Energy-Efficiency Manual for Aquaculture Pond Aeration

Foreword (by EPA Sustainable Industries?)

Aquaculture is an important industry for Queensland. It is part of the developing biotechnology sector, with the promise to divert fishing pressure from wild stocks. The Queensland Government, in partnership with industry, has identified methods for improved environmental outcomes through the employment of energy-efficient practices. A key element of the Government's Smart State strategy is to give Queensland a competitive edge by enhancing our industries with the latest technology. The achievements of Queensland's aquaculture industry in managing pond aeration is testament to the success of this strategy, where effective environmental management in this industry is viewed proactively as yet another opportunity for Queensland to lead the way. Information on energy-efficient aeration should now be widely dispersed and this manual provides an up-to-date, comprehensive consolidation of this information. The Queensland Government will continue to work with aquaculture industry representatives to ensure the continuing profitability and good environmental performance that assures a more livable environment for all Queenslanders

While every attempt has been made to ensure that the information in this publication is correct at the time of printing, errors can occur. The information is provided as general information only. Specific issues relevant to your workplace should be considered in light of this and on an individual basis. The information provided in this publication should not be construed as legal advice. You should consult with professional advisors familiar with your particular factual situation for advice concerning specific environmental requirements

This manual was written by Eric Peterson, Adjunct Senior Research Fellow, Centre for Marine Studies, at the University of Queensland, on behalf of Queensland Environmental Protection Agency. John Welch of Maunsell Australia P/L designed the latest wiring diagram and provides an article on the electrical engineering of variable speed drives. Kenneth Ian Berry also provides a report on an earlier prototype pond aeration speed control system, based on his student internship from the JCU Aquaculture Department and subsequent employment as a pond technician at Seafarm. The authors wish to acknowledge the resolute support of Seafarm managers Alistair Dick and Rob Scott, who directed Seafarm capital into the latest prototype, with Engineering funded by EPA. We are all indebted to Seafarm Electrician Len Leihn for on-the-ground attention to details and problem-solving to develop a system that has proven to work at Australia's leading prawn.

Introduction

This manual explores opportunities to employ energy-efficient practices for aquaculture pond aeration. Energy-efficiency is being adopted by industries world-wide to reduce greenhouse gas emissions while reducing operating costs. There are many reasons for adopting energy-efficiency practices. Financial savings are generally the most attractive, but many companies have elected to adopt energy-efficiency for other reasons - stricter environmental standards, greater community expectations, improved image with customers, the expectation of increasing costs for energy, or the longer-term sustainability and competitiveness of their businesses. In the case of prawn farming, we have discovered that aeration speed control also improves the conversion from feed to product.

This manual has been developed to assist aquaculture pond owners to adopt more energy-efficient approaches to their operations. First by informing aquaculture pond technicians how to switch aerators off during daylight feeding operations. Secondly by informing qualified electricians with an example wiring diagram of a variable speed drive (VSD) to automatically control several ponds at once. The first step is recommended as a temporary measure to save money until capital can be raised to invest in the long term opportunity for increasing profits offered by automatic speed control of aeration systems.

The manual covers pond aquaculture pond aeration for marine prawn farms. Some reference is also made to red-claw and barramundi farming, recognising the fact that inland property owners maybe able to harvest aquaculture products from dams. Prawn pond aeration is the focus of this manual, due to its dominance of the Queensland aquaculture industry. Pond managers of other species should still find this manual of considerable use, but some customization will need to be applied for each sector.

Few publications contain information about energy-efficiency for aquaculture industry or research groups. Most of the information in this manual is based on the PhD thesis and Research Fellowship work conducted at James Cook University by Eric Peterson. The manual represents a consolidation and update of his insights relating to energy-efficiency, supported by case studies and payback particulars from the latest prototype at Seafarm.

Australian aquaculture production of prawns was almost 2, 910 tonnes in 1999/2000, valued at almost $51.3 million (O'Sullivan and Dobson, 2001). Most Australian prawn farms are distributed along the eastern coastline of the State of Queensland.

Definition of 'mechanical aeration system', 'circulation', and 'wasteful aeration'
Throughout this manual reference is made to 'mechanical aeration', for the purposes of describing the mechanical paddling of the air-water interface, spraying droplets through the air, and/or bubbling air through the water column. Phytoplankton should be viewed as a part of a greater whole-pond system, which includes mechanical aeration components. The prawn farmer is challenged to manage the mechanical and biological components of the whole-pond system, to maximize pond productivity and reduce environmental impacts.

A '**mechanical aeration system**' is the set of paddlewheels, propeller-aspirators and/or blower-driven pipework, which deliver dissolved oxygen and simultaneously strip carbon dioxide from pond waters WHEN PHYTOPLANKTON ARE NOT WORKING. Mechanical aeration requirements confront the aquaculturalist 7-nights per week, when pond biomass is high.

Mechanical aeration is not required when ponds are first stocked with post-larvae or fingerlings, but at least one paddlewheel is normally deployed in each pond to de-stratify the water column and to ensure homogeneous mixing of plankton in every corner. This function should be managed as a '**circulation**', 'thou often confused with aeration.

Natural re-aeration processes of phytoplankton and surface diffusion will support fish or prawn biomass up to about 2000 kg per hectare, but from that time onwards about one kW of mechanical aeration needs to be added for each 500 kg growth of the target biomass (fish or prawns, as recommended by Boyd 1998). Aeration requirements generally increase until the time of harvesting, when biomass is removed. Aeration requirements can be offset by the photosynthetic effect of algae in sunlight. Figure 1 illustrates how pond oxygen levels oscillate from a super-saturated high in the afternoon, to be gradually depleted overnight, with the risk of a crash at dawn if mechanical aeration were not provided to match the respiration requirements of plankton and sediments, added to the respiration requirement of the target biomass (fish or prawns).

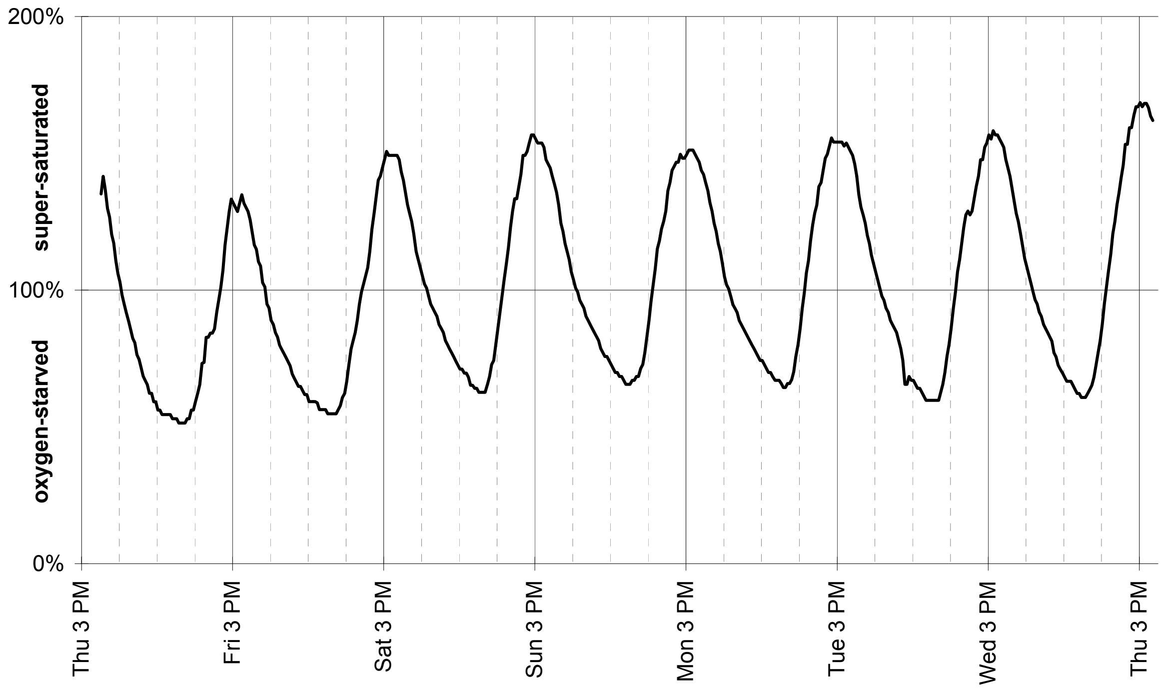


Figure 1: Plot of oxygen saturation through one week, in a typical intensive prawn pond (provided by Doug Pearson with a Royston probe). 9kW of paddlewheels and propeller-aspirators were run full speed, day and night, with 6500 kg product biomass. The aerators were delivering oxygen into the pond nightly from 9 PM until 9 AM each morning, but at other times they were working counter-productively: (A) stripping-out oxygen; (B) blowing away feed pellets, and (C) consuming electric power at the most expensive time of day.

This manual advises prawn farmers to avoid **'wasteful aeration'**: First by manually switching-off aerators during the day, and eventually installing automatic aeration systems when capital can be raised to renovate existing facilities. New prawn farms should be developed with automatic aeration systems integrated into the design of the electricity supply network. Financial institutions and government agencies should promote aeration control systems on all new aquaculture pond developments, (except extensive facilities). Prawn farmers might convince the federal government that "green power" Renewable Energy Certificates (RECs) should be earned for the electric energy saved by switching off mechanical aeration to store photosynthetic oxygen generation for use at night.

Overview of pond aquaculture energy use

Energy is required for intensive aquaculture systems. Energy-audits commissioned by Queensland and Federal governments (Peterson and Patterson 2000) determined that aeration accounts for about 80% of the energy demand on typical marine prawn grow-out farms, while pumping accounts for another 10%. The remaining 10% is required for food processing. The perishable nature of aquaculture products means that they need to be fresh chilled, and cooked and/or frozen in order to preserve them if not sold fresh. This involves the use of electricity for ice-making for pond-side harvesting, as well as additional refrigeration after processing. The need to maintain strict food hygiene standards also necessitates the use of hot water for sterilisation of plant and equipment. Energy demand of hatcheries has not been investigated, as these are always managed as separate business enterprises. An energy audit of a zero-exchange freshwater barramundi farm found one-third of power was required for pumping and recirculation, increasing the total energy budget, such that aeration was responsible for half (50%) of the total load.

Some facts about energy use in Queensland

• Coal fired electricity plants are the primary input into Queensland electricity supply networks, such that about one kg of carbon dioxide is produced for each kW-hr unit of electric energy consumption (pers. Com. Martin Gellender, EPA sustainable industries).

• Network electricity demand is minimal at night when air-conditioning loads disappear and businesses are closed, but steam turbines and generators must be kept on-line, ready for the next day's demand (reference Stanwell, Enertrade, and Energex websites).

• Economics of "supply-vs-demand" dictate that electricity prices are much cheaper at night, and this can be a great advantage to the Queensland aquaculture industry, since aeration is rarely needed during daylight (refer Queensland Electricity Act tariff structures).

Essentials of managing stocking density

Australian prawn farmers have increased intensified pond stocking well over 30 PL/m² (Peterson 1997 and Lobigieger 2003). Stocking density is the number of post larvae transfered from hatchery to pond, divided by the pond area. This initial investment will mature into a valuable harvest if infant stock are hatched as potent individuals, and then only if these animals are reared without stress in a healthy pond environment. The higher the stocking density, the greater the challenge to provided suitable feed and good quality water, which includes high dissolved oxygen (DO) and minimal ammonia. DO raised at night with mechanical aeration, and ammonia may be converted to algal biomass by water exchange to bioremediation ponds, or nitrified if pond substrate (i.e. sediment) is prevented from becoming anaerobic.

A remote farm location (such as Queensland's west coast of Carpentaria) may not be served by electric power and so the aquaculturalist may be forced to develop a semi-intensive production system. The key would be to reduce stocking densities, monitor DO and ammonia levels every day, and to partial harvests to hold production biomass under 2 tonnes per hectare. Semi-intensive (aeration-free) shrimp farming methods have proven to be profitable in Honduras and in Belize, but should not confused with the super intensive system developed at Belize Aquaculture Ltd. The semi-intensive system employed in the Honduras reduces the risk of disease, improves FCR, and lowers waste. Production could be increased by building more ponds.

Australian Prawn Farmers already know about managing stocking density, so I focus this manual on to topics which I have developed some expertise: ***Aeration*** and ***Circulation***

Effects of Mechanical Aerators

Postdoctoral Research at the JCU School of Engineering sought to quantify the effects of mechanical aerators so that they might be used more efficiently by the aquaculture industry. A number of thesis-year students from the Engineering and Aquaculture Departments worked with Dr Peterson to document aerator performance in the laboratory (Figure 2) and in service at working prawn and barramundi farms near Townville.

