ESTIMATION OF POLLUTANTS BY PREWet MODEL FOR SURFACE FLOW CONSTRUCTED WETLAND IN EGYPT

تقدير الملوثات باستخدام نموذج إزالة الملوثات للأراضي الرطبة المشيدة ذات السريان السطحي في مصر

By

Zidan, A. A.[1], S. T. Abedel Gawad[2], Moharram, S. H.[3], and A. A. Rashed[4]

خلاصة:

الأراضي الرطبة المشيدة هي مناطق انتقالية بين اليابسة و الماء تخدم البيئة و الكائنات الحية البرية و البحرية. تقوم الأراضي الرطبة بحجز الرواسب و الملوثات و تدوير العناصر مع معالجة مياه الصرف ، ولأن إعادة استغلال مياه الصرف هدف استراتيجي في مصرفان الأراضي الرطبة المشيدة تعد أحد البدائل الاقتصادية لمعالجة مياه الصرف و ذلك لاحتياجها البسيط من الطاقة و الأيدي العاملة. تم إنشاء مشروع توضيحي للأراضي الرطبة المشيدة علي مصرف بحر البقر بغرض تقليل صرف الملوثات في بحيرة المنزلة حيث تتواصل الأبحاث و الدراسات لتقييم أداء المشروع في معالجة الملوثات . في هذه الدراسة تم استخدام برنامج تقدير معالجة الملوثات في الأراضي الرطبة (PREWet 2.4) لتقييم معالجة الملوثات المختلفة بالمشروع كالاحتياج الأكسوجيني الحيوي و المواد العالقة الكلية و النيتروجين الكلي و الفسفور الكلي و البكتيريا القولونية الكلية بالإضافة إلى الحديد. يعتمد البرنامج علي نموذج رياضي ذو فرضيتين: السريان المسدود و السريان كلي الخلط لمحاكاة معالجة الملوثات ، وقد تم تحليل حساسية النموذج المستخدم بالنسبة إلى معاملات الأراضي الرطبة المختلفة و ذلك لتحقيق أنسب المعاملات التصميمية للأراضي الرطبة. أظهرت نتائج الدراسة إمكانية محاكاة مشروع الأراضي الرطبة المشيدة علي مصرف بحر البقر بتطبيق برنامج (PREWet 2.4) ، حيث أعطت فرضية السريان ذو الخلط الكلي نتائج متقاربة لمعالجة المواد العالقة الكلية و النيتروجين الكلي و الفسفور الكلي مع النتائج الحقلية و ذلك أفضل من فرضية السريان المسدود بينما أعطت فرضية السريان المسدود نتائج أفضل في حالتي الاجتياح الأكسوجيني الحيوي و البكتيريا القولونية الكلية.

Abstract

Constructed wetlands are artificial transitional zones between terrestrial and aquatic system serving ecological functions such as fish, wildlife, waterfowl and aquatic plants. They also trap sediments and pollutants, cycle nutrients, and reuse treated drainage water. Treating and recycling drainage water in irrigation is a strategic Egyptian target. Constructed wetland is an attractive alternative for treatment of Bahr El Baqar drainage water before reaching Egyptian Northern Lakes since it has low energy input and labour cost. A demonstration wetland project has been established close to Lake Manzala in order to treat and reduce pollutants of drainage water that discharges at the lake. Studies and researches are ongoing to evaluate the performance of the constructed wetland in treating polluted drainage water. A wetland treatment performance model (PREWet 2.4) of the United States Corps of Engineers was applied to estimate the pollutant concentrations for free water surface (FWS) constructed wetland. The model had two approaches based on mixed flow and plug flow. Sensitivity analysis of different wetland parameters was carried out based on the model considered to verify the most significant

1, and 3 Prof., and Assoc. Prof. Irrigation And Hydraulics Dept., Faculty of Eng., Manosura Univ.
2, and 4 The Chairperson and Researcher, National Water Research Center, MWRI.

