

## Water Quality Effluent From a Recirculating, Vertical-Flow, Constructed Wetland

AUTHORS

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### ABSTRACT:

Subsurface constructed wetlands have been used for more than a decade in LaGrange County, Indiana, to remove wastewater contaminants that could reach groundwater supplies. Performance of a subsurface constructed wetland using a recirculating vertical flow to treat sewage from a single-family home was examined. Effluent water samples were taken biweekly and analyzed for total suspended solids (TSS), five-day biochemical oxygen demand (BOD<sub>5</sub>), total nitrogen (TN), total Kjeldhal nitrogen (TKN), nitrate-N, ammonia-N and fecal coliform bacteria. Water analyses collected on site included temperature, dissolved oxygen, oxido-reduction potential and pH. The constructed wetland system efficiency was high after a year operation. Average treatment efficiencies for TSS, BOD<sub>5</sub>, TN, TKN, ammonia-N, and coliforms removal were 96, 97, 83, 93, 92 and 99 percent respectively. Nitrate-N final mean value was 9.8 mg/L, and dissolved oxygen concentration increased from 0.8 to 4.5 mg/L. These results indicate that a constructed wetland using a recirculating, vertical-flow is a viable alternative to pretreating conventional septic systems effluents before underground discharge.

Conventional septic systems are commonly used to treat residential sewage in areas without sanitary sewers. However, septic systems are not suitable for all sites and have been considered a primary contaminant source for private water wells (Bhardwaj, 2003). Septic tanks effluents contain high concentrations of pollutants, including dissolved nitrogen that could contaminate groundwater with nitrate, thereby impairing human water supplies (Whitehill et al., 2003; Hanson et al., 2002).

Subsurface constructed wetlands have been used for more than a decade in northeast Indiana's LaGrange County to remove human wastewater pollutants and reduce contaminants that could reach the groundwater supplies. At present, more than 150 subsurface constructed wetlands using horizontal flow are in use in the county.

The water quality testing data for the installed constructed wetlands effluents with horizontal flow shows biological oxygen demand (BOD) and total suspended solids (TSS) to acceptable concentrations. However, the horizontal-flow constructed wetlands show low efficiency for eliminating nitrogenous compounds because of the limited oxygen transfer.

Anaerobic conditions predominate in horizontal-flow constructed wetlands (EPA, 2000). As a result, oxidation of ammonia-N, which is the predominant form of nitrogen in septic tank effluents, cannot achieve low levels

as desired. To improve removal of nitrogen compounds from septic tank effluents, a recirculating vertical-flow constructed wetland, serving a single-family home was constructed and evaluated in LaGrange County.

### Materials and Methods

A constructed wetland measuring 15 ft. (4.6 m) x 15 ft. and 43 inches (1.1 m) deep was built to treat sewage from a single-family home (Figure 1). The volume of sewage treated was assumed to be approximately 1,700 L (450 gallons) per day for the three-bedroom home according to current Indiana State Department of Health regulations (ISDH, 1990). The house is inhabited year-round by three people. The assumed daily flow of 450 gallons per day (gpd) is excessive by comparison to metered flow from sanitary sewer connections. The LaGrange County Sewer District has found a metered sewage flow of 120 gpd for home connections with a mean family size of two adults.

The subsurface, recirculating, vertical-flow constructed wetland utilized a timer to apply pretreated sewage over the entire top bed area planted with river bulrush (*Scirpus fluviatilis*), hard-stemmed bulrush (*Scirpus acutus*), soft-stemmed or great bulrush (*Scirpus validus creber*), prairie cord grass (*Spartina pectinata*), common rush (*Juncus effuses*), dark green rush (*Scirpus atrovirens*) and great spike

solved oxygen (DO) using an oxygen meter (YSI, Model 95/50 FT), oxygen reduction potential (ORP), and pH using a combined ORP & pH meter (WTW, Model 340). The removal efficiency was calculated according to the equation used by Ebeling et al. (2003) as follows:

$$\text{removal efficiency (\%)} = \frac{\{(\text{influent-effluent})/\text{influent}\} \times 100}{\text{(equation 1)}}$$

