not migrate anymore (non-migrating Stickleback stay much smaller than the ones that grow up at open sea (Wintermans, 1998).
One of the most striking birds of Texel, the Eurasian Spoonbill, feeds mainly on sticklebacks. It is a contrasting situation, the number of Spoonbills in The Netherlands have increased dramatically the last years, from around 250 around 1980 to 1543 in 2002, with 220 pairs on Texel alone (van Dijk, 2003; Overdijk, pers. Comm., 2002). The Spoonbill is a highly valued species on Texel, as being a big white bird. A favourite bird of many people, inhabitants of the island as well of tourists. It can be considered a an indicator for the success of nature conservation and for water quality measures on the island (Kampf, Eenkhoorn, et al., 2002).
All these aspects are brought together in the development of a step-wise food-chained water system, in a Dutch catchword (difficult to translate): the “kwekelbaarsjes system”, described in Figure 3.

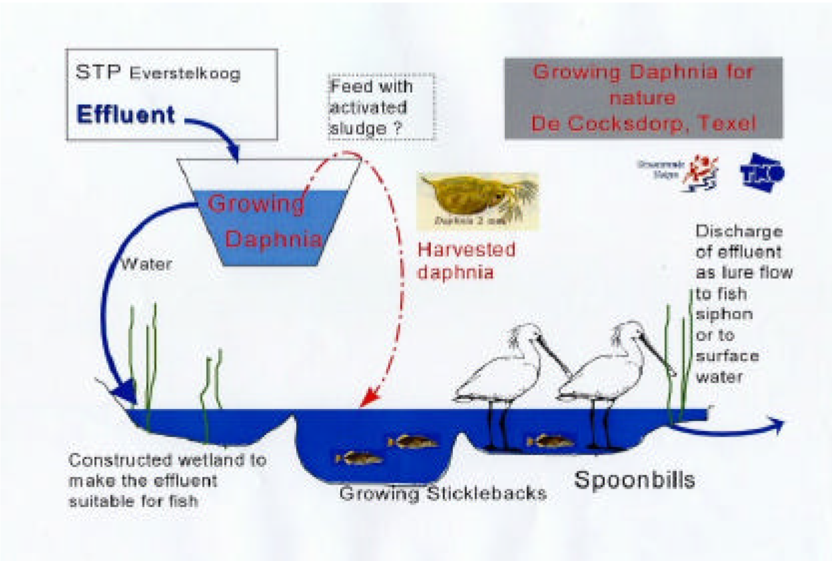

Figure 3. Sketch of the “kwekelbaarsjes system” to grow biomass on the “energy available” in treated wastewater

Basically, the system comprises a step-wise ‘food-chain type’ system to increase the ecological value of effluents from oxidation ditches. In the *Daphnia*-basin the sludge particles are used to culture *Daphnia*. The effluent flows to the constructed wetland to make the water suitable for fish. The harvested *Daphnia* can be transported to a deeper part of the "kwekelbaarsjes system" to be used as food for fish, such as Sticklebacks. This part is to deep for Spoonbills to forage. The last, shallow, part of this specially constructed wetland could be constructed as foraging area for Spoonbills. The board of the Waterboard accepted this idea and gave permission for further development of the process. Interesting in this decision was that the Waterboard choose for a more or less uncertain and innovative ecological engineering process, instead of the original choice of demolition of the De Cocksdorp plant and the construction of a pipeline to the Everstekoog STP.

One of the uncertainties in the "kwekelbaarsjes process" is the "Growing *Daphnia*-module" in figure 3. Despite the enormous amount of knowledge about *Daphnia* available (both in scientific literature as in the practice of growing *Daphnia* for fish food), we could not find systematic knowledge about the process of growing *Daphnia* on treated wastewater. Therefore the Waterboard and TNO carried out a research project to assess the feasibility of the idea (in 2001 and 2002, to be continued in 2003). In the laboratory we focused on the possibility of production of *Daphnia* with activated sludge as the main food source. We have continued the research project with experiments aimed at the cultivation of *Daphnia* on effluent at a pilot scale. Also harvesting of *Daphnia*, based on the work of Proulx (Proulx & La, 1985), has been taken into account. The experimental work was carried out on the Everstekoog STP in four 20 m^3 ponds and four 2 m^3 mesocosms (Figure 7). In 2002 we focused on process stability of the system and on ecotoxicological aspects. Results have been published in Dutch ((Foekema & Kampf, 2002)) and on the Internet site www.rekel.nl/kwekelbaarsjes. Description of the results goes beyond the scope of this publication. However, in future publications more attention will be given to the *Daphnia* basins, growth and harvesting of *Daphnia*, etc.
Result of the literature study and biological tests (Foekema, Blankendaal, et al., 2003) with effluents of nine STP's (including Everstekoog and De Cocksdorp) showed little to some eco-toxicological effects on the growth of *Daphnia* in pure effluents. More effects on the growth of algae have been found, as was expected based on earlier experiments ((Groot, 1998), (Kampf, Jak, et al., 1999)). Special attention should be paid to avoiding overloading of STP's with a "food-chained constructed wetland" if this leads to lower removal efficiencies and thus increasing the risk of negative effects of the effluents, due to compounds with toxic effects

