Nutrients in Pond Based Aquaculture Discharge Water Used for Irrigation.

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Abstract

A survey was undertaken to measure the nutrient levels in closed (no discharge to waterways) freshwater pond based aquaculture facilities. Of particular interest were the nitrogen and phosphorus levels of the effluent (waste) waters used to irrigate agricultural crops or pastures.

Previously, the NSW Department of Primary Industries (NSW DPI) supplied State and local government agencies with estimated figures based on modeled nutrient levels. To provide these agencies with more accurate data, NSW DPI has recently surveyed 12 freshwater pond-based aquaculture facilities located on the Mid Coast and Murrumbidgee regions of NSW. The surveyed farms practiced extensive or intensive production strategies.

Total nitrogen (Oxidised & Kjeldahl) and phosphorus concentrations in the surveyed aquaculture facilities were measured in accordance with the methods described in the Standard Methods for the examination of Water & Wastewater, 2005 (Anon. 2005). The data was then compared to recommendations in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000 (ANZECC, 2000) and the NSW Environmental Guidelines, Use of Effluent by Irrigation Guidelines, 2004 (NSW Guideline). In addition, the potential irrigation of land using effluent water from aquaculture facilities was used to draw a comparison to the general application of agricultural fertilisers to an area of irrigated pasture or lucerne.

The results of the survey indicated that the average total nitrogen (2.9-4.5 mg L^{-1}) and total phosphorus (0.11-0.16 mg L^{-1}) concentrations of aquaculture waste waters were low and lower than the long-term trigger values for irrigation concentrations of these nutrients recommended by ANZECC 2000. The nitrogen and phosphorous concentration of the aquaculture waste waters could also be classified as “low” (i.e. nitrogen < 50mg L^{-1}, phosphorous < 10 mg L^{-1}) according to the NSW Guideline. The measured nutrient concentrations from surveyed farms also represents less than 25% of the nitrogen and less than 3% of the phosphorus application rates generally applied through agricultural fertilisation of irrigated pasture or lucerne in the Mid-Coast and Murrumbidgee Regions.

Based on the data collected during this survey, the nitrogen and phosphorus levels in the waste water from a pond based aquaculture farm used for irrigation is unlikely to cause a significant impact on the environment or its waterways.

Introduction

The enrichment of water bodies with nutrients, in particular nitrogen and phosphorus, has the potential to cause eutrophication of our natural waterways. This may cause abundant aquatic plant growth, including algae, and can change the aquatic biota and lead to the degradation of our waterways.

Freshwater aquaculture in NSW relies on both groundwater and surface water resources. It is therefore important that aquaculture does not pollute the waterways from which it sources its water or from which other users may source their water.

In NSW, freshwater aquaculture (except for approved flow through system) is not permitted to discharge its waste water (effluent) into natural waterways. Freshwater aquaculture enterprises are encouraged to reuse or recycle (i.e. secondary use) the water they use and any nutrients contained therein. The secondary uses may include;

- Reuse after particle and nutrient removal back through the aquaculture facility
- Irrigation of pastures, lucerne crops, trees and garden beds
- Utilisation within hydroponic systems
- Loss through evaporation

In addition it is a requirement under the NSW Land Based Sustainable Aquaculture Strategy (NSW LBSAS) that an aquaculture development should not be within flood prone areas to mitigate any accidental discharges of nutrients to waterways. The NSW LBSAS also requires that areas used for irrigation should have a riparian buffer of 50 metres.

To date NSW DPI has supplied State and local government Agencies with estimated figures of the nitrogen and phosphorus concentrations within aquaculture waters using modeled nutrient values (see appendix 1). However, some of the agencies have requested more detailed information, including "actual" or in-situ determination of the nutrient concentrations in aquaculture waters, particularly from waste water ponds or storage facilities. One of the major concerns held by different agencies is that stored effluent water from aquaculture may contain substantial quantities of nutrients that may leach into ground waters or be washed from areas irrigated by these waters during rainfall events.

Maximum growth rates of temperate fish species reared in pond-based aquaculture facilities in NSW generally occur over the summer and autumn periods of the year. At these times, feed inputs and biomass on respective aquaculture farms will also generally be at their highest which should result in the highest levels of nutrients within the aquaculture systems. In contrast, feed inputs and standing biomass is likely to be much lower during the winter months and therefore nutrient levels on farms are expected to be lower.

This study provides a "snapshot" of the average nutrient concentrations from 12 freshwater pond-based aquaculture farms and also compares these concentrations to ANZECC 2000, NSW Guidelines and agricultural fertiliser application rates for irrigated pastures and lucerne.

