# A Hybrid Wetland for Small Community Wastewater Treatment in Morocco

***This paper presents design parameters for a hybrid constructed wetland and tentative strategies for optimizing treated effluent reuse for irrigation.***

Authors: Bouchaib El Hamouri, Christopher Kinsley, Anna Crolla


## Abstract

A pilot hybrid constructed wetland system was established in 2007 at the Institut Agronomique et Véterinaire Hassan II (IAV) in Rabat, Morocco aiming at: i) adapting constructed wetland technology to small communities in Morocco ii) defining tentative nitrogen management strategies for durable effluent reuse applications. The three stage system includes a primary vertical flow wetland, a secondary horizontal flow wetland and a tertiary vertical flow sand filter. Recirculation from stage three to stage two was used to prompte denitrification. The system reduces COD by 95%, TSS by 94% and E.coli by 2.6 logs. Total nitrogen is reduced by 65% with a recycle rate of 100% which balances nitrogen demand for irrigated crops in arid regions. This passive wetland technology has been shown to function well under Moroccan climatic conditions and provides a low cost wastewater treatment system for small communities.


## Introduction

Morocco, as with other countries in North African and the Middle East, is situated predominantly in arid and semi-arid climatic zones and is confronted with a growing water crisis. Agriculture remains the primary consumer of water at 88 percent of mobilised water resources and it is projected that available water resources will decline from 1000 $m^3$/cap/yr in 2000 to 570 $m^3$/cap/yr in 2025 (Government of Morocco, 2001). As well, wastewater treatment in rural areas of Morocco is significantly lacking, with uncontrolled discharge. Due to a lack of irrigation options, farmers often use untreated wastewater and subject themselves and consumers to significant health risks. In the case of Morocco, approximately 70 million $m^3$ of untreated wastewater are used each year without any sanitary precautions to irrigate an area of more than 7000 hectares (El Kettani et al., 2008).

A pilot hybrid constructed wetland system was established in 2007 at the Institut Agronomique et Vétérinaire Hassan II in Rabat, Morocco in order to adapt constructed wetland technology for small community wastewater treatment and agricultural reuse under Moroccan climatic conditions.

## Technical Data:

The pilot wetland system consists of three stages: a primary vertical flow wetland, a secondary horizontal flow wetland and a tertiary vertical flow sand filter. Design details include:

- Design flow = 12 $m^3$/d
- Total system occupies 4.5 $m^2$ per person equivalent (PE)
- Three primary vertical flow wetlands operated in sequence with 4 d operation and 8 d rest period. Hydraulic loading rate = 0.5 m/d
- Horizontal flow wetland residence time = 3.1 d
- Vertical flow sand filter hydraulic loading rate = 0.25 m/d
- Optimum recycle rate for denitrification = 100%

## Overview of the Wastewater Technology

### Hybrid Constructed Wetland Technology

The hybrid wetland technology is depicted in Figure 1 and consists of three stages: a primary vertical flow (VF) wetland to remove solids, a secondary horizontal flow (HF) wetland to remove organic matter and nitrogen and a tertiary VF sand filter to remove pathogens and to nitrify effluent. Wastewater is recycled from Stage 3 to Stage 2 to promote denitrification.

The first stage is a primary VF wetland following the CEMAGREF design (Molle et al., 2005). The filter consists of: a 15 cm drainage layer of 20-40 mm gravel, a 10 cm intermediate layer of 10-20 mm gravel and a 30 cm layer of 8-10 mm gravel (Figure 2 and Figure 3). Three filters (5 x 5 m) are planted in native *Phragmites australis*. Each filter is dosed for 4 days at 12 $m^3$/day followed by an 8 day rest period. The primary filter receives raw wastewater and removes solids and organic matter through filtration and biological treatment. Organic matter accumulates in the filter and mineralizes over time. Root penetration and wind induced swaying of the Phragmite stems act to maintain drainage pathways and alleviate clogging of the filter surface.