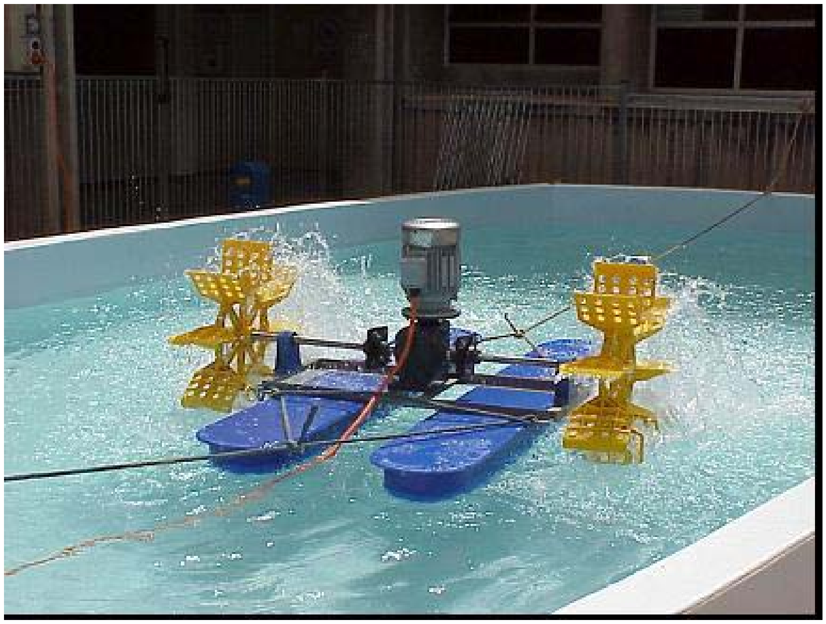


Figure 2: One of many aerators that were speed tested at JCU

The functionalities of mechanical aerators can be broadly separated in terms of ***Aeration*** (gas transfer) and ***Circulation*** (movement of water). Aeration is intended to provide DO for animals; minimise anerobic sediments; maximise aerobic bacteria; strip-out ammonia & CO_2. Circulation is intended to provide mixing of DO; provide destratification; maintain sediments in suspension; maintain aerobic state of sediments; and localise deposition.

The aeration effect of many different designs of mechanical aerators have been tested overseas at constant speed and at variable speeds at JCU, with standard methodologies.

Standard aerator efficiencies
(after Boyd and Ahmed 1987)

Aerator	($kg\ O_2$ / kWh)
paddle wheel	1.1 - 2.2 - 3.0
propeller-aspirator	1.3 - 1.6 - 1.8
vertical pump	0.7 - 1.4 - 1.8
pumped sprayer	0.9 - 1.3 - 1.9
diffused air system	0.7 - 0.9 - 1.2

.

Figure 3: Range of standard aeration results at full speed (photo of propeller-aspirator)

The standard aeration efficiency (SAE) of a machine can be determined in a controlled experiment, following methods published by the American Society of Civil Engineers (ASCE) which have been promoted by Professor Claude Boyd at World Aquaculture Society meetings. JCU established an equivalent facility, where we connected various aerators to a variable speed drive to establish the effect of speed control. We had expected a general increase in performance with speed, so it was a surprised to see a peak in the efficiency of paddlewheels at something less than the nominal operational speed of 100 rpm. This is illustrated in Figure 4 below.

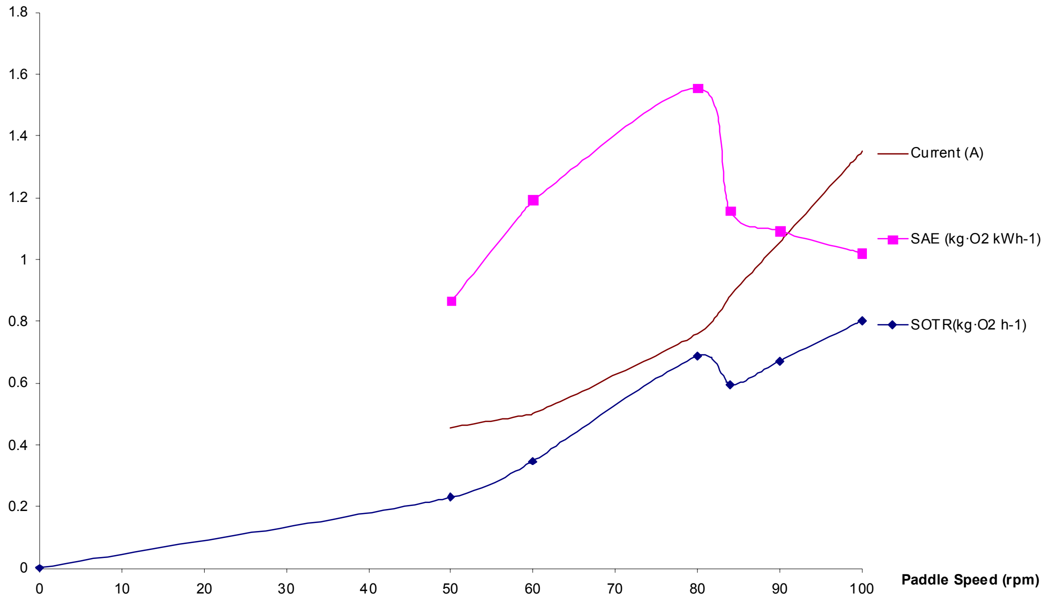


Figure 4: Paddlewheel aerator efficiency, power draw, and oxygenation rate vs speed

It has been established (Peterson and Walker 2002) that many paddlewheels ***backsplash*** at full speed, and that expensive mechanical energy is being wasted to list droplets high into the air, splashing all around the machine. Much of the oxygen-saturated droplets land at the inlet to the paddlewheel, effectively diluting the oxygen-starved ponds water, so that the process is partially short-circuited. It would be more efficient to run paddlewheels at a slightly slower speed with a VSD, or if manufacturers were to redesign them with a lower gear ratio, or to have about half the diameter paddlewheel (330 mm rather than 680 mm).

Figure 5: Backsplashing paddlewheel operating at full speed

Propeller-aspirator aerators do not improve performance at speeds less than their nominal full load speed, and so VSD adjustment of an entire pond power supply should increase to full 50 Hz (normal mains alternative current) at night to ensure that all aerators deliver oxygen into the pond. Ideally the paddlewheels and propeller-aspirators could be installed on separate electric circuits, but that is not the situation on existing prawn farms.

The most important point to remember is that daytime aeration by paddlewheels and propeller-aspirators is un-necessary (and counter productive) afternoon, because they effectively strip-out saturated oxygen. Mechanical aerators do not generate oxygen.

During the daylight some aerators may be useful to provide aeration, but others should be switched off of slowed down. The circulation function of aerators is idealized by Figure 6 below. The stratification of sunlight on the surface of an algal bloom has stability per m² $(S_t/A) = (1/12)\ (\rho_h - \rho_0)\ h^2$, where h is the pond depth. Typical stability of a stagnant pond would be 36 kJ per ha. This is easily overcome by a small input of wind or a fraction of a horsepower of mechanical circulation, perhaps 100 Watts per hectare.

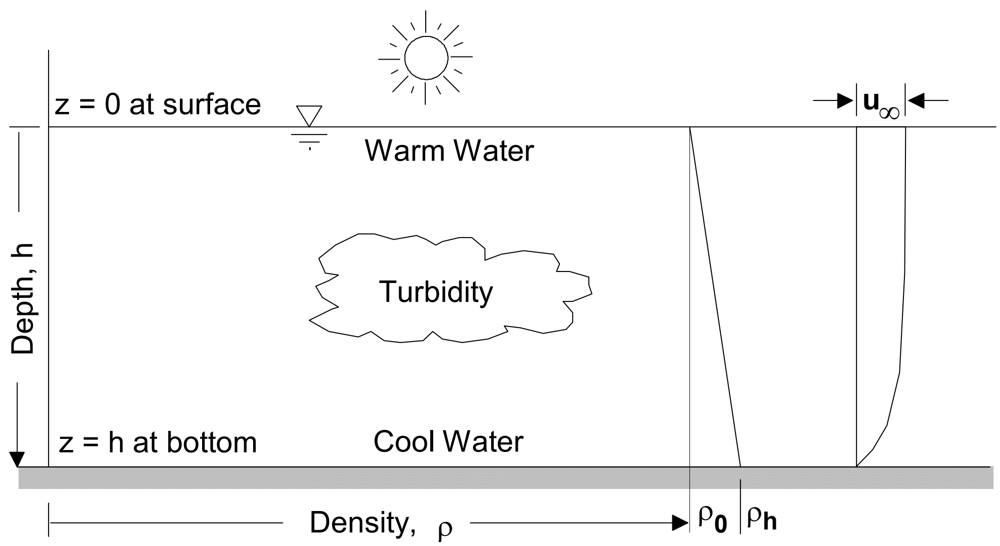


Figure 6: Circulation destratifies pond water column by creating a bulk water speed U_∞

Real ponds are more complicated, and so it is important to understand that the variety of aerators have differing effects, some of which are intended, and other side effects which may be adverse. Excessive circulation may be a consequence of increasing aeration to match intensive stocking and feeding. Circulation is excessive when the banks and bottom of a pond are scoured and erode. Excessive circulation can be catastrophic if pond banks “blows out” with the sudden lose of several tonnes of product. Excessive circulation gradually eats away at profits because roads must be re-constructed and surfaced with gravel, and because feed is “swept away”, to be covered by an overburden of mineral silts, and to decompose anaerobically, resulting in sulphur-reduction and high levels of ammonia. This chain reaction of adversity is summarised in Figure 7 below.

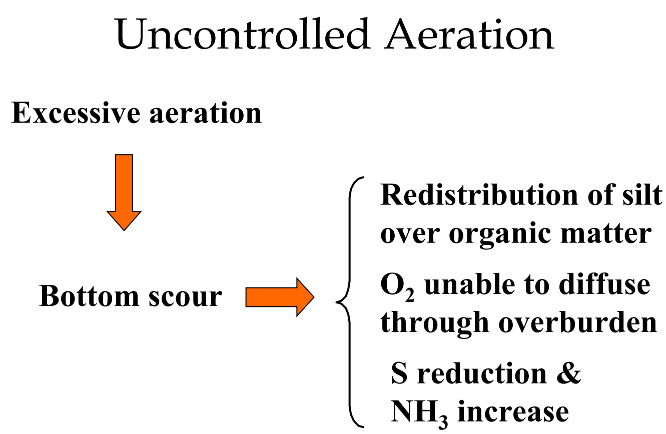


Figure 7: Uncontrolled aeration causes excessive circulation in a pond

Too much circulation is often provided on intensive prawn farms, especially during daylight when expensive feeds are spread around the perimeters of ponds. This is one of many reason why full speed aeration is "out of control". Because of the compounding factors, I reclassified the functionalities of mechanical aerators as outlined in Figure 8 below.

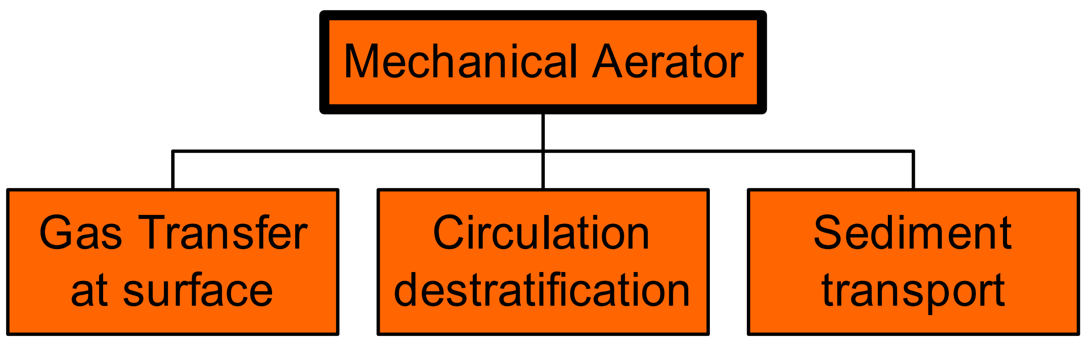


Figure 8: Aeration functions evaluated by Dr Peterson during his postdoc

The sediment transport function was not previously quantified, and so Dr Peterson applied the computer model developed in the course of his PhD thesis to evaluate alternative aeration deployment strategies, as published by Peterson, et al (2001). APFA members had been surveyed regarding the popular deployment strategies, and so it was found that Seafarm's ponds were a fair representative of "average" Australian prawn ponds, tending to be rectangular in rough proportion to an A4 sheet of paper. It should be noted that some farms have adopted almost perfectly square ponds (such as Gold Coast Marine), where Doug Pearson developed the "Doug diamond" to point corner paddlewheels to wash-out deadspots and concentrate sediments in the centre. Don Thompson's round ponds near AIMS do this even better, because there are no corners in a round pond.

