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Ecological Urban Civil Engineering for Constructed Multi-functional Wetlands, an Asian Perspective

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Abstract

The article overviews the present situation with regard to large scale multi-functional wetlands (both constructed and natural) in Asia and Australasia, representing the most degraded ecosystems on the planet, particularly focusing on developing countries. It scrutinizes a spectrum of wetlands ranging from integrated pond-reedbeds simulating natural habitats to mangrove-based facilities. Approaches are pointed out for further harmonization of human-oriented functions with interests of nature. Lessons derived from experience at a relatively few existing sites are rationalized for successful promotion among a wider range of communities. The main trend for the application of the technology in developing communities is to gradually steer to tertiary treatment from frequently used primary and secondary treatment. If artificially enhanced trophic level of these ecosystems is properly managed and contained, while microbial, plant and animal diversity is not compromised, these re-created habitats will harbour a significantly higher abundance of wildlife. Not only will they save the environment from eutrophication, but these constructed ecosystems can compensate for the habitats and wildlife lost to ever-increasing human development. Furthermore, implications of the 2003-2006 global outbreaks of Highly Pathogenic Avian Influenza for the present and future of the wetland technology encouraging wild birds are discussed stating that political and trade considerations must not override humanitarian needs of biodiversity conservation.

Keywords: Wetlands; Wastewater treatment; Aquaculture; Agriculture; Nature conservation and education

Introduction

Though development and the multi-functional use of wetland systems based on freshwater marshes, estuarine mangroves and mudflats, land/grass treatment systems, border strips, irrigation-related technologies, bio-engineering systems, etc) was pioneered by the developed countries, the developing world is potentially their greatest application area. However, the Asian developing world, preoccupied with the necessities of human existence, is barely enlightened to endorse the concept of landscape and biodiversity beneficiation as does the developed world. As a result, very few sites combining waste treatment with agriculture,

landscape beneficiation and biodiversity conservation exist in Asia. However, these sites should provide an impetus for the developing communities worldwide, an incentive, which is still to be realized on a scale it deserves. For decades the professional community has been talking of the futility of solving pollution problems globally through high tech approaches, only recently this has been realized at the political and decision-making level. At the same time innovative farmers and conservationists have begun to mitigate the impact of human activities on landscape and biodiversity by developing the concept of “eco-agriculture”, the concept striving to increase agricultural productivity and farmer incomes, while sustaining or increasing wild biodiversity in a better landscape. Coastal ecosystems, naturally comprising large number of wetlands, came to the fore with the recent tsunami which accentuated the major importance of wetlands, mangroves, etc, for the mitigation of coastal impacts [1, 2] and stimulated efforts to conserve and rehabilitate them. Large scale approaches are urgently needed for agricultural communities producing in or near areas of high biodiversity and watershed value, and those working in degraded landscapes where the ecosystems are in need of urgent rehabilitation. No other technologies suit the task better than wetlands. Moreover, few other types of land use will save existing natural wetlands in urban and peri-urban locations from omnipresent and powerful real estate developers, which see wetlands as “wastelands” to build on and prefer lucrative construction, rather than environmentally friendly wetlands with multi-functions.

Though the use of multi-functional wetlands was extensively reviewed, particularly for Europe and USA [3-5], the situation was never scrutinized in its entirety in Asia, the continent where major, albeit very few, wetland-based facilities operate [6-12]. Most prominent among these cases, success stories of inspirational value are described below. Even in the developed countries, the conservation potential has been appreciated only fairly recently [13]. Though substantial research was conducted in the USA [5], a dearth of information exists for this topic in tropical and subtropical Asia, as well as other regions. The present article overviews both constructed and natural wetlands comprising freshwater and coastal ecosystems focusing on those which feature functions of wastewater treatment, aquaculture/agriculture and nature conservation/education.

One of the reasons for the lack of popularity of wetland-based technologies in the developing world is a missing agricultural component cementing the necessities of conservation and waste management with the will and interest of local communities and their livelihood-related needs. Enhancement of the acceptance of the wetland-related bio-diversity conservation by the developing communities could be effected through the provision of linkages between waste management and economic gains derived from nature and agriculture.

