Chapter 6

Case studies

6.1 REPORTING TREATMENT WETLAND DATA

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Rational

When reporting data on TWs, a proper description of the wetland system under investigation is required. The experience from reviewing TW papers shows that a number of times, not all data related to the design of the system that are required to understand the system's functioning and/or all data-related sampling location/frequency and data evaluation are included. The following list should provide guidance on the minimum requirements of information on the wetland system that has to be provided.

Minimum information required on the TW system

- General information
  - Treatment capacity in PE, design flow and maximum flow to treatment
  - Dimensions of the system in m^2
  - Influent wastewater characterisation
  - Wetland plants used and harvesting frequency

    - Start of operation or length of operation before experimental data have been obtained.
    - Hydraulic loading rate (HLR) and pollutant loading rate.
- Specifically for VF beds
    - Depths and filter material of each layer of the VF bed
    - Characteristics of each filter material: granularity, d_{10}, U, etc.
    - Loading regime: intermittent or continuous
    - For intermittently loaded systems: loading interval, volume of a single dose, duration of the dose.
- Specifically for HF beds
    - Water level in relation to media depth
    - Flow distribution arrangement
    - Differentiate between plan area (length × width) and cross-sectional (depth × width) surface loading rates.

Reporting experimental data

- *Sampling*: description of location of sampling, sampling frequency and numbers of samples taken
- *Removal efficiencies* should be calculated from load data
- A minimum statistical evaluation of data is required.
- *Use of digits after decimal separator*: The way data are reported should reflect the accuracy of the measurement with which the data have been obtained, e.g. TSS is usually measured as integer number, also average values of TSS should be presented as integer (even MSExcel® presents data differently)
- Numbers on axes in figures should be integers, unnecessary digits after decimal separator shall be avoided.

6.2 CASE STUDY 1 – CSO TREATMENT WETLAND (GERMANY)

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Project Name:	Retentionsbodenfilter Kenten
Location:	Bergheim (Erft), Germany
Wastewater Type:	Combined sewage from retention tank overflow (pre-settled)
Design Flow:	Approx. 1,000 m^3/h (maximum capacity: approx. 4,200 m^3)
Completion Date:	2006
Technology:	VF wetland for the treatment of combined sewer overflows
Description of project need:	Requirements of EU Water Framework Directive makes further treatment of overflows from combined sewer systems necessary.
Description of project solution:	The TW is situated after two retention tanks and is only charged when the overflow from the sewer network exceeds their capacity. The filter has a surface of 2,200 m^2 and is designed to treat up to 4,200 m^3 with a filtration velocity of 0.025 $L/s/m^2$. The minimum interval between two events is 36 hours (Figure 6.1).
Special benefits of using TW technology compared to other solutions:	This technology is currently the only one available to provide biological, biochemical and mechanical treatment of combined sewer overflows. Retention of TSS (>90%), COD (60–85%), nitrification of ammonium (>60%) and indicator bacteria (1–3 $\log_{10}$) have been very well documented (Table 6.1).

Figure 6.1 Case study 1 – CSO treatment wetland (Germany).

Table 6.1 Performance data case study 1: mean influent and effluent concentrations in mg/L ten years after starting operation*.

Parameter	Influent Concentration	Effluent Concentration
TSS	53 ($n = 4$)	8 ($n = 3$)
COD (homogenized)	86 ($n = 7$)	24 ($n = 6$)
TOC ($n = 4$)	41.8	16.4
DOC ($n = 3$)	21.0	13.7
NH_4-N ($n = 6$)	5.3	2.4

*No values for P provided, as system was not enhanced for its removal.