Essentials of efficient aeration management

• Aeration demand patterns vary from one pond to the next, and so it is important to monitor and record the dissolved-oxygen level in each pond at dawn each day, and to add aerators only on an as-needs-basis.

• Aerators should be slowed or switched-off during daylight, when dissolved oxygen exceeds 100% sat.

• Daylight aeration is counter productive, by stripping supersaturated oxygen out of the pond, and by disturbing feed pellets which have been presented to the animals at considerable expense.

Essentials of circulation management

• The circulation effect of aerators can inadvertently cause bank erosion and disturb feed pellets, such that anaerobic sediments are formed – with the result of high ammonia levels in the water column. Prawn farmers may then attempt to strip the ammonia out of the pond by deploying additional aeration horsepower, but this only compounds the problem, as further erosion proceeds to bury organic matter under silt. The traditional response in the past was more water-exchange, but this has been restricted by government regulations, and so the prawn farmer is advised to add aeration only as required to hold dawn dissolved oxygen about 70% saturation. Restated: Aeration is a powerful tool, but don't use too much of a good thing!

• If high stocking densities require intensive aeration, then the problem of soil erosion can be mitigated by armouring banks with gravel, and covering feed areas of the pond bottom with sand. Seafarm's Cardwell site is blessed with stony-sandy soil which has a natural tendency to armour, and with proper aerator arrangement tends to centralize sediment. A typical Seafarm prawn growout pond is illustrated below in Figure 9.

Figure 9: Seafarm pond with armoured banks, sandy feed areas and central sediment

The preliminary results of this present report was presented at the Australian Prawn Farmers Association meeting in Darwin, where Seafarm R&D Manager Alistair Dick (2003) asked the APFA membership: "What are the optimal flow velocities for feeding?"

Then he presented findings by Rod McNeil (Meridian Technologies) reveals that flow velocities in intensive ponds (often between 35 and 120 mm/sec) may lead to higher (worse) FCR's. The recommendation is that flow velocities for optimal feeding efficiencies should be less than 15mm/sec, (McNeil, pers com.2003), as illustrated below in Figure 10.

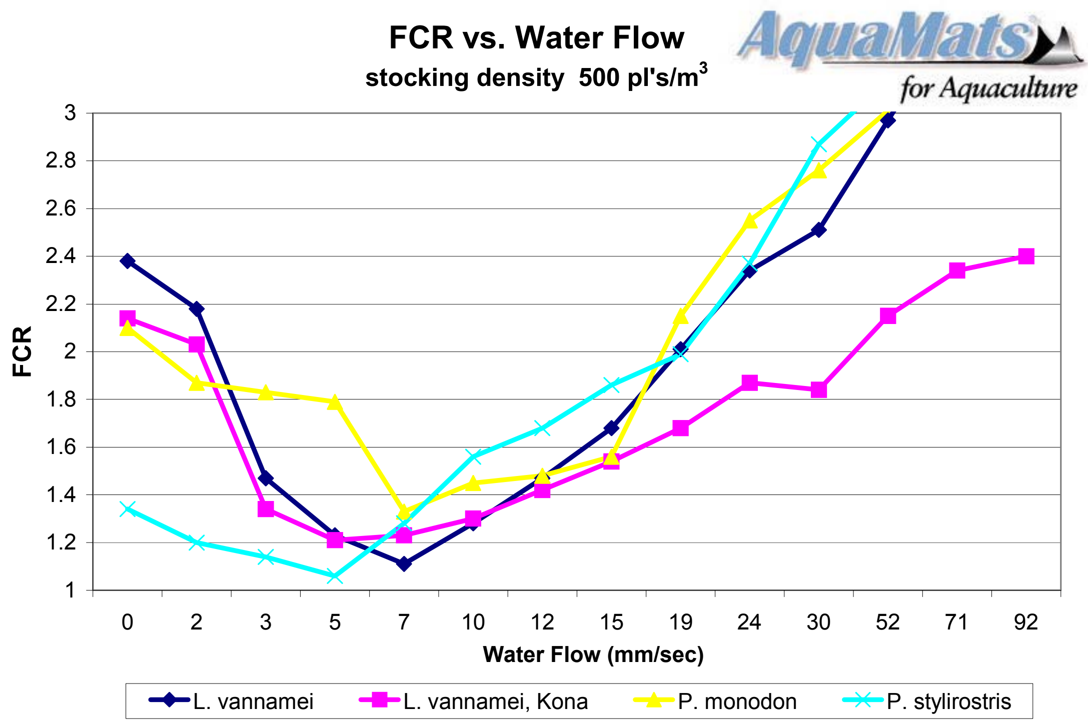


Figure 10: Effect of water velocity on FCR (ratio of feed input to harvest) – as presented by Alistair Dick at APFA 2003 meeting, with permission of Rod MacNeil (Meridian Tech.)

Aquamats, or other artificial reef structures, create drag that opposes pond circulation. So By reference to benthic shear stress theory (Peterson 1999), I argue that water velocity in a typical pond (without aquamats) should be double those recommended by MacNeil. Benthic shear stress analysis also predicts a relationship between FCR and water velocity in terms of the tractive-stress caused by aeration. My theory is illustrated in Figure 11, where perfect sorting of organic and mineral particles would be achieved if the tractive stress across the bottom were uniformly regulated at 0.01 N/m² (central horizontal line).

Figure 11's vertical axis is easily understandable in terms of the thrust of aerators: Connect a fish-weight scale to an aerators' downstream mooring line and measure tension as a kilogram-force (careful not to let it get away from you, as it can takeoff like a jet-ski). The total horizontal thrust of aerators should be divided by the pond area, to express kg per ha, and then divide that figure by 1000 kg per ton. At full speed paddlewheels and propeller-aspirator aerators generally produce 10 kg thrust per motor horsepower, so one horsepower machine in a one-ha pond will produce 10kg/hav= 0.01 tons/ha = 0.01 N/m².

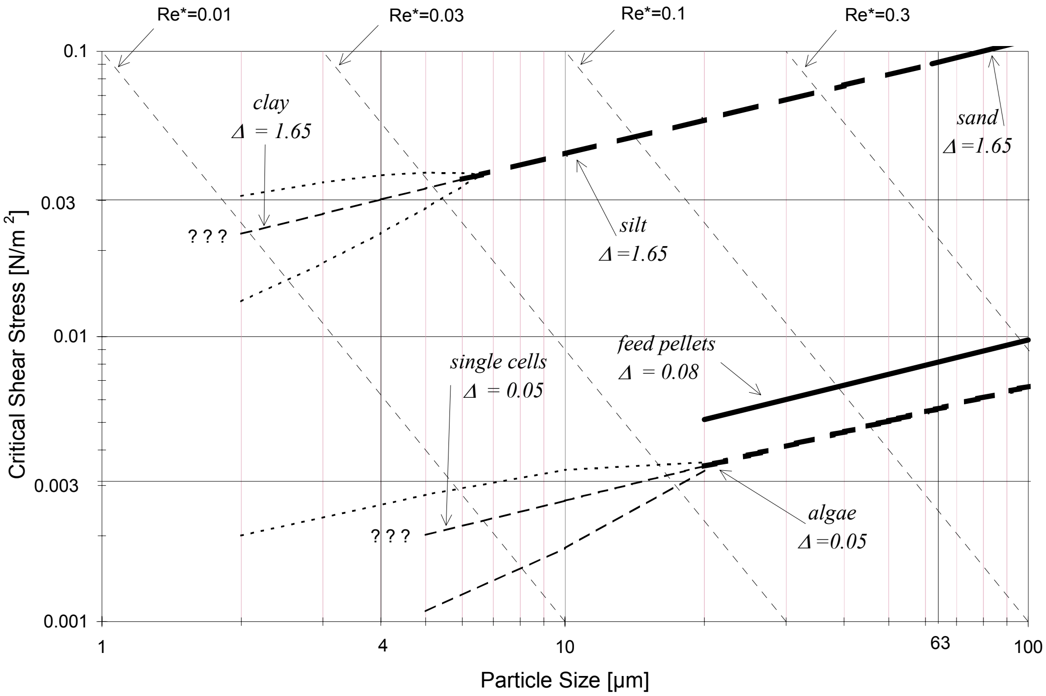


Figure 11: the relationship between circulation (expressed as benthic shear stress) and resuspension of feed and plankton (as organic matter of various sizes), and also soil and sediment (classified as mineral particle sizes “sand”, “silt”, and “clay”).

But the translation of bottom shear stress to bulk water velocity (observed at the surface) depends on pond characteristics such as shape and roughness. The conversion between surface water velocity and bottom shear stress usually involves the intermediate factor “shear velocity”, U* defined as the square root of shear stress divided by density of water (which is 1024 kg/m³ for sea water at 30°C). The ratio of surface speed to shear velocity is $U/U^* = 5.64 \times \log_{10} (12 \times R/ks)$, where R/k_s is the ratio of pond depth to roughness. As an extreme example of easy flow, the depth-to-roughness ratio maybe ten-thousand In a circular polypropylene tank, and there it often works-out that bulk velocity (m/s) equals the square-root of the driving stress (N/m²). At the other extreme is the situation of a mangrove swamp or a pond filled with Aquamats, in which case flow maybe one-quarter of the square-root of driving stress. Flow speed would be typically half the square-root of driving stress in a normal prawn ponds which has been properly rip-rapped with gravel.

I am arguing that it does not matter what surface speed you have, so long as the critical shear stress of 0.01 N/m² (central horizontal line in Figure 12) is not exceeded during the daylight hours, and even better that you drop stress down to the 0.003 N/m² line during times of feeding. The 0.01 N/m² is satisfied with just one horsepower (0.75 kW) two-wheel paddlewheel operating at full speed, or with the whole gang of aerators slowed down to half speed with a variable speed drive. Speed should be dropped further at feeding times. The forgoing is summarized in Table 1 below, with bold indicating the expected condition with speed control of 9kW aeration (4 two-horsepower machines) reduced to half speed.

Table 1: Management of the quality of your pond bottom by controlling power-input

		Density of water:		1024 kg/m³	Plastic tank	rip-rap	Aquamat
Aerator motor size		horizontal thrust		1 ha pond	40,000 = d/k_s	54 = d/k_s	2 = d/k_s
9.0 kW	12 hp	1197N	0.12 ton	0.12 N/m²	351 mm/s	174 mm/s	85 mm/s
7.5 kW	10 hp	998 N	0.10 ton	0.10 N/m²	320 mm/s	159 mm/s	78 mm/s
5.0 kW	7 hp	665 N	0.07 ton	0.07 N/m²	261 mm/s	129 mm/s	64 mm/s
2.2 kW	3 hp	293 N	0.03 ton	0.03 N/m²	173 mm/s	86 mm/s	42 mm/s
1.8 kW	2.4 hp	239 N	0.02 ton	0.024 N/m²	157 mm/s	78 mm/s	38 mm/s
1.5 kW	2 hp	200 N	0.02 ton	0.02 N/m²	143 mm/s	71 mm/s	35 mm/s
0.75 kW	**1 hp**	**100 N**	**0.01 ton**	**0.01 N/m²**	**101 mm/s**	**50 mm/s**	**25 mm/s**
0.38 kW	½ hp	50 N	0.005 ton	0.005 N/m²	72 mm/s	35 mm/s	17 mm/s
0.19 kW	¼ hp	25 N	0.003 ton	0.003 N/m²	51 mm/s	25 mm/s	12 mm/s

The forgoing is a theoretical extrapolation, and so you should triangulate with some real-world data, to get closer to the optimum for your circumstances. Please read the enclosed article by K I Berry evaluating the effect of an earlier speed control prototype at a number of ponds at Seafarm, but note that the results were inconclusive. So we are fortunate that Rod MacNeil established the FCRs for *P. monodon* with Aquamats at water velocities up to 15 mm/s, which equates to less than 0.005 N/m² shear stress. This is consistent with the theory of benthic shear stress (Peterson 1999) and so it is reasonable for prawn farmers to shut off or slowdown aeration during feeding, even if they do not subscribe to Aquamats.