Work carried out on multi-functional mangrove wetlands in Hong Kong and in Thailand [14-16], and based on ecological considerations [17], demonstrated that it was possible to enhance the status of a mangrove-mudflat ecosystem (and potentially many other ecosystems) in terms of plant and animal abundance without compromising biodiversity. This and other observations

pave the way towards healthy artificial environments simulating nature in an intensive manner and thereby effectively compensating for numerous habitats lost due to human urban and agricultural expansion.

Though the fact that waste C, N and P can enhance productivity of wetlands was known and scientifically researched for quite some time [e.g. 18], it is still far from clear what are safe limits for such enhancement. There are still many questions to be answered. One issue in particular deserves a special attention: that of the impact of anthropogenic nutrients on biodiversity and a fuzzy divide between notorious unintentional eutrophication (a nutrient-induced enhancement of the primary productivity of an ecosystem) and the intentional waste-induced enhancement of the productivity of a wetland (or any other ecosystem for that matter) without a loss of biodiversity. This is important if one remembers that nutrient levels originating from human activities will continue to rise globally (particularly due to activities in the developing countries) and are unlikely to disappear in the foreseeable future. Amount of nutrients delivered by rivers to the Great Barrier Reef and coastal waters has quadrupled since 19th Century [19]. Human activities have approximately doubled the global rate of nitrogen fixation by terrestrial and aquatic bacteria between preindustrial times and the present [20]. Ecologically robust constructed ecosystems which harbour biodiverse communities despite the impact of pollution must be chosen and encouraged in situations (e.g. urban and peri-urban environments) where natural ecosystems fail.

Historically, engineered wetland systems, artificially simulating natural systems, were the first type of wastewater treatment systems. Frequently these systems are prohibitively expensive not only for the developing communities, but also for more affluent societies. Natural wetlands systems have been used for wastewater treatment in the U.S.A. and Europe. However, in view of the major impacts on natural ecosystems the U.S. EPA has limited the use of natural wetlands to tertiary treatment of waste. The reasons for this limitation include lack of knowledge about natural systems, concerns for contamination of wildlife or humans, concerns for process reliability and for the containment of effluents [1]. As already mentioned, these issues, though being addressed, still generate more questions than provide answers. Even in tropical and subtropical ecosystems, where greater pollution loads can be handled under near optimal climatic conditions, an encouraged approach to applications of natural wetlands should steer towards secondary and tertiary treatment (storm water drainage) rather than frequently undertaken primary treatment.

An important development with a major potential for a future occurrence was a series of recent outbreaks of avian influenza (AI) in 2003-2006. AI to a great extent compromised the wetland technology, which *inter alia* encourages wild birds since it enhance existing and creates new habitats for them. Apart from major impacts on people's livelihoods, international commerce of poultry and poultry products, it also killed an unprecedented number of wild birds ranging from Bar-headed geese in Asia to Mute swans in Europe. Though poultry production and commerce have played the largest role in the spread of the disease, wild birds have also contributed to the introduction of the virus to new geographic locations. Rapid spread of Highly Pathogenic Avian

Influenza (HPIA) strain H5N1 in wild birds had impacted public's perception of wild birds and questioned the very issue of their conservation, which indirectly influenced attitudes towards wetlands. Furthermore, the situation was exacerbated by an overall poor understanding of the epidemiological role of wild birds in the occurrence of HPAI H5N1 outbreaks affecting wildlife, poultry and human health in Asia, Middle East, Europe and parts of Africa. Much of the known AI virus ecology in wildlife is based on knowledge of and has been extrapolated from low pathogenic avian influenza strains to H5N1 strain, which appears to have a fairly different ecology.