Accepted September 17, 2005.

design parameters. The BOD, TSS, TP, TN, and total coliform bacteria were estimated and tested with the collected measured field data. Generally, the mixed flow assumption of the model showed closer output results to the field data in case of TN, TP, TC, and Fe comparing with the plug flow approach. Moreover, the plug flow approach showed relatively close results to the field data in case of BOD and TSS than the mixed flow approach.

Keywords: Wetland, drainage water, plug flow, mixed flow, and pollutants.

Introduction

Wetlands are one of the earth's most biologically rich ecosystems. Constructed wetlands are specially engineering systems designed to imitate natural processes in wetland soils, vegetation, and associated microorganisms to meet human needs. As water flows through a wetland, it slows down, and suspended sediments and pollutants are transformed or removed, improving water quality (U.S.EPA. 2004). Constructed wetlands also have significantly lower total lifetime costs and often lower capital costs, less electricity and less labor than conventional treatment systems compared to conventional systems, USEPA (1988) and ITRC (2003).

A small scale constructed wetland project was conducted within Lake Manzala in order to demonstrate a low cost treatment alternative of the polluted drainage water. The project was located within El Salam Canal area served west of Suez Canal on the left bank of Bahr El Baqar Drain. The wetland project was planned to treat 250 m^3 /day of drainage water before it reached Lake Manzala. The project main objective was to demonstrate a sustainable economic technique that could protect the Lake from the pollution carried by drainage water. This research includes the following objectives:

- Carrying out a sensitivity analysis for the PREWet model to find out the major affecting wetland parameters on pollutants treatment.
- Comparing the PREWet model results with filed results obtained from a small scale surface flow wetland in Egypt.
- Studying the applicability of the PREWet to estimate pollutant removals for constructed wetland design purposes.

PREWet 2.4 Model

The Pollutant Removal Estimates for Wetlands, (PREWet) version 2.4 model was representing screening-level, analytical model introduced by the U.S. Army Corps of Engineers. The model objective was to estimate the removal efficiency for a specific pollutant by a wetland which was given a limited amount of basic information about the wetland. The model used simplified quantitative methods that minimize time and effort for the end user. Dortch, and Geralcl, (1995) and (2000) reported that the model was called PREWET, which was an acronym for Pollutant Removal Estimates for Wetlands. The equations and logic were programmed in C^{++} language, and a commercially available graphical user interface (GUI) library, Zinc, which was written in C^{++}, was utilized. PREWET used menus for selection of variables and parameters, and default values were also provided for parameters. The model was designed to be self-explanatory, but on-line help features were available if necessary.

The model advantage was that it could be rapidly applied with few input data for estimating pollutant treatment efficiency of wetlands. With the wetland characteristics as input data, pollutant removal efficiency (RE) could be computed for total suspended solids (TSS), total coliform bacteria (TC), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), and contaminants (e.g., organic chemicals and trace metals). The RE depends on the wetland detention time (τ) and the removal rate, K_T (day^{-1}), for the constituent. The removal rates depend on biological, physical and chemical processes, such as microbial metabolism, adsorption, volatilization, denitrification, settling, etc., and water temperature as well. The model also depends on the long-term pollutant removal mechanisms, making use of literature values or mathematical formulations for those processes when possible.

Study Area

A small scale surface flow constructed wetland is executed with treatment capacity of 150 m^3 /day of drainage water lifted from Bahr El Baqar drain Northeastern Nile Delta, Egypt. This wetland was used as a low cost treatment option of drainage water as a measure of protecting Lake Manzala from pollution. The wetland consists of 3 parallel cells each cell dimensions are 20 m length, 10 m width and 0.5 m water depth with a discharge of 50 m^3/day. Reeds were planted in cells to complete treatment functions through filtration, nutrient uptake and biodegradation of pathogens. Water inters the wetland after spending 2 days at a sedimentation basin as a primary treatment stage. Wetland cells were designed to keep water for 2 days as a secondary treatment stage. Field and laboratory studies were carried out to evaluate drainage water treatment at the Lake Manzala constructed wetland.