6.3 CASE STUDY 2 – FWS WETLAND FOR TREATMENT OF AGRICULTURAL DRAINAGE WATER (ITALY)

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Project Name:	Green infrastructures for management and protection of water resources (Green4Water)
Location:	Bologna, Italy
Wastewater Type:	Agricultural drainage water
Completion Date:	Constructed in 2001 and operating since
Technology:	Free Water Surface (FWS) wetland
Description of project need:	A 12.5 ha experimental farm of Land Reclamation Consortium Canale Emiliano Romagnolo produces different crops throughout the year. In order to prevent pollution of surface water bodes with nutrient or chemical products, a low-cost and sustainable drainage water treatment solution, that could function with an intermittent inflow, was constructed.
Description of project solution:	The FWS wetland receives water from the main ditch to which is drained all the farm area. Two pumps convey water from the ditch towards the inlet once water in the ditch reaches a certain level. On the other hand, when the water level in the ditch is too high, excess water bypasses the system through a weir gate. The FWS wetland size represent 3% of the total farm area, and the system has a total volume of around 1500 m^3. It is divided into four meanders that create a 470 m long watercourse (Figure 16). The volume of water going in and out of the system is being constantly monitored by a central control station, as well as water level inside the ditch and the system itself. In addition, the control station has two refrigerated sampling units, one for influent and other for effluent, sampling being done on the basis of volume and time (Figure 6.2, Figure 6.3).
Special benefits of using TW technology compared to other solutions:	The water flow in the system is gravitational and therefore operating costs are low, especially since only occasional maintenance works are needed every few weeks. Long-term monitoring (2003–2017) showed that the system contributes to water quality in the area since it removes nutrients from the farm's drainage water and acts as a biofilter for different pollutants. Most importantly, the wetland technology applied was able to cope with different inflow volumes and pollution loads that are characteristic for agricultural drainage water (Lavrnić *et al.,* 2018). In addition, being located in the middle of arable land, vegetated and surrounded by trees, the FWS wetland provides ecosystem services and hosts various organisms such as birds, frogs or crayfish.

More information:

- https://site.unibo.it/green4water/en
- Lavrnić *et al.* (2018), *Water* 10(5), 644, https://doi.org/10.3390/w10050644.

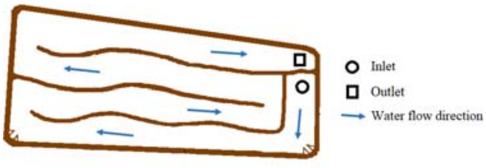

Figure 6.2 Case study 2 – Schematic of FWS wetland for treatment of agricultural drainage water (Italy).

Figure 6.3 Case study 2 – FWS wetland for treatment of agricultural drainage water (Italy).

6.4 CASE STUDY 3 – LANDFILL LEACHATE TREATMENT WETLAND SYSTEM (AUSTRALIA)

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Project Name:	Burnie Landfill Leachate Treatment Wetland System
Location:	Burnie, Tasmania, Australia
Wastewater Type:	Landfill leachate
Design Flow:	Average flow of ~280 m^3/d, with a peak treatment capacity of 600 m^3/d
Completion Date:	January 2017 – construction completed February–July 2017 – commissioning & validation monitoring July 2017 – start of operation
Technology:	The system is comprised of vegetated surface-flow and subsurface-flow wetlands, followed by an evapotranspiration/infiltration forested wetland which further polishes effluent and mainly indirectly discharges the water to the creek via subsurface seepage.
The main drivers for the project:	This project was initiated because of (i) pressure to remove the leachate from the existing sewer network, (ii) impacts of leachate migrating off-site to the receiving environment, and (iii) changing community expectations due to urban encroachment. Environmental impacts were complicated by the fact that the treated leachate was to be discharged to a local creek used for irrigation and which is home to many nationally protected fauna species. These sensitivities invoked significant regulatory pressure to ensure any treated leachate discharge would need to be to a very high standard in order to protect environmental values.
Description of project need:	The wetland system needed to address the following key challenges: • Very complex hydrogeological setting (landfill is within a groundwater discharge valley catchment) with all surface/groundwater ultimately reporting to a nearby creek. • Unique leachate characteristics (high-volume, low-strength leachate), due to a complex interaction between leachate, groundwater and stormwater. • Very stringent discharge standards set to protect the sensitive receiving creek system. • Space limitations on site; apart from the landfill itself, very little available land surrounds the site.
Description of project solution:	The project solution is an integrated on-site leachate management (treatment and disposal) system that includes: (1) a treatment wetland system; (2) a separate stormwater treatment system; and (3) a raw leachate interception collection and phytoremediation treatment system to manage infrequent ponding events associated with seepages from the landfill during large rainfall events. Local species were used for planting of vegetated zones.

The design makes provision for interpretive elements (boardwalks, signage) and educational/recreational engagement (school groups, researchers, tours, local residents). In time, as the urban zone advances, the landfill 'park' will become a key public open space element (Figure 6.4).