Recent authoritative conventions on the issue [e.g. FAO/OIE, 21] have come to a conclusion that political and trade considerations must not override humanitarian needs for the conservation of national and regional bio-diversity (including wild bird species) in accordance with international agreements. Destruction of wild bird habitats or indiscriminate culling of wildlife was recognized to be scientifically unjustified as a method to prevent disease transmission and as a response to future HPAI H5N1 outbreak. It should not be included as a control strategy in regional, national, or international plans and must be opposed by decision makers. These activities would contribute to environmental degradation and reduce bio-diversity, thus making the decisions inappropriate as contradicting a number of resolutions (the Ramsar Convention on wetlands, the Bonn Convention on Migratory Species and the African-Eurasian Waterbird Agreement). There is a need for a long-term investment to better understand interactions between wildlife, livestock, and humans. In Africa, evidence to date indicates that the H5N1 virus introduction and spread was poultry-related and chiefly based on human production and commercial factors. Further research is needed to fully understand other possible routes of virus introduction, including those posed by bird migration. One of the concrete practical moves in mitigation of future AI-related threats would be strategically avoiding locating animal farms in proximity to wetlands. Overall, the case of AI accentuates the importance of a biodiversity-centered approach in the light of other potentially threatening wildlife-related diseases.

Asian multi-functional wetlands: success stories

These cases, albeit few and far between, are of major inspirational and practical significance and need to be promoted further.

1. East Kolkata Wetlands, India

Kolkata City, situated in the proximity of the large 125 km² wetlands to the east (part of the Greater Ganga river delta), has grown as a metropolis without any formal sewage treatment plant. Lying within the tidal reaches of the Hooghly river, the flat area slopes gently from west to east and historically its sewage was drained either directly into the Hooghly river or through the East Kolkata Wetlands, EKW, located 5 km east of the city. Out of 770 ML day⁻¹ (domestic: 540 and industrial wastewater: 230 ML day⁻¹) which the city presently generates, up to 30 % is

discharged to EKW. Hence the wetlands, sometimes referred to as “nature’s kidneys and supermarkets”, play a significant role in converting municipal wastes into resources (i), protecting river environment from pollution (ii), benefiting landscape (iii) and saving people of Kolkata from floods (iv) and unemployment (v). Through the unique natural process waste liquid nutrients are transformed into food by fish aquaculture. Wastewater reuse for aquaculture traditionally practiced in a number of Asian countries was commercialized in West Bengal not less than 300 years. EKW act now as the perhaps largest waste-fed aquaculture farm in the world (58 km²) with 250 fishing ponds producing 50 tons of fish daily for human consumption [6]. Analysis of metal and bacterial presence in fish muscles carried out by the Fisheries Department shows that toxic accumulation in the fish is below the permissible limit and does not pose significant public health threats. To mitigate potential impacts from hazardous industrial effluents entering EKW, strict regulatory activities are being carried out, such as mandatory relocation of all tanneries to an industrial site and strict enforcement of existing industrial treatment requirements. De-silting of fish ponds and secondary canals is regularly undertaken to maximize the amount of sewage treated. Dissolved oxygen levels are monitored and the health of fish is promoted through pond aeration which achieves currently recommended BOD level in the fish ponds (45 mg L⁻¹). Furthermore, city’s garbage is dumped at the wetlands and due to a unique system of solid waste disposal a valuable wastes-to-food recycling is undertaken. Long strips of water bodies are left in between two dumping grounds. This low-cost technique drains nutrients from garbage to be subsequently used in irrigation of vegetables generating 370 tons of vegetables ha⁻¹ annum⁻¹. Another traditional agricultural activity, sewage farming, is based on rice cultivation: nutrient-rich fishery effluent is irrigated on paddies covering nearly 50 km². This yields up to 2.5 tons of rice per ha annually, as well as other products of floriculture and horticulture. The total man-power utilization at EKW is a tremendous achievement in the unemployment-ridden mega-city. The aggregate employment has been estimated to be about 40-50 thousand persons, particularly those below the poverty line, with an engagement of 11.8 mln man-days annum⁻¹.