Monitoring water treatment through free water surface wetland started from July 2003 and to April 2004. Twenty two events were carried out during this period. In each event, composite water samples were collected from the sedimentation outlet which represents the wetland cells inflow. Other water samples were collected from the middle of the wetland cells and from the wetland cells outlets. Water samples were tested to determine the pollutant concentrations or loads at the entrance, middle part and outlet of the 3 wetland treatment cells. The outlet pollutant concentrations were the arithmetic mean of the 22 data sets that were collected from the wetland cells. Table 1 presents the summary of the field data obtained from the project. Results show that; about 70 % of the Biological Oxygen Demand, BOD and 80% of the Total suspended solids TSS, and 50% of both total Nitrogen, TN and Total Phosphorus, TP are removed from the influent water. Treatment efficiency of TC and fecal coliform, FC was recorded 98%.

Sensitivity Analysis of PREWet 2.4 Model on the Wetland Design Parameters

The PREWet 2.4 model was tested, with several runs, for different wetland design parameters such as physical dimensions and hydraulic detention time. Each parameter was studied by changing its value and fixing the other parameters to calculate the corresponding discharge and detention time that copes with the estimated parameters. Using the plug flow approach of the model would assume a 58% reduced detention time and could not be compared with the field results. Therefore, the mixed flow approach was only used since its detention time was similar to the design detention time.

Table 1 Summarized Field Data for Different Pollutants

Item	Removal Rater Constants	Units	Field Data analysis				
			Inflow	outlet Cell 1	outlet Cell 2	outlet Cell 3	average cells outlets
BOD	0.374	mg/l	28.6	7.9	8.2	8.5	8.2
TSS	0.275	mg/l	23.5	9.5	9.3	9.5	9.4
TN	0.256	mg/l	6.53	3.83	3.65	3.77	3.75
TP	0199	mg/l	0.703	0.466	0.429	0.420	0.43V
TC	0.833	mpn/ 100ml	63000	1150	1200	1250	1230
Fe	0.264	mg/l	0.313	0.147	0.132	0.177	0.154

To study the effects of changing the significant modeling parameters such as detention time τ, a study was carried out on effects of changing physical dimensions (wetland length L, width W or water depth h) as well as the treatment capacity (discharge, Q) on pollutant treatment with fixed removal rate constants. The study led into two directions; firstly to change one of the wetland dimension parameters keeping τ equals to the 2 days design value that means changing wetland capacity and discharge Q. The second direction was to change one of the wetland dimensions with keeping Q as the design value (50 m^3/day) and using different τ according to the new dimensions.

Table 2 presents the sensitivity results on the different wetland parameters with changing τ and Q.

Results showed that fixing detention time on the design value (2 days) and changing wetland depth had no effects on the wetland pollutant treatment since similar effluent pollutant concentration were obtained from wetlands with the same and different wetland length, d except for TP and Fe. On the other hand, changing wetland depth and fixing wetland discharge Q (different values) showed that, wetland treatment efficiency was increased with increasing wetland depth and the correspondence detention time for a fixed discharge rate and vice versa except for TSS, TP and Fe. Treatment of TSS, TP, and Fe depends mainly on sedimentation velocity and the depth had no effect of the sediment process.

The governing parameter in wetland design to obtain the same treatment efficiency was the hydraulic detention time, τ not the physical dimensions (L, W, or h). Increasing wetland treatment efficiency required increasing wetland dimensions with correspondence increasing detention time or decreasing wetland discharge (pollutant load).