### Results and Discussion

The wetland effluents results for DO, ORP, pH, air and water temperature, BOD<sub>5</sub>, TSS, coliform bacteria (Table 1), and nitrogenous compounds (Table 2) fluctuated during the experimental period. Mean concentrations were relatively low, though some values fall below, between, or above the Indiana Department of Environmental Management (IDEM, 2005) final effluent standards for sanitary sewage plants under the National Pollutant Discharge Elimination System (NPDES) for BOD<sub>5</sub> (15 mg/L as a monthly average and 23 mg/L as a weekly average), TSS (18 mg/L as a monthly average and 27 mg/L as a weekly average) and NH<sub>4</sub><sup>+</sup>-N (1.4 mg/L as a monthly average and 3.4 mg/L as a daily average during the summer period). The final wetland effluent meets Clean Water Act requirements for direct discharge to a surface water body with mean values for BOD<sub>5</sub>, TSS, and NH<sub>4</sub><sup>+</sup>-N of 5.2, 3.4, and 3.2 mg/L, respectively.

The pH requirements of the final effluent must be between 6 and 9 standard units to maintain a well-balanced microbial community. In this study, the pH fluctuated from 6.5 to 7.8 standard units. The Clean Water Act requires DO concentration of the discharged effluent from sanitary sewage plants to be above 6 mg/L as a daily minimum average during summer or 5 mg/L during winter. The final mean concentration for DO during the testing period was 4.5 mg/L with a summer and winter mean concentration of 4 and 5.1 mg/L, respectively.

Bacteria (*E. coli*) values are limited to 235 count/100 mL as a daily maximum average and 125

rush (*Eleocharis palustris*), with a density of about seven plants per square meter. The wastewater was collected in a 3,800-L (1,000-gallon) septic tank, and then gradually released by gravity flow to the feeding inlet bottom of the wetland. The wetland cell was built with a 30-mil PVC liner fabricated by Environmental Protection, Inc. (Mancelona, Michigan) and filled 18 inches (46 cm) deep with 13- to 25-mm diameter stone in the bottom layer, and 24 inches (61 cm) deep with 4-mm diameter gravel in the top layer.

Treated water was collected in the outlet sump pit, consisting of a 5-foot (1.52-m) section of 24-inch (61-cm) diameter black corrugated drain tile installed vertically. The bottom of the drain tile was filled with concrete to avoid infiltration into the ground, and the top was fitted with a drain tile cap. During each 30-minute period, the wetland effluent collected in the sump pit was pumped for two minutes via a 1-inch (2.5 cm) PVC manifold pipe onto the top of the gravel and stone bed. The pump (Myers, Model ME3F), with a maximum recirculation flow of 66 gallons per minute, was controlled by an electronic repeat cycle timer (Omron, Model H3CR).

Water samples from the effluent collected in the sump pit were taken biweekly for one year and submitted to a certified U.S. Environmental Protection Agency (EPA) testing laboratory and analyzed using the methodology described in *Standard Methods* (SM) (APHA et al., 1998) and in the EPA manual, *Methods for Chemical Analysis of Water and Wastes* (EPA) (EPA, 1983), for the following parameters: five-day biochemical oxygen demand (BOD<sub>5</sub>) (SM, 5210-B), nitrate (NO<sub>3</sub><sup>-</sup>-N) (EPA, 353.2), ammonia-N (NH<sub>4</sub><sup>+</sup>-N) (EPA, 350.3), TSS (EPA, 160.2); fecal coliforms bacteria (*E. coli*) (EPA, Coliscan) and TKN (EPA, 351.4). TKN is defined as the sum of the free NH<sub>4</sub><sup>+</sup>-N and organic nitrogen compounds. Total-N (TN) is determined by the combination of TKN and NO<sub>3</sub><sup>-</sup>-N.

