Pacific Reef Fisheries

Guthalungra Prawn Farm

Water Quality Management
Preliminary Concepts

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"There are things we know that we know. There are known unknowns – that is to say, there are things that we now know we don't know, but there are also unknown unknowns. There are things we do not know we don't know. So when we do the best we can and we pull all this information together, and we then say, 'Well, that's basically what we see as the situation', that is really only the known knowns and the known unknowns. And each year we discover a few more of those unknown unknowns."

US Defence Secretary Donald Rumsfeld talking to NATO on 7 June 2002, as reported in *The Australian*.

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CONTENTS

1. Introduction

Pacific Reef Fisheries propose to construct and operate a prawn farm on 800 ha of land near Guthalungra, 40 km north west of Bowen (Lambert & Rehbein, 2001). Lambert & Rehbein are preparing an Environmental Impact Statement for the development.

Approaches to water quality management in prawn farms are currently in a state of flux. Ken Hartley has therefore been engaged to provide a preliminary assessment of water treatment and exchange options.

2. Approach

The current focus on water quality management in prawn farms is driven by:

- Increasing awareness of the economic opportunities in aquaculture and the resultant interest in the development of new prawn farms.
- Efforts to improve productivity and export competitiveness.
- An increasing R&D effort which has produced significant results over the last few years.
- New EPA criteria for effluent discharges from prawn farms.

To rationally determine the most appropriate method of water quality management at Guthalungra, a fundamental water quality model for a prawn farm is needed. Unfortunately, it appears that such a model does not currently exist. It has therefore been necessary to develop a simple water quality model, which can be used to determine the critical design and operating parameters and their effects on performance and cost.

For simplicity, the initial model developed assumes steady state operation representing average operating conditions over a growout season. The greater complexity of a dynamic model replicating the changes occurring over the growout season has been avoided at this stage. The model has been used to assess pond performance characteristics, effluent discharge quality and cost over a range of operating conditions.

Before describing the development of the model, relevant water quality criteria and prawn farm characteristics used for calibration of the model will be summarised.

3. Water Quality

3.1. EPA Criteria

Criteria proposed by the Queensland EPA for effluent discharge from prawn farms are summarised in Table 3.1 (APFA, 2001). These are still subject to further consideration, particularly with respect to new farms.

Table 3.1 EPA Criteria

	Concentration (mg/L)			Mass Discharge (kg/ha.d)		
	SS	**Total N**	**Total P**	**SS**	**Total N**	**Total P**
Mean	20	0.8	0.1	12	0.96	0.06
Maximum	50	3.0	0.3	---	---	---

3.2. Prawn Growth

Representative water quality limits for optimum prawn growth are summarised in Table 3.2 (Lee & Wickins 1992, Wyban & Sweeney 1991).

Table 3.2 Desirable Water Quality for Penaeids

Parameter		Desirable Range
Temperature	degC	26-30
Salinity	ppt	15-30
DO		>5 mg/L, 85-120%
pH	units	7.8-8.3
Un-ionised NH_3-N	mg/L	<0.1 (<0.02 in presence of NO_2)
NO_2-N	mg/L	<0.2
Ca	mg/L	160-400
H_2S	mg/L	<0.002
Fe^{2+}	mg/L	<10
Secchi Depth	m	0.35-0.75

The most common toxins are NH_3, NO_2, H_2S and CO_2 and of these, ammonia is the most critical. For an un-ionised NH_3-N limit of 0.1 mg/L, the total NH_3-N limit varies with pH as follows:

pH 7.5	pH 8.0	pH 8.5	pH 9.0
6.4 mg/L	2.1 mg/L	0.73 mg/L	0.30 mg/L

Data for a typical untreated growout pond effluent (Seafarm - Preston et al, 2001) give an average total N concentration of about 2 mg/L, of which 40% is soluble and 10-20% (0.2-0.4 mg/L) is ammonia N. Therefore, limiting total N to a maximum of 2 mg/L will maintain non-inhibitory un-ionised ammonia levels for pH values of up to about 9.0 (which can be reached during diurnal peaks).

Table 3.2 indicates that care needs to be taken with nitrification processes to minimise nitrite level. The DO requirement will prevent the formation of inhibitory levels of sulfide and ferrous iron, and both algal uptake and mechanical aeration will strip carbon dioxide.

3.3. Prawn Farm Characteristics

Preston et al (2001) provide operating data for three Queensland prawn farms, TruBlu, Seafarm and Rocky Point. The Seafarm data were regarded as the most typical for untreated growout pond effluent: the TruBlu farm was in an atypical operational phase and Rocky Point incorporated varying degrees of treatment in separate ponds. Discharge data are summarised in Tables 3.3 and 3.4.

Table 3.3 Average Quality of Effluent Discharged

Parameter	Concentration (mg/L)			
	TruBlu	**Seafarm**	**Rocky Point**	**EPA Mean Limit**
Exchange Rate d^{-1}	11%	4%	4%	---
SS				
Intake	60	20	25	---
Discharge	110	70	35	20
Total N				
Intake	0.3	0.3	0.7	---
Discharge	1.8	2.0	2.8	0.8
Total P				
Intake	0.06	0.03	0.08	---
Discharge	0.19	0.25	0.28	0.1

Table 3.4 Average Net Mass Discharge[1]

Parameter	Mass Discharge (kg/ha.d)				
	TruBlu	**Seafarm**		**Rocky Point**	**EPA Limit**
		Total	**Soluble**		
Exchange d^{-1}	11%	4%		4%	---
SS	87	30	---	3.7	12
Total N	2.0	1.0	0.41	0.9	0.96
NH3-N	---	---	0.12-0.22	---	---
Total P	0.22	0.12	---	0.08	0.06
Chlorophyll *a*	---	0.039	---	---	---
Algal SS[2]	---	4	---	---	---

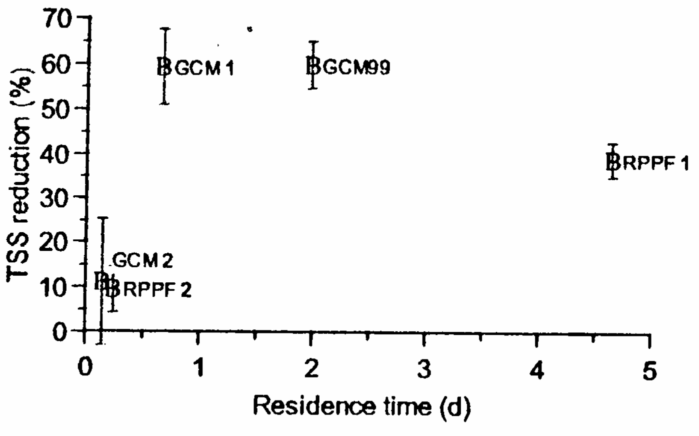
[1] Net discharge = total discharge - intake

[2] Estimated assuming chlorophyll *a* content = 1% of algal SS

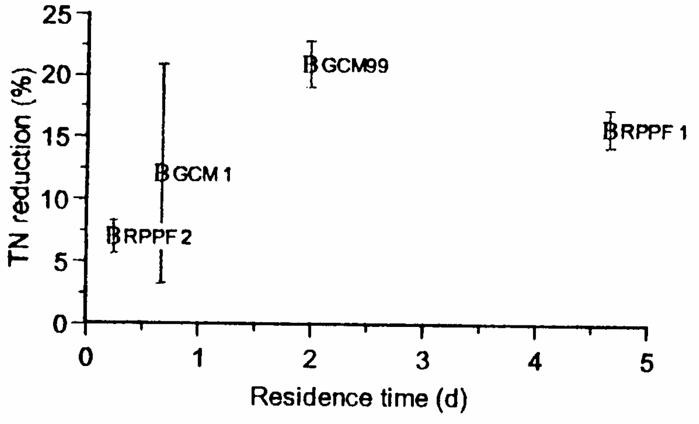
3.4. Settlement Pond Performance

Preston et al (2001) monitored the performance of settlement ponds used at the Rocky Point prawn farm (1.5m deep) and the Gold Coast Marine prawn farm (2m deep) for treatment of growout pond effluent. The most useful outputs are their correlations of SS, N and P removal with pond hydraulic residence time, reproduced in Figure 3.1. In these plots, data designated RPPF2 and GCM2 represent the second pond in a two-pond series.

(a) SS



(b) Total N



(c) Total P

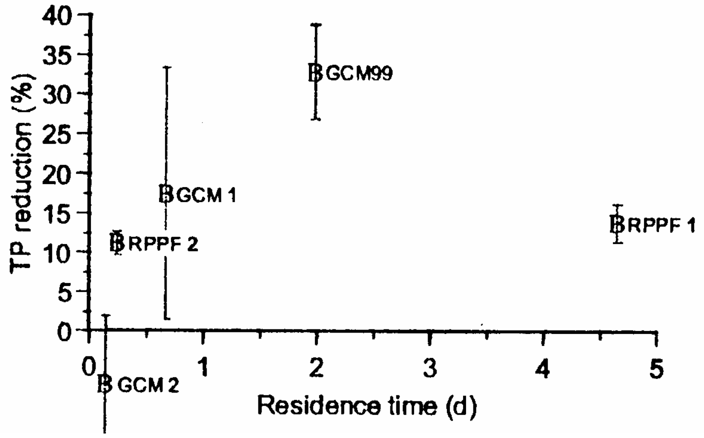


Figure 3.1 Settlement pond performance (Preston et al (2001)

Although pond performance is undoubtedly affected by the influent characteristics, the extent of sludge accumulation and the associated degree of N and P feedback from the sludge layer, the following representative performance data have been used in the water quality modelling work described below:

Hydraulic residence time	2 days
SS removal	60%
Total N removal	20%
Total P removal	30%

N and P removal are almost totally associated with suspended solids removal, with modification by feedback from the sludge layer.

