



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

$$CM: L = L_0 / (1 + k HRT) \quad k = 0.3 (1.05)^{T-20} \text{ (Mara, 1976)}$$

$$PF: L = L_0 e^{-k HRT} \quad k = 0.071 (1.09)^{T-20} \text{ (USEPA, 1983)}$$

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

$$k = 2.622 \times 10^{-3} \lambda S - 0.194$$

- 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° 32' W; 3° 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

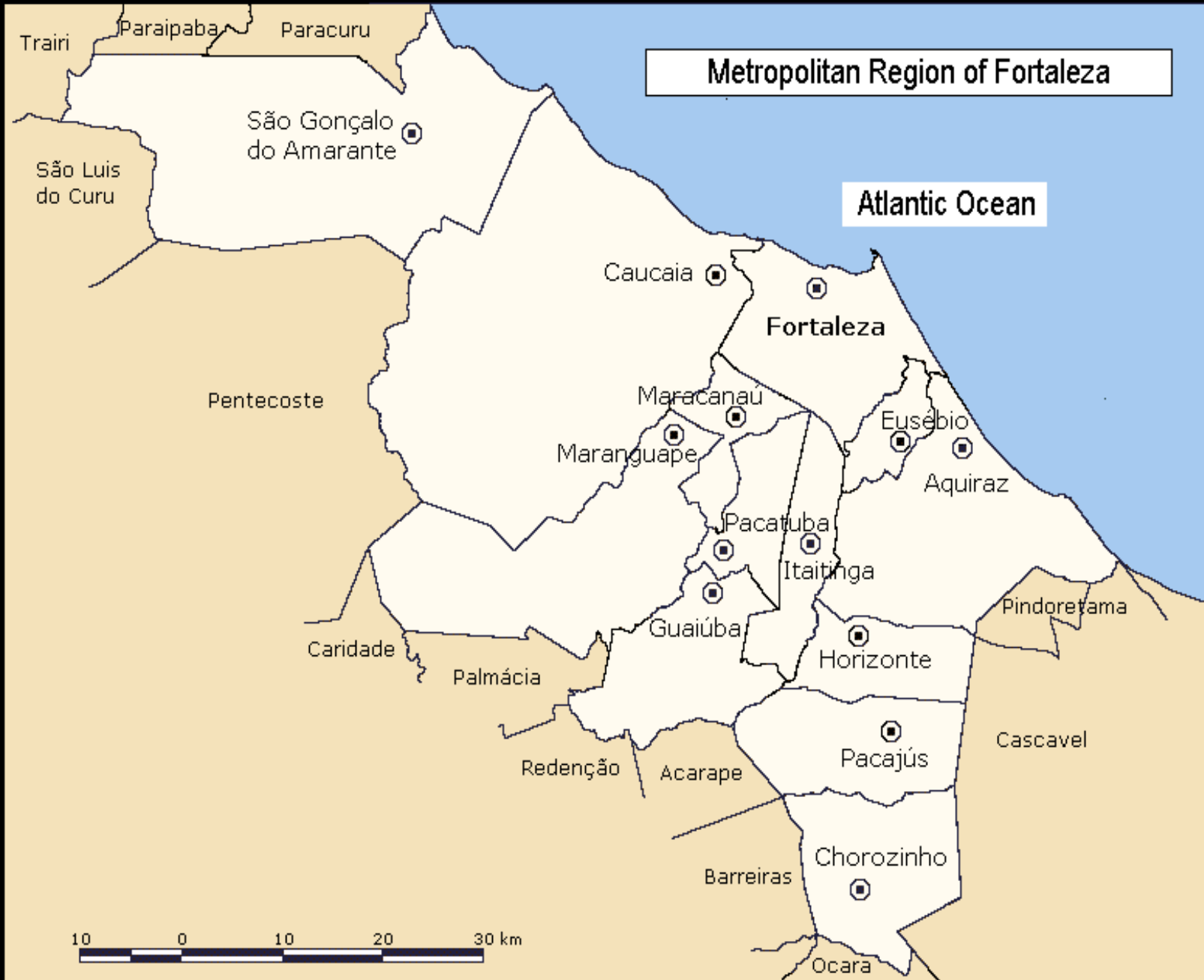


Table 1. Design characteristics of the primary facultative ponds.

| <i>Pond system</i> | <i>HRT (d)</i> | <i>λ_s (kg BOD/ha.d)</i> | <i>Volume (m³)</i> | <i>W to L ratio</i> | <i>Mean depth (m)</i> |
|--------------------|----------------|---|-------------------------------|---------------------|-----------------------|
| 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 (BOD_f) and COD (COD_f)