Water analyses collected on-site in the outlet sump pit included temperature (air and water), dis-

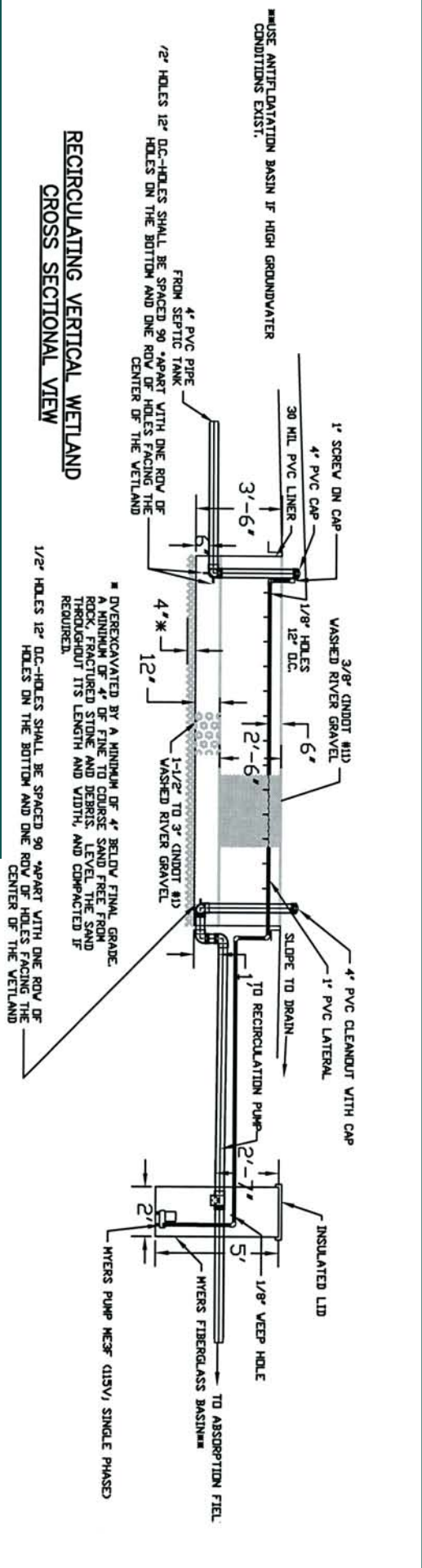


Figure 1—Diagram of subsurface constructed wetland using a recirculating vertical flow.

count/100 mL as a monthly maximum average. The final mean concentration of fecal coliform bacteria in the wetland effluent during the experimental period was 6,511 count/100 mL, but this concentration decreased drastically to 64, 190, 100 and 160 count/100 mL on effluents sample during days 69 and 83 (spring), 230 (summer) and 286 (fall), respectively.

The removal efficiency (Table 3) for TSS, BOD<sub>5</sub>, Total-N, TKN, NH<sup>+</sup><sub>4</sub>-N, and fecal coliform bacteria was 96, 97, 83, 93, 92 and 99 percent, respectively. The nitrate-N concentration showed a final mean value of 9.8 mg/L. The concentration of DO, pH, BOD<sub>5</sub> and TSS (Figure 2), and nitrogenous compounds such NH<sup>+</sup><sub>4</sub>-N, NO<sup>-</sup><sub>3</sub>-N, TKN, and TN (Figure 3) fluctuated during the experimental period and the results were highly variable. However, the constructed wetland achieved rates of 100 percent removal during days 41, 55, 69, and 83 (spring) and 146 (mid-summer) for TSS, days 69 and 83 (spring) for BOD<sub>5</sub>, and days 181, 202, 230, 258, and 286 (summer and fall) for NO<sup>-</sup><sub>3</sub>-N.

