The Use of Treated Wastewater for Nature: The Waterharmonica, a Sustainable Solution as an Alternative for Separate Drainage and Treatment

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ABSTRACT

During the last decennium separation of wastes has matured into practical use. Separation not only reduces the amount of drinking water spilled in toilets, but makes reuse of nutrients attractive. The main drawback of separation is that it is rather expensive, especially in areas with an existing sewage system. Large centralised sewage treatment plants discharge waste water from large areas on one spot, with a considerable effect on surface water quality. It results in an ambivalent situation. Drinking water is becoming more and more expensive. After use in households and industry this water, collected together with rain water, is considered as a waste. It is transported in sewer systems and treated at huge costs in sewage treatment plants. But after discharging in surface water ecologists consider this cleaned water, originating from drinking water, as “dead water” compared with healthy surface water, not complying with the ideas about natural water quality, as described in the latest directives on ecological water quality of the European Union.

To bridge the gap between these two “worlds” (producing drinking water, transporting waste water on one hand and on the other hand the caretakers of surface waters) the *Waterharmonica* have been postulated. It is a low-tech concept based on ecological engineering, using food-chain approach to transfer well treated waste water into "healthy and useable" surface water. The main function is converting treated waste water into a usable natural surface water, but aspects like water buffering, recreation, buffer zones, nature development, water buffering during floods, creating fish spawning areas, growing fish for stocking wild populations are getting more and more important. In this paper the development of the concept is described. The *Waterharmonica* concept has resulted in a research and implementation programme (2003- 2004) of two of the main Waterboards in The Netherlands, supported by the Dutch Foundation for Applied Water Research.

This paper describes the development of the concept within integral water management.

KEYWORDS

Integrated water management; ecological engineering; effluent; nature development; constructed wetland; food chains; *Daphnia*, Spoonbills

Introduction

In 1970 the Dutch Pollution of Surface Waters Act became into force. That was the start of a large scale effort to improve environmental quality in The Netherlands. From the very beginning the emission reduction approach (from point- as well as from diffuse sources) formed the main strategy for upgrading surface water quality. The water system approach was added later on as a second strategy focused on reaching surface water quality standards. Although tremendous efforts have been realised since then, surface water quality standards are still exceeded, especially for nutrients, transparency and chlorophyll. This discrepancy needs a reconciliation to decrease the gap between aquatic-ecological objectives and actual surface water quality, or -as a consequence- between emissions and receiving water system. The discharges from sewage treatment plants (STPs) still form, as point sources, an important percentage of the loads to Dutch surface waters. So, a further upgrading of wastewater before discharging into surface water seems to be needed.

Another development is coming up, that is the interest in reuse of effluents from STPs. The reasons for water reuse are quite various, as e.g. replenishing of ground water sources related to combating desiccation, as a source of fresh water in situations of water shortage or salty water, for irrigation in agriculture, and for recreational and nature development. However, actual effluent quality doesn’t fit the specific standards for direct reuse; it does not matter for which intended use. So, in general additional treatment or polishing of the effluent seems to be necessary.

The concept of the Waterharmonica has been postulated to bridge the gap between both approaches, for the effluents of STPs, by upgrading the effluents to reanimated and useable water, feasible for many purposes. Creating short-circuits is possible in the lope of emissions of wastewater (within the water chain) and surface waters (within the water system). Environmental profits and contributions to sustainable management can be reached by incorporating this water cycle into regional plans and measures of integrated water management.

Texel

The island Texel is an attractive island for testing new policy for integrated water management. This island in the north western part of 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 drinking water 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. Until recently many measures in the water system on the island were taken without taking all these 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. The high dikes of the island, a safeguard against seawater, also form a huge barrier for migrating fish. The De Cocksdorp siphon fish ladder has been an important step towards a 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”. In the Water for Texel Master Plan all parties on the island who have interest in water management (agriculture, nature, recreation) 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 and on enhancement of the natural values of the surface waters on Texel by separating the different flows and qualities. The total estimated costs of the master plan are about € 25 million.

The Everstekoog constructed wetland

The effluent from Everstekoog, located in the centre of the island, 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 attractive to use the effluent in an area with high agricultural values south of the Everstekoog STP. 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. A joint 4-year research project has been started in 1995 to monitor the efficiency (Schreijer et al, 2000).