Figure 4. Test facilities on Texel. On the foreground the four 2 m^3 mesocosms, behind the four 25 m^3 ponds. In the background the Everstekoog constructed wetland

The research confirmed that the "kwekelbaarsjes system" near the village of De Cocksdorp, in connection with the siphon fish ladder, the extension of the sewage treatment plant of De Cocksdorp would be feasible. It is expected to lead to an innovative co-operation between engineering and nature (ecological engineering). The construction of the system is already part of the Water for Texel Master Plan (Projectgroep Masterplan, 2000).

Demonstration of the values of the surface-flow constructed wetland on Texel lead to a slow, but steady increase of interest in The Netherlands for this type of upgrading effluents. The first large scale constructed wetland of this type was developed at the STP Land van Cuijk, where an intensive monitoring programme is being carried (Eijer-de Jong, Willers, et al., 2002).

Friesland Water Authority is planning a similar project on the island of Ameland, an island comparable to Texel. The idea that could be worked out is not to discharge the effluent anymore into the Wadden Sea, but to keep it on the island itself. This is encouraged in Dutch governmental policy. Plans are in a developing phase to bring the water into the dunes to replenish the groundwater, after a pre-treatment in ponds. The water can be infiltrated in some dune valleys, "shaped according to ecological engineering principles". It will support a groundwater stream for several farmers who are located downstream in the polder and will strengthen the "fresh water lens" in the dunes, making it possible to restore some wetlands in the dune valleys in the nearby nature reserve. Another possibility could be an idea for the STP Grou on the mainland of Friesland, as pictured in Figure 8. After an Everstekoog-type surface-flow wetland, including some *Daphnia* ponds, a system of ponds could function as a fish spawning area (especially for Pike) for the surrounding canals, which are lacking natural values. The recently built constructed wetland Sint Maartensdijk, a combination of a root-zone constructed wetland for effluent polishing of effluent and a nature and recreation area, see Figure 5 demonstrates how this can be demonstrated in practice.

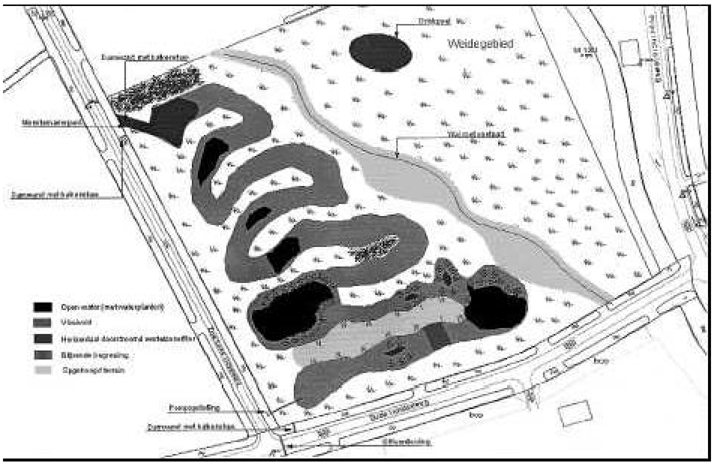

Figure 5. A “natural” constructed wetland Sint Maartensdijk (`www.neerslag-magazine.nl/artikel.asp?key=82`)

These principles of ecological engineering are further applied in the Waterpark Groote Beerze, a combination of a constructed wetland and its surroundings. The extension of the STP Hapert (Waterboard De Dommel) is combined with a river restoration project. The effluent is polished by passage through root-zone reed-beds, open-ponds and wetland forest before it is discharged to the river Dommel (Figure 6 (NN, 2001).