Hanson et al. (2002) reported that due to the high evapotranspiration (ET) rate occurring in the planted bed, the constructed wetland cell in their study produced no discharge to the absorption field. In the current study, effluent was observed discharging to the absorption field only during January and February (winter) and November (late fall). This observation is important considering the reduction of leach field allowed by the Indiana State Department of Health. Currently, the leach field reduction using constructed wetland fluctuates from 33 to a maximum of 50 percent, depending on soil conditions in the area of the absorption field.

Also, a review of the data indicates that ET may be affecting treatment performance. During the high ET summer months, water losses would cause a concentration effect that would explain the higher levels of BOD and TSS and the change in the pH values. Warm water carries less DO, and a smaller overall volume of water in the system

**Table 1—Values for the recirculating vertical-flow constructed wetland built in LaGrange County, Indiana.**

Date (Day)	DO (mg/L)	ORP (mV)	pH (SU)	Air (°C)	Water (°C)	BOD <sub>5</sub> (mg/L)	TSS (mg/L)	E. coli (count/100 mL)
1	6.4	70	6.5	3.5	6.5	5	3	6,800
27	6.4	72	7.8	2.3	4.0	4	2	58,000
41	5.4	-15	7.3	1.9	4.2	3	0	470
55	7.2	-15	7.5	2.7	6.3	2	0	16,000
69	7.1	-27	7.6	2.9	5.9	0	0	64
83	5.8	-32	7.6	6.3	8.7	0	0	190
97	4.2	-25	7.5	20.1	13.9	6	6	570
113	2.5	44	7.3	11.6	14.7	ND	ND	ND
125	2.3	272	7.2	24.4	17.5	4	2	4,800
146	4.7	47	7.3	27.1	19.4	2	0	1,300
160	3.7	70	7.3	19.2	19.9	9	4	11,000
181	3.6	44	7.4	25.6	21.1	7	8	3,300
202	3.6	47	7.4	31.1	21.9	14	13	4,500
230	5.0	290	7.5	24.6	21.8	6	3	100
258	3.8	368	7.5	22.6	21.2	8	5	1,800
286	5.5	413	7.7	14.7	13.9	6	4	160
321	1.3	350	7.3	0.5	10.9	7	6	1,000
349	1.8	88	7.5	-17.2	6.7	6	2	640
Mean	4.5	115	NA	12.4	13.3	5.2	3.4	6,511
SD	1.8	126	NA	10.9	6.7	3.5	3.5	13,981
Max	7.2	413	7.8	31.1	21.9	14	13	58,000
Min	1.3	-32	6.5	-17.2	4.0	0	0	64

Mean concentration, standard deviation (SD), maximum (Max), and minimum (Min) values of dissolved oxygen (DO), oxido-reduction potential (ORP), pH, air and water temperature, biochemical oxygen demand (BOD<sub>5</sub>), total soluble solids (TSS), and fecal coliform bacteria (*E coli*) NA: not Applicable, ND: not data.

**Table 2—Values for the recirculating vertical-flow constructed wetland built in LaGrange County, Indiana.**

Date (Day)	NH <sup>+</sup> <sub>4</sub> -N (mg/L)	NO <sup>-</sup> <sub>3</sub> -N (mg/L)	TKN (mg/L)	TN (mg/L)
1	4.2	18.3	6.0	24.3
27	1.7	20.0	2.4	22.4
41	2.8	24.5	3.4	27.9
55	0.8	18.6	2.4	21.0
69	1.3	22.0	2.0	24.0
83	1.8	19.2	3.3	22.5
97	1.9	4.1	3.4	7.5
113	ND	ND	ND	ND
125	4.4	11.7	5.7	17.4
146	1.4	10.9	1.8	12.7
160	5.1	5.5	5.1	10.6
181	2.8	0	3.8	3.8
202	5.2	0	5.4	5.4
230	1.9	0	2.3	2.3
258	4.7	0	5.2	5.2
286	5.1	0	5.4	5.4
321	5.6	7.0	6.3	13.3
349	3.9	5.5	4.8	10.3
Mean	3.2	9.8	4.0	13.8
SD	1.6	8.9	1.5	8.4
Max	5.6	24.5	6.3	27.9
Min	0.8	0	1.8	2.3

