WETLAND AS POLLUTION CONTROL TREATMENT SYSTEM FOR AGRICULTURAL DRAINS

By

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ABSTRACT

Observation of the natural conditions found in the agricultural drains in Egypt show that they receive municipal and industrial effluents, which discharge into the river Nile. This increases the river Nile pollution loads. These wastes cause widespread water and environmental pollution problems. The aquatic treatment technology can offer a real potential for application to the treatment of agricultural, raw domestic and industrial wastewater in Egypt. The applying of this technology can be done as in-situ treatment of drainage water in drains or in a series of depression cells can be constructed at the left and right bank of the drains and artificially connected to the drains. This is known as an off-stream wetland. Also wetland can be located on a mouth of major drain. This is known as an in-stream wetland. This study has investigated the possibility of extending the application of aquatic treatment technology for agricultural drains to achieve a certain reduction of the pollution loads discharging into the Nile. The potential of application of the proposed methodology is applied on Sabal agricultural drain and is evaluated under comprehensive field program along three stages. First stage was to present water quality conditions for the study area. The second stage was to perform field observation for Seasonal months of the natural aquatic treatment system (water hyacinth) found in the Sabal drain to study the use of aquatic plants in improving agricultural drainage water. Third stage was to present a pilot field experiment for constructed wetland to adjust full-scale design of wetland area to locate it at the mouth of the drain and analyze the effect of this pilot experiment.

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KEYWORD

Water hyacinth, Aquatic treatment technology, Constructed wetland

INTRODUCTION

The Nile course receives about 78 main agricultural drains discharging municipal, agricultural and industrial wastewater (El-Sherbini, 1998). This increases the River Nile pollution loads. Therefor this drains water need to be treated before they discharge into the River Nile. From a simple observation of the natural conditions in the agricultural drains in Egypt show that it's stocked with macrophytes such as water hyacinth weed in Sabal Drain which is the case study area.

Aquatic treatment system has recently proven to be a reliable, low cost and high performing technology for the treatment of domestic and industrial wastewater. Aquatic treatment technology makes use of the ability of the water hyacinth plant to extract impurities from the surrounding water. Water hyacinth, Eichhornia crassipes, flourish in the canals and drains of Egypt and considerable effort and expense is expended annually to control this plant, considered as a weed.

This study investigated the possibility of extending the application of aquatic treatment technology to achieve a certain reduction of the pollution loads they discharge into the Nile by drains. The study presented a pilot field experiment for constructed wetland to adjust full-scale design of wetland area to locate it at the mouth of the drain.

MATERIALS AND METHODS

- Characteristics of the Study Area

There are 4 major agriculture drains spill into Rosetta branch, which is one of the two Nile branches flows downstream Delta Barrage to the North, West. It ends with Idfina Barrage, which regulate the excess flow of the branch. Sabal drain is one from the 4 major drain spill into Rosetta branch was used for this study as an actual case study. It flows in Rosetta from the East Side at kilometer 71 North of Delta Barrage. Sabal drain is an agricultural drain, which serves about 140000 feddan of fertile old land. The length of the main drain is 47 kilometers and has 13 branch drains (figure 1) which carry the drainage water from agricultural land to the main drain and spills about 290 m.m^3/year to the Rosetta. The sewerage water in Sabal drain comes from Six towns which discharge sewerage water in the drain. These towns are Ashmoun, Talia, Samadon, Sobk El-Ahad, Shama and Shebin El-Kom. The industrial wastewater comes from two existing plants. Sabal drain and its branches were designed to carry a maximum total flow of 0.97 million m^3/day at its discharging point to Rosetta Branch. The sources of this total discharge are 0.81 million m^3/d from agriculture, 0.16 million m^3/d from sewerage and 0.0002 million m^3/d from industry.

- Hydraulic Measurements:
Water velocities, depths and discharges have been measured for main drain cross sections and for secondary drains, which are connected, to Sabal main drain. The velocities were measured using current meter at 0.6 meter depth from the water surface and the discharge was computed using velocities and cross section geometry.