Special benefits of using TW technology compared to other solutions:	Use of wetland treatment technology for treatment of leachate in this project provided an effective, and relatively low-cost solution that goes beyond simply addressing an issue. In addition to a high-level treatment that enables leachate infiltration/discharge (primary project objective), the treatment wetland system provided a range of additional benefits which were not possible with other technologies, making it a showcase for sustainable remediation. These benefits are in line with sustainable triple bottom line principles and include environmental, social and economic benefits. Further to these benefits, delivery of this treatment wetland project provided a range of other important learnings for the different stakeholders involved in leachate management (designers, regulators, managers, operators). These learnings have already been adopted by other landfill managers to start the process of sustainable leachate management on their sites. The project has received wide recognition in Australia, including winning a number of state and national awards for sustainable remediation.
Performance:	Since commissioning was completed the removal efficiency for all key parameters (TN, TKN, ammonia, nitrate) has progressively increased, highlighting the importance of system maturation to overall performance.

More information: https://www.syrinx.net.au/portfolio/burnie/

Figure 6.4 Case study 3 – Landfill Leachate Treatment Wetland System (Australia).

6.5 CASE STUDY 4 – NIMR WATER TREATMENT PLANT (OMAN)

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Project Name:	Nimr Water Treatment Plant (NWTP)
Location:	Nimr, Sultanate of Oman
Wastewater Type:	Produced water from oil exploration and production industry
Design Flow:	175,000 m^3/day
Completion Date:	Phases 1 & 2 (115,000 m^3/day) in operation since 2011, Phase 3 (additional 60,000 m^3/day to reach 175,000 m^3/day in total) under construction (completion: May 2019)
Technology:	The technology used is (i) passive hydro-cyclones for oil in water separation, (ii) FWS wetland for water polishing and hydrocarbons breakdown, and (iii) evaporation ponds for treated effluent disposal (zero-discharge system). Also, partial reuse of the treated effluent for irrigation of crops with market value has already started.
Description of project need:	Oil exploration and production in Nimr area is associated with large volumes of produced water, with a water-to-oil ratio as high as 1:10 after oil separation. A fraction of this produced water is injected to maintain the reservoir pressure and the remainder is disposed into deep aquifers. However, deep-well injection poses environmental risks and demands high energy consumption in a desert area with limited power supply. Thus, an alternative solution was required for produced water management that would be cost-effective, environmentally friendly and sustainable.
Description of project solution:	The NWTP is a hybrid system, incorporating elements of natural systems (green infrastructure) with traditional treatment technologies (grey infrastructure). First, separation and recovery of the majority of oil from the produced water takes place, using a series of passive hydro-cyclone oil separators. Then, the produced water is distributed to a FWS wetland of 360 hectares area via a long buffer pond. The treated water flows with gravity into a series of evaporation ponds (500 hectares), where evaporation results in salt formation, which can be processed into industrial grade salt as end-product. The NWTP currently treats 115,000 m^3/day of produced water, while an expansion with additional 60,000 m^3/day (130 hectares of wetlands to be added) is under construction. The size of the wetland facility makes this system one of the largest treatment wetlands in the world (Figure 6.5).
Special benefits of using TW technology compared to other solutions:	Due to the operation of the NWTP, five high-pressure deep-well disposal pumps have been shut down. Also, the whole NWTP is a gravity-based system with close-to-zero energy demand for the water treatment processes. This is a unique benefit of this technological solution, which translates to 98% reduction in energy consumption. The respective

estimated reduction in carbon emission is more than 1.5 million tons CO_2, or 99% compared to the other technological and disposal options. The NWTP alone contributes by approximately 4.26% to Oman's overall Intended Nationally Determined Contributions (according to Paris Agreement) to reduce emissions by 2% by 2030. This wetland facility is built in a previously arid desert. The large treatment wetlands and the series of evaporation ponds provide a valuable habitat for migratory birds and other wildlife. Given that the site is located in the middle of the East Asia/East Africa flyway, more than 120 different bird species have been identified in and around the wetlands and ponds, which utilize the facility as a comfortable stop-over during their migration. Furthermore, a large-scale three-year experiment will be completed at the end of 2018: it investigates the reuse of the treated effluent for irrigation of salt-tolerant plants with market value, e.g., biofuels, wood biomass etc. Ultimate goal is to make this facility a global example of circular economy with zero-waste production (Table 6.2).

Figure 6.5 Case study 4 – Nimr Water Treatment Plant (Oman). (Pictures reprinted with permission from Bauer Nimr LLC)

Table 6.2 Performance data case study 4: treatment performance (average values in mg/L).

