Universidade Federal do Ceará
DEHA - Depto. de Eng. Hidráulica e Ambiental

REVISITING THE INFLUENCE OF LOADING ON ORGANIC MATERIAL REMOVAL RATES IN PRIMARY FACULTATIVE PONDS

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Introduction

•Individually or in series, primary facultative ponds are the most used pond type as well as the most investigated one

•Analytical models for the design of primary facultative ponds are based on first-order kinetics, assuming either completely mixed or plug-flow

CM: $L = Lo / (1 + k\,HRT)$ $k = 0.3\,(1.05)^{T-20}$ (Mara, 1976)

PF: $L = Lo\,e^{-k\,HRT}$ $k = 0.071\,(1.09)^{T-20}$ (USEPA, 1983)

- k rate varies with organic loading, decreasing as loading is lowered (Thirumurthi, 1974; Uhlmann, 1979; Ellis and Rodrigues, 1995)

$$k = 2.622x10^{-3}\lambda s - 0.194$$

- Pond flow is neither completely mixed nor plug-flow (dispersed flow is more appropriate) (Thirumurthi, 1969)

- For organic material removal the dispersion-based model is difficult to use due to the lack of data from field studies

- This application is limited by a number of factors that may significantly influence dispersion in ponds

Unsteady flow;

Wind;

Inlet and outlet structures

- Investigation on hydraulic pattern has been mainly focused on FC removal with good results (Lloyd and Vorkas, 1999; Shilton and Harrison, 2003; von Sperling, 2003; Shilton and Mara, 2005, Bracho *et al.*, 2006)

Methodology

- Six full-scale primary facultative ponds (PFPs) located in Fortaleza (38^{o} 32' W; 3^{o} 43' S, 15.5 m a.m.s.l.), NEB
- Pond plants have been operating for 22 years on average
- Monitoring during 28 weeks in 2007