4. Model Development

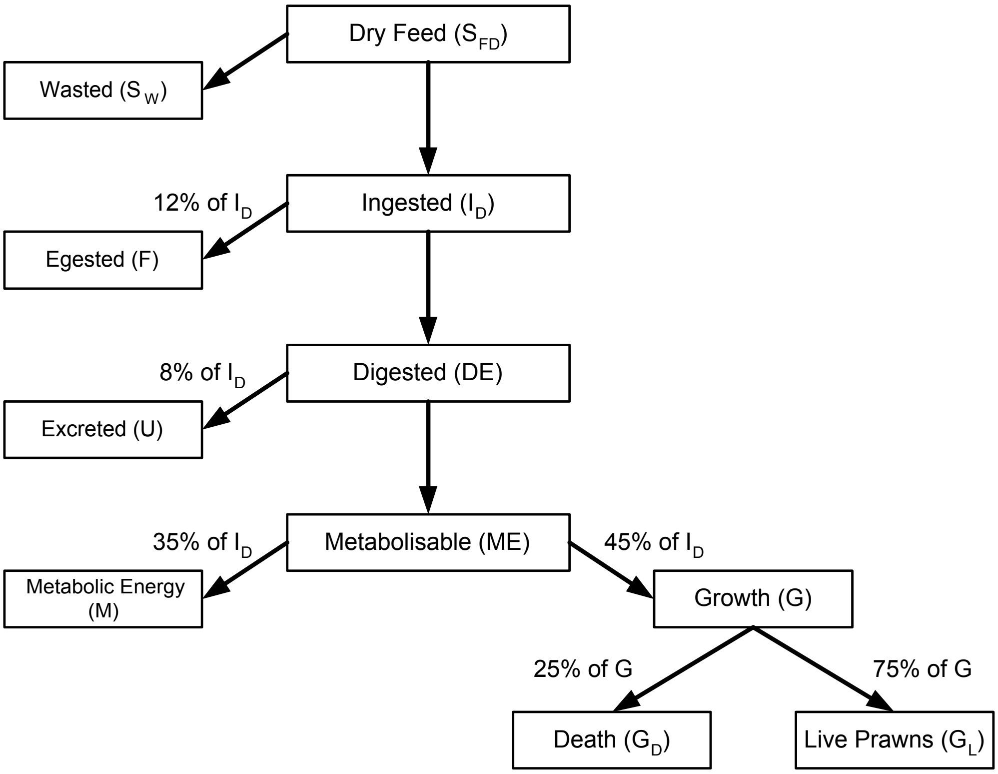
The overall water quality management model for the prawn farm has three components:

- A waste production model
- A water quality model
- A cost model

These will be described in turn.

4.1. Waste Production Model

All waste discharged from the growout ponds originates in the feed. The waste production model is therefore based on a simplified prawn growth model. The energy balance is as follows:



Live prawn production, $G_L = \quad S_{FD} - S_W - F - U - M - G_D$

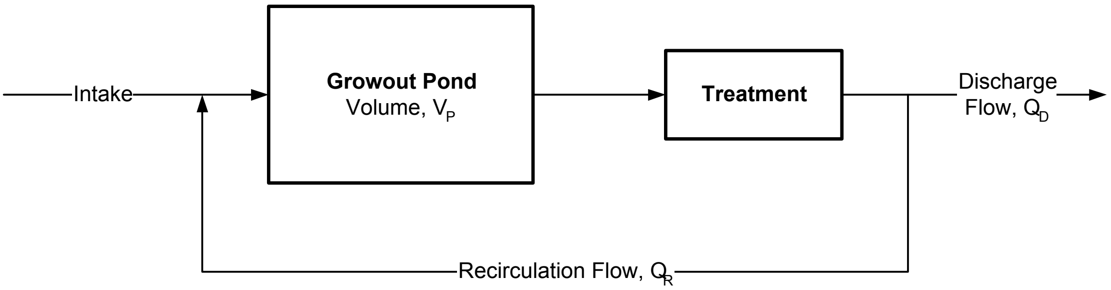
Waste production, $M_W = S_F - G_L$

Development of the simple steady state waste production model from this energy balance is described in Figure 4.1.

Prawn survival over the growout season is typically around 60% and most of the deaths occur soon after stocking. However, the model conservatively assumes 50% survival, with deaths occurring at a constant rate over the whole season. This increases the calculated waste production as shown in Figure 4.1.

4.2. Water Quality Model

The water quality model describes the steady state performance characteristics of the following generalised water management system:



Growout Pond Exchange Rate, $E_P = (Q_R+Q_D) / V_P$

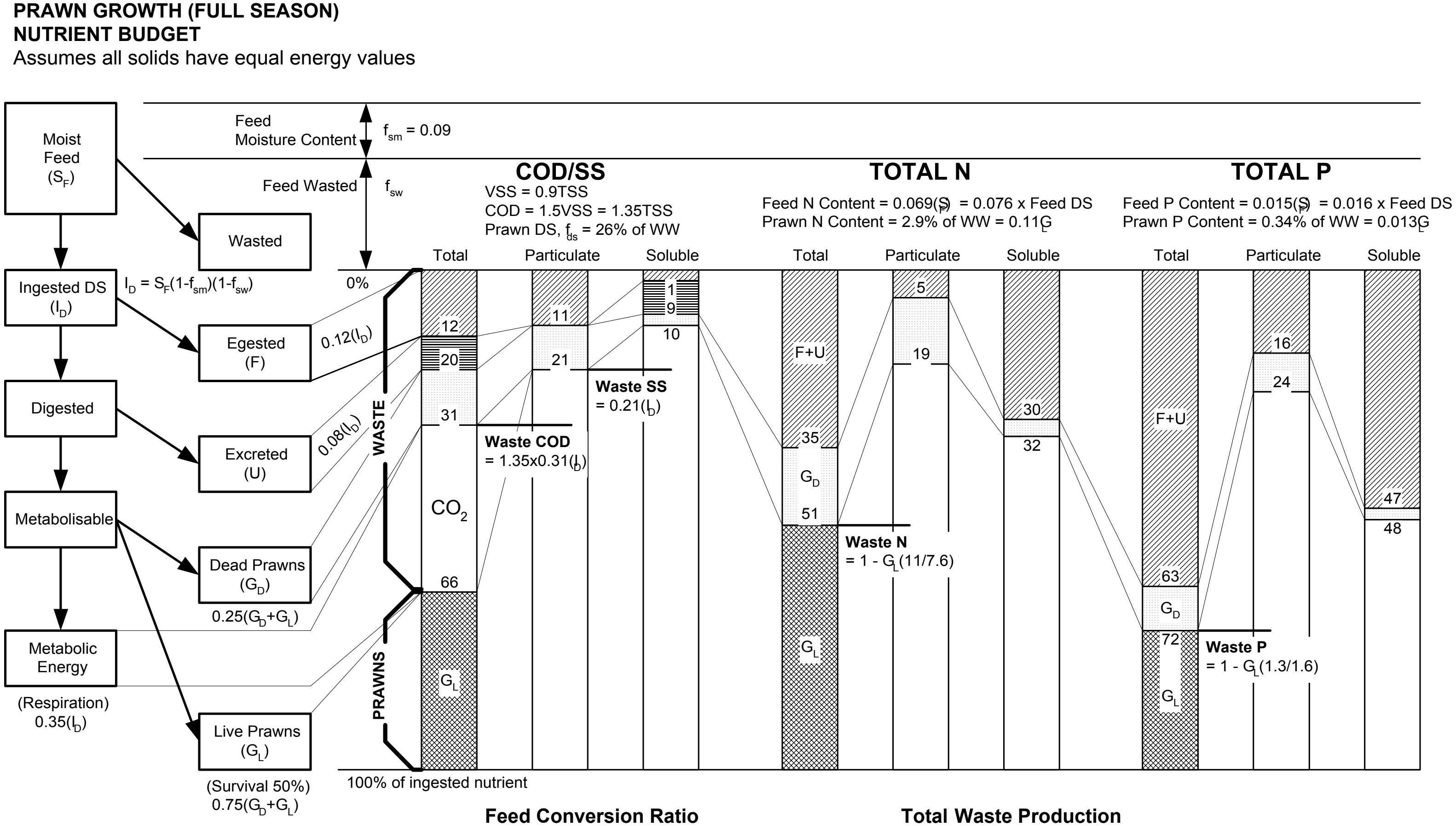
Discharge Ratio, $\rho = Q_D / (Q_R+Q_D)$

Effluent from the growout pond is treated to some degree and then partly recirculated and partly discharged to the environment. The fraction discharged is made up by intake of water from an external source. Two key operating variables have been defined as noted in the diagram: the overall *exchange rate* is the fraction of the pond volume turned over each day, and the *discharge ratio* is the fraction of the total pond throughput discharged to the environment.