Parameter	Inflow	Outflow
Total Dissolved Solids	7,000	12,000
Suspended solids	28	10
Oil in water	280	<0.5
BOD	15.7	<1
Total Nitrogen as N	2.5	<0.5
Ammonia Nitrogen as N	1.3	<0.1
Total Phosphorus as TP	0.03	<0.5
Boron as B (dissolved)	4.5	5.6

6.6 CASE STUDY 5 – CECCHI WINERY WASTEWATER TREATMENT PLANT (ITALY)

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Project Name:	Cecchi Winery Wastewater Treatment Plant
Location:	Castellina in Chianti, Italy
Wastewater Type:	Winery wastewater
Design Flow:	100 m^3/d (mean value during peak vintage season)
Completion Date:	In operation since 2001, upgraded in 2009
Technology:	The technology used is: 1st stage of a French VF wetland raw wastewater of 1,200 m^2; 2nd stage with 4 parallel HF Wetlands of 960 m^2 (240 m^2 each); 3rd stage a single-bed FWS wetland of 850 m^2; optional sand filter of 50 m^2 before discharge into freshwater (Gena River).
Description of project need:	The winery wastewater produced by the Casa Vinicola Luigi Cecchi & Sons (Castellina in Chianti, Siena) has been treated with a multi-stage wetland system since 2001. The system consisted of an Imhoff tank, followed by a single-stage HF wetland of 480 m^2 and then by an FWS of 850 m^2. The system was designed to treat 35 m^3/d, and starting from the year 2006 the production at the winery greatly improved and consequently flows to the wetland increased up to 70 m^3/d. A prolonged overload, for about 2–3 years, resulted in a severe clogging of the HF bed. Therefore, an upgrade of the TW was required in 2009.
Description of project solution:	The choice of a first stage of a French VF wetland for raw wastewater as first stage of a multi-stage TW system enhances the sustainability of the treatment plant, by the reduction of primary sludge production and sludge cycle management costs it is also providing more robustness to the treatment train, minimizing a big part of the problems observed in the above cited experiences with the older 'Imhoff + HF + FWS' configuration. The installation of the new first stage has resulted in removal of the old Imhoff tank, which was creating some problems in the HF due to frequent events of exceptionally high flows and linked wash-out events from the Imhoff tank itself, when unmeasured amounts of primary sludge reached the inlet section of the HF, surely contributing to its clogging (Figure 6.6).
Special benefits of using TW technology compared to other solutions:	Winery wastewater has proved to be difficult to treat with conventional technological solutions (e.g., activated sludge, anaerobic reactors), for the following reasons: (i) variable pH, usually ranging from 4 to 8 in the different periods of the year; (ii) low nutrient content and consequent unfavourable C/N ratio for the microbial growth;

(iii) high content of biodegradable compounds that often leads to difficulties in operating biological systems, for instance poor sludge settleability, floc disintegration and increased presence of solids in the treated effluent;
(iv) seasonality and load fluctuations;
(v) clogging in filtering reactors;
(vi) phytotoxicity and microbial inhibition by toxic organic and inorganic compounds, i.e. sulfur, phenols, tannins.

As well as being a low-cost, low-maintenance and energy-saving technology, the WWTP of Cecchi winery also shows that TWs are an effective solution to cope with winery wastewater issues. The TW of Cecchi winery also shows the potential of multi-stage systems in treatment of winery wastewater. In particular, the first stage of a French VF wetland as the system's first stage is providing more stable performance and no clogging signals have yet been noticed after 10 years of operation from the upgrading (Table 6.3).

Figure 6.6 Case study 5 – Cecchi Winery Wastewater Treatment Plant (Italy).

Table 6.3 Performance data case study 5: treatment performance (average values in mg/L).

Parameter	Inflow	Outflow
TSS	213	25
COD	3,800	67
BOD_5	1833	20
TN	19	7
TP	5	1

More information:

- Masi *et al.* (2015a), *Water Science and Technology* **71**, 1113–1127.