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

Results and Discussion

- Raw wastewater temperature - from 22.0 to 26.2° C (mean of 24.9° C)
- Treated effluent - from 24.9 to 29.1° C (mean of 27.2° C).
- Influent pH around neutral (7.11, ± 0.19)
- BOD and COD showed typical values for domestic wastewater: 430 mg/l (± 150) and 707 mg/l (± 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.

| <i>Pond system</i> | <i>HRT (days)</i> | $\lambda_{S_{DBO}}$ <i>(kg/ha.d)</i> | $\lambda_{S_{DQO}}$ <i>(kg /ha.d)</i> | <i>Removal %</i> | | | |
|--------------------|-------------------|---|--|------------------|------------------------|------------|------------------------|
| | | | | <i>BOD</i> | <i>BOD_f</i> | <i>COD</i> | <i>COD_f</i> |
| 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 |

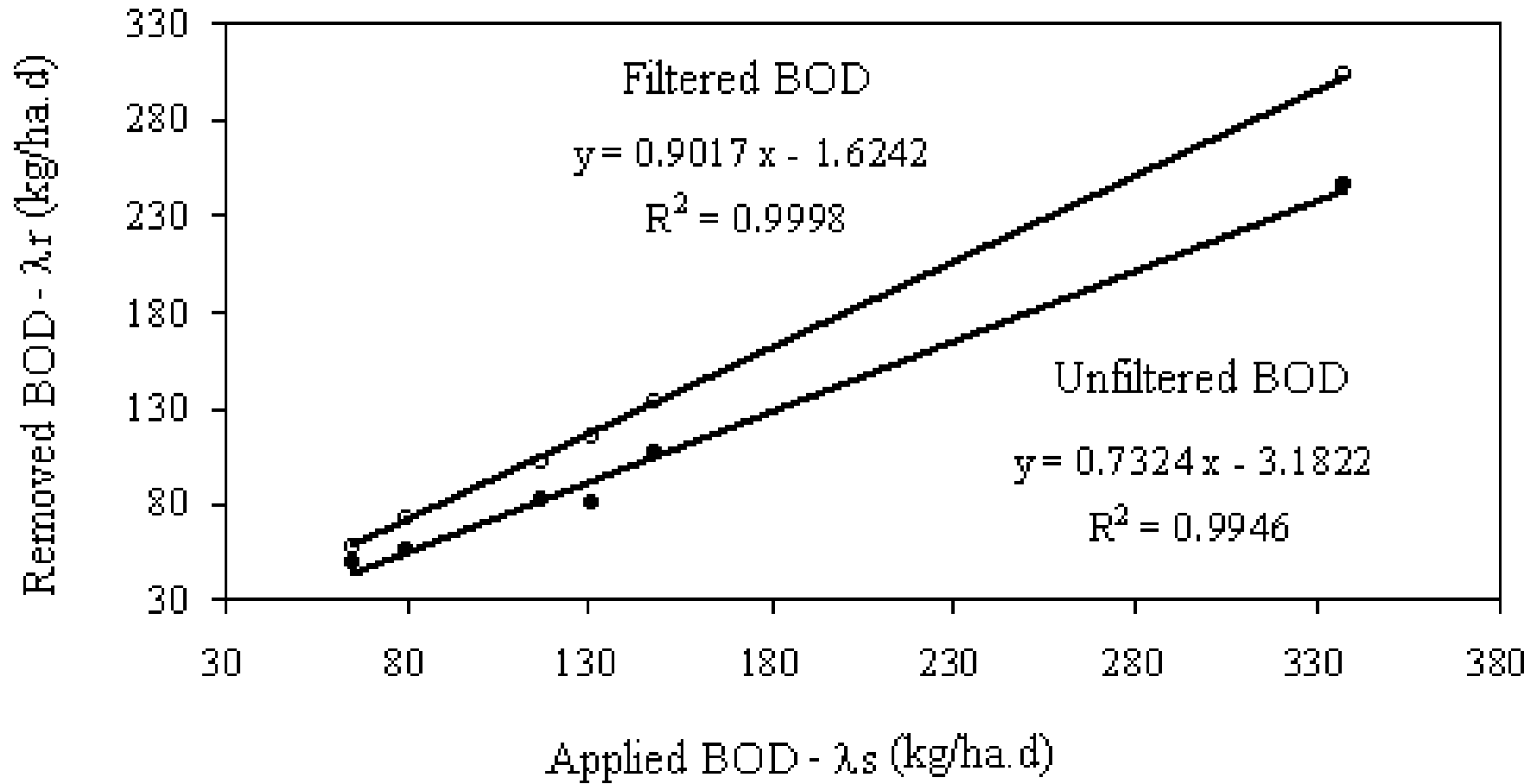


Figure 1. Unfiltered and filtered BOD removal rates as a function of surface loading.