Model development is based on mass balance principles and is summarised in Figure 4.2.

4.3. Cost Model

A comparative cost model has been developed to determine the effect of the various design and operating parameters on the total annual cost of the system. The components included in the comparative total annual cost are as follows:



G_D assumes death rate is constant % of surviving prawn number over 26 week season.
Season duration T_G

Feed Conversion Ratio

FCR = Total Moist Feed / Live Prawn WW

$$= I_D / [(1-f_{sm})(1-f_{sw})(G_L/f_{ds})]$$

Pond Yield

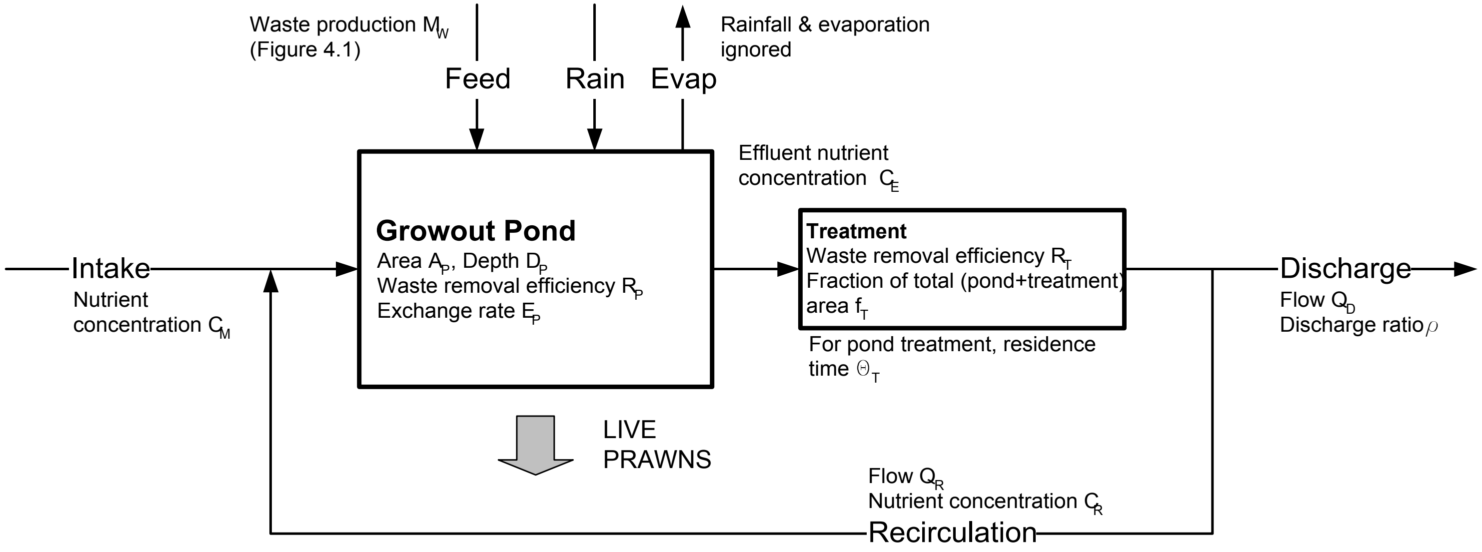
$$Y_P = S_F T_G / FCR$$

Total Waste Production

(waste ingested + waste feed components)

SS: $M_{WSS} = S_F[0.19(1-f_{sw}) + 0.91f_{sw}]$
COD: $M_{WCOD} = S_F[0.38(1-f_{sw}) + 1.23f_{sw}]$
TN: $M_{WN} = S_F[0.032(1-f_{sw}) + 0.069f_{sw}]$
TP: $M_{WP} = S_F[0.010(1-f_{sw}) + 0.015f_{sw}]$

Figure 4.1 Prawn growout pond waste production model
]



Pond Nutrient Concentration

$C_E = [(M_W/A_P)(1-R_P) + C_M.E_P.D_P.\rho] / [E_P.D_P(\rho + (1-\rho)R_T)]$

Pond Algal Concentration (carbon limited)

$C_{EA} = [(M_{WCOD}/A_P) / (E_P.D_P)]\ [0.4 / \{1+(0.15/E_P)\}]$

Treated Nutrient Concentration

$C_R = (1-R_T)C_E$

Mass Nutrient Discharge to Environment (kg/ha of growout pond area.d)

For constant total area (growout pond + treatment)
Any treatment method: $M_D = E_P.\rho.D_P.C_R / (1-f_T)$
Pond Treatment: $M_D = E_P.\rho.D_P.C_R(1+E_P.\Theta_T)$

Figure 4.2 Water quality model

CAPITAL COST

Annual value equivalent to recovery of capital over 5 years at 8% interest (annual cost 0.250 of capital cost)

- Fresh water intake and effluent discharge system
- Pond distribution system including intake balancing storage and distribution conduits (which also allows for effluent recirculation)
- Effluent treatment system

OPERATING & MAINTENANCE COSTS

- Intake/discharge/recirculation power & maintenance
- Distribution system maintenance
- Treatment power, chemicals, labour, maintenance
- Land opportunity cost – potential profit lost from land used for treatment

Costs for pond cleanout and sludge disposal have been excluded.

Comparative annual costs have been estimated for an active total area (growout ponds plus treatment) of 250 ha. Growout ponds were assumed to be 1.5m deep. Cost estimates were built up as follows.

Costs for standard sized components were first estimated. Then, to develop the comparative annual cost of a particular management option, the costs of the individual components were scaled in proportion to the 0.7 powers of their capacities and summed to give the total cost.

5. Management Concepts

Three conceptual schemes for water quality management have been evaluated as follows:

1. *Settlement ponds.*
   The flowsheet for this scheme is identical to that shown in Figure 4.2. The settlement ponds have a hydraulic residence time of 2 days and sludge is allowed to accumulate in the ponds. Removal performance assumed is 60% for SS, 20% for total N and 30% for total P. There is a risk of nutrient removal performance deteriorating with time due to increasing feedback from the sludge layer. Settlement ponds also use area which could be used for additional growout ponds.

2. *Sand filters with mechanical dewatering of sludge.*
   The flowsheet for this scheme is shown in Figure 5.1 (a). The removal efficiency is higher – 80% for SS and 50% for total N – and feedback is prevented by continuous dewatering of the separated solids. Because of the high solids load, a conservatively low filtration rate is assumed (7 m/h). This scheme would utilise negligible land area.

3. *Coarse media filters with sludge lagoons.*
   Recent developments in filtration using coarse plastic media (Oderdaal et al, 2002) suggest that filtration rates of up to 30 m/h could be viable for this application. The assumed flowsheet is shown in Figure 5.1 (b). The high rate filters are combined with a different sludge handling scheme using lagoons for sludge storage and digestion. Nitrogen released from the sludge is removed by nitrification and denitrification in a sequencing batch reactor (SBR). Molasses is dosed as a carbon source for denitrification. Land area used by this scheme is also small.

The base cost estimate is appended and is summarised in Table 4.1. Comparing the two filtration schemes, coarse media filters appear substantially cheaper than sand filters but, based on these preliminary estimates, the sludge management system chosen for the latter appears to be the more economical.

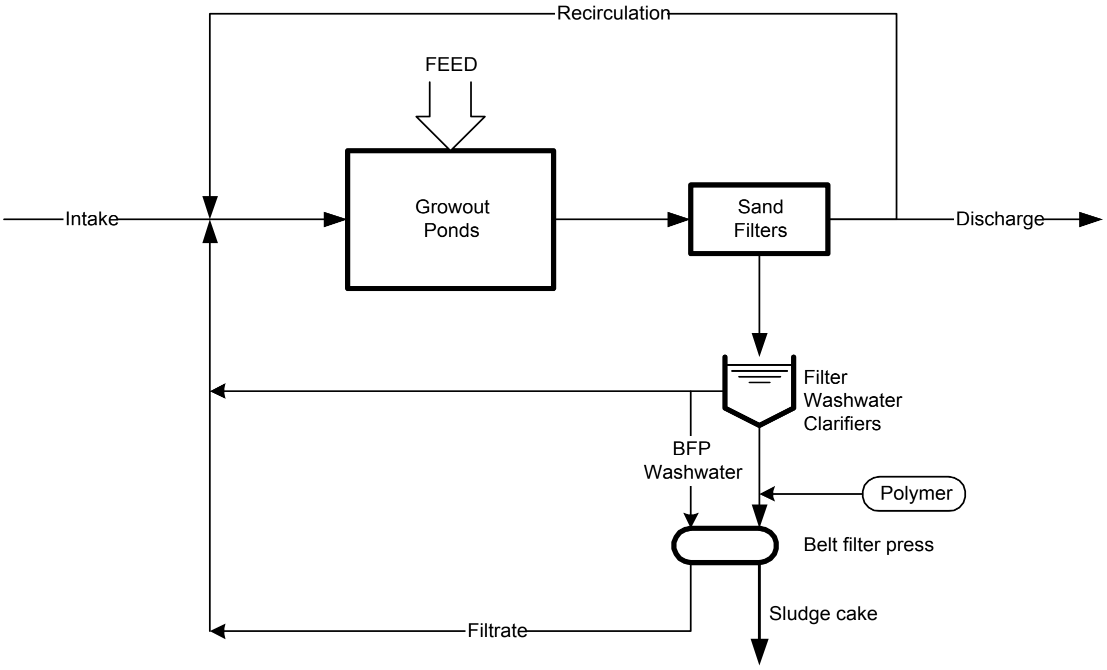
A detailed evaluation of the alternative concepts is set out in the next Section.