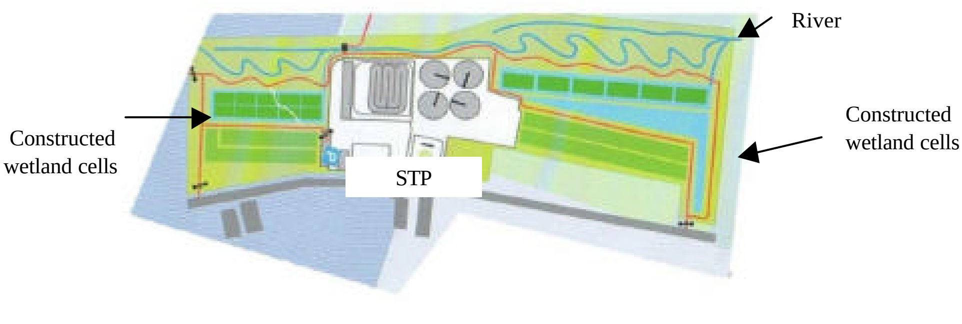

Figure 6. Waterpark Groote Beerze ((NN, 2001)).

On the STP Wervershoof, a low-loaded activated sludge plant with a capacity of 214,000 Population Equivalents, falling under the authority of the Waterboard Hollands Noorderkwartier, the effluent is disinfected with chloride for over ten years now, but only in summertime to protect the health of swimmers in a nearby recreation area. Table 2 learns that even at a HRT of 2 days an open water constructed wetland can lead to a very reasonable disinfection. The difference between the average values and the median shows a lack of process stability during rainy periods. This emphasises the need of buffering the water. It shows that a wetland system, like Everstekoog, results in a better disinfection than chemical disinfection, even at a relative low hydraulic retention time of 2 days. This knowledge led to the decision to postpone the nearly ordered UV-disinfection unit and to start the planning of a constructed wetland, mainly for disinfection purposes. It appears that the Ekeby constructed wetland in Sweden is a good example for a disinfecting constructing wetland in Wervershoof (http://www.kuai.se/~leilin/vatmark/wetland.htm).

Tabel 2. Comparising the disinfection of effluents (summer 1996) in the Everstekoog constructed wetland (hydraulic retention time 2 days) and the results of the disinfection with choride of the effluent of the STP Wervershoof

	Everstekoog constructed wetland	*Wervershoof chemical disinfection*
	E.coli (per ml)	
Number of observations	12	22
Average number	27	111
Median	2,2	8
Standard deviation	74	262

THE RESULTS IN A WIDER PERSPECTIVE: THE “WATER HARMONICA”

In development of ecological engineering several authors struggled with the contrast between engineering and nature. A good introduction is the publication “Ecological Engineering – the 7 year itch” (Mitsch, 1998) in a special issue of the journal Ecological Engineering. Basically, a constructed wetlands, including food-chain based water systems, like the “kwekelbaarsjes system” is a medium between “conventional” engineering (sanitary or process engineering in a sewage treatment plant, conventional polder and ditch management and waterway management in canals and lakes. For constructed wetlands it already has been tackled on a theoretical way by Theo Claassen of the Friesland Water Authority (Claassen, 1996). The basic idea, which was honoured by a prize at the occasion of the 25th year jubilee of the Dutch Foundation for Applied Water Research STOWA (www.stowa.nl) in 1996, is depicted in Figure 7.

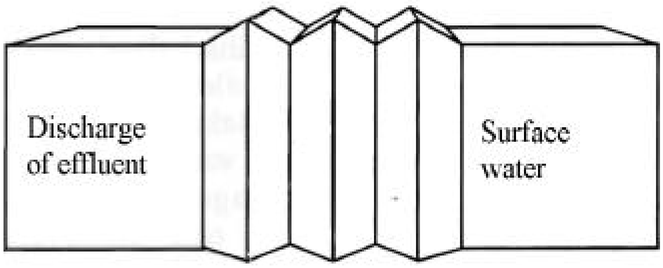

Figure 7. The “Water harmonica” as a buffer between the sewage plant and surface water, based on (Claassen, 1996)

This model uses a "buffer" between the sewage treatment plant and the surface water, on which the effluent of the STP is discharged. In this buffer the different fields of engineering and ecology meet each other to improve the quality of the STP effluent into natural "living" surface water. The examples, described in the paragraph above (not only the Everstekoog constructed wetland and the “kwekelbaarsjes system”, but also the other examples fit very well within the “water harmonica”. It seems to be an useful way of describing the use of ecological engineering principles in water management. Multifunctional constructed wetlands seem to be good tools in water management focused on improving water quality, natural values, buffering water, recreation and using nutrient for agricultural production may all go hand in hand.