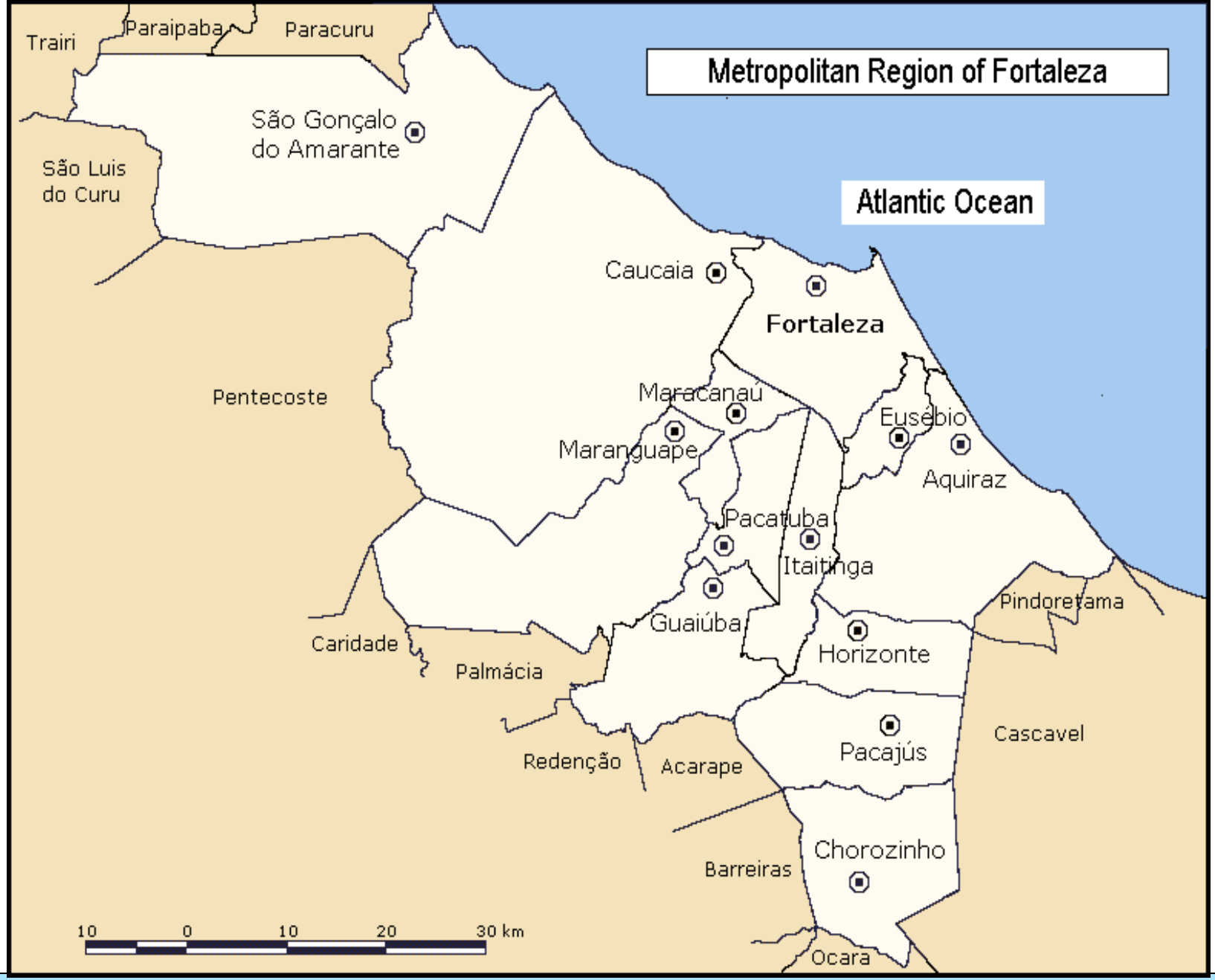

Metropolitan Region of Fortaleza
Atlantic Ocean
Trairi
Paraipaba
Paracuru
São Gonçalo do Amarante
São Luis do Curu
Caucaia
Fortaleza
Pentecoste
Maracanaú
Maranguape
Eusébio
Aquiraz
Pacatuba
Itaitinga
Guaiúba
Pindoretama
Caridade
Palmácia
Horizonte
Cascavel
Pacajús
Redenção
Acarape
Chorozinho
Barreiras
Ocara
10 0 10 20 30 km

Table 1. Design characteristics of the primary facultative ponds.

Pond system	*HRT (d)*	*λs (kg BOD/ha.d)*	*Volume (m^3)*	*W to L ratio*	*Mean depth (m)*
PFP1	26.9	178	22,194.0	1:1.52	1.7
PFP2	62.0	128	168,400.0	1:1.52	2.0
PFP3	25.7	261	25,710.4	1:2.10	1.6
PFP4	25.0	230	51,000.0	1:2.04	1.7
PFP5	22.3	283	45,736.8	1:1.78	1.7
PFP6	18.8	287	17,910.0	1:1.84	1.8

PFP1

PFP5

- Raw wastewater and treated effluent samples collected at 10:00 am

Influent : temperature, pH, BOD and COD

Effluent: temperature, DO, BOD (BODf) and COD (CODf)

- The analytical procedures followed the methods described in APHA (1992)

Results and Discussion

- Raw wastewater temperature - from 22.0 to 26.2^{o} C (mean of 24.9^{o} C)
- Treated effluent - from 24.9 to 29.1^{o} C (mean of 27.2^{o} C).
- Influent pH around neutral (7.11, $\pm$0.19)
- BOD and COD showed typical values for domestic wastewater: 430 mg/l ($\pm$150) and 707 mg/l ($\pm$278), respectively
- The HRTs were on average 51% below the design assumptions
- Actual surface BOD loadings were on average 56% below the design considerations

Table 2. Operational performance of primary facultative ponds in Fortaleza.