6.7 CASE STUDY 6 – DICOMANO WASTEWATER TREATMENT PLANT (ITALY)

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Project Name:	Multi-stage treatment wetland of Dicomano (Italy)
Location:	Dicomano, Italy
Wastewater Type:	Municipal wastewater
Design Flow:	525 m^3/day
Completion Date:	In operation since 2003
Technology:	The technology used is: first stage with two parallel HF wetlands of 1,000 m^2 (500 m^2 each); second stage with eight parallel VF wetlands of 1,680 m^2 (210 m^2 each); third stage with two parallel HF wetlands of 1,800 m^2 (900 m^2 each); fourth stage with single-bed FWS wetland of 1,600 m^2. Total surface of 6,080 m^2.
Description of project need:	Dicomano is a little settlement situated in the Florence countryside, about 160 m above sea level: before the new wastewater treatment plant (WWTP) the urban wastewater was discharged into the Sieve River, the most important Arno River tributary. Therefore, the settlement needed a WWTP suitable to treat the municipal wastewater according with the strict Italian law (especially in terms of nutrients), while achieving low operation and maintenance costs.
Description of project solution:	The concept design is based on the benefits given by multi-stage systems in terms of multiple water quality targets to be met. Therefore, a multi-stage wetland system has been realised with specific roles for each compartment: first, HF beds for organic and suspended solid removal; second, VF beds to obtain an enhanced nitrification; third, HF beds for denitrification; fourth, final FWS to improve pathogen removal and advanced denitrification (Figure 6.7, Figure 6.8).
Special benefits of using TW technology compared to other solutions:	The WWTP was able to meet specific limits set by Italian law (D. Lgs. 152/2006): BOD_5 (40 mg/L), COD (160 mg/L), TSS (80 mg/L), nitrogen compounds (35 mg/L), phosphorus (10 mg/L), and pathogens (5,000 cfu/100 mL). These strict limits, especially for nutrients, were met exploiting a multi-stage approach. In this way, the system was designed with a lower footprint in comparison to single-stage TW system, i.e. less than 2 m^2 p.e.$^{-1}$. A greater flexibility to influent variation in wastewater load was given adopting TW instead of conventional technology. Indeed, the multi-stage TW of Dicomano was able to respect Italian water quality standard even under severe influent fluctuation, due to the mixed nature of the municipal sewer system. Indeed, the sewer also drains in some periods 'parasite' rainwater from the ground and has been affected by a severe infiltration of water from a torrent for few years. The operation and maintenance costs were 20,000 € per year, significantly lower (0.1 €/m^3) than conventional technological solutions. Finally, the use of nature-based solutions has given the possibility to provide an additional ecosystem service in terms of biodiversity increase, since the FWS stage was planted with 16 different Tuscany's native macrophytes (Table 6.4).

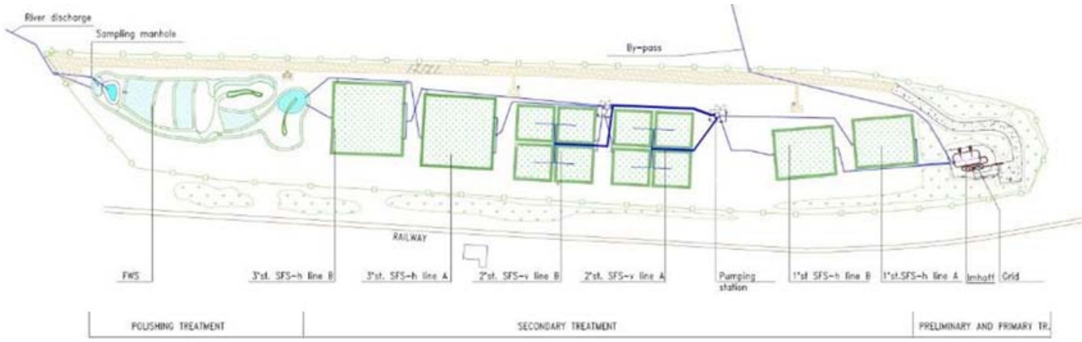

Figure 6.7 Case study 6 – Schematic of Dicomano Wastewater Treatment Plant (Italy).

Figure 6.8 Case study 6 – Dicomano Wastewater Treatment Plant (Italy).

Table 6.4 Performance data case study 6: treatment performance (average values in mg/L).

Parameter	Inflow	Outflow
TSS	51	5
BOD	66	4
COD	160	18
NH4+	31	7
TN	28	10
TP	2.7	1.6

More information:

- Masi *et al.* (2013), *Water Science and Technology* **67**, 1590–1598.