Mean concentration, standard deviation (SD), maximum (Max), and minimum (Min) values of ammonia-N (NH<sup>+</sup><sub>4</sub>-N), nitrate-N (NO<sup>-</sup><sub>3</sub>-N), total Kjeldahl nitrogen (TKN), and total-N (TN=TKN + NO<sup>-</sup><sub>3</sub>-N) for the recirculating vertical-flow constructed wetland built in LaGrange County, Indiana. ND: Not Data



would result in a greater residence time in the saturated anoxic bottom portion of the constructed wetland bed. This could account for the low DO, ORP, and nitrate-N levels observed in the summer months.

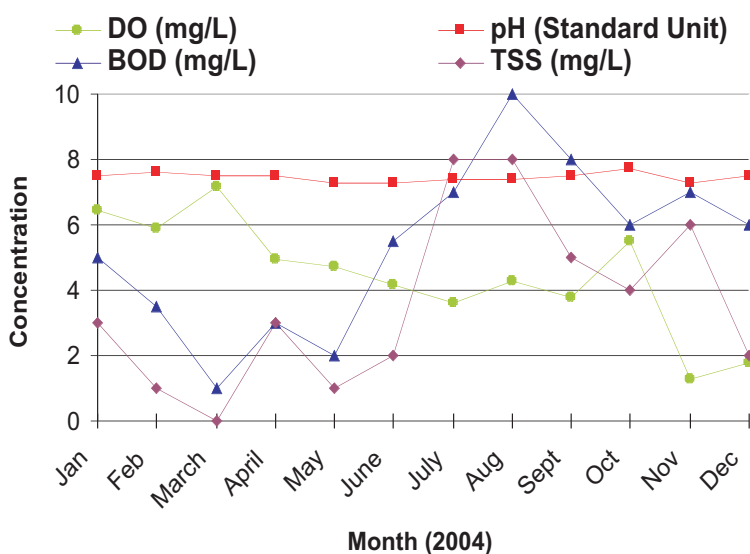
Results for the oxido-reduction potential parameter were as expected with high variable trend, and it is well correlated with DO concentrations. Sewage effluents from a septic tank have a high oxygen demand and a high reducing environment with ORP values reaching as low as -400 mV. Treated effluents usually have low oxygen demand and can reach values of +300 mV (Easton et al., 1998). Favorable ORP conditions for nitrification and denitrification processes can occur from +200 to +400 mV and -50 to +225 mV, respectively. The ORP values during the testing period fluctuated from -15 to +413 mV with a final mean value of +115 mV.

Cooper and Green (1995) found that a vertical-flow constructed wetland can achieve essentially complete BOD<sub>5</sub> removal because of high amounts of oxygen transfer through the gravel/root hair bed. Kurniadie and Kunze (2004) reported higher DO in effluent (6.6 mg/L) of constructed wetland with vertical flow than in influent (1.1 mg/L). High oxygen content in the filter bed is required for bacteria to remove both organic and nutrient pollutants.