Pond system	*HRT (days)*	λs_{DBO} *(kg/ha.d)*	λs_{DQO} *(kg /ha.d)*	*Removal %*			
				BOD	*BODf*	*COD*	*CODf*
PFP1	51.8	117	188	71	87	55	82
PFP2	64.0	148	225	73	89	48	83
PFP3	80.7	80	145	71	90	52	86
PFP4	25.2	338	501	73	90	46	78
PFP5	41.5	130	270	63	88	51	83
PFP6	139.9	65	105	75	89	45	87

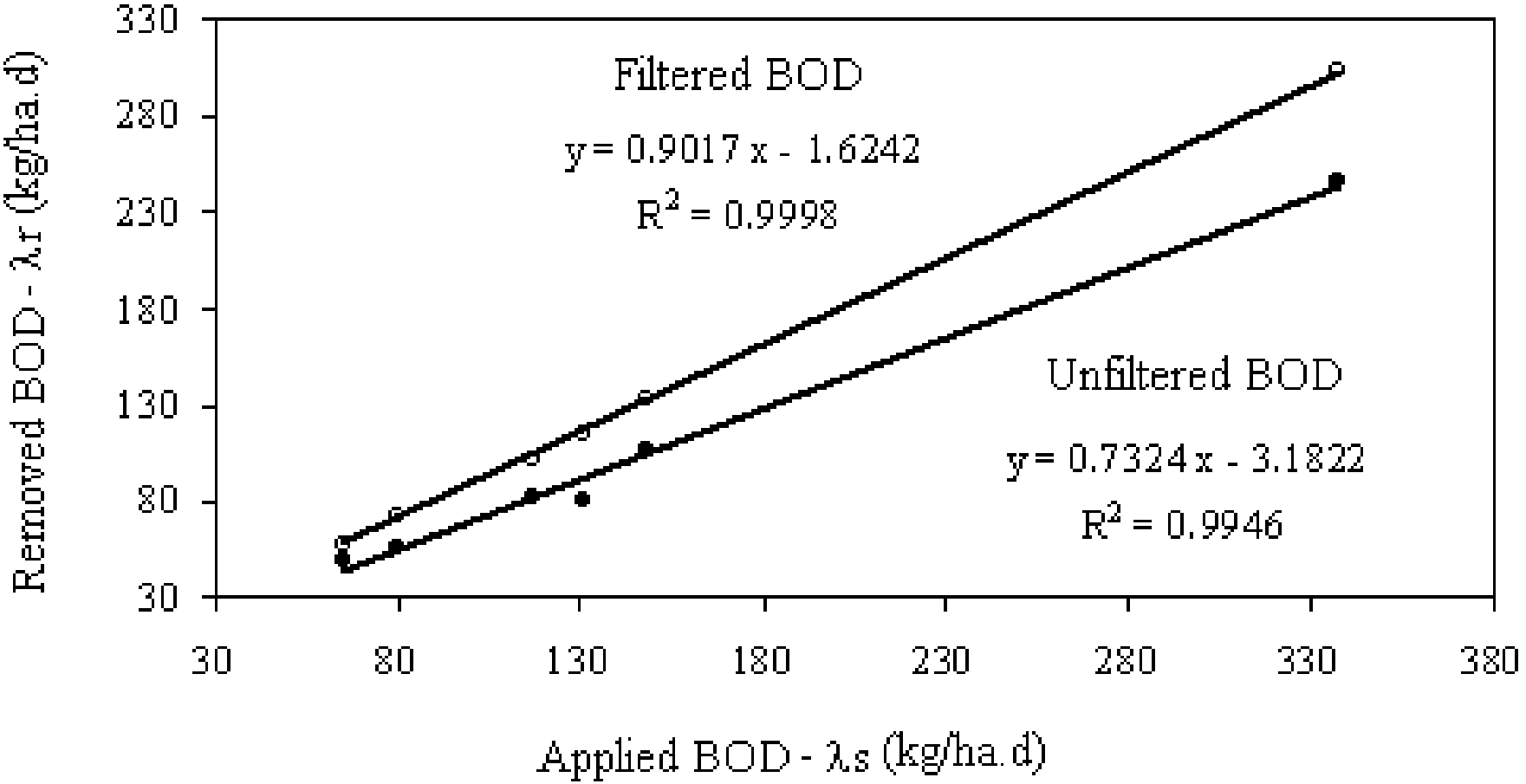


Figure 1. Unfiltered and filtered BOD removal rates as a function of surface loading.