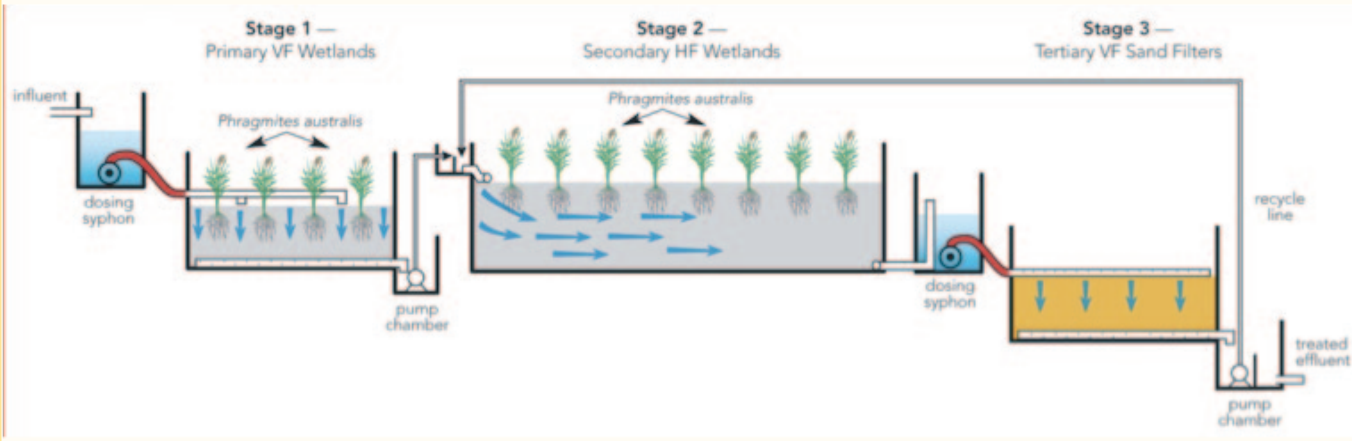


**Figure 1: Hybrid Pilot Wetland Cross-Sectional View**

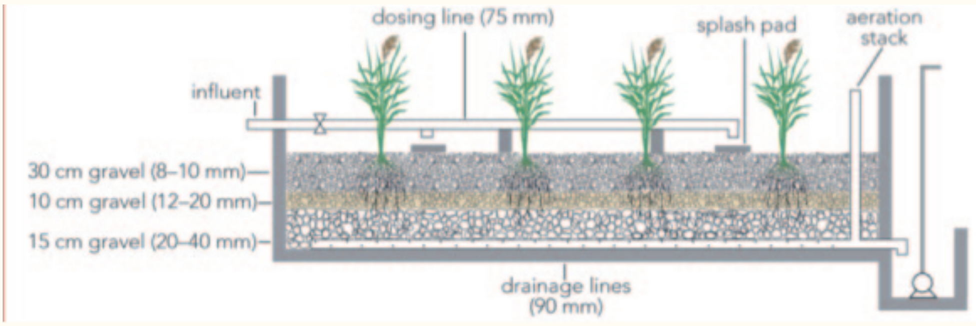


**Figure 2: Primary VF Wetland Cross-Sectional View**

**Figure 3: Primary VF Wetland - Photos (2007, left, and 2011, right)**

The second stage is a HF wetland planted in native *Phragmites australis* (Figure 4 and Figure 5). The wetland sizing is based on first order kinetics for removal of organic matter (Young et al., 1998; El Hamouri, 2007). The HF wetland consists of three parallel cells of 20 m × 2.45 m each with a depth of 0.65 m of 12-20 mm gravel (middle cell unplanted). The HF wetland has a hydraulic retention time of 3.1 days.

The third stage is comprised of a series of three VF sand filters in parallel for nitrification and pathogen attenuation (Figure 6 and Figure 7). The design is based on a single pass sand filter designed for nitrification (Crites and Tchobanoglous, 1998; Cooper, 2005). Each filter (4 x 4 m) consists of: a 20 cm drainage layer of 12-20 mm gravel, a 40 cm layer of 1-5 mm washed sand and a 20 cm layer of 12-20 mm gravel.