- Hydrochemical Analysis:
Water Sampling:
(i) Location of sampling sites:
To perform this study, water samples were collected from Sabal drain and its 13 branch drains (figure 1). The water samples were collected from the agricultural drains located along Sabal drain and from the Sabal main drain using grab sampler during 1999-2000.

(ii) Field measured parameters:
Field measurements such as DO dissolved oxygen, pH, temperature and EC water conductivity were carried out in situ by using portable field equipment's.

(iii) Laboratory chemical analysis:
The field experiment was carried out for five months representing different seasons on Sabal drain between Tahway drain and Damlig drain (Figure 1) to observe the ability of the water hyacinth plant to extract impurities from the agricultural drainage water in Sabal drain. Water samples collected for ammonia, nitrate, total organic carbon, Ortho phosphorus PO4, total suspended solids, BOD and total dissolved solid according to the methods described by American Public Health Association Standard methods (APHA, 1989).

- Field Experiment for Pilot Wetland
A field experiment was carried out in the West Bank of Sabal drain to get the same conditions such as temperature and wastewater of Sabal drain as shown in Figure 2.
The main objectives of the experiment were to:

- Confirm the capabilities of a natural aquatic treatment system in the agricultural drains to reduce the pollution loads.
- Obtain the decay rates (K) for BOD and TSS at certain retention time accommodated to Egyptian conditions.