Figure 1 Everstekoog: Aerial View of the constructed wetland, on the background the STP , (photo Simon Smit, Texel)

The STP Everstekoog is an oxidation ditch with a load of 45.000 P.E. (Population Equivalents) in summer due to the tourism and only 10.000 P.E. in winter (Figure 1). 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 iron-chloride to the aeration basin. The quality of the effluent of the STP Everstekoog is typical for a well functioning oxidation ditch (very low loaded activated sludge plant): NH_4-N ca. 1 mg/l, NO_3-N ca 2.5 mg/l, COD ca. 30 mg/l. Due to simultaneous P-removal with FeSO4 total-P is ca. 1 mg/l. The constructed wetland consists of a presettling basin, nine parallel ditches with a length of 150 m and a discharge ditch (Figure 2). Total water surface is 13,000 m$^{2.}$ 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 of 1.8 up to 11 days

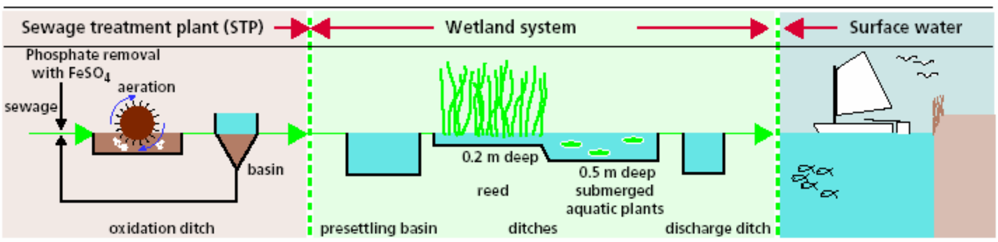

Figure 2 The Everstekoog constructed wetland in relation with the STP and surface water

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 longest hydraulic retention times, even in winter. The load of N and P with the

STP effluent into 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. At the above mentioned N-load a HRT of 5.5 days will be needed for a low ammonium concentration in the effluent throughout the year (Toet, 2003), 10 days hydraulic retention time will lead to more natural values in the constructed wetland. Phosphorus 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. Effluent from a STP is “dead water” from a surface water quality point of view. But, already in the presettling basin of the Everstekoog 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* and also *Daphnia pulex*.

The oxygen level in the effluent of the STP 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 oxygen was also stable during longer periods, and functioned even under ice in wintertime.

The effluent of the constructed wetland was more turbid than the effluent of the STP, but it was a different kind of suspended solids. Instead of activated sludge flocks, 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*. During daytime when the load of nitrogen is higher than the nitrification capacity of the STP ammonia levels will rise. This leads to high free NH_3, especially at higher temperatures and higher pH-values, which can be toxic for fish.

Only after a HRT 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. Constructed wetlands can be rich in wildlife (Kadlec and Knight, 1995 and Knight, 1996). Although the Everstekoog constructed wetland is situated in the agricultural part of the island natural values are attractive. The numerous fishes attract high numbers of birds. Especially Spoonbills (Platalea leucorodia) come to feed on small fish. In 1997 eleven bird species bred in the constructed wetland (Kampf et al., 1999; Kampf et al., 2002).

The high numbers of *Daphnia* in the constructed wetland effected also the disinfection capacity of the system. For disinfection from 500 – 1000 faecal coliforms per ml in the effluent of the STP to a level of 10, a HRT of 2 days will be sufficient. Possibly, due to wildlife in the system, the coli numbers were rarely below 1 per ml. For 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.

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. The lay-out is 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-chained based constructed wetland

The massive development of *Daphnia* and other zooplankton in the presettling basin of the Everstekoog constructed wetland in summertime 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? As stated above fish is absent in this basin, but also the numbers of algae in this basin (<10 µg chlorophyll-a /l) 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). This led to the hypothesis that the zooplankton lived mainly on bacteria, the so called "pin-point flocks" in the effluent. The number of *Daphnia* in the pond was determined by the availability of activated sludge flocks and loose bacteria, *Daphnia* indeed consumed activated sludge flocks, as the guts contents proofed (Kampf et al, 1999). The effect of *Daphnia* in a pond with well-treated wastewater can also be described by the filtration capacity. McMahon & Rigler (1965) and Lampert (1987) give values of up to 4 ml per *Daphnia* per hour. Thus, a population of 100 *Daphnia* / litre can filtrate 400 ml/l/h or 10 l/l/d, or "every drop of water" in the presettling basin will pass the body of a *Daphnia* 10 times per day.

It was concluded that growing *Daphnia* in a surface flow constructed wetland could be an interesting process. For the sewage treatment plant De Cocksdorp on the northern tip of Texel there could be another benefit. The improved effluent could be used as a lure flow for a fish trap to siphon fish from the sea across the dike. One of the problems on the island is that high dikes have been built for defence against the sea. This makes the island much more difficult to reach for fish migrating from the sea to land. Three Spined Stickleback 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, fish is easily pumped or flushed out with superfluous water. The new high dikes resulted thus in lower number of fish on the island. One of the most striking birds of Texel, the Eurasian Spoonbill, feeds mainly on sticklebacks. The Spoonbill is a highly valued species on Texel, a favourite bird of many people, inhabitants of the island as well of tourists. It can be considered as an indicator for the success of nature conservation and for water quality measures (Kampf 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 (Kampf et al, 1999 and www.rekel.nl/kwekelbaarsjes).