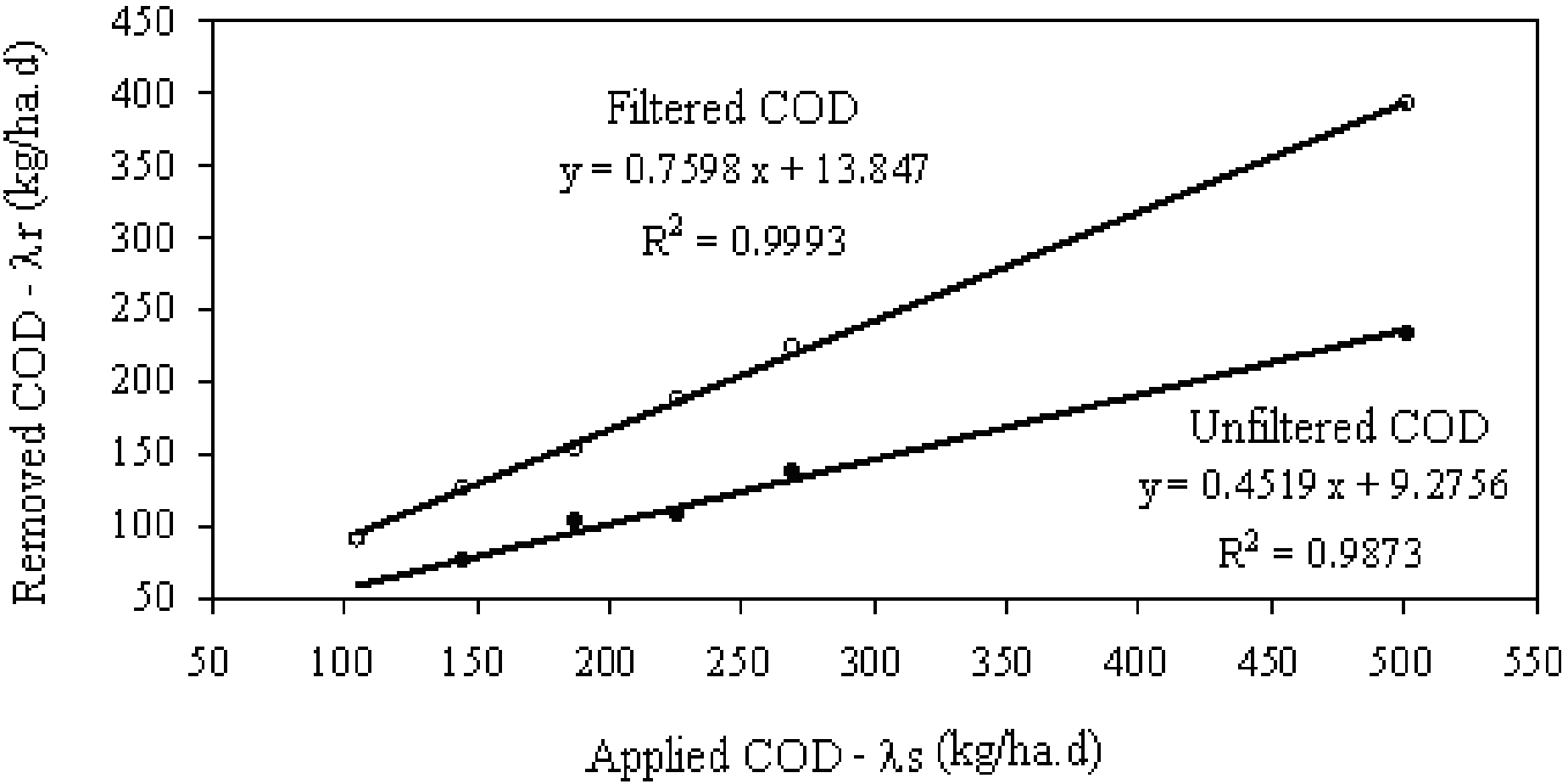


Figure 2. Unfiltered and filtered COD removal rates as a function of surface loading.

Table 3. First order removal rates (d^{-1}) in primary facultative ponds of Fortaleza.

Statistic	*Completely mixed*				*Plug-flow*			
parameter	BOD	BODf	COD	CODf	BOD	BODf	COD	CODf
Mean	0.048	0.159	0.019	0.091	0.024	0.043	0.013	0.034