Table 2. Effects of changing wetland parameters on PREWet model treatment outputs *(mixed flow approach)*

Wetland Physical features					Effluent Pollutants concentrations					
Length, m	Width, m	Depth, m	Discharge, m^3/d	τ, days	BOD	TSS	TN	TP	TC	Fe
Actual wetland features										
20	10	0.5	50	2	11.46	11.19	3.23	0.39	14540	0.13
Changing Length										
30	10	0.5	75	2	11.46	11.19	3.23	0.39	14540	0.13
40	10	0.5	100	2	11.46	11.19	3.23	0.39	14540	0.13
20	5	0.5	25	2	11.46	7.83	3.23	0.39	14540	0.13
Changing Width										
20	20	0.5	100	2	11.46	11.19	3.23	0.39	14540	0.13
20	5	0.5	50	1	16.36	15.16	4.33	0.50	23630	0.18
Changing Depth										
20	10	0.25	25	2	11.46	7.34	2.14	0.27	14540	0.08
20	10	0.75	75	2	11.46	13.56	3.88	0.46	14540	0.16
Changing Detention time										
30	10	0.5	50	3	8.82	8.87	2.58	0.32	10500	0.10
20	10	0.75	50	3	8.82	11.19	3.23	0.39	10500	0.13
40	10	0.50	50	4	7.16	7.34	2.14	0.27	8220	0.08
20	20	0.50	50	4	7.16	7.34	2.14	0.27	8220	0.08

Table 3 presents the effect of changing τ on pollutant treatment.

It is basically clear that increasing τ will improve the treatment of all pollutants.

Table 3. Effects of changing wetland hydraulic detention time on PREWet model treatment outputs

Pollutants	Units	Detention Time (days)			
		1	2	3	4
BOD	(mg/l)	16.36	11.46	8.82	7.16
TSS	(mg/l)	15.16	11.19	8.87	7.34
TN	(mg/l)	4.32	3.23	2.58	2.14
TP	(mg/l)	0.50	0.39	0.32	0.27
TC	(mpn/100ml)	23630	14540	10500	8220
Fe	(mg/l)	0.18	0.13	0.10	0.08

Figure (1) summarizes the effect of hydraulic detention time values on treatment in the wetland cells where τ varies from one day to four days. With increasing hydraulic detention time the pollutants treatment improve significantly.

Thus, the designer may select the best design option that realizes both acceptable treatment limits with the best economical construction, operation and maintenance costs.

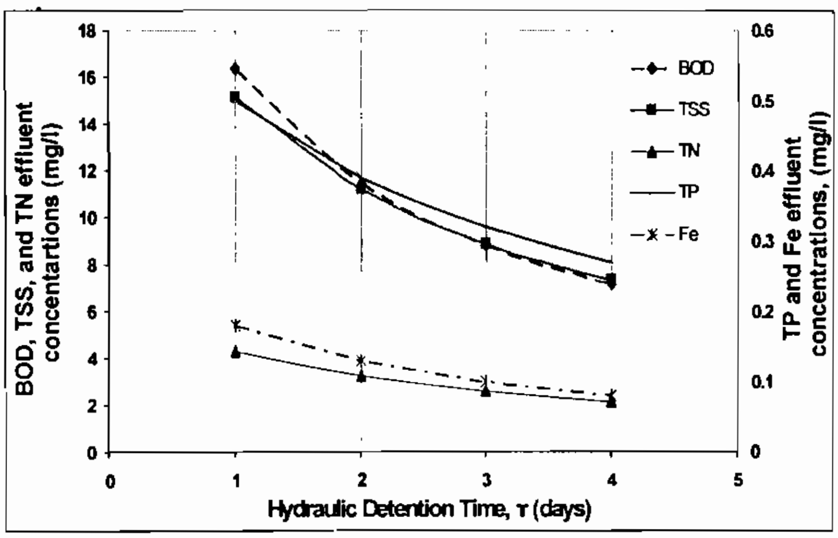

Figure 1. Effects of changing wetland hydraulic detention time on PREWet model treatment outputs

Application of PREWet 2.4 Model for FWS Wetland

The PREWet 2.4 model was used to simulate the pollutants treatment through constructed wetland. The input data used were the dimensions of wetland cells (length, depth, width), discharge, detention time), and the actual practical data collected from field such as concentrations of pollutants at inlet. The removal rate coefficients of different pollutants were obtained from the in-out field concentrations, Table 1. The output data were representing the concentrations of pollutants in effluent water samples and the correspondence removal efficiencies.