6.8 CASE STUDY 7 – ORHEI WASTEWATER TREATMENT PLANT (MOLDOVA)

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Project Name:	Orhei Wastewater Treatment Plant
Location:	Orhei, Moldova
Wastewater Type:	Municipal wastewater
Design Flow:	1,000 m^3/d (mean value)
Completion Date:	In operation since 2013
Technology:	The TW occupies a gross area of 50,000 m^2 and is designed as French VF wetland. Four independent two-stage treatment lines working in parallel are present, with first and second stage surface area for each line equal to 4,489 m^2 (three sectors of 1,496 m^2 each) and 4,248 m^2 (four sectors of 1,062 m^2 each), respectively.
Description of project need:	The Orhei municipality (20,000 PE) needed a new WWTP. The new plant was promoted and funded by the World Bank, who highlighted the need to minimize the operation costs according with the maximum affordable water tariff in the local economic situation.
Description of project solution:	In order to minimize the operation and maintenance costs, a French VF wetland was chosen to avoid the yearly cost given by classical primary treatment (septic or Imhoff tanks). The design followed the French VF wetland principles and guidelines. The first stage is fed with raw wastewater, designed for high removal of TSS, COD, and ammonia. The second stage is designed to refine the treatment and to complete the nitrification (Figure 6.9).
Special benefits of using TW technology compared to other solutions:	The Orhei WWTP design and supervision of the construction was promoted and funded by the World Bank. A TW treatment technology was chosen to minimize the operation costs. Indeed, the World Bank consultants have compared TW with other common systems (activated sludge plants, SBRs, and percolating filters), showing that TW would be the only financially feasible technology with the maximum affordable water tariff in the local economic situation. Moreover, the Orhei WWTP confirms that there are no upper limits, in terms of maximum treatable person equivalent, for the application of wetland systems for municipal wastewater treatment when land is available at a proper cost (Table 6.5)

Figure 6.9 Case study 7 – Orhei Wastewater Treatment Plant (Moldova).

Table 6.5 Performance data case study 7: treatment performance (average values in mg/L).

Parameter	Inflow	Outflow
TSS	583	23
COD	222	32
BOD_5	106	15
N-NH4+	47	16

More information:

- Masi *et al.* (2017b), *Water Science and Technology* **76**, 68–78.

6.9 CASE STUDY 8 – MULTIFUNCTIONAL WATER RESERVOIR IN LJUBLJANA (SLOVENIA)

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Project Name:	Multifunctional water reservoir (MWR) in Ljubljana
Location:	Ljubljana, Slovenia
Wastewater Type:	River water, urban stormwater runoff, septic tanks overflows
Design Flow:	173 m^3/day
Completion Date:	Phase 1 (construction of MWR) in operation since 2006, Phase 2 reconstruction of MWR, upgrading for several ecosystem functions (biodiversity, recreation, education) in operation since 2014.
Technology:	The basic design of MWR in Ljubljana consists of: (1) sedimentation basin, (2) vegetated drainage ditch (VDD) as a type of TW, and (3) a new river bed with meanders. The whole MWR is integrated in a swamp that was created by natural way in an engineered flood reservoir protecting west Ljubljana from floods.
Description of project need:	The City of Ljubljana has been dealing with flooding of rivers for many years, especially because settlements are gradually spreading to areas of periodic flooding. The flood reservoir was constructed in 1986 on Glinščica river to tackle the issue of floods, but later it was facing water quality problems, as it was affected by occasional overflows from septic tanks, polluted tributaries and urban stormwater runoff (gardens, parking places). The authorities have addressed the problem by constructing MWR in 2006 (Phase 1), but the 2010 flood event made the need for additional flood protection measures obvious (Phase 2). MWR was finally constructed to provide several functions regarding environmental protection, namely: (a) flood prevention; (b) water retention for irrigation purposes of nearby green areas; (c) water pollution mitigation from urban gardens and sewage overflows; (d) increased self-cleaning capacity of the ecosystem; (e) increased biodiversity; (f) establishment of recreation and education path. The hydraulic retention capacity of MWR was designed to 10-year flood events.
Description of project solution:	The first rehabilitation step prior to MWR construction was to redirect the flow of max 2 L/s from main river bed and deepen the first part forming a small retention basin (10 m^3), which was watertight, to slow down the water flow and enable efficient sedimentation of particles. After the sedimentation basin, the water

runs over a weir to the VDD, which functions as a horizontal flow TW. It is divided into three segments with a depth of 0.4 m and is lined with foil to ensure water tightness. Individual VDD segments are filled with sand and gravel of 60–80 mm (first segment), 30–60 mm (upper 10 cm layer of the second and third segment) and 16–32 mm (lower 30 cm layer of the second and third segment) and planted with common reed (*Phragmites australis*). For the purpose of water sampling and measurements of water level, there are piezometers installed at the beginning and at the end of each VDD segment. The treated water flows from the VDD into the newly established river bed with meanders. The banks of a riverbed are strengthened by in-built willow wattle fences; spurs, half logs and ripraps were also constructed. The MWR was planted with diverse indigenous wetland plants: at the banks of the riverbed broadleaf cattail (*Typha latifolia*), soft rush (*Juncus effusus*), sedge (*Carex* sp.) and yellow iris (*Iris pseudacorus*) were planted; while for greater distances from water woody plants were selected: willows (*Salix* spp.), common hazel (*Corylus avellana*), black alder (*Alnus glutinosa*) and pedunculate oak (*Quercus robur*). Maintenance on regular basis is required to avoid reduction of the retention capacity due to alluvial deposits and overgrowth of vegetation, including the establishment of safe operating conditions (Figure 6.10).