Survey of Prawn Farmers' Energy use

I prepared this manual after hours, since I am working Monday to Friday in a non-aquaculture job (R&D on energy efficient air conditioning). So I spent Australia Day 26 January 2003 preparing a questionaire for each Queensland farming member of the Australian Prawn Farming Association (APFA) with a self-addressed postage paid envelope for reply to my mailbox at University of Queensland. At first I was very disappointed to receive no replies, but after informal telephone inquiries I came to understand that APFA members are over worked by paper work. So I decided to conduct an systematic telephone survey on Brisbane Show Day, Wednesday 13th August when I was free from my normal responsibilities and could ring up prawn farmers at their offices. This strategy worked because all prawn farms are located outside of Brisbane, and so they were at work and able to chat with me about their energy use. 25 prawn farmers were contacted, of which 12 could provide the number of ponds and approximate annual expenditure on electricity. The reporting prawn farmers had 360 ponds. The average expense was $4900 per pond (each of which averages one hectare area), and so it reasonable to estimate that something like $5 million may have been spent in the approximately 1000 hectares of prawn ponds presently operating in Australia. The standard deviation of my sample was $1600/pond, since some farmers use more or less power than others. For example, I found one who almost avoids the need to aerate with lower densities and partially harvesting.

The most interesting thing I learned was that many APFA members are now switching half of their aerators off during the day by manual means. This is a change from the previously established practice of leaving aerators on 24 hours per day. The following illustrates how manually switching off half of the aerators from 9 AM to 5 PM Monday to Friday can cut 10% of energy use, and 14% of expenses.

Manual switching-off half of your aerators from 9 AM to 5 PM Monday to Friday
Tariff 22 General Supply Time of Use. Low Rate electricity is available between 9pm and 7am, Monday to Friday and all weekend, otherwise charged at higher rate.
Low Rate = 6.2 Cents per kWh (before 7am and after 9pm M to F, and all weekend)
High Rate = 14.2 Cents per kWh (7am to 9pm, Monday to Friday) after higher rates for the first ratchet of consumption each month. Average overall about 10 ¢/kWh.

switching half off	50% reduction on 80% as aeration	otherwise the same pumps & other loads		
$1/kW-week	100%	10 hr	7 to 9 M-F	14.2 ¢/kWh
$3/kW-week	60%	40 hr	9 to 5 M-F	14.2 ¢/kWh
$3/kW-week	100%	20 hr	5 to 9 M-F	14.2 ¢/kWh
$3/kW-week	100%	50 hr	9 to 7 M-F	6.2 ¢/kWh
$1/kW-week	100%	16 hr	9 to 5 SS	6.2 ¢/kWh
$2/kW-week	100%	32 hr	5 to 9 SS	6.2 ¢/kWh
14% cost savings	10% energy saved	168 hr	per week	

Further savings maybe available to the largest prawn farms if you negotiate maximum demand tariffs, but that can be risky if you are not very careful with water supply pumps. For example, under Tariff 43, the penalty for once off use of an extra 110 kW pump to fill your pond costs an extra $7600. This penalty would recure every year you run the extra pump. I recommend you ask your power company for load profiles of your actual consumption profiles, and then we can see if you would save any money by switching tariff. Such tariff penalties are designed to minimize peak loads on the electricity network, but do not really do much to reduce greenhouse gas pollution. The purpose of the present manual is to explore energy efficiencies which save you money. And so I would like to conclude by promoting variable speed drives for aeration. Instead of switching off half of the aerators, I would prefer you keep them all on, but automatically controlled (7 days per week) to slow to half speed from 8 AM through 8 PM. A more uniform circulation rate would be provided, with better food conversion, but there would be an 80% reduction in power use during the High Tariff hours.

The reason that so much power is saved is that it is much more efficient to move many paddlewheels at half speed than to keep half of the paddlewheels going full speed. In the ventilation and air-conditioning industry we call this effect the fan-affinity laws. In the pumping industry we call this the pump affinity law. In either case, the power requirement of the turbo-machinery increases with the cube of the speed increase. Fans and pumps work entirely within one fluid phase, but paddlewheels are a bit different because they work at the air/water interface. I have published tests on the speed control effect of paddlewheels, and it turns out the power adjusts with something like the square of the speed control factor. Propeller-aspirators are more like the classic pump affinity cubic power curve, and so I have found that typical prawn ponds with both types of aerators will see about 80% power reduction at 50% speed.

So I simply advocate a 2 speed control scheme: full speed at night, and half speed during the day. This has been adjusted after on-farm trials, after we learned that speed switching ought to be delayed a couple of hours after sunrise and sunset. The reason being to give phytoplankton a chance to wake up in the morning, and to exploit super-saturation at sunset. This scheme has been trialed at Pacific Reef Aquaculture Ayr, Seafarm in Cardwell, and Rocky Point Prawn Farm in Woongoolba. Power savings assume Tariff 22:

speed control to half speed	80% reduction on 80% as aeration	otherwise the same pumps & other loads		
$1/kW-week	100%	10 hr	7 to 9 M-F	14.2 ¢/kWh
$3/kW-week	36%	60 hr	9 to 9 M-F	14.2 ¢/kWh
$3/kW-week	100%	50 hr	9 to 7 M-F	6.2 ¢/kWh
$1/kW-week	36%	24 hr	9 to 9 SS	6.2 ¢/kWh
$1/kW-week	100%	24 hr	9 to 9 SS	6.2 ¢/kWh
40% cost savings	32% energy saved	168 hr	per week	

In summary,
$700,000 could be collectively saved each year if all prawn farmers manually switched off half of their aerators from 9 AM to 5 PM, Monday to Friday. Alternatively, about two million dollars per year could be saved by Australian prawn farmers if they had variable speed drive controllers on all of their aerators. It has proven difficult to retrofit old farms with VSD control, and only those with coil-free contactors for switching individual machines have proven to be entirely trouble-free. So manual switching maybe the best alternative in many situations.

Manual switching requires staff training, and these machines should be switched back on before the end of work to test they are functioning, and if not then replacements must be deployed urgently before nightfall.

The automatic control alternative provided by VSD requires a capital investment of about $30000 for a 55 kW installation which would save $10000 per year. Consequently the simple payback would be about 3 years, and after that point the VSD would generate profits to the owner.

I made a submission to the Federal Government's Office of the Renewable Energy Regulator to make the case that VSD aeration control ought to be awarded renewable energy certificates (RECs), for trading "green power" on the market. I argue this on the basis that green phyto-plankton would generate oxygen during the daylight, and so offset load on the electricity network. Their response in not due until January 2004. RECs would make it much easier to payback the investment in VSD technology, but I think the APFA ought to make sure it benchmarks the existing situation as best as it can, so that it can make a case to maximize the value of RECs which might be awarded for aeration controls. Consequently I ask all members of APFA to send me copies of your power bills for the past few years (at least 3) so that we can establish a baseline to measure improving efficiencies. This would help existing prawn farms to raise the capital to renovate their aeration systems to be more energy efficient.

HOW TO INSTALL SPEED CONTROL IN YOUR PRAWN FARM

First step: Employ a professional electrical engineer or licensed electrician to establish the suitable place(s) in the prawn farm circuits with no more than 55kW load, and only feeding aerators, because a VSD is not suitable to power computers, mobile chargers or pumps.

Next step: Have your electrician replace all pond-side motor starters with coil-free overloads, because harmonics might burnout coil-type overloads.

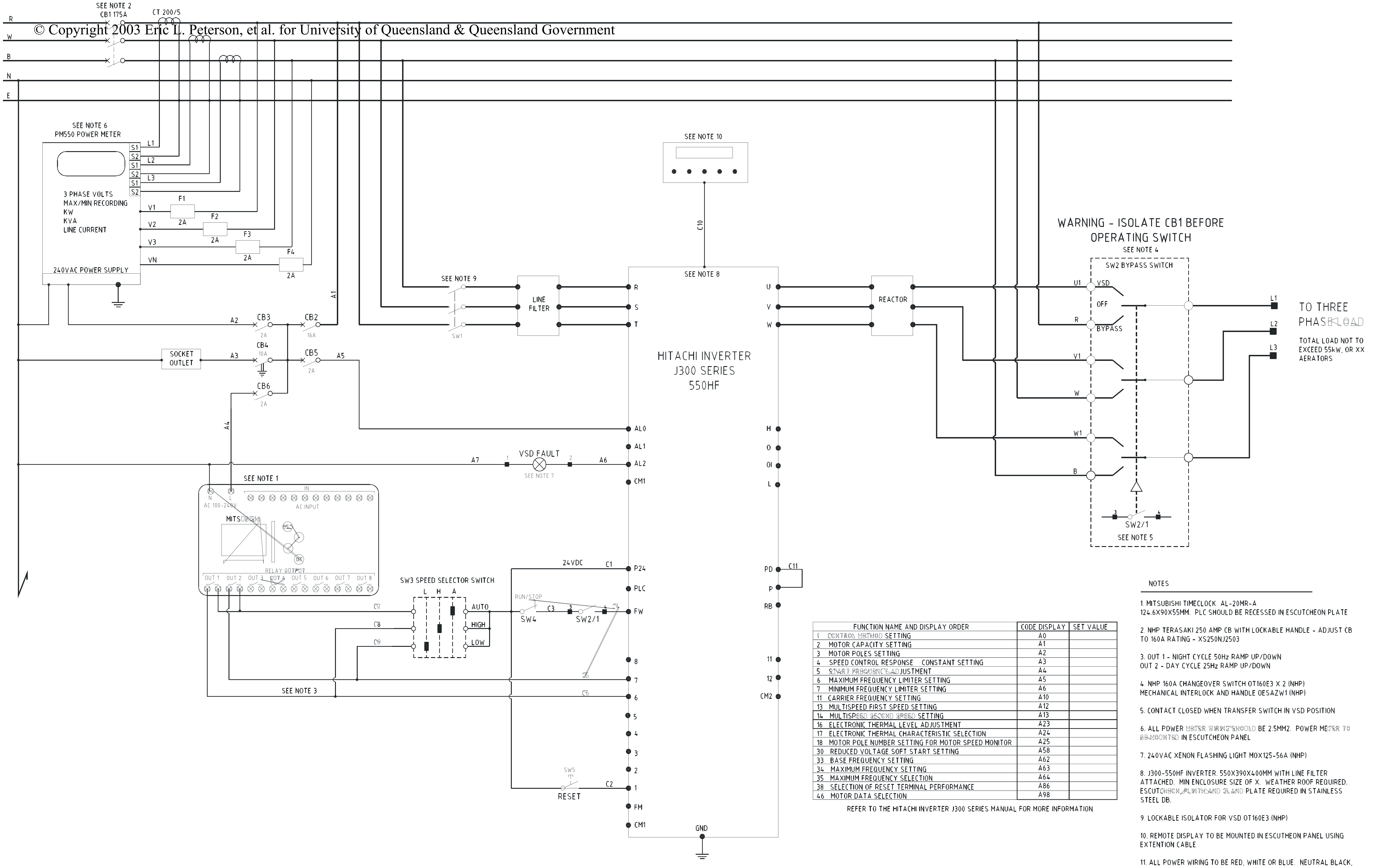
Then: Use the attached wiring diagram and specification to order the speed control unit from a Switchboard manufacturer. For example Minelec P/L in Townsville built the one pictured in Figure 12. Additionally I suggest that you specify thermostatically-controlled filtered forced ventilation of the enclosure whenever it rises more than 40 °C inside. At other times it ought to be closed to minimize exposure to salt-spray.

Figure 12: The latest VFD prototype at Seafarm, with bus shelter to protect from sun

After the switchboard manufacturer has confirmed the enclosure dimensions: Build a concrete foundation to suit the VSD enclosure plus a bus-shelter to prevent solar heating of the installation. The bus-shelter most have air vents at bottom and top, but be shaded all around and on the roof, all painted white to reflect UV radiation and reject IR heat. Ensure that there is 200 mm free space all around and over the VSD control unit.

Finally: Have your professional electrical engineer or licensed electrician program the PLC controller and commission the VSD unit in service.