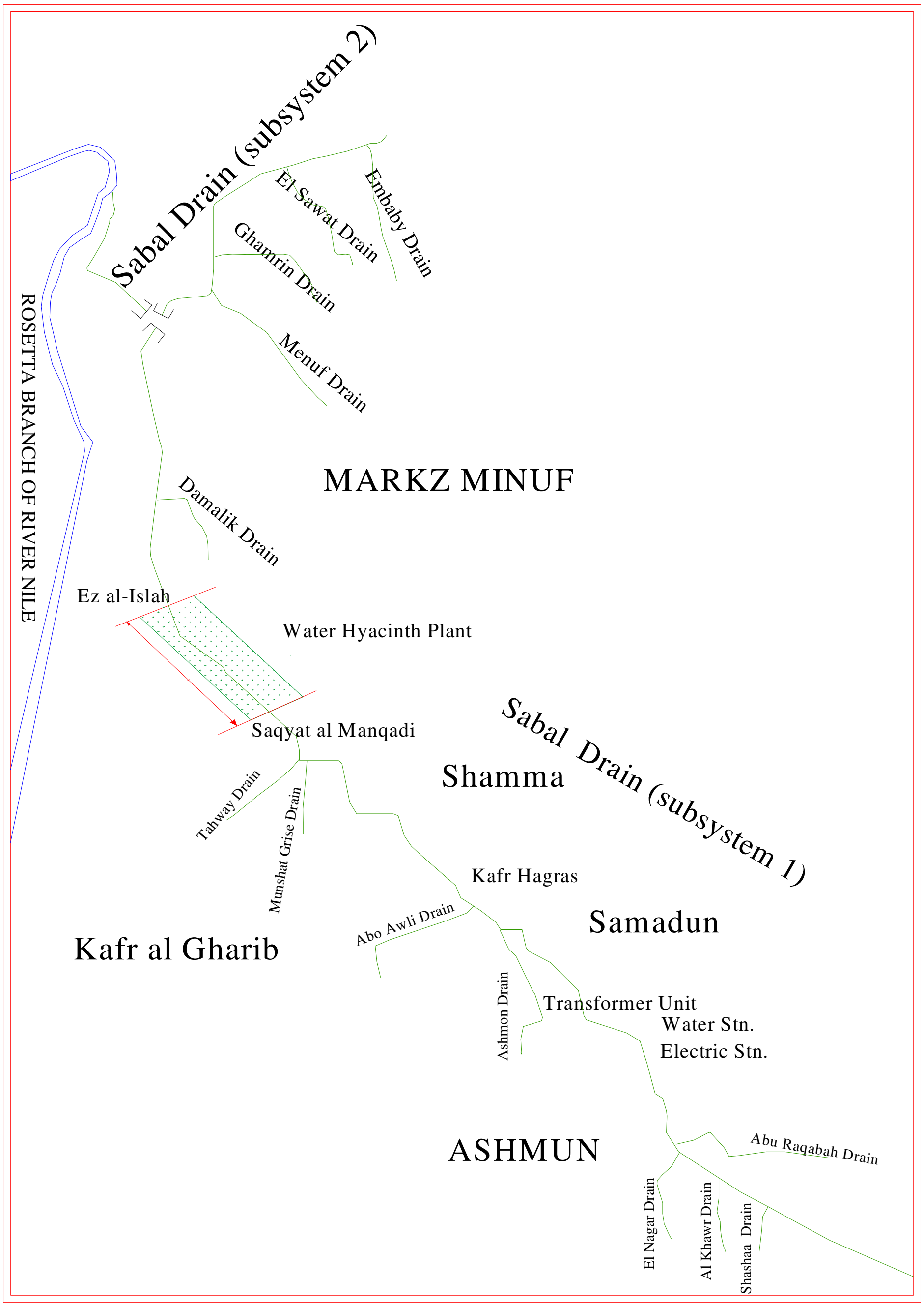

Figure 1: Location of Sabal Drain and its Branches

-Field experiment procedures and operations

1. Select the site to for the experiment in the West Bank side of Sabal drain, to represent the same condition as Sabal drain.
2. A pilot wetland was excavated with a size 6.3 x 2.3 x 0.6 m. The treated effluent was collected by a pipe as shown in Figure 2.
3. A macrophyte plant (water hyacinth) was chosen to be installed in the excavated pond, as it is the common plant found in all agricultural drains in Egypt loads. Although it is nuisance macrophytes, it is creating a natural treatment system in the drains that can certainly contribute to reduce the pollution.
4. The discharge was adjusted to be 1.45 m^3/d. It was lifted with pump from the main Sabal drain to be the same quality.
5. Water samples were collected from influent and effluent water hyacinth pond. DO, EC and pH were analyzed in the field. BOD and TSS parameters were analyzed in Nile Research Institute (NRI) water quality laboratory by the same methods, which mentioned before.

RESULTS AND DISCUSSIONS

- Field Experiment for Pilot Wetland

Field experiment was carried out to determine the Egyptian K values for TSS, BOD parameters. The resulted K values can be applied to perform the constructed wetland design at the mouth of the agricultural drains to reduce pollution loads discharging into the Nile. Also to provide the necessary basis to evaluate the potential of such a natural system for reducing pollution loads in the drains.

Calculations based on the K-C* models (Kadlec and Knight, 1995) were organized by the water quality parameter as shown in Table 1.

Table 1: Model Parameter Values- Preliminary

Model Parameter	BOD	TSS
K , m/yr	34	1000
C* , mg/L	$3.5+0.053C_i$	$5.1+0.16C_i$

Rearrangement and a unit conversion for equation give the area required for a particular pollution:

$$A = \left(\frac{0.0365Q}{K}\right)\ln\left(\frac{C_i - C^*}{C_o - C^*}\right) \tag{1}$$

where A = wetland area (m^2)
Q = flow rate (m^3/yr)
K = first – order areal rate constant (m/yr)
Ci = inflow concentration (mg/l)
Co = outflow concentration (mg/l)
C* = irreducible background concentration (mg/l)

Plug Flow equation is assumed to get (K) first-order removal coefficient, m/year

$$K = \left(\frac{0.0365Q}{A}\right)\ln\left(\frac{C_i - C^*}{C_e - C^*}\right) \quad (2)$$

Applying the equation for the data observed from the pilot constructed surface flow (SF) wetland of the field experiment to get the Egyptian first-order areal rate constant (K) for BOD and TSS. The results are presented and summarized in Table 2.

Table 2: Calculation of model parameters K-C* from field Experiment.