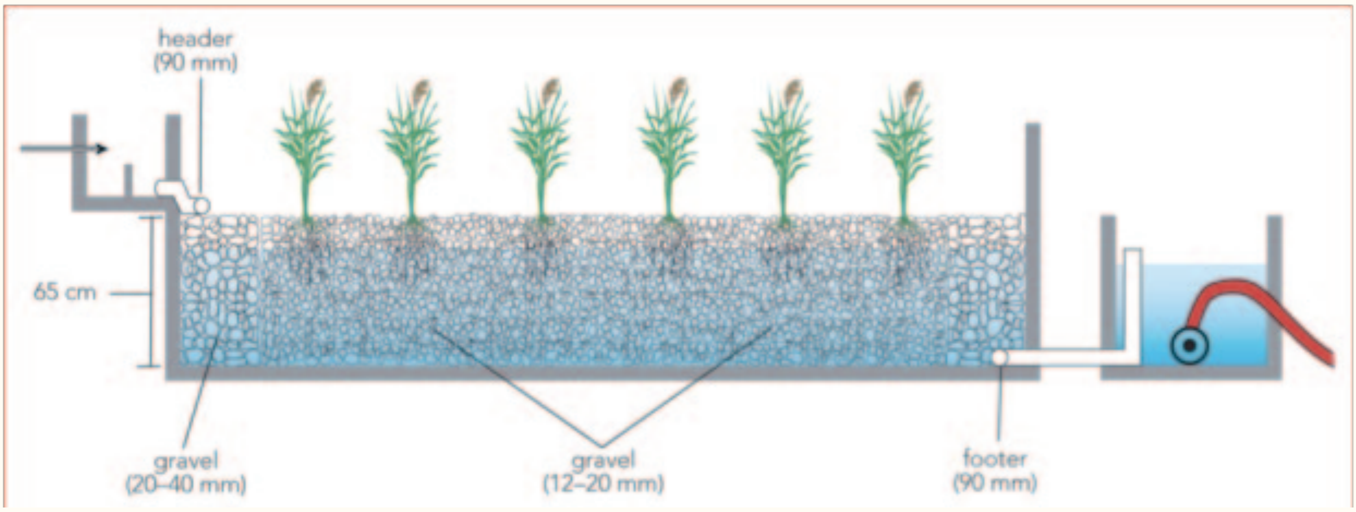


**Figure 4: Secondary HF Wetland Cross Sectional View**

**Figure 5: Secondary HF Wetland Photos (2007 & 2008)**

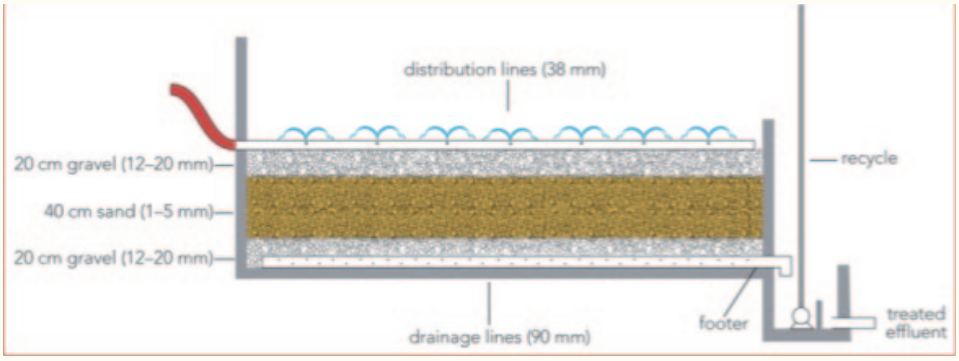


**Figure 6: Tertiary VF Sand Filter Cross Sectional View**

**Figure 7. Tertiary VF Sand Filter Cross Photo (2011)**

## System Performance

Performance of the hybrid wetland technology is presented in Table 1.

### Organic Matter and Solids

The CW system is very effective at removing organic matter and solids with most of the organic matter and solids removed after the HF wetland. For restricted wastewater reuse (i.e. irrigation of forage crops or cereals), TSS must be below 100 mg/L (Government of Morocco, 2002). This level of treatment is achieved by the HF wetland stage. Therefore, if a secondary quality effluent is required, it is not necessary to include a tertiary VF sand filter in the design.

### Nitrogen

A total nitrogen reduction of 65% was achieved with a recycle ratio of 100%. The VF sand filter was effective at nitrifying the ammonia from the HF wetland and the anoxic conditions in the HF wetland were conducive for denitrification. It is important to reduce total nitrogen levels prior to irrigation as nitrogen is often in excess of crop requirements and could contaminate groundwater resources.