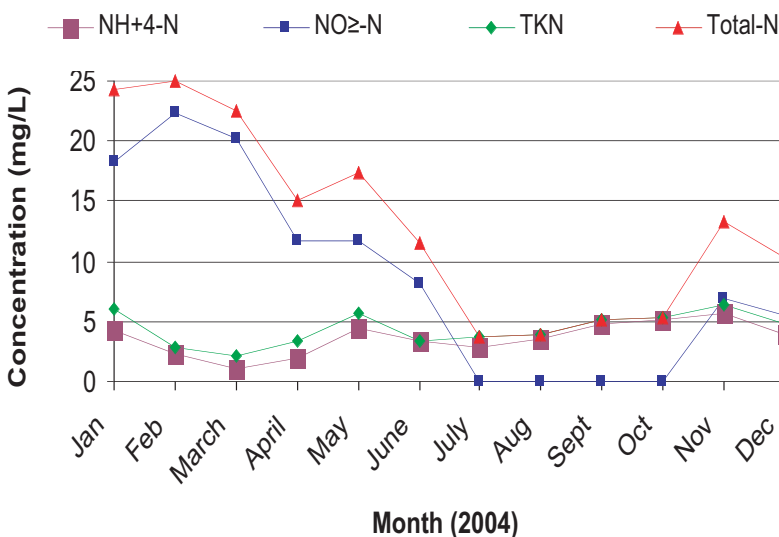
Platzer and Mauch (1997) reported that the removal efficiency of vertical-flow constructed wetlands depend on natural aeration to provide oxygen, and, therefore, BOD<sub>5</sub>, COD and NH<sub>4</sub><sup>+</sup>-N removal is high, but total-N elimination is limited. Luederitz et al. (2001) suggested that denitrification capacity of vertical-flow wetlands is poor. Their study showed TN removal of 71 percent without using recirculation. To improve nitrogen compounds removal in vertical-flow wetlands, they recommend intermittently loading the reed beds. In the present study, the timer allowed every 30 minutes an intermittently loading of the wetland and the TN per-

**Table 3—Treatment efficiency values for the recirculating vertical-flow constructed wetland built in LaGrange County, Indiana. NA: not Applicable**

Water Quality Parameters	Recirculating Vertical-flow Wetland		
	Influent	Effluent	Efficiency
Coliform Bacterium (organisms/100 mL)	320,000,000	6,511	(-) 99.9
Biochemical Oxygen Demand {BOD <sub>5</sub> (mg/L)}	185	5.2	(-) 97.2
Total Suspended Solids {TSS (mg/L)}	94	3.4	(-) 96.4
Total Kjeldahl Nitrogenous {TKN (mg/L)}	53	4.0	(-) 92.5
Ammonia-N {NH <sub>4</sub> <sup>+</sup> -N (mg/L)}	41	3.2	(-) 92.2
Total-N {(TN=TKN+ NO <sub>3</sub> <sup>-</sup> -N) (mg/L)}	80	13.8	(-) 82.8
Nitrate {NO <sub>3</sub> <sup>-</sup> -N (mg/L)}	2	9.8	(+) 400
Dissolved Oxygen {DO (mg/L)}	0.8	4.5	NA
pH (standard units)	7.0-9.0	6.5-7.8	NA
Temperature (°C)	16	13.3	NA
Oxido-Reduction Potential {ORP (mV)}	-350	+115	NA



**Figure 2—Profile concentrations for the recirculating, vertical-flow, constructed wetland built in LaGrange County, Indiana.**



**Figure 3—Profile concentrations for the recirculating, vertical-flow, constructed wetland built in LaGrange County, Indiana.**

formance reached 83 percent of removal efficiency.

According to Gustafson et al. (2002), a properly operating constructed wetland should produce a final effluent with less than 30 mg/L BOD<sub>5</sub>, less than 25 mg/L TSS, and less than 10,000 counts/100 mL fecal coliform bacteria. In the present study, the final low values for BOD<sub>5</sub> (5 mg/L), TSS (4 mg/L) and coliforms (6511 count/100 mL) indicates that this was a properly operating constructed wetland.

### Conclusion

This study shows that the recirculating vertical-flow constructed wetland built in LaGrange County, Indiana had high treatment efficiency. The results indicated that a constructed wetland is a viable alternative technology to pre-treating conventional septic system effluents before land application and surface or underground discharge.

This system was shown to be suitable for residential or commercial projects generating sewage up to 450 gallons per day. However, more recirculating vertical-flow constructed wetlands should be installed and tested to increase the water quality effluent data available to help government entities make decisions.

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