Two simulation runs were carried out; the first run represented the plug flow condition while the second run represented the fully mixed flow condition. A summary of the model output in both plug and mixed flow approaches is presented in Table 4.

Table 4 Measured and Simulated effluent pollutants concentration at wetland outlet

Pollutant	BOD	TSS	TN	TP	TC	Fe
Units	mg/l	mg/l	mg/l	mg/l	mpn/ 100ml	mg/l
Measured Field Data						
Average cells outlets	8.200	9.400	3.746	o.447	1230	o.154
Simulated effluents by PREWet 2.4						
Plug Flow approach	12.01	12.42	3.606	0.443	9121	0.137
Mixed Flow approach	11.46	11.19	3.226	0.391	14540	0.129
Simulated effluents by Chen et al (1999)						
PMF approach	6.080	7.112	1.680	0.287	2840	0.093
FMF approach	7.269	8.384	2.491	0.329	3887	0.121

A comparison between the simulated results and the field data was performed to test the accuracy of the model used. Generally, the pollutant concentrations were overestimate for BOD and underestimate for TSS, while it agreed well with field data for other pollutants except for TC due to algal existence at the wetland cells which cause bacterial death massively.

The removal efficiencies (RE) results were computed and listed Tables 5. The PREWet model results show smaller removal efficiency, (RE) for BOD in case of both plug flow and mixed flow assumptions comparing with the field data. The average field RE of the three-wetland cells was 71 % while it was 58% and 60% for plug flow and mixed flow model respectively.

The model showed better removal efficiency, (RE) for TSS for plug flow and mixed flow assumptions comparing with the field data. The average field RE of the three wetland cells was 63 % while it was 69% for both plug flow and mixed flow model.

The PREWet model showed similar removal efficiency, (RE = 44%) for TP for both mixed flow and the field data. The PREWet model showed small removal efficiency, (RE = 37%) for TP comparing with the field RE (43%). Both actual and model results showed that the wetland had low efficiency for TP removal. Phosphorus removal in most constructed wetland systems was not very effective because of the limited contact opportunities between the Drainage water and the soil.

Table 5 Comparison between field and PREWet model effluent pollutant removal efficiencies

Item	Field Data analysis				PREWet Model	
	Cell 1	Cell 2	Cell 3	Average cells	Plug Flow assumption	Mixed Flow assumption
	Removal Efficiency %					
BOD	72	72	69	71	58	60
TSS	63	63	63	63	69	69
TN	41	44	42	43	45	51
TP	41	44	42	43	37	44
TC	98	98	98	98	86	77
Fe	53	58	43	51	56	59

NS=not simulated by the model

The model showed better removal efficiency, (RE) for TN for both and mixed plug flow assumptions comparing with the field data. The average field RE of the 3-wetland cells was 43 % while it was 45% and 51% for plug flow and mixed flow model assumptions respectively.

Model results of total coliform, bacteria, TC show smaller RE for both plug flow and mixed flow assumptions comparing with the field data. The average field RE of the 3-wetland cells was 98 % while it was 86% and 77% for plug flow and mixed flow model assumptions respectively. The better field treatment may be attributed to the algal existence in the water column which had positive effect on TC death.

As for Iron, Fe, model results showed higher values of RE for both plug flow and mixed flow comparing with the field data. The average field RE of the three wetland cells was 51 % while it was 56% and 59% for plug flow and mixed flow model assumptions respectively.