Min	0.022	0.059	0.006	0.046	0.010	0.016	0.004	0.014
Max	0.106	0.351	0.034	0.144	0.052	0.091	0.025	0.061
CV (%)	62	64	52	37	60	60	53	48

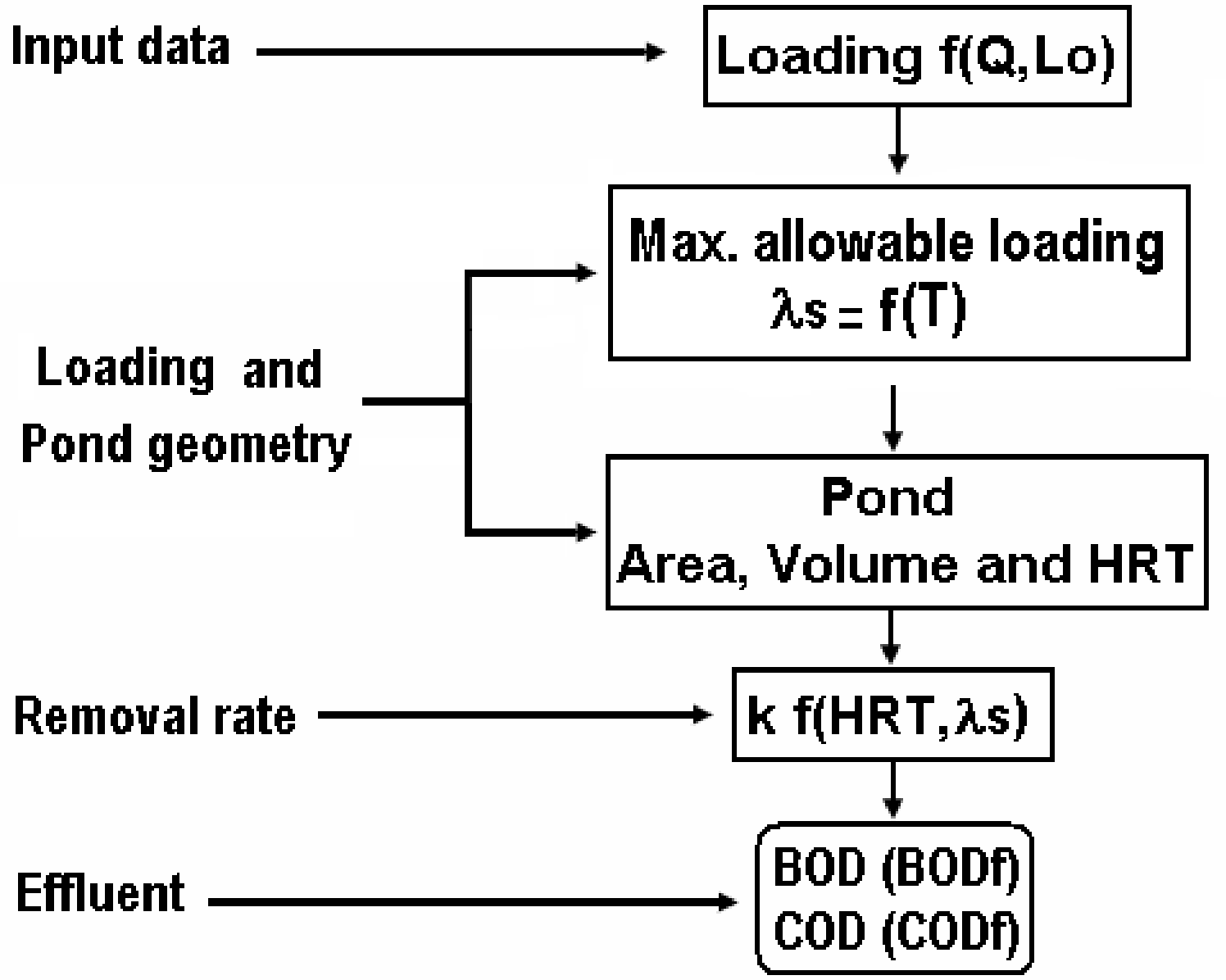
- W to L or depth did not show correlation with removal rates
- There was no influence of loading on dissolved oxygen concentrations.
- First order reaction rates were HTR dependent