Throughout its history, the immense East Kolkata Wetlands was under constant threat of encroachment by human settlement. The situation became particularly acute in recent years due to the lucrative and influential real estate market. Institutionalizing wetlands, at the highest level possible, as most usual all over the world, was the only and most desperate way to save them. Fortunately, the EKW was designated a Ramsar Wetland of International Importance in 2002. The Ramsar Bureau has recognized the EKW as “a perfect example of wise-use wetland ecosystem where usage of city sewage for traditional practices of fisheries and agriculture is practiced, and as one of the rare examples of combination of environmental protection and development management where a complex ecological process has been adopted by local farmers by mastering the resource recovery activities in the largest ensemble of sewage-fed fish ponds in the world” [10]. However, by this time the size of the wetlands was reduced considerably in comparison to its former area in 1945. The Greater Kolkata City has a number of other man-made lakes within the municipal boundaries which can be considered as an integral

part of the greater EKW. Human settlements within the EKW boundaries still occupy 1.3 km², though no further building activities are allowed. As one of the latest developments, the Asian Development Bank financed the Environmental Improvement Project to improve sanitation in the outer areas of Kolkata municipality in the period of 2002-2007. The improvements included (i) the installation of about 424 km of new lines where the drainage and sewerage network did not exist; (ii) renovation and de-silting of approximately 364 km of existing sewers and drains; (iii) rehabilitation and beautification of 15 small water bodies and parks which were in various stages of degradation due to inadequate maintenance. Traditional practices could be enhanced by adopting more effective wastewater treatment prior to re-use, modifying fish production strategies and monitoring to safeguard health [22]. Though biodiversity of EKW area is not extraordinary due to a long term impact of the city, it is still substantial. There are about 34 plant families comprising 104 species. Forty bird species (from eagles to kingfishers) and 20 various mammals including the rare marsh mongoose, small Indian mongoose, palm and small Indian civet are found in and around the EKW area. Amongst other important species is a reptile: the threatened Indian mud turtle which is also reported occasionally from the adjacent areas. The recent program of enhancing the wetland bio-diversity - the first ever undertaken - unfortunately, was not successful. The unused areas of EKW were planted with selected indigenous vegetation by the local people; however, no sustainable change was noticed eventually. The main reason for this (according to experts) was an inappropriate time frame for implementation chosen by the funding agency. On the other hand, the signs of willingness amongst local people to adopt conservation practices were profoundly visible. In general, a healthy bio-diversity would increase the ecosystem's resilience and capacity to adapt to changes. Greater awareness and understanding of conservation issues, particularly among cooperatives, is being developed, as decision-making is usually exclusively influenced by labor demand, fish prices and other economical considerations.

2. Putrajaya Wetlands, near Kuala Lumpur, Malaysia

The Putrajaya wetland is a significant site located 26 km south of Kuala Lumpur at the very heart of the Malaysia's new Federal Government Administrative Centre. The transfer of the capital to a new and more spacious area was initiated in order to balance and disperse development to areas outside of the mega-city. Out of five proposed schemes, the "Garden City" concept was selected and a master plan was prepared in 1997. The master plan covers an area of 49 km², of which 37 % is open green space within the newly built city, where 330,000 people will eventually reside in 67,000 housing units. Within the concept, a large, four km² artificial lake was formed by damming two rivers, the Sg. Chuau and Sg. Bisa, and utilizing other small natural streams which ran through the area. As a result, a 38 km long waterfront area was formed with the creation of the Putrajaya lake. To ensure that the polluted runoff and storm water entering the lake is of a recreational quality, an environmentally friendly approach was adopted: a huge constructed wetland was introduced to treat water from the 50.9 km² catchment area prior to its discharge into the Putrajaya lake. Other goals were to develop a natural habitat for

conservation of indigenous flora and fauna and to establish a center for public education and scientific research. Thereby an aesthetically pleasing environment was created, the environment which enhanced quality of life, as well as domestic and international tourism [8].