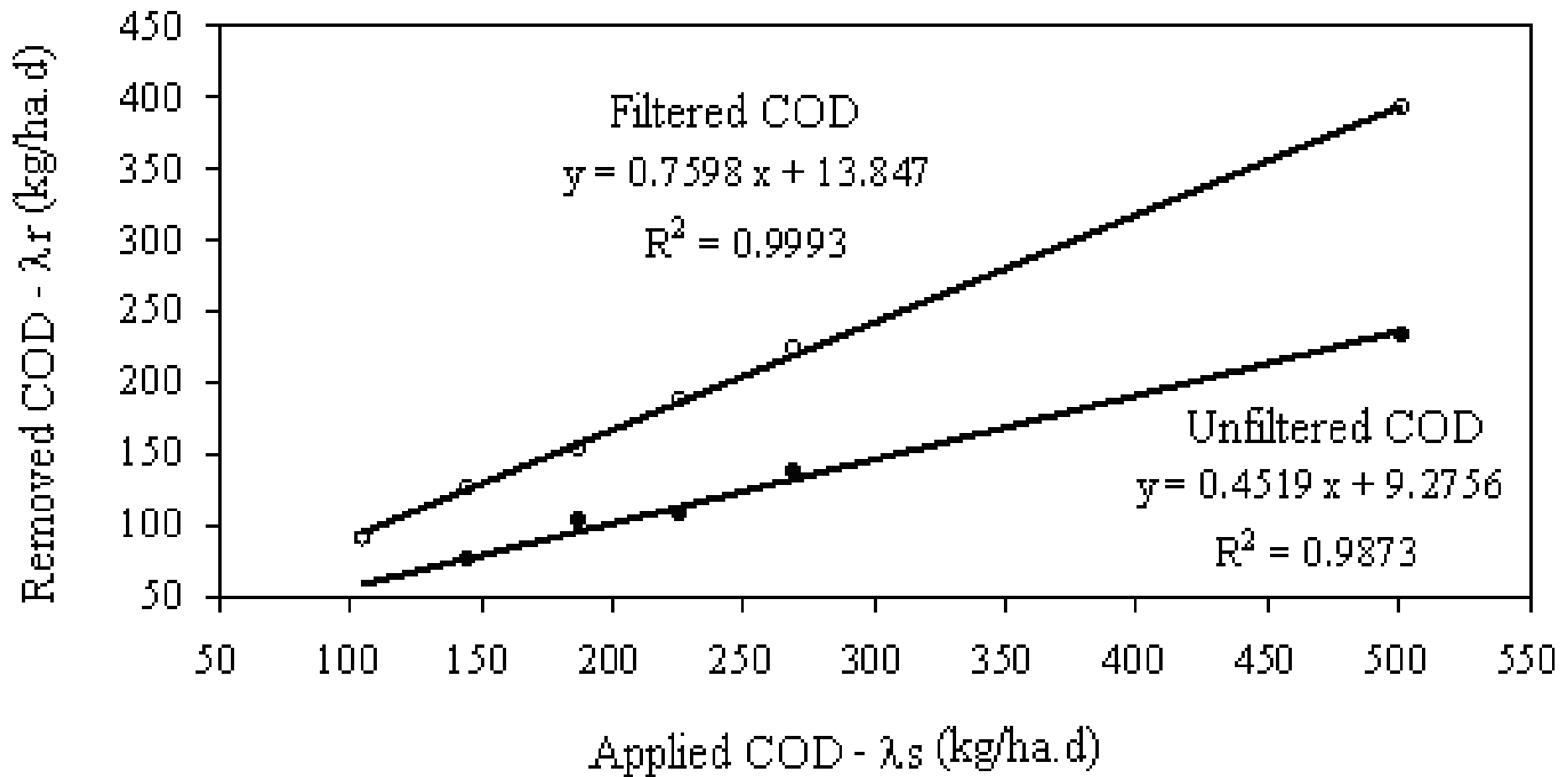


Figure 2. Unfiltered and filtered COD removal rates as a function of surface loading.