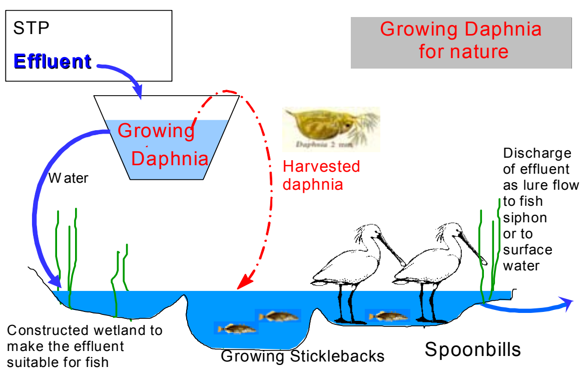

Figure 3 Sketch of the "kwekelbaarsjes system" to grow biomass on the "energy available" in treated wastewater

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 too deep for Spoonbills to forage. The last, shallow, part of this specially constructed wetland could be constructed as foraging area for Spoonbills. 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" (Figure 3). Despite the amount of knowledge about *Daphnia* available we could not find systematic knowledge about the process of growing *Daphnia* on treated wastewater. 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. The experimental work is continued on the Everstekoog STP in four 20 m^3 ponds and four 2 m^3 mesocosms (see Foekema & Kampf, 2002 and www.rekel.nl/kwekelbaarsjes for more information. Results of the literature study and biological tests (Blankendaal et al., 2003) with effluents of nine STP's (including Everstekoog and De Cocksdorp) showed little 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. 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 a lesser degree of removal of toxic compounds.

The research confirmed that the "kwekelbaarsjes system" near the village of De Cocksdorp, in connection with the siphon fish ladder, the extension of the STP of De Cocksdorp would be feasible. It is expected to lead to an innovative co-operation between engineering and nature (ecological engineering).

Prospects for food-chain based water systems

Demonstration of the values of the surface-flow constructed wetland on Texel lead to a slow, but steady increase of interests in The Netherlands of upgrading effluents with surface flow constructed wetlands. The first large scale Everstekoog type constructed wetland with reed beds and ponds was constructed at the STP Land van Cuijk, where an intensive monitoring programme is being carried out (Eijer-de Jong 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. Another plan has been made for the STP Grou on the mainland of Friesland. 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 is a combination of a root-zone constructed wetland for effluent polishing and a nature and recreation area (Ton, 2000).

The 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 (NN, 2001). Good examples elsewhere are the Ekeby constructed wetland in Sweden, the famous Arcata Marsh in northern California and the 7 ha Empuriabrava constructed wetland for polishing and reuse for nature and agriculture in the Costa Brava in Spain (Sala & Mujeriego, 2000). These and other examples will come available trough the project website www.waterharmonica.nl, see also Kampf et al (2003).

The results in a wider perspective: “the Waterharmonica”

Basically, a constructed wetland, 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 already on a theoretical way by Claassen (1996) of Friesland Water Authority. The basic idea is depicted in Figure 4.

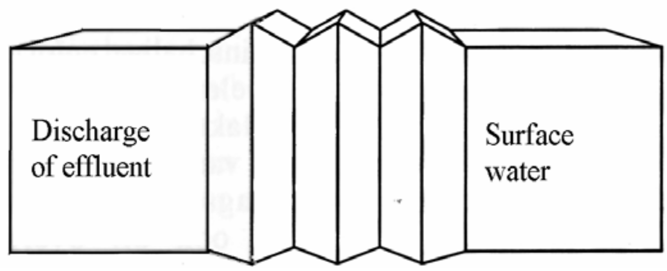

Figure 4 The “Waterharmonica” as a link between the sewage plant and surface water, based on Claassen, 1996

This model uses a "link" between the sewage treatment plant and the surface water, on which the effluent of the STP is discharged. In this link 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 before (not only the Everstekoog constructed wetland and the “kwekelbaarsjes system”, but also the other examples) fit very well with the concept of the “Waterharmonica”. It seems to be an useful way of describing 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.

Much attention has been paid recently in sanitation concepts to separation of water flows, like separate discharge of rain water, but also to a further separation of wastes, to preventing discharge in sewer systems is emerging actually. In many cases it is not (yet) possible however 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 drinking water, plus 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 STP, 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 the “kwekelbaarsjes system”. This opens the door for natural constructed wetlands with recreational, natural and possibly even agricultural functions to convert treated wastewater in usable and biological healthy surface waters.

This concept has resulted in a research and implementation programme (2003- 2004), called the Waterharmonica, and financed by the Dutch Foundation for Applied Water Research.

The project is carried out by consultant Royal Haskoning (www.royalhaskoning.com). Main objectives of this project are to elaborate the concept of the “Waterharmonica”, to promote demonstration projects in The Netherlands as well as abroad and to provide a basis for knowledge exchange in projects fitting in the “Waterharmonica”: constructed wetlands to convert treated wastewater in usable and biological healthy surface waters, based on principles of ecological engineering. The Lettinga Associates Foundation (LeaF, www.ftns.wau.nl) of the Wageningen University is involved in assessing the use of the "Waterharmonica" for conversion of treated waste water into a natural resource in the developing world (Martijn et al, 2003).

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** can be downloaded from www.waterharmonica.nl*