On-going: Record kWhrs, speed (Hz), Hrs run, and pond productivity data to benchmark performance. Please keep a logbook in the enclosure, and advise the author of your findings if you are so inclined. If you have problems with heat build-up then add heat sink fins through the back wall of the enclosure or install an air-to-air heat exchanger or as illustrated in Figure 13.



FUNCTION NAME AND DISPLAY ORDER	CODE DISPLAY	SET VALUE
1 CONTROL METHOD SETTING	A0	
2 MOTOR CAPACITY SETTING	A1	
3 MOTOR POLES SETTING	A2	
4 SPEED CONTROL RESPONSE CONSTANT SETTING	A3	
5 START FREQUENCY ADJUSTMENT	A4	
6 MAXIMUM FREQUENCY LIMITER SETTING	A5	
7 MINIMUM FREQUENCY LIMITER SETTING	A6	
11 CARRIER FREQUENCY SETTING	A10	
13 MULTISPEED FIRST SPEED SETTING	A12	
14 MULTISPEED SECOND SPEED SETTING	A13	
16 ELECTRONIC THERMAL LEVEL ADJUSTMENT	A23	
17 ELECTRONIC THERMAL CHARACTERISTIC SELECTION	A24	
18 MOTOR POLE NUMBER SETTING FOR MOTOR SPEED MONITOR	A25	
30 REDUCED VOLTAGE SOFT START SETTING	A58	
33 BASE FREQUENCY SETTING	A62	
34 MAXIMUM FREQUENCY SETTING	A63	
35 MAXIMUM FREQUENCY SELECTION	A64	
38 SELECTION OF RESET TERMINAL PERFORMANCE	A86	
46 MOTOR DATA SELECTION	A98	

REFER TO THE HITACHI INVERTER J300 SERIES MANUAL FOR MORE INFORMATION

NOTES

1. MITSUBISHI TIMECLOCK AL-20MR-A
124.6X90X55MM. PLC SHOULD BE RECESSED IN ESCUTCHEON PLATE

2. NHP TERASAKI 250 AMP CB WITH LOCKABLE HANDLE - ADJUST CB TO 160A RATING - XS250NJ2503

3. OUT 1 - NIGHT CYCLE 50Hz RAMP UP/DOWN
OUT 2 - DAY CYCLE 25Hz RAMP UP/DOWN

4. NHP 160A CHANGEOVER SWITCH OT160E3 X 2 (NHP)
MECHANICAL INTERLOCK AND HANDLE OESAZW1 (NHP)

5. CONTACT CLOSED WHEN TRANSFER SWITCH IN VSD POSITION

6. ALL POWER METER WIRING SHOULD BE 2.5MM2. POWER METER TO BE MOUNTED IN ESCUTCHEON PANEL

7. 240VAC XENON FLASHING LIGHT MOX125-56A (NHP)

8. J300-550HF INVERTER. 550X390X400MM WITH LINE FILTER ATTACHED. MIN ENCLOSURE SIZE OF X. WEATHER ROOF REQUIRED. ESCUTCHEON, PLINTH AND GLAND PLATE REQUIRED IN STAINLESS STEEL DB.

9. LOCKABLE ISOLATOR FOR VSD OT160E3 (NHP)

10. REMOTE DISPLAY TO BE MOUNTED IN ESCUTHEON PANEL USING EXTENTION CABLE

11. ALL POWER WIRING TO BE RED, WHITE OR BLUE. NEUTRAL BLACK, EARTH GREEN/YELLOW, 240VAC WIRING GREY, VSD CONTROL WIRING (24VDC) ORANGE

REVISIONS				
No	BY	DATE	DESCRIPTION	PASS
A	LBC			

REFERENCES	
DWG No	DESCRIPTION

SCALES NTS

	PREPARED	CHECKED
DESIGN	JW	GJ
DRAFTING	LBC	JW

PASSED GARY JENSEN
DATE 030303

Maunsell
Maunsell Australia Pty Ltd
ABN 20 093 846 925
Consulting Engineers, Planners, Environmental Scientists & Project Managers

SEAFARM
VARIABLE SPEED DRIVE SCHEMATIC

CAD Ref: 80103103-1 | Status: AFC | A1 | 80103103-1 | A

Seafarm Variable Speed Drive Panel.
Maunsell Reference 80103103

Panel Construction Notes

Reference Drawings
80103103-1 Variable Speed Drive Schematic
80103103-2 Variable Speed Drive Labels

Free Issued Equipment:
Hitachi Inverter J 300 550HF
Line Filter and Reactor

Scope of Work
The VSD, line filter and reactor are to mounted into a panel and wired up as shown in Drawing 80103103-1. The builder shall supply all wiring and equipment except for free issued equipment. The builder shall organise delivery to the site at Seafarm, Bruce Highway Cardwell.

Panel Design
The VSD shall be mounted in a stainless steel panel, minimum dimensions 1800 mm high, 1200 mm wide and 600 mm deep. The panel shall be rated as IP55. A stainless steel gland plate shall be supplied on the bottom of the panel. A 300 mm high plinth shall be supplied with the panel to allow bottom entry of cables. The plinth can be either stainless steel or hot dipped galvanised steel. The panel doors shall be fitted with lockable doors and latching hinges to hold the doors in the open position.

The panel shall be fitted with an internal escutcheon plate. The plate shall be powder coated white. All switches, and operating handles, the Mitsubishi controller, power meter and VSD control panel shall be accessible on the escutcheon plate. The position of equipment on the escutcheon plate shall take into account the 300 mm high plinth, so a person of normal height can operate switches. The escutcheon plate shall be hinged to allow access to the equipment inside the panel. The plate shall have a lockable handle to prevent unauthorised access.

VSD Fault Light
The panel builder shall supply a VSD Fault Light as detailed on the drawing. The light will be mounted remote from the panel. The builder shall supply terminals to allow a cable to be terminated within the panel.

Labels
Drawing 80103103-2 details labels required for the panel. The Warning label shall be white on red background. All other labels shall be black on white. Labels shall be fixed to the escutcheon plate by stainless steel screws.

IMPORTANT ADDENDUM TO THE ABOVE IS SUGGESTED BY E. L. PETERSON:

Cooling Ventilation
The panel builder shall supply a filtered forced-air cooling system with thermostatic control. The cooling system shall be capable of preventing more than 5 °K rise above ambient, and be triggered when temperatures exceed 40 °C. The builder shall supply isolator terminated within the panel.

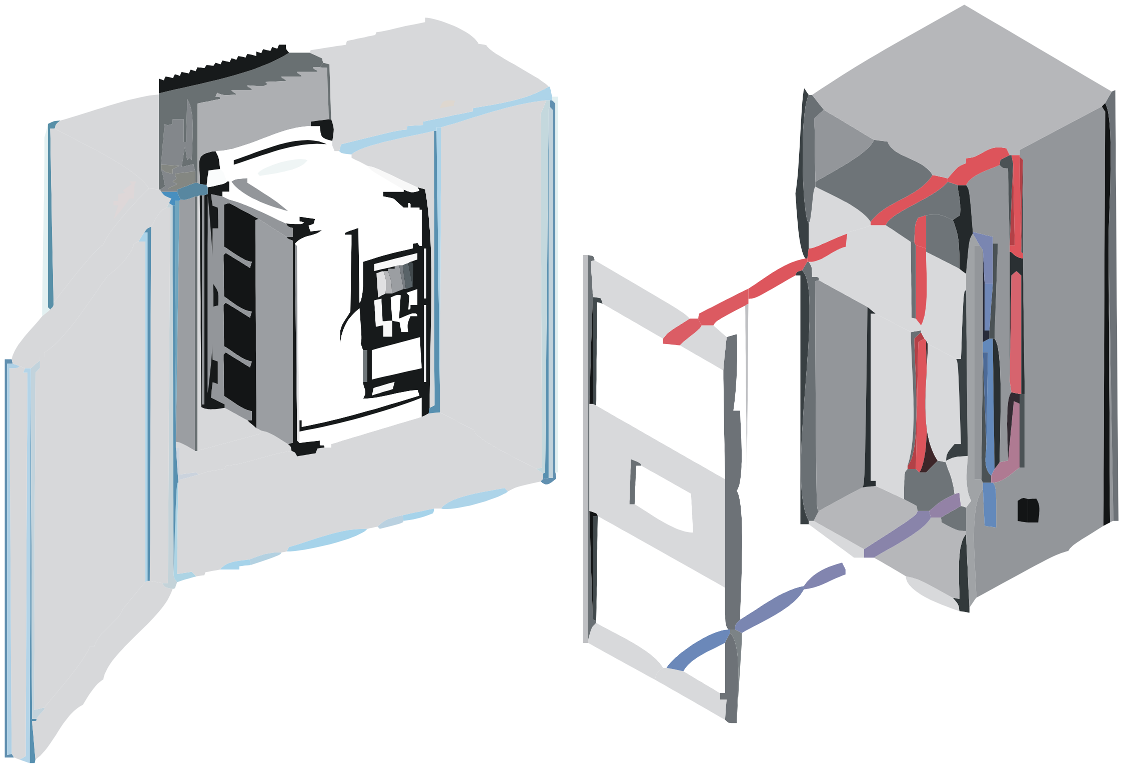


Figure 13: Heat sink through backplate –vs- Air to air heat exchanger forced cooling

Barramundi Cages and Red Claw Dams

I have consulted NQ Barramundi and Captain Red Claw with regard to their particular requirements for aeration. Both are off Allambie Lane, on the Upper Ross River Road, going west of James Cook Uni. Red Claw Association is represented by Captain Red Claw. They generally have many small dams which are aerated by polythene pipework supplied by a centrifugal blower. Airstones soon become clogged with biofouling, and so that industry has been using airlift pumps. Research conducted by JCU thesis student Margaret Walker found that these systems are very inefficient in terms of aeration and circulation. I suggest that a small surface-aerators would be more appropriate for Red Claw dams, such as "splash" marketed by Clayton Engineering. But these should be switched off during the day when phytoplankton make their contribution.

Barramundi pond management is different from prawn pond management for many reasons. Most dramatic difference is the free-ranging of prawns (or red claw) all over the bottom of their ponds, while particular grades of barramudi are confined within various floating cages, each moored within the enclosing pond. Aerators, of both the paddlewheel and propeller-aspirator type, are positioned to wash the high density cages with aerated water.
To assist the Barramundi Farmers Association in more efficient operations, a variable speed drive was provided at NQ Barramundi to drive nine ponds, with comparison to another nine as control. The farm staff were not happy to proceed with the trials because they were not aware of the dissolved oxygen levels in the ponds. So they were give a datalogging TPS meter and a copy of Pondman, which was setup by JCU thesis student Cordellia Lawson. Subsequently this farm was taken over by Good Fortune Bay

Aquaculture, who also acquired Seafood On-line. The barramundi farmers association would benefit from learning how GFBA has progressed with pond aeration controls to save energy. John Welch and I suggested to Trevor Anderson that they consider the lessons learned at Seafarm, and install coil-free isolators on pondside power boxes.

Sincerely,

Eric Peterson, PhD, RPEQ
Adjunct Senior Research Fellow
Centre for Marine Studies
University of Queensland
St Lucia 4072 Australia
E-mail: e.peterson@uq.edu.au

References

CE Boyd and T Ahmad (1987) Evaluation of aerators for channel catfish farming. Bulletin 584, Alabama Agricultural Experiment Station, Auburn, Alabama 52p.

CE Boyd (1998) Pond water aeration systems, Aquacultural Engineering 18: 9-40.

Alistair Dick (2003) "Commercialisation of VFD Technology to Prawn Farming" presentation to Australian Prawn Farming Association, Darwin.

R Lobegeiger (2003). Report to Farmers: Queensland Aquaculture Production Survey 2001 – 2002. Queensland Fisheries Service, Bribie Island Aquaculture Research Centre.

D O'Sullivan and J Dobson (2001) Status of Australian Aquaculture in 1999/2000. Austasia Aquaculture Trade Directory 2001, Turtle Press, Hobart, Tasmania, pages 3-19.

EL Peterson (1999). Benthic shear stress and sediment quality. Aquacultural Engineering 21: 85-111.

EL Peterson and JC Patterson (2000). Energy Auditing Aquaculture Facilities. In: 3rd Queensland Environmental Conference - Sustainable Environmental Solutions for Industry and Government, 25 & 26 May 2000, Brisbane, p177-181.

EL Peterson and MB Walker (2002) "Effect of speed on Taiwanese paddlewheel aeration" Aquacultural Engineering 26: 129-148

Maunsell (Australia) P/L (2003) "Seafarm Variable Speed Drive Panel". Drawing 80103103 and Panel Construction Notes

John Welsh, (2003) VSDs in Aquaculture. In: Peterson 2003 (editor) This Manual.