Table 4.1 Base Cost Estimates for System Components

Component	Capacity	Capital Cost ($ million)	Annual O&M Cost ($ thousand pa)
Intake/Discharge	190 ML/d	24.9	590
Distribution	190 ML/d	9.0	45
Treatment:			
Settling Ponds	190 ML/d (380 MLx1.5m WD)	2.4	95
Sand Filters		19.7	560
Filters	190 ML/d	16.5	290
Sludge System	1100 m^2 Note 1	3.2	270
Coarse Media		12.3	510
Filters	190 ML/d	8.5	220
Filters	400 m^2	3.9	290
Sludge System	Note 2		
		---	30
Land Opportunity	1 ha		

1. Washwater clarifiers, 390 m^2; belt filter presses, 2.4m total belt width.
2. Sludge lagoons, 150 ML x 3m WD (3 years storage); SBR, 6 ML.

(a) Sand Filters



(b) Coarse Media Filters

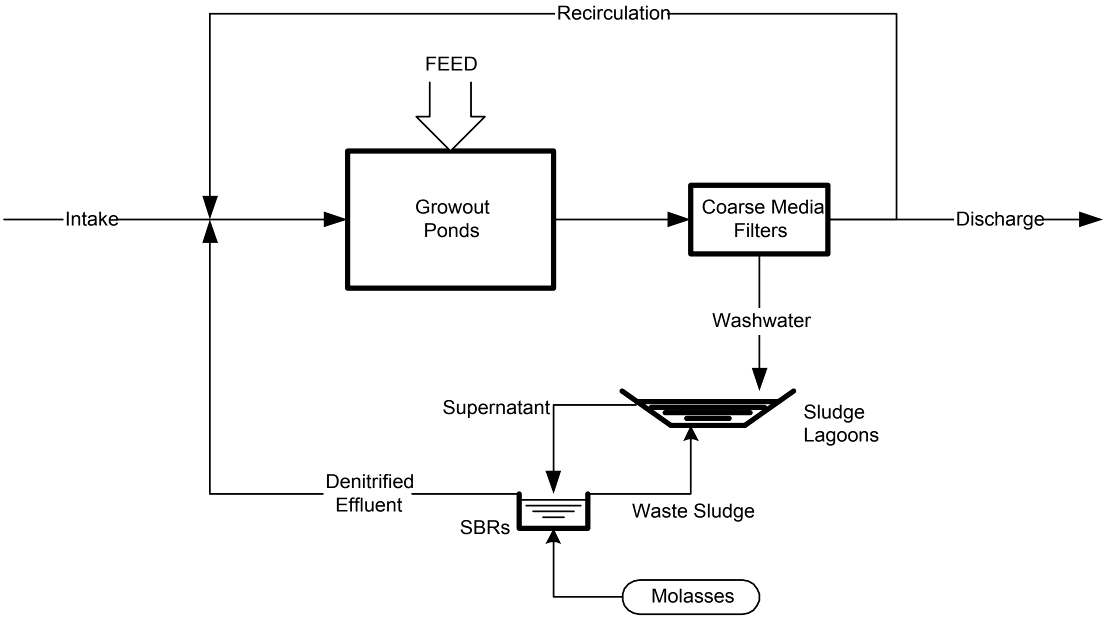


Figure 5.1 Alternative flowsheets

6. Evaluation of Alternative Concepts

6.1. Model Calibration

The model described in Figures 4.1 and 4.2 can be calibrated using the Seafarm data reported by Preston et al (2001). Prawn production data were not given by Preston et al and assumptions have been made as set out in Table 6.1.

Table 6.1 Basis for Model Calibration

Parameter		Value	Source
Pond exchange rate	% per d	4	Preston et al (2001)
Stocking density	PL/m^2	40	Assumed
Prawn harvest wet body weight	g	35	Assumed
Survival	%	50	Assumed
Feed Conversion Ratio	kgWW feed/kgWW prawn	2.0	Assumed
Growout season	weeks	26	Assumed
Feeding rate, S_F/A_P	kg/ha.d	77	Calculated from assumptions
Feed moisture content, f_{sm}	%	9	Preston et al (2001)
Feed wasted (not ingested), f_{sw}	%	58	Calculated from FCR (Figure 4.1)

The effluent quality measured at Seafarm is compared with that calculated using the model in Table 6.2 below.

Table 6.2 Model Calibration

Parameter	Seafarm (Tables 3.3, 3.4)	Model (Figures 4.1, 4.2)		
	Net Effluent Concentration[1] (C_E, mg/L)	Calculated C_E for R_P=0 (mg/L)	Pond Removal Efficiency (R_P) to Match Seafarm C_E (%)	Adopted R_P (%)
COD	---	112	---	---
SS:				
Non-Algal	43	78	45	50
Algal	7	9	---	---
Total	50	87	---	---
Total N	1.7	6.9	75	75
Total P	0.22	1.7	87	85

[1] Effluent concentration – influent concentration

The pond COD loading calculated from the model is 67 kg/ha.d which is low by wastewater treatment pond standards. Algal growth is limited by the carbon dioxide produced through bacterial oxidation of the COD. The bacterial and algal biomasses take up nitrogen and phosphorus.

There seems to be significant settlement of both feed and bacterial solids in the pond. Metabolic uptake and sedimentation is presumably the mechanism for net removal of N and P. Release and feedback from the sludge may be limited by the high dissolved oxygen concentration at which the pond is operated.

Overall, the model appears to give useful results and can be used to provide insight into the water quality and economic effects of varying the system design and operating parameters.

6.2. Feeding Rate and Efficiency

The intensity and efficiency of feeding are critical to both prawn production and waste production. Figure 6.1 (a) shows the relationship between FCR and the fraction of feed wasted (not ingested by the prawns). Theoretically, with zero waste the FCR would be 0.84. At FCR values of around 2 the fraction of feed wasted is 55-60%.

Figure 6.1 (b) shows the effect of FCR on the feeding rate (over 26 weeks) needed to achieve a given crop yield (where yield is the product of stocking density, survival and prawn body weight achieved). For a crop yield of 6 t/ha, improving the FCR from 2 to 1.5 would decrease the feed rate by 25% from 66 to 49 kg/ha.d.

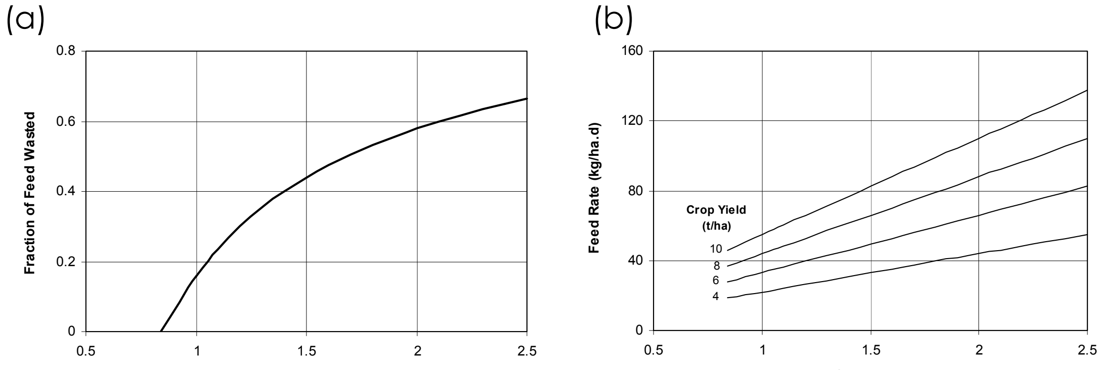


Figure 6.1 Feeding rate and efficiency

The impact of feeding on the quality of effluent discharged from a pond without additional effluent treatment is illustrated in Figure 6.2. These diagrams relate to total nitrogen and assume zero nitrogen in the intake water. The mass discharge rate depends solely on the operating feed rate and FCR and is independent of the exchange rate. Figure 6.2(a) shows how the mass discharge rate varies with the rate of total feed addition to the pond for various FCRs. Theoretically, at low feed rates the discharge will comply with the EPA limit of 0.96 kgN/ha.d. The higher the FCR, the lower the allowable feed rate.