Area ha	HRT (days)	Q (m^3/d)	BOD in	BOD out	C*	K	TSS in	TSS out	C*	K
0.0014	6	1.45	11.30	7.88	4.10	24	250	55	45.10	111
0.0014	6	1.45	6.66	6.58	3.85	1	154	63	14.40	10
0.0014	6	1.45	7.00	6.98	3.87	0	53	49	13.60	4
0.0014	6	1.45	5.50	2.34	3.79	0	65	57	15.50	6

Table 2 illustrates the results from the field experiment for K at hydraulic retention time (HRT) 6 days. K values for agricultural drainage water are equal to 24 m/year for BOD and 111 m/year for TSS at HRT of 6 days. These results are more accurate and close to Kadlec and Knight numbers of 34 and 1000 as shown in Table 1 for BOD, TSS respectively.
The difference in K numbers resulted from the difference in the water quality type (wastewater and agricultural drainage water). Also, from local factors adding some solids from neighboring traffic during the experiment.

- MODEL APPLICATIONS FOR AGRICULTURAL DRAINAGE WATER TREATMENT:

The best-fit value of K resulted from the pilot field experiment = 24 m/year was lower than the global average of 34 m/year determined by Kadlec and Knight. Difference is presumably due to the difficulty of biodegrading the raw sanitary sewage from the villages, which dumped into agricultural drains in Egypt. Generally, it can be assumed that the K-C* model does fit the observed data, but the constants are not the same as the intersystem averages earlier.

The goal of the calculations is the determination of a wetland area, which will meet the design requirements at all times. The calculation tools are the K-C* mass balance model and the water budget. It will be assumed that model is workable for the monthly frequency, which is probably not strictly true. This assumption is more appropriate for constituents that are not stored in soils and vegetation, such as BOD, TSS. It is not appropriate for nutrients such as total phosphorus and some forms of nitrogen, for which there may be large monthly exchanges with that storage. In those cases, seasonal calculations are the highest frequency that should be utilized. A spreadsheet approach is strongly suggested by (Kadlec and Knight 1995), since it is often desirable to exploration of stochastic variation in system variables. This technique was applied to the data observed from the case study area in Sabal drain for four months.

The effluent C_0 values are assumed according to the recommended Egyptian Law limits Law 48/1982. The assumed value for BOD is taken to be 10 mg/l according to the law, while the assumed value for TSS is taken to be 30 mg/l according to (San Diego Pilot project). The required treatment area is determined from the previous equation from the available date for the four months. Each regulated parameter gives rise to a wetland area necessary for the reduction of that pollutant to the required level. The area results are shown in Tables, 3, 4, 5, and 6 for BOD and TSS. The required wetland area is the largest of the individual required areas.

Table.3: Second Field Investigation Sunday 25 March Year 2001

Model parameter		**Water Quality Parameter**	
		TSS	**BOD**
Influent concentration, mg/l	Ci	99	25.3
Target effluent concentration, mg/l	Ce	30	10
Wetland background limit, mg/l	C*	20.940	4.841
Reduction fraction to target	Fe	0.697	0.605
Reduction fraction to background	Fb	0.788	0.809
Areal rate constant, m/year	K	111	24
Required wetland area, ha	A	130.938	387.394
Expected output	Co	21.07	10.0

Q = 184,896 m^3/d

Table.4: Third Field Investigation Monday 23 April Year 2001

Model parameter		Water Quality Parameter	
		TSS	BOD
Influent concentration, mg/l	Ci	38	40.7
Target effluent concentration, mg/l	Ce	30	10
Wetland background limit, mg/l	C*	11.180	5.657
Reduction fraction to target	Fe	0.211	0.754
Reduction fraction to background	Fb	0.706	0.861
Areal rate constant, m/year	K	111	24
Required wetland area, ha	A	10.768	293.573
Expected output	Co	11.18	10.0

Q = 92,448 m^3/d

Table 5: Fourth Field Investigation Monday 23 May Year 2001

Model parameter		Water Quality Parameter	
		TSS	BOD
influent concentration, mg/l	Ci	31	13
Target effluent concentration, mg/l	Ce	30	10
Wetland background limit, mg/l	C*	10.1	4.2
Reduction fraction to target	Fe	0.0	0.2
Reduction fraction to background	Fb	0.7	0.7
Areal rate constant, m/year	K	111	24
Required wetland area, ha	A	2.1	83.1
Expected output	Co	13.1	10.0