Special benefits of using TW technology compared to other solutions:

Flood prevention: MWR reduces hydraulic peaks by retaining water in the system and therefore prevents and mitigates floods and droughts in the nearby area.

Water treatment: Due to integration of VDD, MWR effectively treats the inflow water and increases the self-cleaning capacity of the area.

Energy savings: MWR can provide its services with very little or no energy input if designed appropriately.

Enhanced biodiversity: MWR creates a new habitat for wildlife and contributes to an increased biodiversity in a barren landscape (e.g. spawning ground for frogs and toads, breeding sites for birds etc.).

Recreation: MWR is designed with elements of landscape architecture (banks, walking path and bridge) and creates an attractive recreational place for the community.

Education: MWR is a tangible example (recognized as a good practice by European Environment Agency, 2016) of a measure aimed to achieve sustainable development. It is used by the City of Ljubljana, schools and universities to present the problems of pollution and its remediation in a natural way to different target groups. It offers new perspectives for future developments in water management and flood prevention.

Figure 6.10 Case study 8 – Multifunctional water reservoir in Ljubljana (Slovenia).

Performance data:

Most of the inflow parameters were in low concentrations (TN 2.7 $\pm$ 1.2 mg/L, TP 0.3 $\pm$ 0.1 mg/L, BOD_5 6.9 $\pm$ 3.1 mg/L); therefore high removal rates were not expected. Average removal efficiencies for the MWR reached on average 68% for NO_3-N, 40% for TN, 7% for NH_4-N, 9% for BOD_5 and 3% for TP while SS and COD increased. The VDD was efficient in removal of NH_4-N (38%), and NO_3-N (63%), but these parameters than increased again in the new river bed with meanders, which was on the other hand efficient in removal of TP (10%). The performance of MWR should not be reviewed only through removal of stated parameters but also through the impact on ecosystem services. Concerning the biodiversity, marsh vegetation in this area and algae species are extremely diverse. Also, the area of the flood reservoir is potentially a suitable habitat of endangered animal species and rare birds, like the green woodpecker (*Picus viridis*), the presence of which has been confirmed in the area. With the appropriate arrangements, the flood reservoir is offering an interesting recreational path for local residents and an educational path (bird observation points, observation of self-cleaning elements of the wetland and the river) and a recreational place (walking, jogging) in dry periods.

6.10 CASE STUDY 9 – GREEN FILTERS PROJECT (THE PHILIPPINES)

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Project Name:	Green Filters Project
Partners:	LP4Y; Global Nature Fund; Kärcher; Sika; Holcim Philippines
Location:	Life Project for Youth (LP4Y) Green Village, Calauan, Laguna, Philippines
Wastewater Type:	Domestic Wastewater from LP4Y Green Village
Design Flow:	Target of 200–300 pax capacity when fully operational
Completion Date:	Construction completed (May 2017); not fully operational
Technology:	The Green Filters is composed of the following systems: (i) an Anaerobic Baffled Reactor which serves as the septic/holding tank receives all black wastewater from toilets and showers; wastewater (ii) flows to the VF wetland, then to the (iii) 2-stage HF wetland; and ends at the (iv) Polishing Pond. The final effluent is then released to the creek nearby. The plan is to reuse the treated domestic wastewater for Green Village's organic garden activities.
Description of project need:	Sanitation is a major issue in the Philippines as a result of the high cost of centralized domestic wastewater treatment system. Only about 5% of domestic wastewater is being treated in the Philippines and in mostly urban areas which can afford the expensive cost of centralized system. Rural areas remain a challenge when it comes to sanitation. If these issues are not addressed, waterbodies in the country will continue to degrade and will pose a threat to public health. This is the case in Manila Bay, Boracay, and Laguna Lake in the Philippines which have become "cesspools" due to untreated domestic wastewater discharge.
Description of project solution:	Treatment wetlands as a natural treatment system, harnesses the potential of plants, microbes, and filter materials to clean water. Local vegetation such as *Heliconia sp.*, canna lily, horsetail and sedges are used in the system. TWs are a low-cost system that can be easily adopted in communities and used even without connection to a central wastewater treatment system. This project will minimize household wastewater discharged directly into waterbodies which causes water pollution and health related diseases. Treated wastewater can also be reused for the purpose of irrigation and gardening.