One of the largest constructed freshwater wetlands in the tropics, the two km² Putrajaya wetland, is covered by over 12 million plants which rehabilitate the area previously occupied by an oil palm monoculture and creates a vibrant ecosystem. The wetland was designed to achieve the retention and removal of a range of pollutants and excessive nutrients such as trace metals and organic matter containing C, N, and P. Based on the projected pollutant loading rates, the future mean TP mass loading rates are estimated to be in the range from 8.4 to 15.0 g m⁻² annum⁻¹. The design involved landscaping of the wetland topography due to the site's undulating terrain. The components were designed as multi-cell multi-stage units to achieve better distribution of flow velocity. This maximizes shallow areas required for planting of macrophytes and improves performance for overload flood attenuation. The weirs were designed to control the flow velocity across the wetland cell at below 0.5 m s⁻¹ during an event flow of 100 year return period in order to prevent uprooting of the macrophytes by extreme floods. During the period of normal flow (design inflow rate: 5.9-79.5 ML day⁻¹, mean residence time: 8.2-31.4 days and HLR: 6.2-15.1 cm day⁻¹), the velocity through the wetland cells is to be kept below 0.1 m s⁻¹ in order to enhance the treatment. Primary sedimentation basins were provided to allow for settling of heavier fraction of incoming sediment, this is where de-silting can be carried out at intervals of 3-5 years. Each wetland cell incorporates the following zones: (i) macrophytes zone (0.3-1.0 m deep) to enhance sedimentation, filtration and removal of dissolved pollutants by vegetation and microbial microcosms; (ii) open water zone (1-3 m deep) to facilitate settlement of coarse sediment and trap adsorbed pollutants, as well as to attenuate and distribute inflows to macrophytes zone, and to expose water to UV light for disinfection; (iii) outlet zone to control cell water level and discharge rate; (iv) intermittently flooded zone up to 1.5m above the normal water level of the cell as an important link to adjacent landscape developments.

The wetland cells were planted with 27 species of emergent plants retaining nutrient and toxic substances. 35 species herbaceous plants were planted in the zone of intermittent inundation at the border of the wetland system: these species are to assist in erosion control and bank stabilization. Twenty-two small vegetated islands were created in open water to provide safe habitats for birds and other fauna. The islands are to facilitate water filtration and water diversion to prevent stagnation and encourage the fringe flow in the cells. The ponds planted with locally selected flowering species (water lilies, etc) dramatically enhance the appeal of the site. The system is still under a start-up monitoring but the field data are encouraging [12]. Indigenous fish, including those feeding on mosquito larvae, pelaga (*Beta pugnax*) and sepat siam (*Trichogaster pectoralis*), were introduced into the wetlands for mosquito control. Typical constraint all over the world: a overriding concern for land cost and land availability rather than pollutant removal design considerations has been apparently overcome satisfactorily.

Nevertheless, long-term monitoring is needed not only to ensure success of the treatment function, confirm suitability of botanical components but also to generate important information related to the state of the artificial bio-diversity introduced in lieu of oil palm plantations.

3. That Luang Marsh, Vientiane, Laos

The country's largest urban multi-functional natural wetland and one of the largest in South East Asia, That Luang Marsh is located in the capital city of Laos. The marsh occupies about 20km² and collects storm and wastewater from Vientiane and surrounding areas. The wetland provides a wide range of benefits in terms of valuable products and services. One of the most important of these is flood mitigation and storm water treatment [23]. The city does not have any wastewater treatment plant therefore all wastewater nutrients end up in the marsh (approx. 70 ML day⁻¹), of which up to 50 t of nitrogen and 10 t of inorganic P is being retained by the wetland ecosystem contributing to its aquacultural and agricultural yields. Since the city has no heavy industry all the waste nutrients are reasonably environmentally friendly. Nutrients, apart from being removed from natural streams polluting Mekong river, are channeled into environmental products (fish, shellfish, rice, vegetables etc). The value of these aquatic and non-aquatic products as well as services provided by the multi-functional wetland to people living around the marsh and in Vientiane City was estimated to be up to \$US 5 mln [24]. The further rationalized use of the resources and better management would significantly increase the marsh value and make its exploitation sustainable. However, in recent years, as most common in the region and in the world, the wetland is under constant pressure from the urban development: its area gradually decreases. If the process is not halted such important additional wetland functions as eco-tourism and recreation which are yet to come will never be realized. The loss of the marshland resources would have large implications for local communities and, in particular, poorer households heavily relying on wetland products.