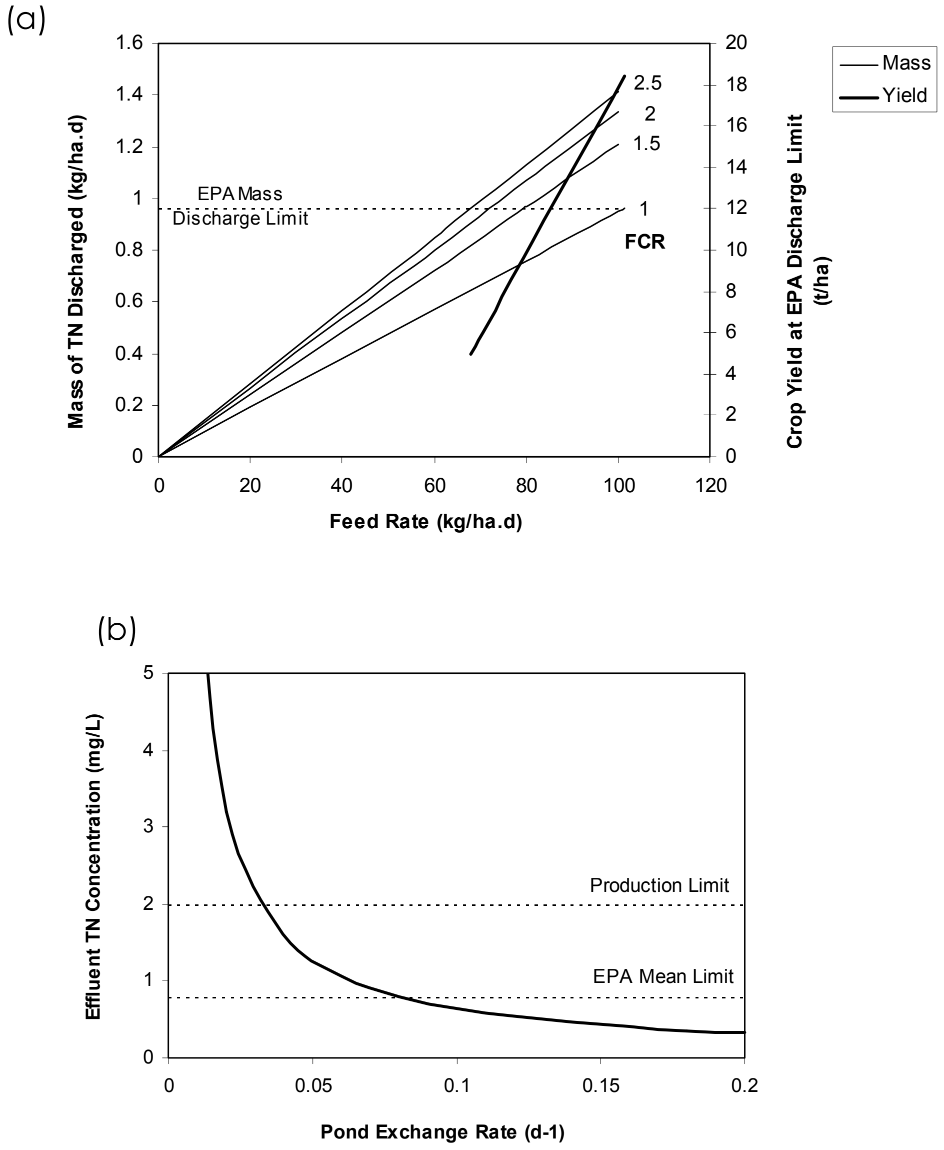


Figure 6.2 Effect of feeding rate and efficiency on effluent discharge

For each FCR, the feed rate corresponding to a nitrogen discharge of 0.96 kg/ha.d has been used to calculate the corresponding crop yield. These yields are also plotted on the graph. Based on this effluent quality constraint, the limiting crop yield increases from 4.9 t/ha at an FCR of 2.5 to 6.5 at 2.0, 9.6 at 1.5 and 18 at 1.0.

Figure 6.2(b) shows what happens to effluent concentration if the mass discharge is maintained at the EPA limit and the exchange rate is varied. A production limit of 2 mg/L, set to prevent ammonia toxicity, would require a minimum exchange rate of about 3.5% while the EPA mean limit of 0.8 mg/L could be met at an exchange rate of around 8%. Increasing the exchange rate from 3.5% to 8% would not change the mass discharge rate, the concentration limit being met simply through the dilution afforded by the higher flow.

6.3. Effluent Treatment

Pond performance characteristics with treatment and recirculation are shown in Figure 6.3. Figure 6.3(a) shows the combinations of exchange rate and discharge fraction which will maintain a pond total N concentration of 2 mg/L, assuming a 20% N removal efficiency in the treatment process (typical of settling ponds). Lines are drawn for three FCRs – 2.0, 1.5 and 1.2 – assuming a constant crop yield of 6,800 kg/ha. This allows the feed rate to decline from 75 to 56 to 45 kg/ha.d. At an FCR of 2.0, 58% of the feed is wasted. At an FCR of 1.2 the waste feed is reduced by half to 30%. This would obviously provide significant benefits in terms of both feed cost and water quality management.

Figure 6.3(b) shows the effect of a change in treatment efficiency on the pond performance characteristic, either a decrease in efficiency due to greater feedback from the sludge layer or an increase in efficiency due to a more efficient treatment process. It is assumed that sand filters could increase SS removal from 60% for settling ponds to 80-85%, while increasing the associated N removal from 20% to 50% because of the avoidance of feedback from the sludge. For an FCR of 2.0, the filter curve approximates the FCR 1.2 curve for settling ponds in Figure (a).

The environmental performance of a system incorporating settling ponds is plotted in Figure 6.4. (Note that discharge levels assume zero nutrient concentrations in the intake.) Mass discharge of total N (per unit growout pond area) varies with discharge fraction and FCR as shown in Figure (a). According to this model, for a crop yield of 6.8 t/ha, the EPA nitrogen limit should be easily met when using settling ponds, particularly when the fraction discharged and FCR are reduced. These curves are calculated for a pond total N of 2 mg/L which means that the total N concentration in the effluent discharged is 1.6 mg/L. This does not meet the EPA mean concentration limit of 0.8 mg/L which can only be achieved through dilution (running the growout ponds at a higher exchange rate and lower nitrogen level).

Similar plots for total P and SS are shown in Figures (b) and (c). These relationships are drawn for a system operated with the growout pond N at 2 mg/L. According to this analysis, the EPA mass limit for SS can be readily met because of the high SS removal in the settling pond. However, the phosphorus limit is more difficult to meet, requiring a low discharge fraction and/or FCR. The settling pond phosphorus removal efficiency could be increased by chemical addition but this would increase sludge production and cost.