Peter Nesbitt (2000) Study of Variable Frequency Drives In Aquaculture. Thesis in partial fulfilment of the requirements for the degree of BE (electrical) James Cook University

Kenneth Ian Berry (2003) Study of the effect of variable speed drives on productivity in a North Queensland prawn farm. In: Peterson 2003 (editor) This Manual.

John Welsh, BE (Electrical), MIEAust

VSDs in Aquaculture

This paper discusses the use of Variable Speed Drives (VSDs) with particular emphasis on their use in aquaculture, and describes the operation of a drive and its main elements. The advantages and disadvantages of VSDs to typical aquaculture installations including capital cost, energy savings, operations and maintenance are compared, and the installation of VSDs in outdoor corrosive environments is addressed. Electrical safety associated with VSDs including protection of plant and personnel is also discussed, as well as the basic parameters and functions available through the use of VSDs. The conclusion provides a buyers guide to assist in the purchase of VSDs for aquaculture.

Variable speed drives are known by many names: VSD, VFD (variable frequency drive) and VVVFD (variable voltage variable frequency drive) are the most popular. In this paper, they are called VSDs. VSDs are electronic devices that are able to produce a variable frequency output from a fixed frequency input, normally 400 V AC 3 phase 50 Hz.

Induction motors are things of simplicity and ruggedness. There are few things to go wrong. However, they could only run at fixed speeds within a few percent. Typically for a 2 pole motor, it is 2950 rpm, 4 pole 1440 rpm, 6 pole 960 rpm and so on. If a variable speed was required, the only way was to use DC drives. DC drives were expensive and high maintenance with their brushes.

The rapid advances in power electronics have provided a cost effective method of varying the speed of an induction motor without compromising the simplicity and ruggedness. A normal induction motor can be connected to a VSD and the speed varied from standstill to twice rated speed with relatively good accuracy.

What makes up a VSD?

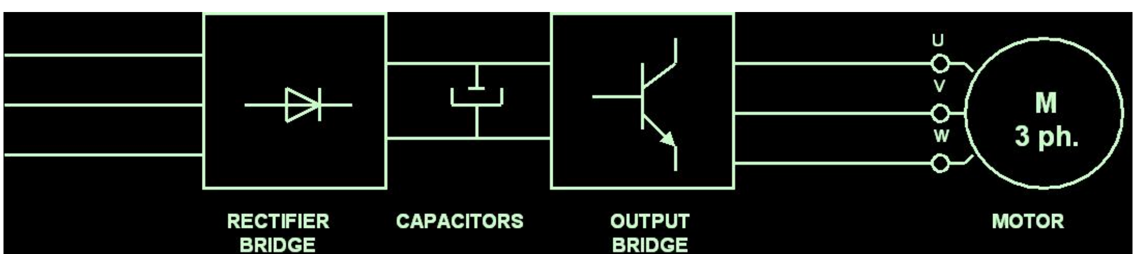


Figure 1 VSD Schematic

A VSD has three main parts:
- A rectifier bridge that converts AC power into DC
- Capacitors that filter the DC
- An output bridge that converts the DC into a variable frequency AC wave form.

The other significant part of the VSD is the controller that controls the operation of the whole unit.

The VSD functions by changing the AC voltage at the input into a DC voltage. The VSD then switches the DC to synthesise a pseudo sine wave at the output as shown in the pictures below.

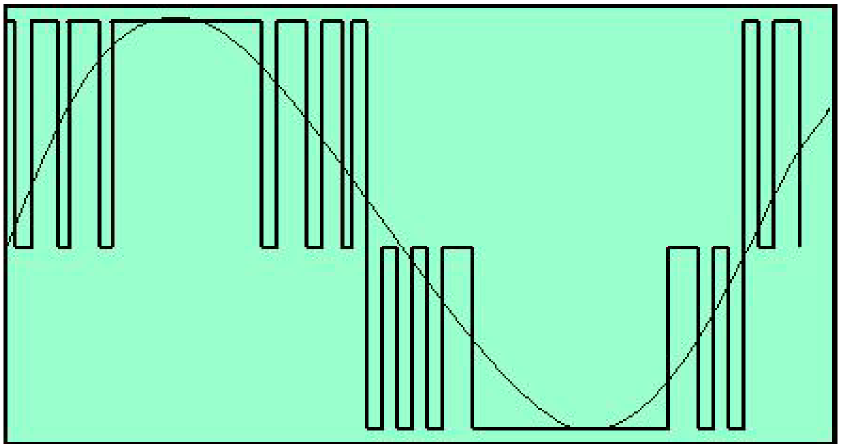


Figure 2 Pulse Width Modulated Waveform

The waveform is called pulse width modulated because the height of the pulse is constant and the width is changed to change the frequency. While the waveform looks little like a smooth sine wave, when it is connected to a motor the current waveform is reasonably close to a sine wave.

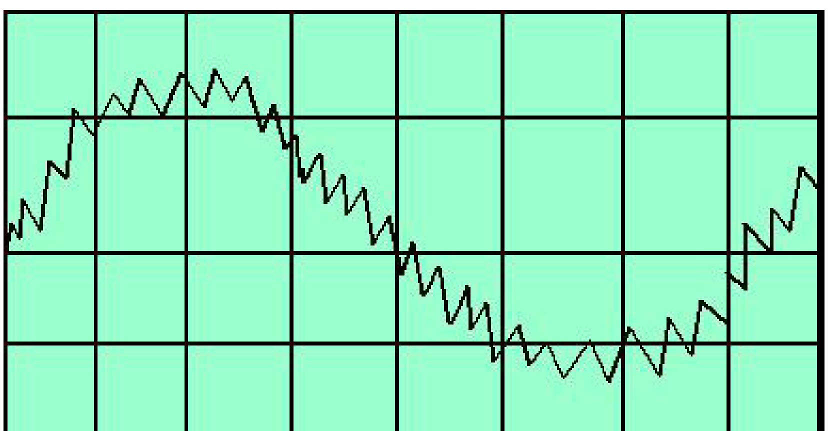


Figure 3 Motor Current Waveform

The VSD controller is able to switch the output bridge at high frequencies (from 2 kHz up to 20 kHz) and provide a smooth waveform to the motor. The high frequency is also responsible for the characteristic whistle from VSDs and VSD driven motors.

The VSD is able to vary the speed by varying the width of the pulses as shown below.

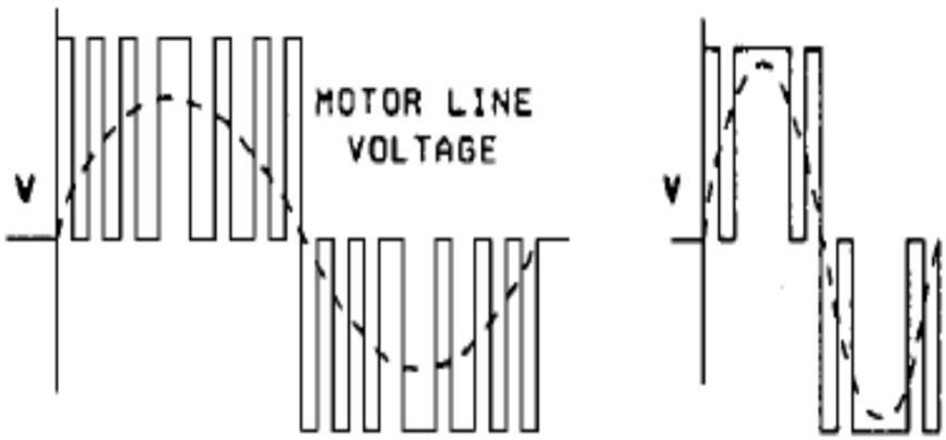


Figure 4 Speed Change by Pulse Width Change

VSD Control
VSDs need to be started and stopped and the speed changed to suit the operation. There are three ways of control:

1. Relay control. A relay contact closes to start the VSD and opens to stop it. Another series of relays operates to provide generally up to 8 preset speeds. This is the simplest and most straightforward method, but the speeds cannot be changed from the presets.
2. Analog control. A relay is still used to start the VSD, but a dial, the VSD controller or a PLC output, varies the speed. The speed can be varied anywhere within the minimum and maximum speeds by adjusting the control. This provides much more precise control over the speed. This is the typical way VSDs are controlled by PLCs and is used whenever a VSD is used to control a process.
3. Digital communications. A high level communications network is used to directly control the VSD. This has the advantage of maximum flexibility and simplest installation (only a single cable is needed), but requires sophisticated equipment to control it and highly skilled people to install and maintain it. This method is used on large industrial installations that may have hundreds of VSDs and where there are real cost savings and control benefits.

Typical Uses of VSDs
VSDs are used wherever motor speed needs to be changed in response to a variation in another area. Some typical uses in aquaculture are:

- Constant flow. VSDs can be used to provide a constant flow from a centripetal pump if either the inlet or discharge pressures varies (for example with tides). The motor is able to speed up on low tide and slow down on high tide to provide a constant flow.
- Pond aeration. For aerators the speed is controlled based on the level of dissolved oxygen in the water. The lower the DO, the faster the aerators are run.

- Level control. Similar to constant flow, a VSD is able to vary pump speed to maintain a constant level in a pond or tank, particularly if the intake or outtake is variable.
- Cooling and Heating. Again the VSD is able to vary the speed of a pump or fan to maintain a constant temperature when temperature may change due to external effects.

The greatest advantage is that a VSD can turn a normal induction motor into a variable speed unit without major cost, except for the cost of VSD. Now it is reasonably easy to vary the speed of a driven device like a pump in response to changes in the process. Previously, speed control was not an option, and so other methods had to be found to overcome process changes. These methods were generally energy inefficient or energy wasteful. Aerators were run continually at high speed even though this wasted energy during daylight hours. Pumps may use throttling or recirculation to limit flow during downtimes.

Pump affinity laws can demonstrate this. Generally pump power is related to the cube of the flow. If a pump flow is halved, the power drops not to a half, but to an eighth. So small changes in flow have a very significant effect on power. This power saving relates directly to the amount of electricity used and hence cost.

In the case of aerators, the power used in running at half speed is less than a quarter of that used at full speed. This related to a saving of ¾ of the energy used to run at full speed.

There are some other advantages of VSDs. VSDs slowly ramp speed up and down, which will minimise shock loadings on mechanical couplings, belts and chains. This will lead to longer life from the equipment.

VSDs can vary their speed over a defined range from zero to the maximum. In aerators, this means the speed can be varied from zero to maximum. If a reliable DO meter was available, the meter could drive the aerator directly, varying the speed to suit DO: high DO low speed, and vice versa. This would maximise aerator efficiency as the aerators automatically run at the speed required to achieve the needed DO.

VSDs can have advantages when powered by diesel generators. VSDs are able to minimise voltage dips on motor starting and so a smaller more efficient prime mover can be used to start the same number of motors. However, a larger generator may be needed because of harmonic effects.

Disadvantages of VSDs
VSDs do have down sides. They are expensive to buy. They also need protection from the elements. They produce electromagnetic interference that may affect other electronic equipment. They are complex pieces of equipment that may be beyond the skills of some electrical trades people to set up and maintain. Because they are electronic, their reliability is less than normal motor starters. Many times a PLC is needed to drive them, which also increases the complexity of the installation.

When not to use VSDs
VSDs are not always the answer. In simple applications, there is no need for VSDs. In many pumping applications, constant flow is not needed so a VSD adds no benefit. When

running at full speed, a straight DOL pump will be more efficient than a VSD. A VSD must convert power from AC to DC and then back to AC, which incurs losses.

Consideration should also be given to VSD installations on sites without suitably experienced staff. Like all electronic equipment, they can suffer from faults and experience may be needed to rectify these faults. VSDs may impact significantly on the capital cost of an electrical installation. While VSDs are generally able to provide a positive return in a reasonably short time, they are expensive.

Installations in Aquaculture

The general environment in aquaculture is characterised by high humidity, corrosive salt atmosphere and high ambient temperatures; all of these will make life difficult for a VSD. VSDs are generally mounted inside panels to provide protection from the elements and for electrical safety. The high humidity and salt mean that air cannot be freely vented through a VSD panel without accelerated corrosion. In aquaculture, panels must be adequately sealed to limit outside air ingress.