Q = 131,328 m^3/d

Table 6: Fifth Field Investigation Monday 11 June Year 2001

Model parameter		Water Quality Parameter	
		TSS	BOD
Influent concentration, mg/l	Ci	191	14.8
Target effluent concentration, mg/l	Ce	30	10
Wetland background limit, mg/l	C*	35.66	4.284
Reduction fraction to target	Fe	0.843	0.324
Reduction fraction to background	Fb	0.813	0.711
Areal rate constant, m/yr	K	111	24
Required wetland area, ha	A	--	104.943
Expected output	Co	44.922	10.000

Q = 113,184 m^3/d

Tables.3 to 6 illustrate these calculations for a set of inlet and a hypothetical target concentration for two parameters, BOD and TSS. BOD is the design "bottleneck" yielding the highest area requirement. The results were summarized in Table7.

Table 7: Parameters for Design Wetland According to BOD area.

Months	Q m^3/d	HLR (cm/d)	HRT (day)	W.D (m)	Tem. C^o	Area (ha)	Reduction %
March	184,896	4.77	13.62	0.65	22.70	387.39	60
April	92,448	3.15	15.24	0.48	23.70	293.57	75
May	131,328	15.80	2.72	0.43	23.70	83.10	23
June	113,184	10.79	5.10	0.55	25.20	104.94	32

The result of the calculations is an estimate for the maximum area in March. This area equals to 387.39 ha at hydraulic loading rate = 4.77 cm/d during, hydraulic retention time 13.62 days and water depth 0.65 m for the active treatment area.

- APPLICABILITY OF AQUATIC PLANT SYSTEM TO THE TREATMENT OF AGRICULTURAL DRAINAGE WATER

Aquatic plant systems are engineered and constructed surface wetland systems that use aquatic plants in the treatment of agricultural drainage water. Aquatic plant systems can be divided into two categories:

1. Systems with floating aquatic plants such as water hyacinth, which are found naturally in all agricultural drains in Egypt.
2. Systems with submerged aquatic plants such as waterweed.

Until recently, most of the floating aquatic plant system has been water hyacinth system. Use of water hyacinth for agricultural drainage water treatment in agriculture drains can be traced back to six months field observations and to field-scale experiment in the Sabal drain. The performance data resulted from the previous sections which are the most common parameters used and needed to size the aquatic plant system are shown in Table 8.

Table 8: Design Parameters from the model and field Observation

Design Parameters	Parameter value
Influent total suspended sediment, TSS, mg/L	99
Influent organic concentration, BOD, mg/L	25.3
Expected Effluent, mg/L BOD_5 TSS	 10.0 21.07
Design flow Q, m^3/d	184896
Hydraulic detention time, days	13.62
Required area, ha	387.39
Hydraulic loading , $m^3/ha\text{-}d$	477.3
Water depth, m	0.65

- PROCESS DESIGN CRITERIA FOR WATER HYACINTH SYSTEMS

Water hyacinth systems represent the majority of aquatic plant systems that have been constructed. Organic loading is a key parameter in the design and operation of water hyacinth systems. The characteristics of the water hyacinth systems are summarized in Table 9. These characteristics match the design factors from the model and field observation in Table 8. The water hyacinth system can be constructed in series depression cells at the Left and Right Bank of the drain and artificially connected to the main drain. This is known as an off-stream wetland as shown in Figure 3. Also wetland can be located on a mouth of major drain or tributary. This is known as an in-stream wetland (Figure 4).

Table 9: Design Criteria for Water Hyacinth Systems (USEPA, 1996)

Factor	Type of Water Hyacinth System		
	Aerobic Non-aerated	**Aerobic Non-aerated**	**Aerobic Aerated**
Influent Wastewater	Screened or Settled	Secondary	Screened or Settled
Influent BOD_5, mg/L	130 – 180	30	130 – 180
BOD_5 Loading, kg/ha-d	40 – 80	10 - 40	150 - 300
Expected Effluent, mg/L BOD_5 TSS	 < 30 < 30	 < 10 < 10	 < 15 < 15
Water Depth, m	0.5 – 0.8	0.6 – 0.9	0.9 1.4
Detention Time, days	10 – 36	6 - 18	4 – 8
Hydraulic Loading, $m^3/ha\text{-}d$	> 200	< 800	550 – 1,000
Harvest Schedule	Annually	Twice per Month	Monthly