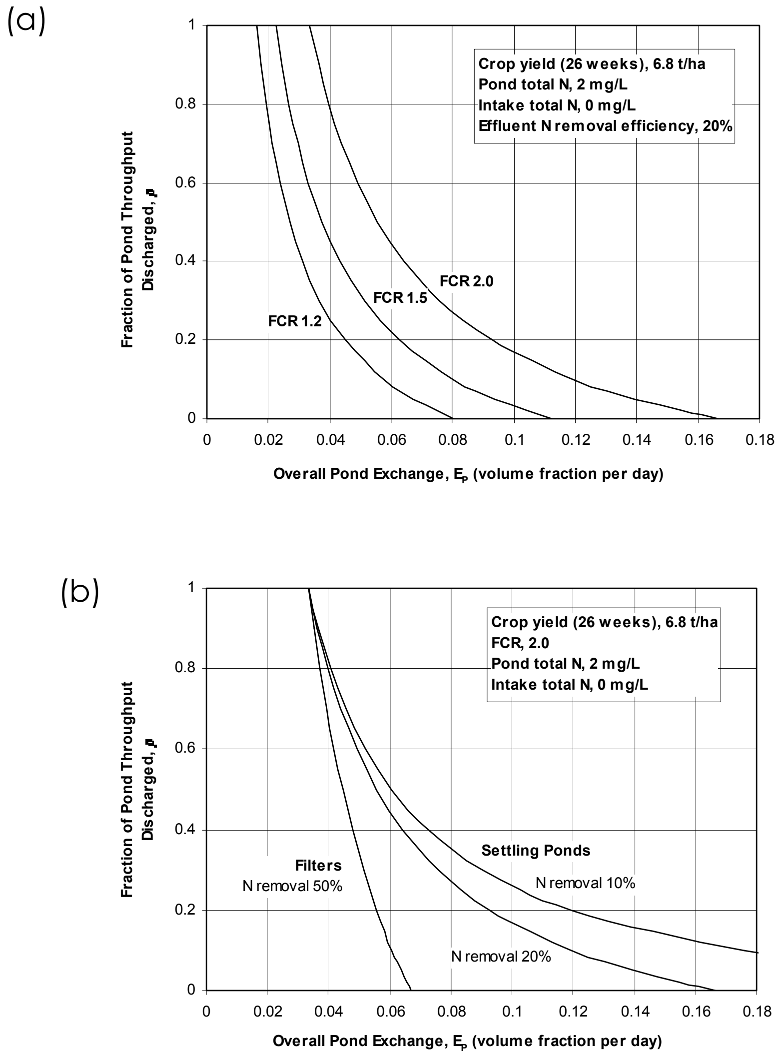


Figure 6.3 System performance

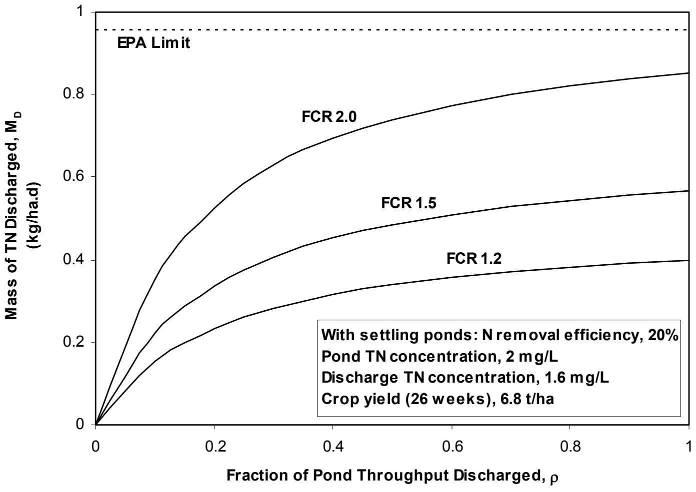
Suspended solids concentration discharged would be 22 mg/L, slightly above the EPA's mean discharge limit of 20 mg/L. Total P concentration in the discharge would be 0.20 mg/L, double the EPA's mean limit of 0.10 mg/L. As for nitrogen, meeting the limits would require additional dilution achieved by running the growout ponds at higher exchange rates and lower concentrations.

6.4. Costs

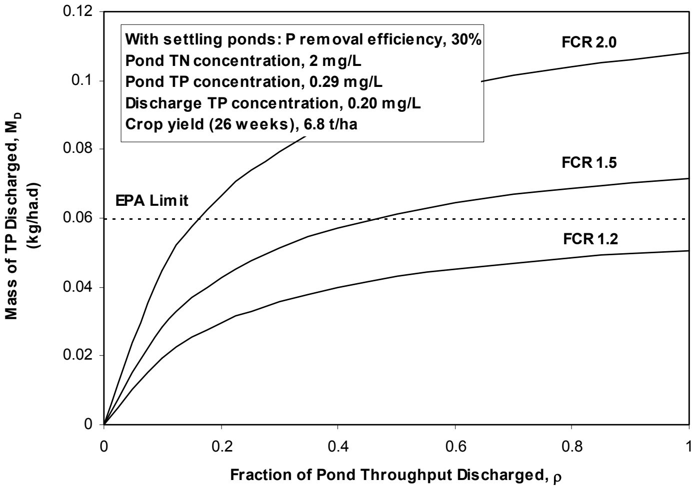
In Figure 6.5 (a), the results of the cost modelling are added to Figure 6.3 (b).

With settling ponds, overall cost varies little regardless of the combination of exchange rate and discharge fraction selected to meet the water quality goals. With increasing pond exchange rate (decreasing discharge fraction), increase in the cost of flow

(a) N


EPA Limit
FCR 2.0
FCR 1.5
FCR 1.2
With settling ponds: N removal efficiency, 20%
Pond TN concentration, 2 mg/L
Discharge TN concentration, 1.6 mg/L
Crop yield (26 weeks), 6.8 t/ha
Mass of TN Discharged, M_D (kg/ha.d)
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
Fraction of Pond Throughput Discharged, ρ

(b) P


With settling ponds: P removal efficiency, 30%
Pond TN concentration, 2 mg/L
Pond TP concentration, 0.29 mg/L
Discharge TP concentration, 0.20 mg/L
Crop yield (26 weeks), 6.8 t/ha
FCR 2.0
FCR 1.5
EPA Limit
FCR 1.2
Mass of TP Discharged, M_D (kg/ha.d)
0
0.02
0.04
0.06
0.08
0.1
0.12
0
0.2
0.4
0.6
0.8
1
Fraction of Pond Throughput Discharged, ρ

(c) SS

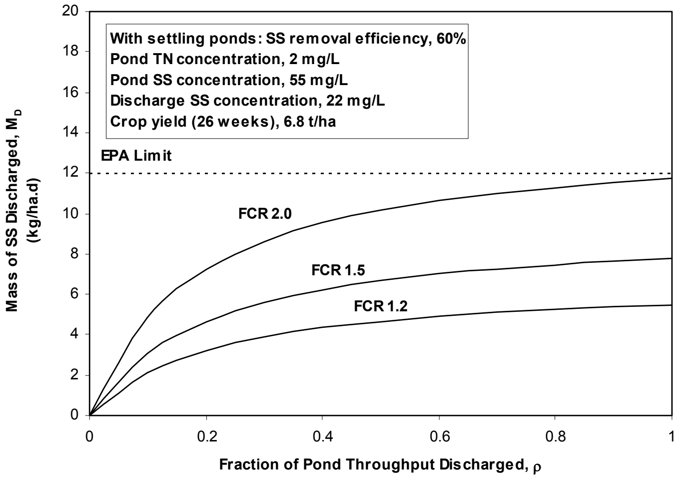

With settling ponds: SS removal efficiency, 60%
Pond TN concentration, 2 mg/L
Pond SS concentration, 55 mg/L
Discharge SS concentration, 22 mg/L
Crop yield (26 weeks), 6.8 t/ha
EPA Limit
FCR 2.0
FCR 1.5
FCR 1.2
Mass of SS Discharged, M_D (kg/ha.d)
0
2
4
6
8
10
12
14
16
18
20
0
0.2
0.4
0.6
0.8
1
Fraction of Pond Throughput Discharged, ρ

Figure 6.4 Environmental discharge with settlement ponds

distribution and treatment facilities is compensated by decrease in the cost of intake and discharge facilities.

With filtration, total cost decreases as discharge fraction is reduced because the reduction in the cost of intake/discharge facilities outweighs the increase in filter cost. Coarse media filters are cheaper than sand filters because of the higher filtration rate. Coarse media filters appear cost-competitive with settling ponds at the lower discharge fractions. The sludge dewatering system appears slightly cheaper than the alternative sludge lagoon system but this does not affect the overall cost comparison.

The components of the total comparative costs are shown in Figures 6.5 (b) and (c). These diagrams show the components as cumulative costs at each discharge fraction. The components are plotted in the same order as the legend, with capital recovery at the bottom and O&M at the top. Negligible components are so-marked in the legend.

The previous comparisons assume 20% N removal in the settlement ponds. If the N removal were to fall to 10% because of feedback from the sludge layer, the exchange rate and/or the discharge fraction would need to increase to maintain the same growout pond quality, as shown in Figure 6.3 (b). If these operating parameters were not enhanced, the growout pond total N concentration would deteriorate as shown in Figure 6.6 (a).

If the settlement pond system were designed for only 10% N removal to cope with poorer performance, the cost would increase as shown in Figure 6.6 (b). The coarse media filter system would then be significantly cheaper for the lower discharge fractions.

6.5. Comparison of Options

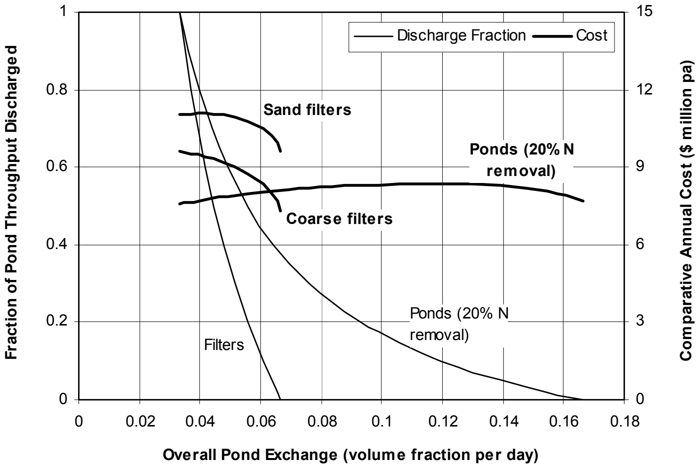
Non-economic features of the settlement pond and coarse media filter options are compared in Table 6.3. Filtration has performance and control advantages over settlement ponds.