This in turn causes another problem. VSDs give off significant heat in operation, and this heat must be removed to prevent the VSD overheating. Normally, vent fans circulate cool outside air through the panel. However this is not acceptable in aquaculture. The panel can be cooling by using a size large enough to radiate the heat out without the need for fans. Alternatively cooling fins and fans can be mounted on the outside on the panel. These units can be easily replaced if they fail or are corroded. Needless to say the panel should be stainless steel.

Another simple method of cooling is to limit the effect of solar heating. A simple roof over a panel can lower the internal temperature significantly in summer.

When VSDs are used for aerators, the length of cabling from the VSD to the motors can cause voltage problems. An output filter (sometimes called a dv/dt filter) should be installed in the VSD panel to prevent damaging voltages occuring.

VSDs can cause electromagnetic interference if they are not properly installed. This may be a problem in populated areas and may cause interference to radio and TV signals. VSDs should always be installed with an input filter. In fact it is illegal to sell a VSD without an input filter. Special shielded cable may also be necessary to limit interference.

Given the impacts of a failure of a VSD, it may be necessary to hold spare units or to provide a bypass switch so that if a VSD fails, it can be bypassed or replaced without affecting production.

Electrical Safety

VSDs are not a particular safety risk, but they do have some characteristics that should be addressed. VSDs have capacitors that can hold charge even after the unit has been turned off. Most manufacturers recommend that personnel wait a few minutes after turning the VSD off before touching the terminals.

Some VSDs can be damaged if the output is switched when it is running. VSDs should be switched off at the input before motors are switched off or disconnected.

Special Facilities
Most VSD manufacturers offer vector control with their units. Vector control provides better low speed control and is useful on VSDs driving a single motor, especially if the motor has a high starting load. The other method is V/f (voltage over frequency) control. This simpler method can be used when driving multiple motors off a single VSD or when starting loads and speed accuracy are not important. This would generally be the case with aerators and pumping in aquaculture. So there is no need for vector control.

Typically there will be about 100 different parameters available to set on a VSD. In most cases there are only about 15 that matter significantly, and the large number of parameters can often confuse. Most manufacturers now offer the same facilities

Buyers Guide
There are at least 20 suppliers of VSDs in the Australian market, and all are offering slight variations to a standard. The choice of supplier can be confusing, but should not be based only on price. The suitability of any brand will depend on many things, including:

- Local support and spares. Support should include sales representatives who understand the operation of the units as well as holding spare units.
- Local electrical contractors experience. Your contractor may have had experience in setting up a particular brand that will save time in your installation.
- Weather proofing. Some VSDs are weatherproof and so will not need a panel and so can save installation costs.
- Understandable manual. Check the users manual for clarity. Some manufacturers have rough translations that are very difficult to understand. This will extend commissioning and fault finding as staff try to understand what exactly the manual is saying.
- Fast setup. Some manufacturers only require 10 or so parameters to set up and commission a VSD. This saves having to spend time and money reading through the whole manual and can speed up commissioning.
- Legible control panel. Most VSDs come with a control panel that shows operating parameters. Check that the panel can be read in direct sunlight. Check that the panel shows speed, amps, power and alarms in an understandable format, not in some code that requires you to consult the manual before you can understand it.
- Temperature derating. VSDs are generally derated if they operate at higher temperatures. When comparing VSDs make sure that they are rated at the same temperature. A 75 kW VSD might only be rated at 50 kW at 50 ºC.
- Make sure the price includes the input filter and if necessary an output filter.
- Software. Some manufacturers supply set up software as part of the drive. Remember that in most cases, the drive will provide reliable service once it is set up so the software is only used once.
- Digital communications. If you have a large complex installation, high level communications may be useful. However for simple installations, this is not needed.

Summary
VSDs have now come of age as a reliable, cost effective method of providing varying speed through simple induction motors. While not practical for all motor installations, they can provide significant energy savings over other methods of speed control or over direct on line motors. Generally aquaculture does not require sophistication in the application of VSDs, and so basic control and corresponding lower cost units are readily applicable.

summary of

Thesis submitted by **Peter Nesbitt** October 2000

Study of Variable Frequency Drives In Aquaculture

In partial fulfilment of the requirements for the degree of BE (electrical)
James Cook University of North Queensland

Supervised by John Nielsen and Eric Peterson

(Summary by Eric Peterson 2003)

This thesis assessed electrical problems associated with the use of single variable frequency drives (VFDs) to control the speed of several paddlewheel and propeller-aspirator aerators at Seafarm Stage I, Cardwell, and also at Pacific Reef Aquaculture, Ayr.

The Seafarm prototype was a Hitachi unit rated at 55kW constant torque and up to 75 kW at variable torque (this has been re-used in the latest Seafarm prototype at Stage II). While the Pacific Reef prototype was an Vacon unit rated at 11kW which severed only one-pond's set of aerators (this unit is now at Rocky Point Prawn Farm, Woongoolba).

The Seafarm installation served several ponds, and the consequent long lengths of cable amplified harmonics when running at low speed such that coil-type motor starters emitted annoying audible noise. And so the reduced speed was increased from 25Hz to 35Hz. (Note that Seafarm Stage 2B was consequently built with coil-free motor starters, so that VFD harmonics no longer upset the pond-side motor starters).

The thesis explains that electromagnetic problems associated with VFDs can be either radiated through the air or funnelled as harmonics through the cables. Computers and radios can be adversely effected by RFI. Airwaves at Seafarm were scanned between 150kHz and 1 GHz at varying distances from the VFD prototype, and RFI was significant only within a few meters, and was absolutely undetectable at 200 m. So it was decided to remove the controller out of the main enclosure at Seafarm to a satellite box 3 m away. This was not necessary for the smaller prototype at Pacific Reef Aquaculture.

In-cable harmonics was tested in a laboratory experiment at James Cook University with a single paddlewheel driven by a 2.2 kW Vacon VFD. No harmonics could be detected 30 meters down the line. Measurements could not be provided in the field, but spot checks with a spectrum analyser found no impact upstream at any of the other low voltage transformers at Seafarm. Harmonic problems at Seafarm had probably been suppressed by line reactor and filter that were built into the prototype, but more can be done if desired.

The thesis suggested that comprehensive retrofit of existing aquaculture facilities could be much more expensive than situations where VFDs are provided-for in a new development. Ideally new operations or expansions should include K-rated transformers (built to cope with harmonics), oversized transmission lines, and shielded cables. The thesis also suggested a compromise be established between the level of harmonics and radio frequency interference (RFI) when there are several hundred-meters separation between prawn farm and other industrial facilities or residential sub-divisions. Consequently faster rise-times should be allowed on prawn farm installations, to create smooth sine-waves and fewer harmonic problems.

Kenneth Ian Berry, B App Sci (Aquaculture, JCU)

Study of the effect of variable speed drives on productivity in a North Queensland prawn farm

ABSTRACT

Variable speed drives (VSDs) have the potential to be of great benefit to the prawn farming industry. The effect of such a unit was studied on a north Queensland Penaeid prawn farm. Several benefits are expected as a result of using VSDs in aquaculture pond aerators, some of which were examined in this study. Two ponds were studied in detail while the production data of six ponds were also studied. Although differences were found between the ponds, especially in the quality of the sediment, more ponds are needed for further study to get results of any significance. Particularly encouraging was the quality of the sediment in the VSD controlled pond.

INTRODUCTION

A VSD is a power control unit used for stepless speed control of three phase motors. Controlling the speed of aerator motors has the potential to save energy and protect machinery as well as have beneficial side-effects such as improved water and sediment quality, increased production with reduced FCRs and reduced erosion of pond banks. The purpose of this study was to examine the effect of a prototype VSD controller in a working prawn farm. The aeration motors were set up to work slower during daylight hours when such devices are only required for circulation and not aeration (due to high levels of photosynthesis in ponds producing oxygen to the point of saturation).

Two prawn ponds in north Queensland were examined with particular emphasis on;

- Sediment quality - determined by redox potential.
- Sediment distribution – mapped using surveying equipment, and
- Examination of production data – particularly yields and FCRs.

Differences between ponds whose aeration devices were equipped with and without VSD units were compared to look for differences that may have been due to the VSD. Sediment quality and distribution are believed to have influences on the production of a penaeid prawn pond and were studied accordingly. The size of the study was restricted by cost limitations and as such clear and concise conclusions were very hard to draw.

Materials and Methods

Two ponds were examined. Pond A had a VSD unit attached to the aeration devices while Pond F did not. The layout and redox potential of these two ponds was studied in this project. Production data from the same ponds over the last three years and other ponds for the same crop are compared.

The farm manager supplied FCR (food conversion ratio) and yield data under the condition that only comparative values be published. The uncontrolled pond, (Pond F), was taken as the standard pond and assigned relative yield and FCRs of 1. FCRs were calculated to show the amount of food in to produce a certain yield (FCR = kg food investment/kg prawn harvest) so lower values represent better value to the farm than higher values. Ideally yields would be high and FCRs low.

Redox Study

A rope, marked at ten-meter intervals, was tied between feed tray platforms on opposite banks. A kayak was used to paddle out to each point along the rope so that the pond sediment was not disturbed in any way. Five measurements were taken within one-meter of each point. Readings were made with a TPS-90-FLMV sensor, attached to a pole with a flat plate at the bottom to prevent it from penetrating more than 1 cm into the sediment.

The two ponds (A and F) were mapped after harvest using a Total Station Theodolite (TST). One person walked around the pond with the reflector, which was tracked by the operator of the TST. Points were taken around, the top of the bank, the water level, various sediment types and star-pickets which held aerators in place. Mapping included:

- Stone – marked an area from the water line to the bottom of the bank which was generally covered in stones of various sizes.
- Clean – marked out a clean sandy area between the stone line and an area of sludge.
- Sludge – marked out an area inside of which thick sludge was observed.

The depth of sludge was not measured and was only guessed. The same person selected all points for stone, clean and sludge to reduce irregularities. The sludge depth seemed to increase with distance to bank, but there were two areas where the increase was very rapid when compared to other areas. These were the initial areas near the clean sandy zone where feet would sink below the surface of the sludge and then further in towards the middle where legs would sink mid-way down the calves. These were the areas recorded (as sludge and thick sludge) by the TST.

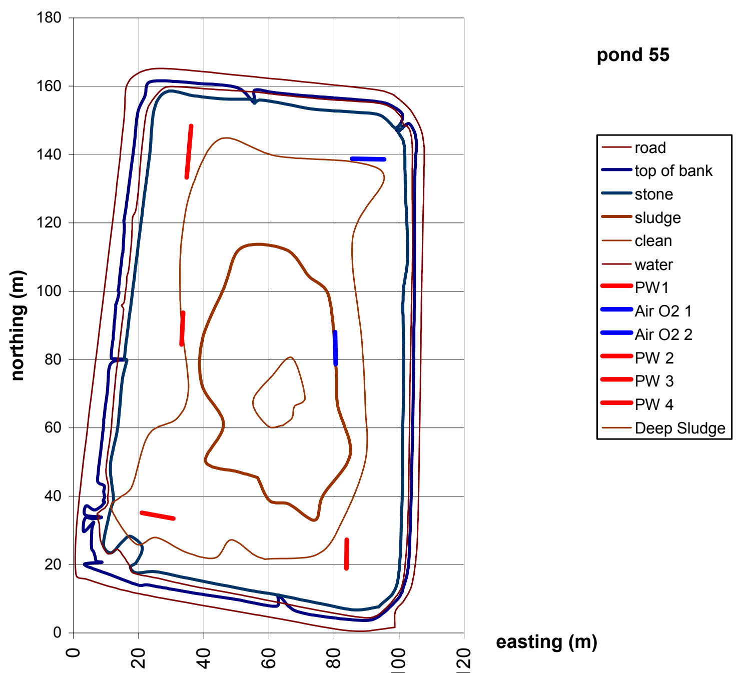


Figure 1: Pond A provided with variable speed control though-out one crop cycle. Aerator types, locations and orientations are noted in the legend.