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

| <i>Statistic parameter</i> | <i>Completely mixed</i> | | | | <i>Plug-flow</i> | | | |
|----------------------------|-------------------------|-------|-------|-------|------------------|-------|-------|-------|
| | 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 |

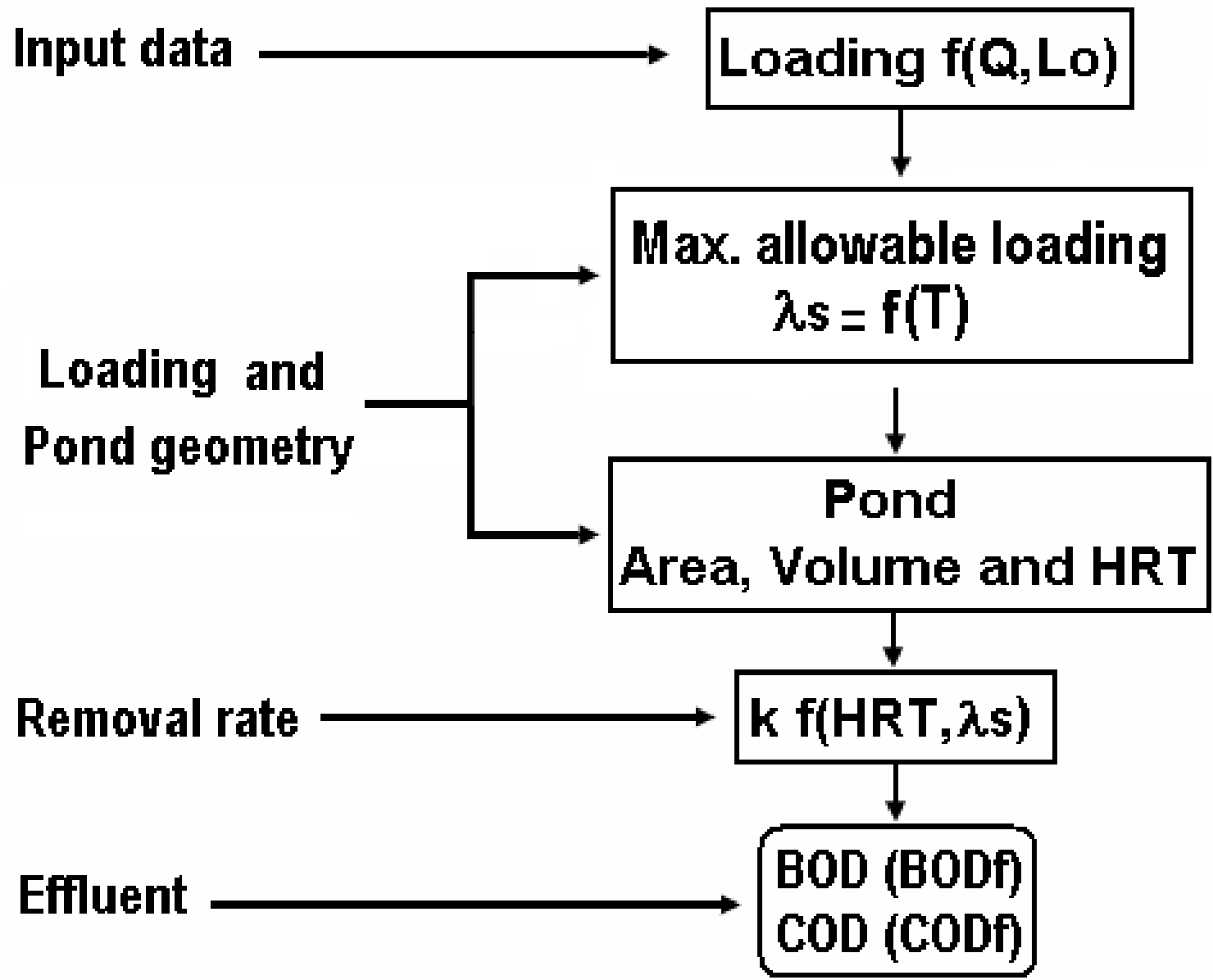
- W to L or depth did not show correlation with removal rates
- There was no influence of loading on dissolved oxygen concentrations.
- First order reaction rates were HTR dependent

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

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

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

| <i>Removal parameter</i> | <i>Completely mixed</i> | <i>Plug-flow</i> |
|--------------------------|--|--|
| BOD | $k = 0.0003 \lambda_{S_{BOD}} + 0.0043$ $R^2 = 0.9723$ | $k = 0.0001 \lambda_{S_{BOD}} + 0.0031$ $R^2 = 0.9594$ |
| BOD _f | $k = 0.001 \lambda_{S_{BOD}} + 0.0132$ $R^2 = 0.9464$ | $k = 0.0003 \lambda_{S_{BOD}} + 0.0066$ $R^2 = 0.9142$ |
| COD | $k = 0.0172 \ln(\lambda_{S_{COD}}) - 0.0727$ $R^2 = 0.8305$ | $k = 0.0125 \ln(\lambda_{S_{COD}}) - 0.0536$ $R^2 = 0.8798$ |
| COD _f | $k = 0.0601 \ln(\lambda_{S_{COD}}) - 0.2305$ $R^2 = 0.9092$ | $k = 0.029 \ln(\lambda_{S_{COD}}) - 0.1213$ $R^2 = 0.9387$ |



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.