Table 4. Variation of first order removal rates in primary facultative ponds of Fortaleza as a function of HRT.

Removal parameter	*Completely mixed*	*Plug-flow*
BOD	$k = 1.3401\ HRT^{-0.851}$ $R^2 = 0.8824$	$k = 0.8719\ HRT^{-0.9141}$ $R^2 = 0.9610$
BODf	$k = 7.6572\ HRT^{-0.9889}$ $R^2 = 0.9750$	$k = 2.1546\ HRT^{-0.9952}$ $R^2 = 0.9958$
COD	$k = 1.1918\ HRT^{-1.0476}$ $R^2 = 0.9360$	$k = 0.7883\ HRT^{-1.0353}$ $R^2 = 0.9649$
CODf	$k = 1.2396\ HRT^{-0.6573}$ $R^2 = 0.9667$	$k = 0.9307\ HRT^{-0.8397}$ $R^2 = 0.9954$

Table 5. Variation of first order removal rates in primary facultative ponds of Fortaleza as a function of surface loading.

Removal parameter	*Completely mixed*	*Plug-flow*
BOD	$k = 0.0003\ \lambda s_{BOD} + 0.0043$ $R^2 = 0.9723$	$k = 0.0001\ \lambda s_{BOD} + 0.0031$ $R^2 = 0.9594$
BODf	$k = 0.001\ \lambda s_{BOD} + 0.0132$ $R^2 = 0.9464$	$k = 0.0003\ \lambda s_{BOD} + 0.0066$ $R^2 = 0.9142$
COD	$k = 0.0172\ Ln(\lambda s_{COD}) - 0.0727$ $R^2 = 0.8305$	$k = 0.0125\ Ln(\lambda s_{COD}) - 0.0536$ $R^2 = 0.8798$
CODf	$k = 0.0601\ Ln(\lambda s_{COD}) - 0.2305$ $R^2 = 0.9092$	$k = 0.029\ Ln(\lambda s_{COD}) - 0.1213$ $R^2 = 0.9387$


Input data
Loading f(Q,Lo)
Max. allowable loading
λs = f(T)
Loading and
Pond geometry
Pond
Area, Volume and HRT
Removal rate
k f(HRT,λs)
Effluent
BOD (BODf)
COD (CODf)

Conclusions

- The PFPs had hydraulic and organic loading at least 50% below of the values considered in the design assumptions
- OM removal was satisfactory considering the fact that these ponds have been operating for at least two decades
- The discussion should not be addressed to hydraulic regimen but to the fact that higher HRT and lower loading rates cause decrease in removal rates
- PFPs have a limit for organic material removal
- Ponds are under utilized and an up-grading should be considered.