Irrigation and nitrogen requirements are given for several crops for the irrigated region of Tadla, Morocco which receives annual average precipitation of 268 mm/yr (Berrada, 2009) (see Table 2). Calculations were based on total nitrogen concentrations ranging from a typical value of 70 mg/L (Crites and Tchobanoglous, 1998) to the 115 mg/L reported in this study (see Table 1). Nitrogen from treated wastewater meets crop N requirements in most cases when 65 % is removed through recirculation. Therefore, recirculation to

**Table 1: Hybrid Wetland Performance (Avg. ± Std. Dev.)**

| | COD (mg/L) | TSS (mg/L) | TN (mg/L) | E.coli (CFU/100mL) |
|---|---|---|---|---|
| **Raw Wastewater** | 746 ± 137 | 328 ± 94 | 115 ± 11 | $5.6x10^6$ |
| **Primary VF Wetland** | 199 ± 38 | 62 ± 32 | 68 ± 27 | $3.0x10^6$ |
| **Secondary HF Wetland** | 56 ± 13 | 25 ± 21 | 40 ± 14 | $2.1x10^5$ |
| **Tertiary VF Sand Filter** | 35 ± 15 | 20 ± 26 | 40 ± 14 | $1.5x10^4$ |
| **Removal Rate** | 95% | 94% | 65% | 2.6 log |

**Table 2: Example of Crop Nitrogen Demand met by Wastewater Reuse (Tadla, Morocco)**

| Crop | Irrigation Water Requirement 1 ($m^3$/ha/year) | Plant N Requirement (kg/ha/year) | Wastewater N Supplied | |
|---|---|---|---|---|
| | | | With No Recirculation (40% removed) (kg/ha/year) | With Recirculation (65% removed) (kg/ha/year) |
| **High N Required** e.g. alfalfa, grain corn, citrus and olive plantations [2] | >8000 | 200-300 | 336-550 | 200-320 |
| **Medium N Required** e.g. wheat [3] | 4000 | 100-150 | 168-280 | 100-160 |
| **Low N Required** e.g. barley | 2500 | 80-120 | 105-170 | 63-100 |

[1] Belabbes, 2004; [2] Walali et al., 2003; [3] Moughli and Cherkaoui, 2002

promote denitrification will often be necessary to avoid nitrate contamination of the groundwater in arid regions with significant water demand.

### Pathogens

The two pathogen indicators governing wastewater reuse are E.coli bacteria and helminth eggs. E.coli numbers are reduced by 2.6 logs throughout the system from 5.6 x $10^6$ in the raw wastewater to 1.5 x $10^4$ CFU/100mL at the outlet of the VF sand filter. Although not enumerated in this study, helminth eggs are effectively removed through filtration and will likely be removed in the first filter, as they are closely associated with wastewater sludge (Kengne et al., 2009).

For unrestricted reuse (i.e. irrigation of produce eaten raw) pathogen standards are typically $10^3$ CFU/100mL E.coli and <1 helminth egg/litre (WHO, 2006). A further disinfection step would therefore be required as the VF Sand Filter reduces E.coli to only 1.5 x 104 CFU/100mL.

## Conclusions

The hybrid constructed wetland technology is a promising wastewater treatment alternative for small communities in Morocco and for communities with comparable socio-economic and climatic conditions. The system has been shown to function well over four years of continuous operation. The passive wetland technology provides several advantages including: low capital and operating costs, low energy requirements and high levels of treatment. The system produces tertiary quality effluent suitable for direct discharge or for irrigation of forage crops, cereals and fruit trees while reducing pathogen risk and protecting groundwater from excess nitrogen leaching.

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**Name**: Bouchaib El Hamouri
**Organisation**: Département Eau Environnement et Infrastructures, Institut Agronomique et Vétérinaire Hassan II
**Town, Country**: Rabat, Morocco
**eMail**: belhamouri@gmail.com

**Name**: Christopher Kinsley
**Organisation**: Ontario Rural Wastewater Centre, University of Guelph-Campus d'Alfred
**Town, Country**: Ontario, Canada
**eMail**: ckinsley@alfredc.uoguelph.ca

**Name**: Anna Crolla
**Organisation**: Ontario Rural Wastewater Centre, University of Guelph-Campus d'Alfred
**Town, Country**: Ontario, Canada
**eMail**: acrolla@alfredc.uoguelph.ca