This may look novel, but basically it has many parallels with the recent developments in agriculture, where farmers are learning in a quick way to “work with nature instead of against nature”. Useful entrances to this subject on international sustainable water management are the sites www.sida.se and www.gtz.de/ecosan. Also in The Netherlands a lot of work has been done recently on separation of water flows, like separate discharge of rain water, but also a further separation of wastes, preventing discharge in sewer systems is emerging actually (Mels, Mes, et al., 2002). In principle, the old “honey bucket system” of our ancestors is It seems contrasting with recent trends in wastewater treatment to use (new) high technological processes, like membrane filtration, biofilm processes, etc. However, it should fit also in recent developments of ecological engineering. Much more information is available on this subject. 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. In integrated water management it opens nice perspectives in using technical processes in “nature” and more natural processes in “engineering”, comparable with what has done on Texel. getting modern again (Winblad, 1998). The basic principles for possible application in a rural Nepali community are depicted in Figure 8. The principles of re-using not only the water (volume), but also the nutrients still present in the waste water 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 $9x10^{10}$ 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 $x10^{10}$ kg/year)”. To say the least it is an encouragement for re-use of nutrients, separation of wastes at the source, etc.

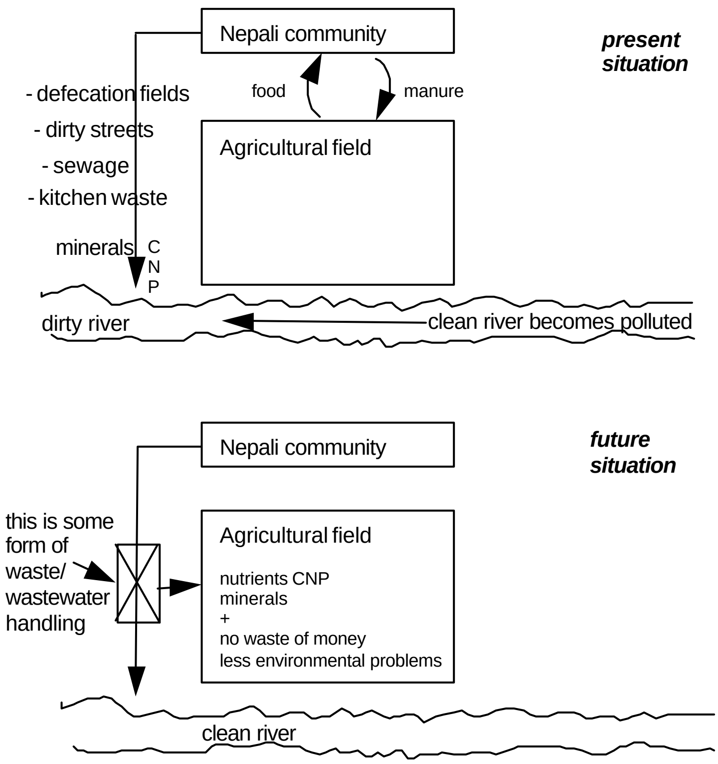

Figure 8. Closing the nutrient cycle, as an example of useful (re)use of water and nutrients in a Nepali community (Bolt, Claassen, et al., 1999)(Claassen & Kampf, 1999) . More information on the de website: www.rekel.nl/closethenutrientcycle

In many cases it is not (yet) possible to separate wastes at the source. In those cases it is obvious to choose for a clever solution, bearing in mind that wastewater was often “the best water we had” . Before using it was rather expensive: drinkingwater and rainwater that has been “mis-used” to discharge relative small volumes of wastes (about 700 l faeces, urine and kitchen wastes are diluted into a total stream of 30.000 l waste water per person annually). As is demonstrated in the Everstekoog research project it is possible to convert wastewater, after treatment in a well functioning wastewater treatment plant, followed by a constructed wetland, into usable and valuable surface water. Even the nutrients and sludge particles in the effluent can be used beneficial, as demonstrated in the research carried out for “kwekelbaarsjes system”. This opens the door for natural constructed wetlands with recreational, natural and possibly even agricultural functions. The Dutch Foundation for Applied Water Research STOWA (www.stowa.nl) funded a two-year research project, carried out by consultant Royal Haskoning (www.royalhaskoning.com). Main objectives of this project, including the first part of the first authors PhD-project, are to elaborate the “water harmonica”, to promote demonstration projects in The Netherlands as well as abroad and to provide a basis for knowledge exchange in projects fitting in the “water harmonica”: constructed wetlands to convert treated wastewater in usable and biological healthy surface waters, based on principles of ecological engineering.

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