The Green Filters project aims to demonstrate a method of treating domestic wastewater using a technology that employs natural and local resources. Specifically, it aims to: (1) provide an economically and ecologically sound alternative technology for treating domestic wastewater before discharge to waterbodies; (2) contribute to food and water security in the community; (3) establish a model for economically and ecologically sound alternative technology for treating domestic wastewater; and (4) increase the awareness of local communities and local government units on the problems caused by pollution and its effects on people and the natural ecosystems. The Green Filter project will achieve an overall design that blends with the natural environment in accordance with the landscape of the Green Village. Environmental awareness and protection, biodiversity enhancement, and social acceptance of the "natural wastewater treatment system'' will be realized through this project (Figure 6.11).

Figure 6.11 Case study 9 – Green Filters Project (The Philippines).

6.11 CASE STUDY 10 – BAHCO TREATMENT WETLAND FOR EFFLUENT FINAL POLISHING (ARGENTINA)

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Project Name:	Bahco treatment wetland for effluent final polishing (Argentina)
Location:	Santo Tome, Santa Fe (Argentina)
Wastewater Type:	Metallurgical industry wastewater
Design Flow:	100 m^3/day
Completion Date:	In operation since 2002
Technology:	A FWS wetland of 2,000 m^2 was constructed. It is 50 m long, 40 m wide and 0.4–0.5 m deep. A central baffle was constructed, parallel to the flow direction, dividing the wetland into two sections of equal area and forcing the effluent to flow in “U” form, covering double the distance, resulting in a 5:1 length–width ratio. The wetland was rendered impermeable with 6 layers of compacted bentonite, in order to achieve a hydraulic conductivity of 10^{-7} m s^{-1}. A layer of 1 m of soil was placed on top of the bentonite layer. Several locally available macrophyte species were planted into the wetland. *Typha domingensis* became the dominant species, covering the total area of the wetland. Hydraulic residence time ranged from 7 to 10 days. The effluent, after passing through the wetland, was led to a 1.5 ha pond in the factory facilities. Phreatic water meters were placed around the wetland to monitor groundwater quality, as a security measure.
Description of project need:	Bahco metallurgical industry for toolmaking needed an effluent final-stage treatment. A large land area was available in the factory facilities and costs for maintance and operation of watewater treatment are limiting factors in Argentina. In addition, sewage from the factory also required a final treatment.
Description of project solution:	A FWS wetland was constructed. This type of TW was selected due to the efficiency in metal removal and the low costs for operation and maintenance. Although FWSs requires a large area, this is not a problem in this case. Industrial wastewater containing metals and sewage from the factory are treated together, both after a primary treatment (25 m^3 d^{-1} of sewage + 75 m^3 d^{-1} of industrial wastewater). Sewage improves the ability of macrophytes to take up heavy metals from wastewater (Figure 6.12).
Special benefits of using TW technology compared to other solutions:	The FWS wetland showed high removal efficiencies of Cr, Ni, Zn, Fe, COD and BOD. Treated effluent meets the Argentinian law limits for discharge. FWS performance improved with wetland maturity. Sediment and macrophyte roots were responsible for the metal removal. Metals were bound to sediment fractions that would not release them into water while the chemical and environmental

conditions of the system were maintained. Although this FWS wetland was faced with accidental events, it was capable of recovering its performance, demonstrating its robustness**.** FWS and the discharge pond provide an additional ecosystem service with a high diversity of macrophytes and have become the habitat for diverse wildlife, such as ducks, geese, coots, coypus, lizards, capybaras, turtles, etc (Table 6.6).

Figure 6.12 Case study 10 – Bahco treatment wetland for effluent final polishing (Argentina).

Table 6.6 Performance data case study 10 (Argentina). Ranges (minimum and maximum values in mg/L) of measured parameters at the inlet and outlet and removal efficiencies.

Parameter	Inlet	Outlet	% Removal
pH	10.4–12.2	7.9–9.3	–
Conductivity (μS/cm)	3890–8700	1400–2500	–
Fe (mg/L)	0.05–2.54	0.05–0.430	89.4
Cr (mg/L)	0.023–0.204	0.002–0.033	84.7
Zn (mg/L)	0.022–0.070	0.015–0.050	51.2
Ni (mg/L)	0.004–0.101	0.004–0.082	69.5
COD (mg/L)	27.9–154.0	13.9–42.9	74.6
BOD (mg/L)	9.8–30.9	3.0–20.1	73.2

More information:

- Maine *et al.* (2017): *Ecological Engineering* **98**, 372–377.