4. Mai Po Marshes and Futian Nature Reserve, near Hong Kong, China

Two adjacent areas on both sides of Shenzhen River entering the Deep Bay north-west of Hong Kong, these jointly cover an estuarine area of approx. 7 km². It comprises mangroves (18 species: dominant *Kandelia candel*, *Aegiceras* and *Avicennia*), mudflats, reedbeds and ponds. Both sites are under pressure from ever-increasing pollution and urban development of the fast-growing Shenzhen City and other human settlements upstream. Due to the rapid urbanization in the 1980s, major part of mangroves have been lost giving way to expansion of aquacultural, industrial and agricultural activities in the area with simultaneous development of tourism and construction of harbors and highways. Nevertheless, these areas are still of a major significance due to considerable botanical and animal diversity, particularly as a wintering ground for a large number of migrating birds.

The Futian Nature reserve was established in 1988, while the 1.5 km² wetlands around Mai Po were declared as a Ramsar site in 1995 and presently function as a high profile nature education facility run by the WWF-Hong Kong and Bird Watching Society. Over 340 bird species were found in and around the area in the Deep Bay with the highest bird count being over 20,000 birds during migration period. An estimated 2-3 million waterbirds, gulls, ducks, herons and other waterfowl, migrate from their breeding grounds in northern China, Mongolia and Siberia to winter in Southeast Asia and Australasia. Prominent endangered species include Black-faced spoonbill (the world population: 1,400), of which a quarter of the existing population relies on the area as a wintering ground. Some of other 22 threatened species are Oriental stork, Chinese egret, etc. Nearby waters harbor a critically threatened Chinese white dolphin while other mammals recorded in the area comprise a number of mongoose species, otter, pangolin, Chinese Leopard Cat, etc. Some 400 invertebrate species were recorded from the reedbeds at Mai Po (including an endangered dragonfly) while over 20 discovered species were new to science [7].

The mangrove forests at Mai Po and Futian together with those in the Deep Bay cover an area of some 4 km² constituting the 6th largest protected mangrove area in China. The 0.5 km² reedbeds are among the largest in the province, while 2.4 km² shrimp ponds (gei wai) are among the largest areas of traditionally operated ponds left in southern China. The latter are seen as sustainably managed wetlands benefiting both local communities and surrounding ecosystems. The ponds perform an aquacultural function of the multi-functional Futian-Mai Po wetland producing fish (*Mugil cephalus*, etc) and shrimp (*Metapenaeus ensis*, etc) of high economic importance [8]. Issues of the aquacultural product safety due to bio-accumulated chemical pollutants (heavy metals, PCB, PAH, etc) originating from upstream industries raised concerns recently and need to be managed [25,26]. On the other hand, carbon-related pollution, if not excessive, was seen in a positive light: as a vehicle enhancing nutrient balance of mudflats and serving as feeding grounds for shorebirds [15]. 50% of nutrients channeled through the food web into feed for birds is thought to originate from the polluting stream. Data showed that the predominant carbon source for invertebrates was of anthropogenic origin. More than estimated 20,000 ton of pollutant carbon enter the Deep Bay yearly through wastewater discharge from two main rivers making it a major source of carbon budget for the ecosystem. According to the authors “what appeared to be a major pollution problem from the viewpoint of water quality management was actually a blessing to the conservation value of this mangrove-fringed embayment”. Additional nutrients appeared to stimulate ecosystem, which was estimated to be near carrying capacity for birds, and allowed to avoid displacement of populations to alternative feeding grounds. Needless to say that a close monitoring of the situation would not only be important for its sustainability, but also provided invaluable information allowing to harness these all too common phenomena elsewhere. A parallel study demonstrated that the impact of moderate pollution on benthic macrofauna (polychaetes, mollusks, crustaceans and mudskipper fish) was not significant and community structures remained unchanged [14].