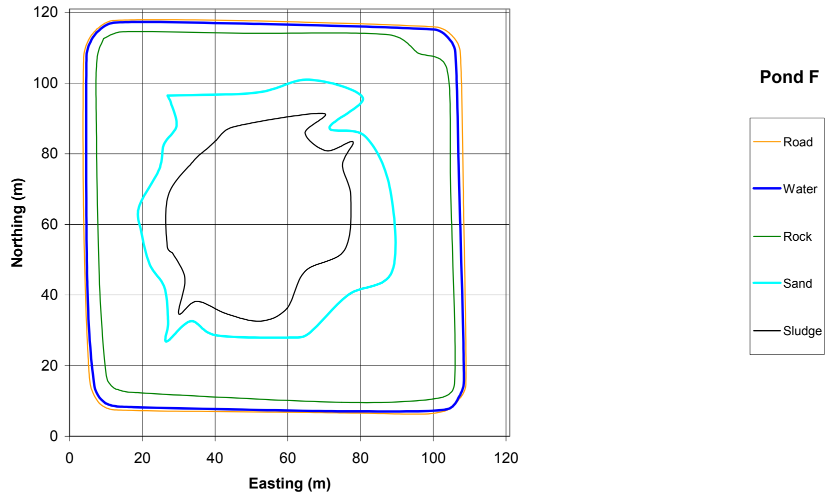


Figure 2: Pond F without variable speed control (aerator locations were not recorded).

RESULTS

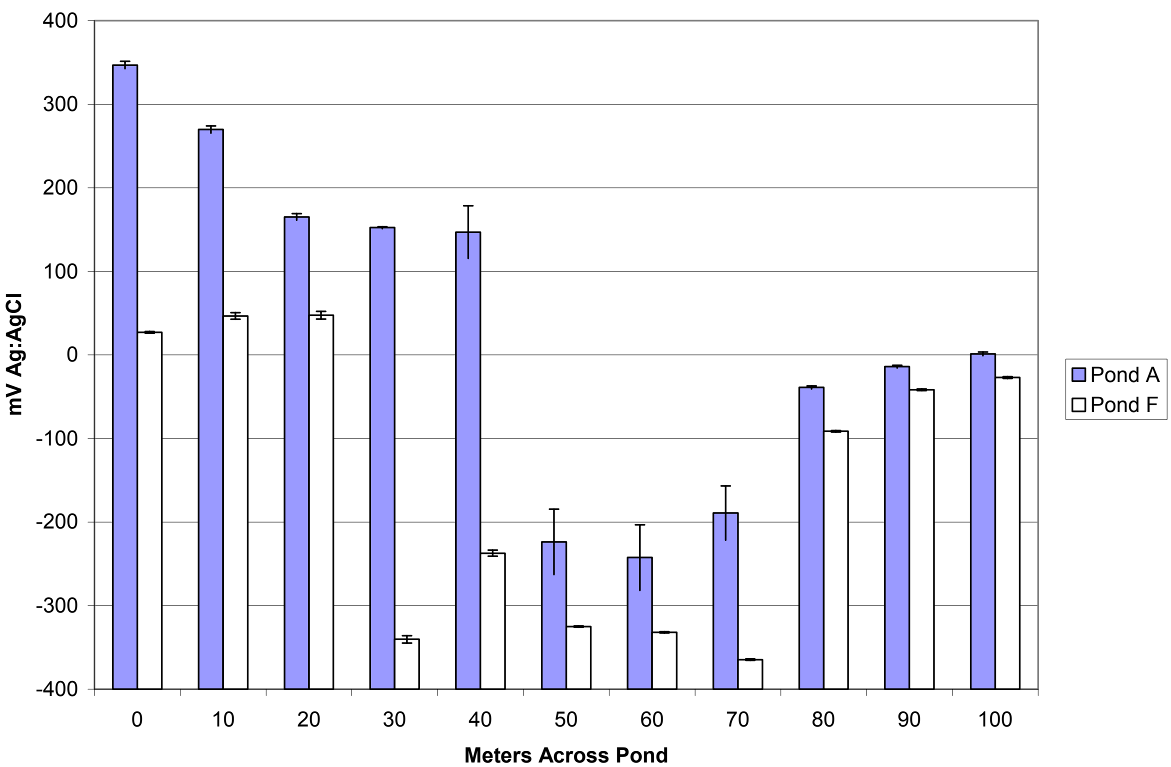


Fig. 3. Mean redox measurements comparing ponds A and F (error bars indictate+1SE). This figure presents redox measurements in cross section of ponds with and without speed control of aeration. Different patterns can be seen across each pond as well as between ponds. Pond A (with speed control) benefited from generally higher oxidation-reduction potential of sediment condition.

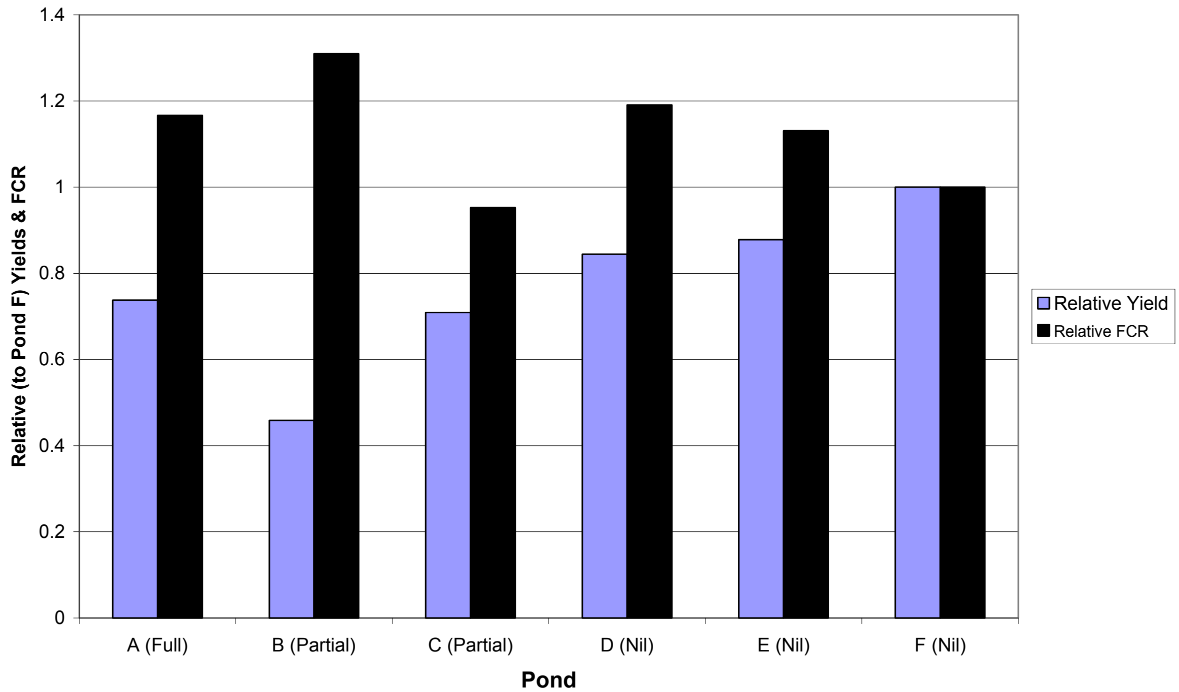


Figure 4: Relative Yield and FCR of six ponds (A, B, C, D, E and F) stocked in year 2000 with different levels of VSD control. Pond A was fully controlled by VSD, while Ponds B and C were partially controlled (about half of the aerators). Ponds D, E and F were not speed controlled.

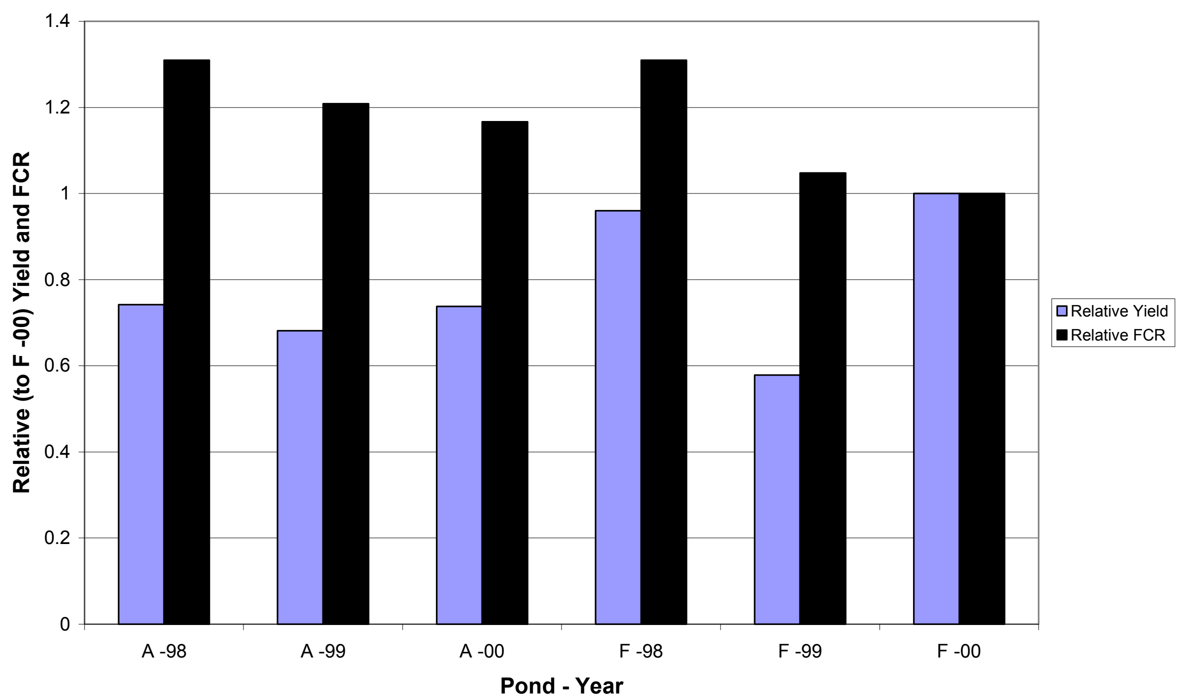


Figure 5: Relative yield and FCR of two ponds (A and F) over a 3-year period 1998-2000.

DISCUSSION

Positive oxidation-reduction potential indicates an aerobic substrate, while negative values indicate anaerobic conditions prevail in the sediment. This can give an indication as to the type of bacteria present in the sediment with sulfur reducing bacteria predominating anaerobic sediments. This type of bacteria produces hydrogen sulfide (H_2S).

Figure 3 showed that Pond A, equipped with a VSD, had higher redox potentials than Pond F which lacked the VSD. At distances of 30 and 40 meters from the bank, the difference was greatest, but it should be noted that 30 and 40 meters from the opposite bank (60 and 70m on the graph) the variation is not as great. In this instance, the use of a VSD seems to have had a positive effect on the quality of the sediment in the pond.

The sediment mapping of Ponds A and F showed certain similarities between the two ponds – they both shared the same basic layout with thick sludge in the center fading to somewhat cleaner perimeters. Pond F appears to have less area devoted to sludge but a greater portion of it is devoted to thick sludge when compared to pond A. This would suggest that the heavy circulation maintained throughout the day (no VSD) does a better job at depositing sediment in the center of the pond than lighter circulation for daylight periods when a VSD is installed to the aeration devices. Areas of thick sludge gave the most negative redox potentials. Pond A (VSD controlled) appeared to have a wider, thinner distribution of sediment displaying aerobic characteristics.

The larger clean area around the perimeter of Pond F may have contributed to the better results obtained by the farm in Pond F. This is due to this area being the area that food is deposited in during feeding sessions. It has been suggested that reduced circulation may improve feedings rates and conversion ratios as too much circulation may mix sediments and food pellets. This study shows that the opposite may be true, and that food being deposited is the clean perimeters is more important than whether sediment may fall on feed. Perhaps the amount of sediment that is disturbed during the feeding time is very minimal when compared to the accumulation of sediments over many days. This is an area that certainly warrants further examination as achieving improved FCRs, is an important aspect of increasing profit margins. Certainly the VSD slows circulation down during daylight hours when the feeds take place, but no improvements were noticed in Pond A when compared to Pond F for the same crop. It should also be noted that the FCRs have improved in both ponds over the past three years, but more so in pond F.

Pond C, with partial VSD control, had the best FCR while Pond B, also with partial VSD control of the aeration, had the worst FCR observed. These ponds had worst yields of the six studied ponds. With the exception of Pond C, decreased production was correlated with worse FCRs. There was a lot of variation in ponds, and to draw any meaningful conclusions, a few ponds should be looked at over a long timeframe or a lot of ponds together – neither of which was done in this study. After personal communications with the farm manager, it is believed that while VSDs may play a role in improving the future practices of prawn farming, other environmental factors - mostly the quality of the algal bloom within each pond - are still considered to be of more importance when it comes down to the bottom line of producing high yields with low FCRs.