Table 6.3 Comparison of Options

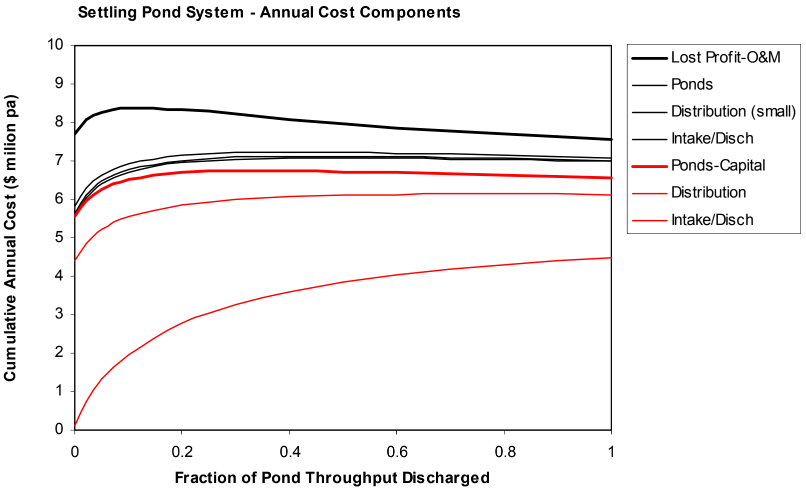
ADVANTAGES	DISADVANTAGES
Settlement Ponds	
♦ Simple operation ♦ Experience exists	♦ Lack of positive control over average performance and performance variability ♦ Potential performance deterioration due to feedback from sludge layer ♦ Need to dry and clean between seasons

Coarse Media Filters	
♦ More positive control via washing frequency, polymer dosing, flow rate adjustment – more consistent performance ♦ No performance deterioration ♦ Integrated off-line sludge management	♦ More sophisticated operation ♦ No experience – needs pilot study

(a)


Discharge Fraction
Cost
Sand filters
Ponds (20% N removal)
Coarse filters
Ponds (20% N removal)
Filters
Fraction of Pond Throughput Discharged
Comparative Annual Cost ($ million pa)
Overall Pond Exchange (volume fraction per day)
0
0.2
0.4
0.6
0.8
1
0
3
6
9
12
15
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18

(b)


Settling Pond System - Annual Cost Components
Lost Profit-O&M
Ponds
Distribution (small)
Intake/Disch
Ponds-Capital
Distribution
Intake/Disch
Cumulative Annual Cost ($ milion pa)
Fraction of Pond Throughput Discharged
0
1
2
3
4
5
6
7
8
9
10
0
0.2
0.4
0.6
0.8
1

(c)

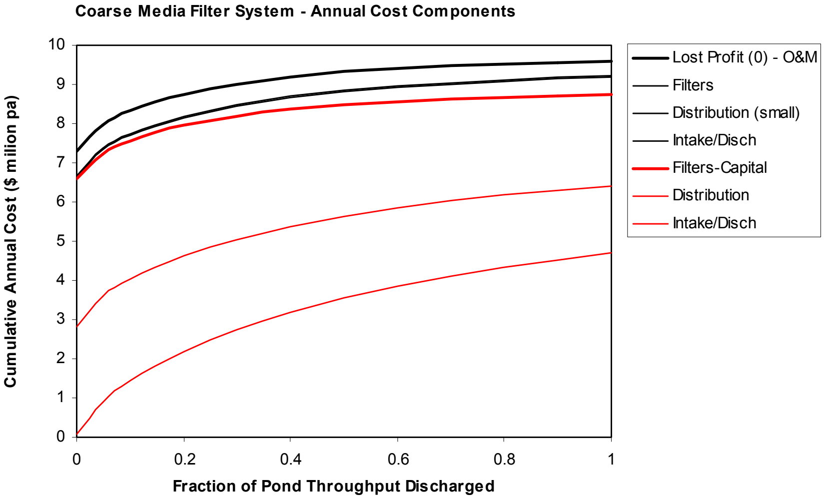

Coarse Media Filter System - Annual Cost Components
Lost Profit (0) - O&M
Filters
Distribution (small)
Intake/Disch
Filters-Capital
Distribution
Intake/Disch
Cumulative Annual Cost ($ milion pa)
Fraction of Pond Throughput Discharged
0
1
2
3
4
5
6
7
8
9
10
0
0.2
0.4
0.6
0.8
1

Figure 6.5 Comparative costs

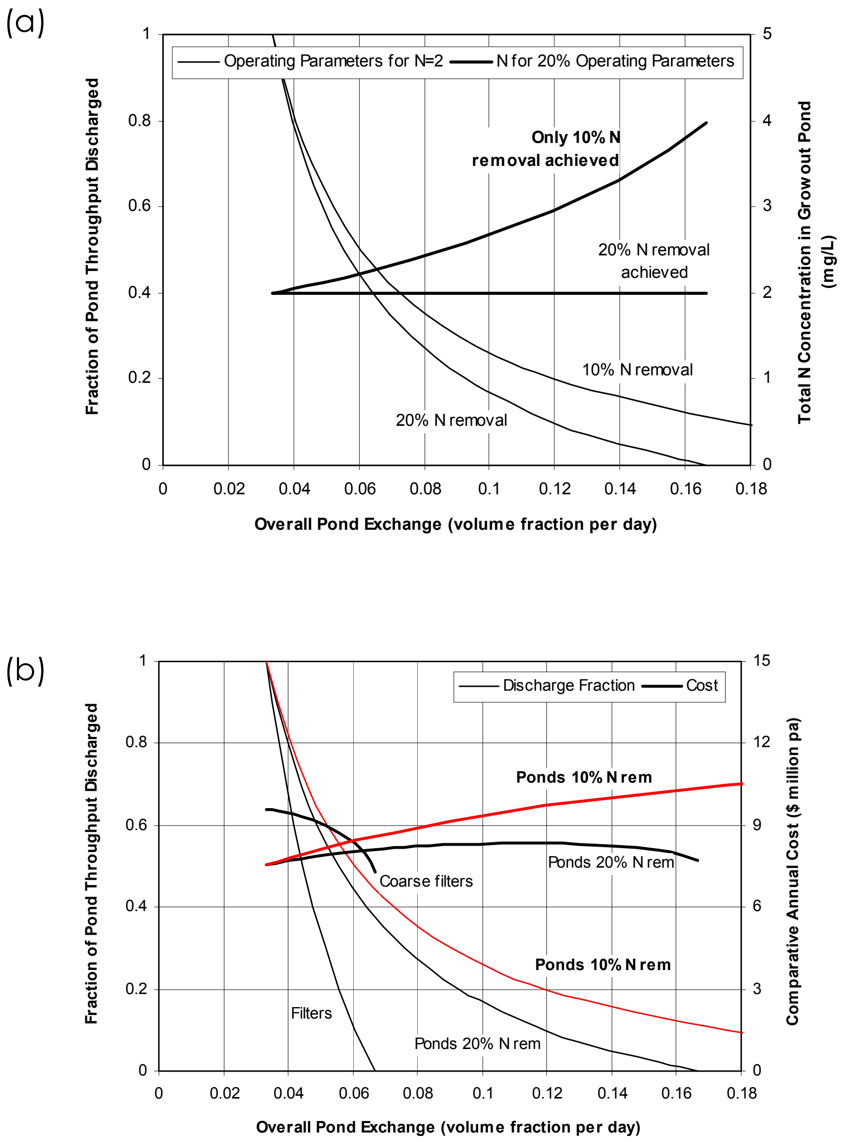


Figure 6.6 Potential deterioration in settlement pond performance

7. Implementation Strategy

Based on this preliminary analysis, filtration has performance advantages over settlement and can be implemented for about the same overall cost. However, its major drawback is the lack of experience with filtration of growout pond effluent, particularly using the newly developed plastic media filters.

Following is a possible implementation strategy:

1. Construct the first stage of the farm using additional growout ponds as settlement ponds. Choose operating parameters which will allow future stages to convert to filtration or to continue with settlement ponds. Choose an intake/discharge capacity which will suit both an ultimate filter development and the initial settlement pond development. Choose a minimum practical discharge fraction to minimise environmental impact and cost.

2. Conduct a filtration pilot study on part of the new farm or an existing farm.

3. If the pilot study is successful, expand the farm using filtration. If not, continue the use of settlement ponds (or other new technology).

Possible design parameters are tabulated below (refer to Figure 6.5). Ongoing improvement in the operating FCR will provide an operating safety margin.

Table 7.1 Design Parameters

Parameter	Initial Stage	Ultimate Development
Growout Ponds		
Exchange ratio d^{-1}	0.07	0.07
Discharge fraction	0.4	0.1
Hydraulic residence time d	14	14
Area ha	63	250
Depth m	1.5	1.5
Volume ML	945	3750
Recirculation flow ML/d	66	260
Intake/discharge flow ML/d	26	26
Fill/drainage time d	36	144
Settlement Ponds		
Hydraulic residence time	2	Not Used

d	132	
Volume ML	1.5	
Depth m	9	
Area ha	14	
% of growout area		
Filters		
Filtration rate m/h	Pilot Study	30
Area m^2		360

With a low intake/discharge flow, fill and drainage times for the complete farm would be long, as tabulated above. This would require that only part of the farm be empty at one time and that fill/harvest/clean operations be conducted sequentially by transfer of water within the farm. This is more practical for a farm operating only one growing season per year. Development of a practical operating schedule would require detailed consideration.

8. Conclusions

The preliminary water quality modelling conducted in this study leads to the following conclusions:

1. Waste Production

All waste discharged from the growout ponds originates in the feed. The critical parameters which define the mass of waste produced are the crop yield (tonnes of prawns harvested per hectare) and the Feed Conversion Ratio (FCR). The yield is a function of the stocking density, the prawn survival and the prawn body weight achieved. The FCR (kg moist feed/kg prawn wet weight harvested) is a measure of the feed utilisation efficiency.

Typical FCR values currently achieved are 1.8 – 2.0. For a prawn survival of 50% and a uniform death rate over the growing season, the theoretical FCR with zero wastage (100% of feed ingested by the prawns) is 0.84. A value of 2.0 indicates that 60% of the feed is wasted (not ingested by the prawns). If the wastage rate were reduced by half to 30%, the FCR would fall to 1.2.