CONCLUSIONS

At stage two, the field observation program was carried out, representing different seasons on Sabal drain area stocked with natural water hyacinth, from one bank to the other bank. The treatment performance of water hyacinth for agricultural drainage water resulted from these observations are concluded as shown in Table (10) as follow:

1. The Biological Oxygen Demand (BOD) is considered organic pollution indicator. The percentage of reduction according to water hyacinth is about 37%, which illustrates that water hyacinth can achieve high removal efficiency.
2. The field observation shows that water hyacinth achieve high reduction of total suspended solid (TSS), of about 80%.
3. The percentage of reduction of the concentrations of Ammonia (NH_3) and Nitrate (NO_3) are about 14%, 2% respectively. This show that water hyacinth has more effect on removing NH_3 than NO_3.
4. The percentage of reduction of the concentrations of PO_4, Total P and TN are about 20%, 9%, 12% respectively.

According to the above results, a pilot scale field experiment for water hyacinth system was conducted to get the decay rate (K) for BOD and TSS.
A first-order areal constant (k) for BOD and TSS for the agricultural drainage water was resulted from a field experiment. The determined k values are computed according to local Egyptian conditions 24 m/year for BOD and 111 m/year for TSS. The research applies the maximum water hyacinth treatment area of about 387.39 ha at hydraulic loading rate 4.77 cm/d resulted from the K-C* model at the mouth of the agricultural drains as serial cells.

RECOMMENDATIONS

It is recommended to apply this study to the other type of drainage water such as municipal and industrial wastewater. Also apply this study to the other aquatic plants such as duckweed and for other water quality parameters using different meteorological conditions to study their effect on the treatment processes.
Perform extensive and long-term field experiments to compute the local values for the decay rate for the K-C* model.
Perform long-term economical and social study for this type of aquatic treatment for different locations.
The utilization of water hyacinth to control its spread requires therefore a harvesting rate equal to more than the growth rate. Water hyacinth can be used as follows:

- Biogas production.
- Animal feed.
- Fertilizer, compost or mulching material.
- Paper, carton or hard board.

Table 10: Average Influent and Effluent quality from floating aquatic plant systems (Water Hyacinth) in Different Seasons

Hydraulic Parameters	Influent	Effluent	Egyptian law 48/1982	% Reduction
Depth, (m)	0.63	0.5		
Discharge, (m^3/s)	1.83	1.36		
Velocity, (m/s)	0.33	0.32		
Physical W.Q. Parameters				
Water temperature, C^o	22.38	22.04		
Dissolved Oxygen (DO), mg/l	3.08	4.17	5	
pH unit	7.78	7.69	7-8.5	
Electric Conductivity, mhos/cm	1079.6	1070.4		
Chemical W.Q. Parameters				
Biochemical Oxygen Demand (BOD), mg/l	11.19	7.08	10	37
Ammonia (NH_3), mg/l	1.33	1.14	0.5	14
Nitrite (NO_2), mg/l	0.55	0.47		15
Nitrate (NO_3), mg/l	30.91	30.31	45	2
Ortho phosphorus (PO_4-P), mg/l	0.71	0.57		20
Total Phosphorus (P), mg/l	0.94	0.86	1	9
Total Dissolved Solids (TDS), mg/l	697.8	645.16	500	7.5
Total Suspended Solids (TSS), mg/l	75	14.8	30	80