There are other models that can be used to estimate pollutant treatment of constructed wetland. One of these models was based on the fully mixed flow (FMF) through the wetland, Chen, et al. (1999). Another model was an assumption based on the mixed flow model considering partial mixing flow (PMF) between the wetland internal reactors. The results obtained by these models from the Lake Manzala wetland (Moharram et al. (2005) and Rashed (2005) were used to validate the applicability of the PREWet model for pollutant treatment. The results of the mixed and partial mixed flow models based on Chen et al. (1999) for pollutant treatment are listed in Table 4.

As for BOD and TSS effluent concentrations, the FMF model had nearest results to the field data followed by the PMF model and the PREWet model. However, the PREWet with plug flow approach gave the best results for TN, TP, and Fe effluent concentrations followed by mixed flow PREWet approach and both of FMF and PMF approaches, respectively. Moreover, the TC results were better in the case of PMF followed by FMF model.

The plants death assumption of the PREWet model consider that the wetland vegetations and plants had an annual life – death cycle and the plants litter dropped naturally at the wetland bottom. The litter will decay by the microorganisms biological processes. This plant litter will be a source of TP and absorbed contaminants release. The situation in Lake Manzala wetland is different from that of the PREWet model site specific conditions. Climate in Egypt is not so cold to cause wetland plants death and the used aquatic plants are ever green the whole year. The constructed wetland plants are occasionally harvested by cutting half of the plant length to get rid of the stored pollutants at plants parts and to enhance plant growing before reaching the plant senescence stage.

Conclusions

From this research paper, it is concluded that:

- The governing parameter in PREWet model application is only the hydraulic detention time and not the physical dimensions (L, W, or h).
- The PREWet model was applied on two assumptions, the plug flow and the mixed flow showed an over pollutant treatment estimates than the field results in cases of, TN, and Fe and under treatment estimates in cases of BOD, TSS, TP, and TC.
- The PREWet 2.4 models gave good effluent consternations for TN, TP, and Fe comparing with the field data followed by Chen FMF and PMF models.
- The FMF model followed by the PMF model performed the best results for pollutant removal of BOD and TSS than the PREWet.

Acknowledgment

This paper is fully based on a Ph. D. thesis prepared by Eng. Ahmed. A. Rashed under the supervision of the other authors in Irrigation and Hydraulics dept., Faculty of Engineering, Mansoura University. The authors acknowledge the National Water Research Center, Ministry of Water Resources and Irrigation, and Faculty of Engineering, Mansoura Univ. for technical support and scientific cooperation during this research.

References

Chen, S., Wang G. T., Xue S. K., (1999), Modeling BOD removal in constructed wetlands with mixing cell method. Journal of Environmental Engineering, Vol. 125, No. (1), pp. 64-71.

Dortch, M. S. and J. A. Gerald (2000). Pollutant Removal Estimates for Wetlands (PREWet),Ver2.3. Vicksburg, VA, United States of America, US Army Corps of Engineers.

Dortch, M. S., and Geralcl, J. A. (1995). "Screening-level model for estimating pollutant removal by wetlands, " Technical Report WRP-CP-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Interstate Technology & Regulatory Council (ITRC). 2003. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands. The Interstate Technology & Regulatory Council Wetlands Team.

Moharram, S. H., A. A. Zidan, S. T. Abdel Gawad, and A. A. Rashed. (2005). Modeling BOD Treatment in Surface Flow Constructed Wetland Using Convective Dispersion Mixing Flow Model. Manosura Engineering Journal (in press).

Rashed, A. A., (2005). "Constructed free surface wetlands for drainage water treatment a case study in Egypt" Ph. D. Thesis, Dept. of Irrigation Hydraulics, Faculty of Engineering, Mansoura Univ.

U.S.EPA. 2004. Constructed Wetlands. EPA-843-F-013.

United States Environmental Protection Agency (USEPA). 1988. Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. EPA 625-1-88-022. U.S. EPA Office of Research and Development, Center for Environmental Research Information. Cincinnati, OH. U.S.A.