Of the feed actually ingested by prawns, 30% of the carbon, 50% of the nitrogen and 70% of the phosphorus are returned to the growout pond as waste.

2. Water Quality Behaviour

A significant fraction of the waste derived from the feed is removed from the water column within the growout pond. This occurs predominantly through bacterial oxidation, metabolic uptake and settlement, with apparently low rates of nutrient feedback from the sludge layer. Algal growth also occurs and is limited by the carbon dioxide produced by bacterial oxidation. Net removals of non-algal SS, N and P in the growout pond appear respectively to be in the order of 50%, 75% and 85% of the waste inputs.

Water quality behaviour has been modelled for a system in which the growout pond effluent is treated in a settling pond or filtration process, and is then partially recirculated to the growout pond and partly discharged to the external environment. The discharge volume is made up by intake of fresh water from an external source. In all of the modelling results presented, it has been assumed that the intake water has zero nutrient concentrations. Water quality behaviour is governed by two key variables: the overall *exchange rate* which is the fraction of the growout pond volume turned over each day, and the *discharge ratio* which is the fraction of the total pond throughput discharged to the external environment.

Under steady state conditions, the crop yield and FCR set the waste input rate to the growout pond and therefore the mass discharge rate in the growout pond effluent. The exchange rate governs the concentration of nutrients within the pond and therefore in the pond effluent. The growout pond effluent quality may be further modified by treatment. The discharge ratio then governs the mass discharge rate of nutrients to the external environment. In analysing the system behaviour it has been assumed that for a given effluent treatment efficiency and discharge ratio, the exchange rate is set at the value maintaining the desired water quality within the growout pond. For production purposes, a growout pond total N concentration of 2 mg/L has been selected to avoid ammonia toxicity to the prawns. For a given growout pond quality, a zero discharge ratio can be achieved by setting the exchange rate high enough to ensure that the mass of waste added in the feed is removed in the treatment system.

Two alternative levels of treatment have been examined – settling ponds and filters. In settling ponds, removal efficiencies for SS, total N and total P have been assumed to be 60%, 20% and 30% respectively, based on data from Preston et al (2001). The filtration alternative has been chosen for its ability to increase the removal of SS and the associated nutrients without suffering from sludge layer feedback. Respective removal efficiencies for SS and total N have been taken as 83% and 50%. Two filter options with assumed similar performance have been evaluated – conventional sand filtration and a newly developed process using coarse plastic filtration media (Oderdaal et al, 2002). These filter systems have been combined with two alternative sludge management schemes aimed at preventing the recycle of nutrients. The sand filter option incorporates washwater clarifiers and mechanical sludge dewatering while the coarse media option is paired with sludge lagoons and biological nitrification/denitrification of the lagoon supernatant. This arbitrary pairing could be switched.

3. Predicted Performance

Performance predictions have been compared with the draft EPA limits for effluent discharge: mean mass discharge limits (kg/ha of growout pond area.d) for SS, total N and total P of 12, 0.96 and 0.06 respectively, and mean concentration limits (mg/L) of 20, 0.8 and 0.1 respectively. All performance predictions summarised below are based on a growout pond total N concentration of 2 mg/L and zero nutrients in the intake water.

With no effluent treatment or recirculation, it would be possible to meet the EPA mass discharge limit by limiting the crop yield to values varying with the FCR as follows: 4.9 t/ha at an FCR of 2.5, 6.5 t/ha at 2.0 and 9.6 t/ha at 1.5. Effluent discharged would have a total N concentration of 2 mg/L at an exchange rate of 3.5% per day while the EPA limit of 0.8 mg/L could be met by increasing the exchange rate to 8% to further dilute the effluent.

With settling ponds, pond water quality could be maintained by various combinations of exchange rate and discharge fraction. The exchange rate required decreases as FCR is decreased. For a pond total N concentration of 2 mg/L, settling pond effluent total N would be 1.6 mg/L. Mass discharge rate to the external environment then varies with discharge fraction. Analyses conducted for a crop yield of 6.8 t/ha indicate that the EPA mass discharge limit for total N should be easily met for all discharge fractions and practical FCR values. Environmental performance improves as discharge fraction and FCR decrease and mass discharge falls to zero for zero discharge fraction. Maintenance of growout pond N at 2 mg/L with zero discharge theoretically requires an exchange rate varying from 17% per day at an FCR of 2.0 to 8% per day at an FCR of 1.2. The EPA concentration limit for N of 0.8 mg/L could only be met by increasing the exchange rate to further dilute the effluent.

Under these operating conditions, the EPA mass limit for SS could also be readily met, with the calculated SS concentration in the discharge running at 22 mg/L, slightly above the EPA concentration limit of 20 mg/L.

The phosphorus mass discharge limit would be more difficult to meet, requiring the discharge fraction to be limited to about 0.15 at an FCR of 2.0, 0.45 at 1.5 and 1.0 at 1.2. The discharge P concentration would be 0.2 mg/L, double the EPA limit of 0.1 mg/L which, again, could only be met through increased effluent dilution.

There is a possibility that settling pond performance could deteriorate with time as nutrient feedback from the sludge layer increases. If N removal efficiency dropped from 20% to 10% and exchange rate or discharge fraction were not increased to compensate, total N concentration in the growout pond would increase; total N would then range from 2 mg/L at 100% discharge fraction up to 4 mg/L at zero discharge fraction.

With treatment by filtration, the same results would be achieved at lower exchange rates and/or discharge fractions. For example, at zero discharge fraction, the exchange rate needed to maintain pond total N at 2 mg/L (crop yield 6.8 t/ha, FCR 2.0) would be 17% per day with settling ponds and 7% per day with sand filters.

A similar improvement in performance could be achieved by retaining settling ponds and reducing the FCR from 2.0 to 1.2.

4. Costs

With settling ponds, overall cost varies little regardless of the combination of exchange rate and discharge fraction selected to meet the water quality goals. With increasing pond exchange rate (decreasing discharge fraction), increase in the cost of flow distribution and treatment facilities is compensated by decrease in the cost of intake and discharge facilities.

With filtration, total cost decreases as discharge fraction is reduced because the reduction in the cost of intake/discharge facilities outweighs the increase in filter cost. Coarse media filters are cheaper than sand filters because of the higher filtration rate. Coarse media filters appear cost-competitive with settling ponds at the lower discharge fractions.

The sludge dewatering system paired with sand filters appears slightly cheaper than the alternative sludge lagoon system incorporated in the coarse media filter option but this does not affect the overall cost comparison.

5. Comparison of Options

Filtration has several advantages over settlement ponds: more positive control, more consistent performance, no risk of performance deterioration due to nutrient feedback from a sludge layer and integrated off-line sludge management. The only real disadvantage is the lack of experience with filtration in this application and with the new coarse media filters in particular, requiring a pilot study to determine true performance and economics.

A staged development strategy for the prawn farm would allow piloting of the filters (at Guthalungra or elsewhere) while using future growout ponds as settlement ponds in the first stage. Depending on the outcome of the experimental work, filtration could be incorporated at the next expansion.

More detailed consideration needs to be given to the sludge management strategy. Of the two options developed to prevent nutrient feedback with filtration systems, the dewatering option appears slightly the cheaper and produces a dewatered cake whereas the sludge lagoons will still require dewatering at intervals.

6. Uncertainties

The modelling conducted in this study is very preliminary, using a simplified, untested model applying to steady state conditions averaged over a 26 week growout season and incorporating a large number of assumptions. Attention has been focussed on nitrogen as the key parameter. Various aspects of process behaviour have been simplified, guesstimated or ignored, including prawn growth and death characteristics, explicit interactions between pond supernatant and sludge layers, sludge accumulation and management, factors governing nutrient speciation, factors affecting treatment process performance, intake water quality, draining and refilling of ponds and the effects of rainfall and evaporation.

The conclusions and recommendations therefore need to be interpreted in the light of practical experience. However, the study identifies key design and operating variables, provides useful insight into water quality behaviour and should contribute to improvement in methods of water quality management.

9. Recommendations

It is recommended that:

1. The water quality management system for Guthalungra incorporate treatment and effluent recirculation.

2. The system be designed with a high exchange rate and low discharge fraction to allow the mass discharge of nutrients to be minimised.

3. Consideration be given to conducting a pilot study of coarse media filtration for effluent treatment.

4. Consideration be given to the sludge management strategy to be paired with the effluent treatment system.

5. The initial stage of development utilise future growout ponds as temporary settlement ponds and be designed flexibly to suit the future addition of filtration or other developing technology.

6. Investigations be conducted to assess methods of reducing the operating Feed Conversion Ratio.

7. Negotiations be conducted with the EPA with the aim of modifying the effluent discharge criteria as follows:

   - Delete concentration limits and restrict the standards to mass discharge only.

   - Where water intake and effluent discharge utilise the same water body, apply the mass discharge limits to the net increase through the pond system (ie. discharge minus intake).

8. Based on informed review of this study, conduct appropriate follow-up investigations.

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APPENDIX
COST ESTIMATES