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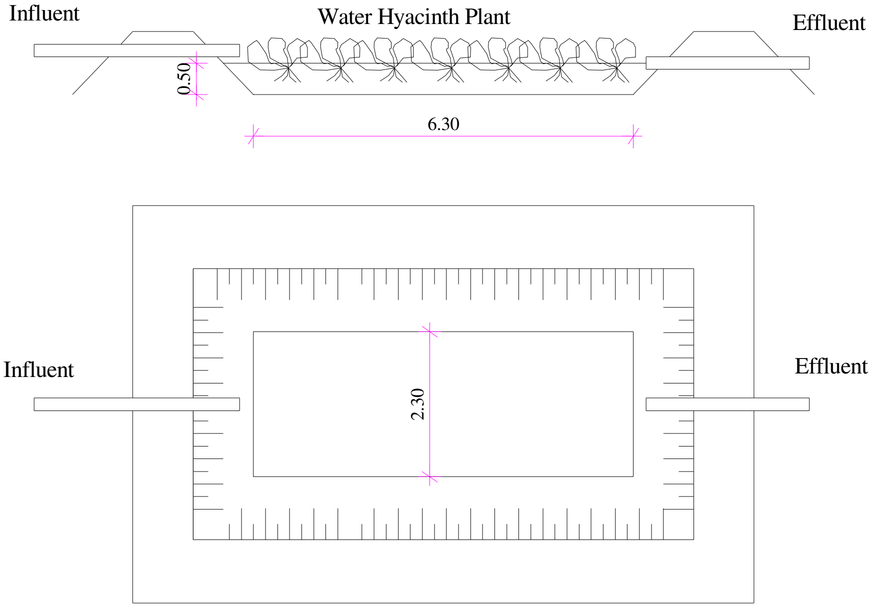