Though mangrove ecosystems are rich in organic matter, in general they are nutrient-deficient which coupled to high turnover of organic matter and N constitutes conditions conducive to the high performance in terms of waste recycling. Similar natural phenomena were documented elsewhere [27] showing that naturally leached organic matter exported from mangrove forest could enhance phytoplankton productivity in adjacent lagoon waters. Furthermore, according to the ecological model proposed by Pearson and Rosenberg [17], species diversity may increase with mild organic pollution due to an increased food and nutrient availability.

Full-scale trials on municipal wastewater treatment by mangrove patches undertaken in Mai Po demonstrated that mangroves can successfully perform significant purification of water, recycling considerable amounts of carbon, nitrogen and phosphorus [28-30]. The use of remnant mangroves in the majority of cases (i.e. in areas where they are scarce) should not be encouraged. However, growing mangrove replanting in areas, where they were lost to urban and agricultural development, can incorporate the use of these ecosystems as treatment facilities and multi-functional ecosystems. Sequestering small areas of mangroves (or any other wetland) for the treatment would allow not only saving the main ecosystem but also decreasing polluting nutrients to safer levels, the levels which have a stimulating effect on the overall flora and fauna.

5. Multi-functional wetlands of Thailand

All Thai projects are situated in the coastal zone of the Gulf of Thailand.

Royal Laem Pak Bia project

This Royal Project at the experimental site at Laem Phak Bia (Phetchaburi province) is situated on the coast about 100 km south west of Bangkok and covers one km² [31]. Treating 4.5-10.0 ML day⁻¹ of municipal wastewater (BOD 80 mg L⁻¹, TKN 20 mg L⁻¹) it comprises (i) waste stabilisation ponds, (ii) papyrus-, vetiver grass- and cattail-based free surface flow wetland treatment generating products of value, (iii) grass filtration units for livestock feed production and (iv) mangrove forest filtration system. Many of the birds frequenting the area are globally or regionally endangered species, such as the following waders: Asian dowitcher, Malaysian plover and spoon-billed sandpiper. The large-billed reed-warbler (*Acrocephalus orinus*), the world's least known bird, was re-discovered in the area in 2006, after it was first described in India 137 years before. The fact further substantiates the fact of unique bio-diversity of wetlands and accentuates necessity for creation of new wetland-based habitats.

Bang Pu Nature Reserve, Greater Bangkok

A high profile mangrove conservation area managed by the Royal Thai Army and WWF Thailand, it is a popular destination for the citizens of Bangkok. Situated in the recognized Priority Corridor within the Indochina Biodiversity Hotspot and a high priority area for conservation, the one km² reserve serves as an educational facility for thousands of school students and the general public through the recently established WWF Nature Education Centre. The area supports large number

of wintering gulls and terns, many of which breed in China. Bang Pu represents one of the last patches of coastal mangrove ecosystems (*Avicennia alba* and *A. marina*), while the offshore mudflats attract large concentrations of wintering and migratory shorebirds, including globally endangered vagrants such as Asian dowitcher, Nordmann's greenshank, Indian skimmer, black-faced spoonbill, milky stork and spoon-billed sandpiper, as well as other 160 bird species.

The local population belongs to the poorest sector of society and is engaged in fishing, gathering of shells, crabs, prawns and other marine life on the adjacent mudflats, and thereby depends on the multi-functional wetland for their livelihoods. The rapid increase in human population and industry in the area, coupled with an inadequate wastewater management, has resulted in the pollution of the coastal waters. The Bang Pu area is surrounded by some 330 industries and although sewage and industrial wastes are often treated, the effluents usually do not meet environmental standards before being discharged into the water bodies closely linked to the reserve. Another threat is a long-term impact posed by pollution to the livelihood sources in the wetlands. However, pollution appears to be mitigated by the mangrove soil without compromising bio-diversity. On-going research is conducted to rationalize waste management, maximizing its efficiency while minimizing the impact on ecosystem and livelihoods [16]. Long-term trial data demonstrated that at least one type of mangrove can act as a vegetative buffer at significantly higher pollution treatment efficiency than was previously thought [29, 31-33]. Crabs and mudskippers, as major and critically important mangrove groups, exhibited stability in terms of abundance and diversity under the major decade-long pollution pressure of one of the most problematic wastes, pig manure. The diversity and abundance was even found to increase in locally contained area increasing aquacultural, conservational and educational potential of the neighboring nature reserve. If the process is controlled and contained, it can perform the function of pollution mitigation even in sensitive situations without compromising natural status of neighboring conservation areas.

“The Flower-Butterfly” integrated system, Phi Phi island

If seen from above this wetland-based wastewater treatment plant-cum-landscaped community park looks like a giant butterfly sitting on a flower. The world famous tourist destination, a coral paradise island of Phi Phi in the Andaman Sea, was tragically hit by the 2004 tsunami. When its existing infrastructure was ruined, the Danish Government, after a public consultation, supported construction of an appropriate multi-functional wastewater treatment facility with a design capacity of $400 \text{ m}^3 \cdot \text{day}^{-1}$ of septic tank effluent and grey-water from households, restaurants and hotels. Built to the modern eco-engineering standards, the plant performing secondary treatment has wastewater (BOD and TKN, respectively, 100 and 20 mg L^{-1}) feeding “the Flower” vertical flow/horizontal subsurface flow units, which outflow is then fed into “the Butterfly-wings” free water surface units. The final effluent (BOD and TKN, respectively, 10 and 5 mg L^{-1}) is stored in the “Butterfly-body” pond from where it is re-used (irrigation, etc). The low cost facility with an overall wetland area of $8,200 \text{ m}^2$ blends into the tropical environment of an international resort island providing nature education and recreational area for the residents and tourists who hardly

notice that their wastes are treated in this flower garden recycling waste nutrients into beautiful *Canna* and *Heliconia* blossoms [34].

6. Western Treatment Plant, Melbourne, Australia

An internationally recognized Ramsar site (area 110 km²) involved in agricultural and conservation activities, Western Treatment Plant, WTP, is situated at the outskirts of the Melbourne City [35]. The plant comprising ponds, wetlands, lakes and grasslands is considered to be one of the top 10 bird-watching areas in Australia, second only to the UNESCO heritage site, tropical Kakadu National Park in Northern Australia. Highly diverse ecosystems, such as lake Borrie, surrounding ponds and freshwater wetlands as well as coastal mudflats attract an estimated 65,000 birds at any one time. Melbourne produces nearly 1000 ML of sewage per day to be treated and the plant provides an essential public health service, processing up to 52% of these wastes. After an environmentally friendly treatment in extensive series of waste stabilization ponds followed by the activated sludge process for N removal, effluent is discharged into the sensitive ecosystem of Port Phillip Bay. The plant aims at the target of 20% water recycling by 2010 when 30,000 ML of recycled water per year is expected to be used for irrigation of paddocks commercially raising 15,000 cattle and 40,000 sheep on over 85 km² pastures. Sludge bio-solids from the pond de-sludging are recycled in landscaping, soil conditioning, composting, land rehabilitation and brick manufacture. However, bio-solids at WTP are high in industrial contaminants and are, as a result, unsuitable for agricultural use; new technologies including phyto-remediation are being used to improve quality [36].

7. Shihwa lake-wetland, South Korea

The 61 km² artificial Shihwa Lake was constructed in 1994 for the storage and supply of freshwater to the local industries, municipal area, and agricultural lands on the west coast of South Korea near Seoul. Designed with a purpose not dissimilar to the Putrajaya lake in Malaysia, the lake was intended to be an integral part of the ecologically friendly Songsan green city which was to provide man-power for the development of the multi-tech valley. Such a relocation of industrial and urban development from Seoul had a major impact of existing natural coastal habitats [37]. To rectify the controversial situation, one of the mitigation measures was a subsequent introduction of Shihwa wetland in 1997. The largest constructed reedbed-based marsh in Korea, it occupies an area of 0.75 km² [38]. This artificial free water surface wetland strives to compensate for the lost natural habitats for endangered fauna. It currently treats drainage contaminated by the intensive urban development and as a new ecosystem features activities of nature education for the public.

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