Figure 2: Schematic Diagram for Pilot Field Experiment

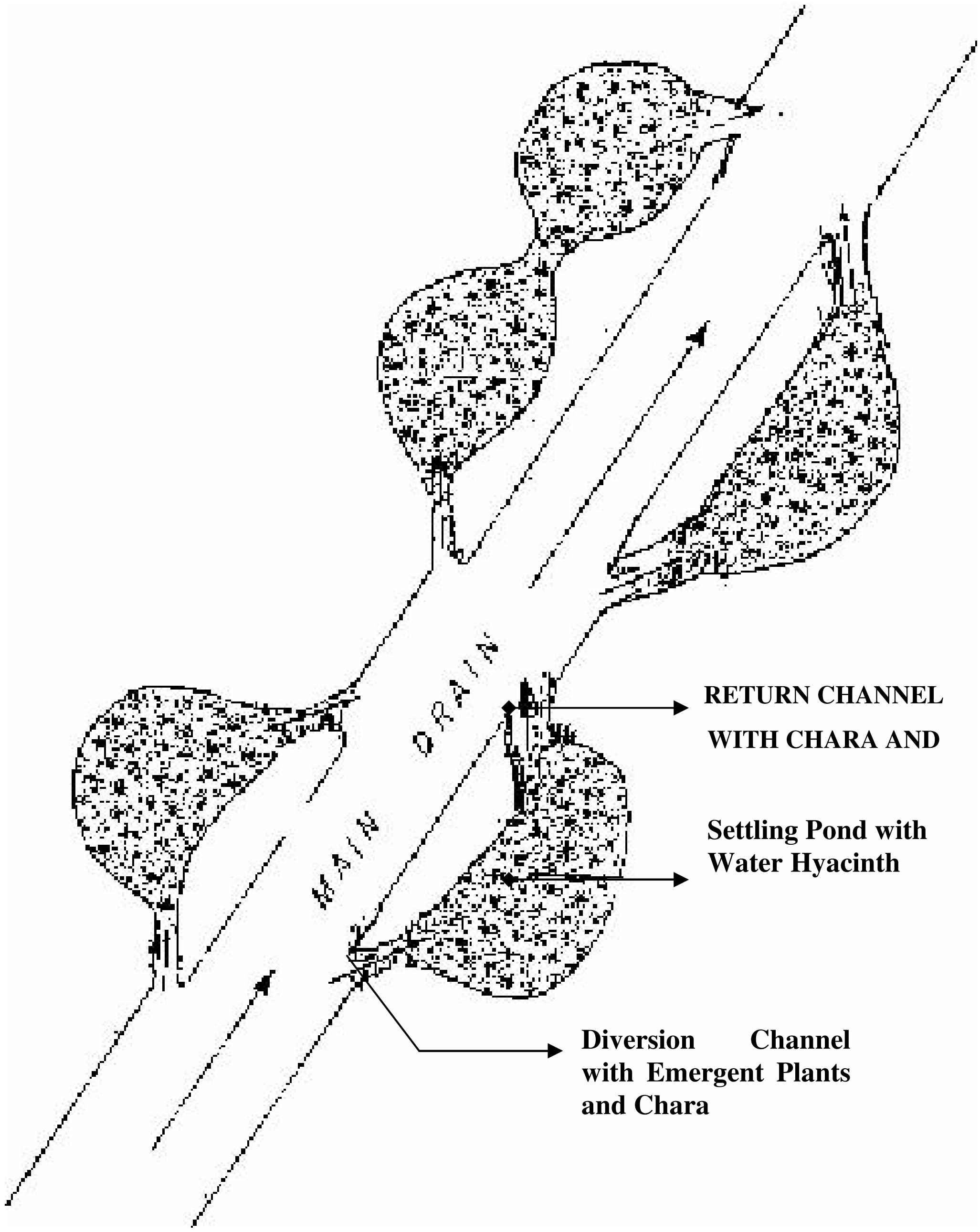

Figure 3: Alternative number one Off-stream constructed wetland design.

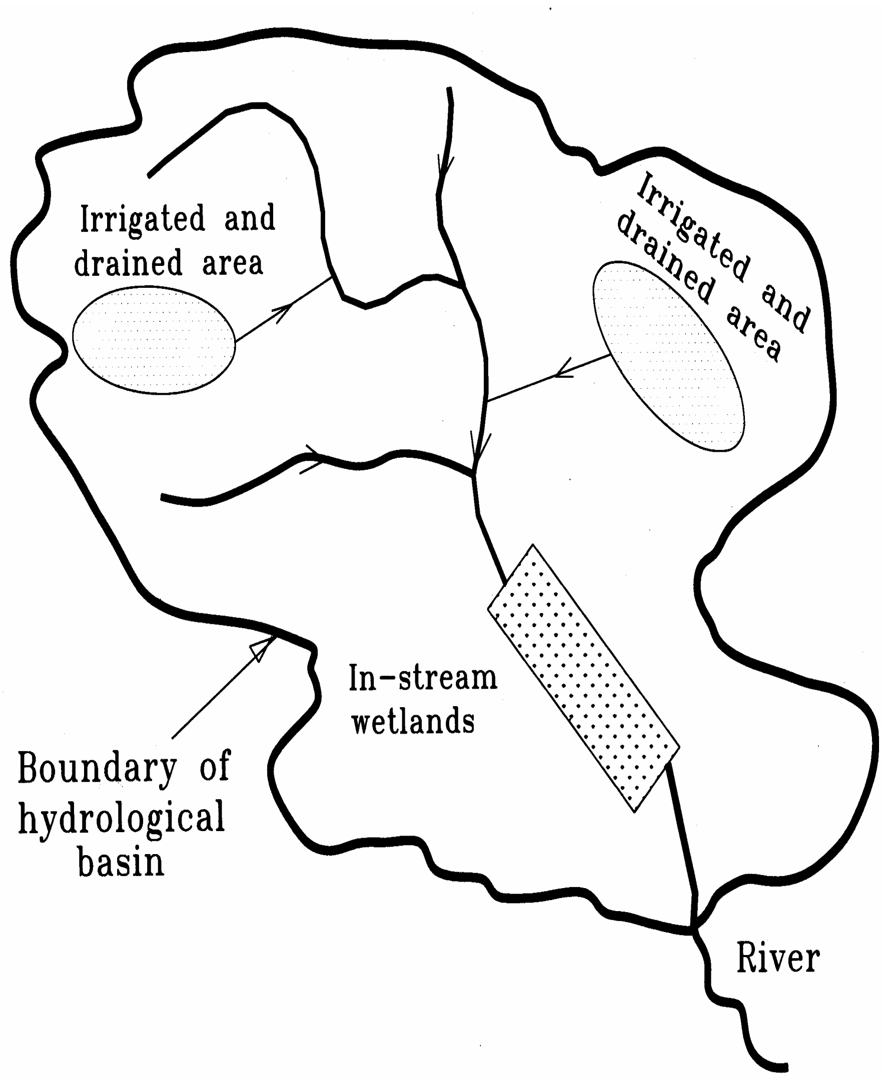

Figure 4: Alternative Number Two, In-Stream Constructed Wetland Design.