Materials and methods

The nutrient survey involved three Murrumbidgee region and nine Mid Coast region freshwater pond-based aquaculture farms. These farms are comprised of eight intensive and four extensive aquaculture farms. Water sampling was undertaken between the 11-13th April 2011 in the Mid Coast Region and on the 3rd May 2011 in the Murrumbidgee Region.

The surveyed farms included both intensive (i.e. use formulated feeds) and extensive (i.e. rely on natural pond productivity to feed the fish) farming strategies which were used to culture a range of species including Silver perch, yabbies (*Cherax* sp.) and Australian bass. The farms were selected to provide a general cross section of eastern and western drainage freshwater pond-based aquaculture facilities. The intensive farms primarily produced Silver perch, but some farms also produced other species such as yabbies and Australian bass. The extensive aquaculture farms cultured yabbies and fish species in fish-out ponds. Extensive systems have stocking rates that are considerably lower than that of intensive systems as they rely on the natural process within the culture ponds to provide the majority of feed for the animals.

Water samples were collected from the following point sources at each farm;

- inlet water which included river extraction, dams and bores
- culture water which included extensive and intensive culture activities
- waste water from holding dams.

The water quality of each of the sampled water sources on the respective farms was measured in-situ for pH, dissolved oxygen, temperature and salinity using a Horiba Water Quality Analyser Model U10.

A 1 litre sample was also taken from the respective water sources and placed within an insulated polystyrene box for transportation to the Hunter Water Laboratory (Hunter Water Australia (HWA), Warabrook, NSW) for analysis of suspended solids, total oxidised nitrogen, total kjeldahl nitrogen and total phosphorus in accordance with the methods described in the Standard Methods for the examination of Water & Wastewater, 2005 (Anon. 2005). The sum of total oxidised nitrogen and Kjeldahl nitrogen were added to provide a total nitrogen value for each water sample.

This study aimed to capture a "snapshot" of the average nutrient concentrations from 12 freshwater pond-based aquaculture farms. As such several important assumptions regarding the collection of the water samples have been made. These include;

- The water samples were taken towards the end of the main growing period for fish in pond-based aquaculture systems and it was assumed that the input of feed and conversely nutrients into the respective culture systems was at or near expected maximum levels.

- Waste water ponds varied in age, location within topography, soil types, liner types (soil or artificial liner), turbidity, the extent of submerged or emergent vegetation, depth (e.g. varied from 2cm to 200cm deep) and surrounding land management practices. This and other variability within and among waste water ponds and the impacts on biological processes were not considered separately in relation to the resultant nutrient levels.

- It was assumed that the prevailing weather conditions over the duration (4 days) of the sampling period or between the regions in which the aquaculture farms were located did not differentially effect nutrient concentration.

Regardless of the aforementioned assumptions it is important to note that each aquaculture farm and associated waste water pond or storage is managed in its own unique way with a range of different factors determining the final nutrient concentrations measured in the waste water. In consideration of this, the original data obtained from the on site measurement of water quality and the results from the analysis were categorised into extensive and intensive groups for each point source (i.e. inlet water, culture water or waste water). The average water quality and nutrient concentrations were compared with water from sewage treatment facility discharges licensed by Office of Environment and Heritage for irrigation use (data provided by HWA and Dubbo City Council).

Results

The range of average pH, dissolved oxygen (DO), temperature and salinity measured at the surveyed farms varied between 6.98-8.31 units, 6.44-9.56mg L^{-1}, 19.18-22.00°C and 0.00-0.24%, respectively (Table 1). The average concentration of nutrients measured from inlet water is presented in Figure 1. In all cases the average inlet concentrations of total phosphorous, total nitrogen, Kjeldahl nitrogen and oxidised nitrogen from the surveyed farms were lower than typical concentrations in sewage discharge.

Table 1: Averages of the values for each of the water types from 12 pond based aquaculture farms and the irrigation discharge waters from three sewage treatment works irrigated waters.

Water type	pH	DO (mg/L)	Temperature (°C)	Salinity ppt	Nitrogen Oxidised mg/L	Nitrogen Kjeldahl mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L	Suspended solids mg/L
Extensive/inlet	6.98	7.40	22.00	0.00	0.06	2.24	2.13	0.14	33.00
Intensive/inlet	7.18	6.44	19.18	0.2	0.23	1.49	1.72	0.08	7.75
Extensive /culture	7.40	8.40	21.25	0.00	0.07	2.31	2.38	0.11	23.50
Intensive/culture	7.98	8.35	19.22	0.3	0.80	7.56	8.29	0.47	139.09
Extensive/waste	7.95	9.03	20.75	0.00	0.03	2.60	2.86	0.11	42.00
Intensive/waste	8.31	9.56	19.45	0.8	0.56	3.96	4.52	0.16	28.63
Sewage discharge	8.667				1.087	2.600	3.687	3.530	3.667

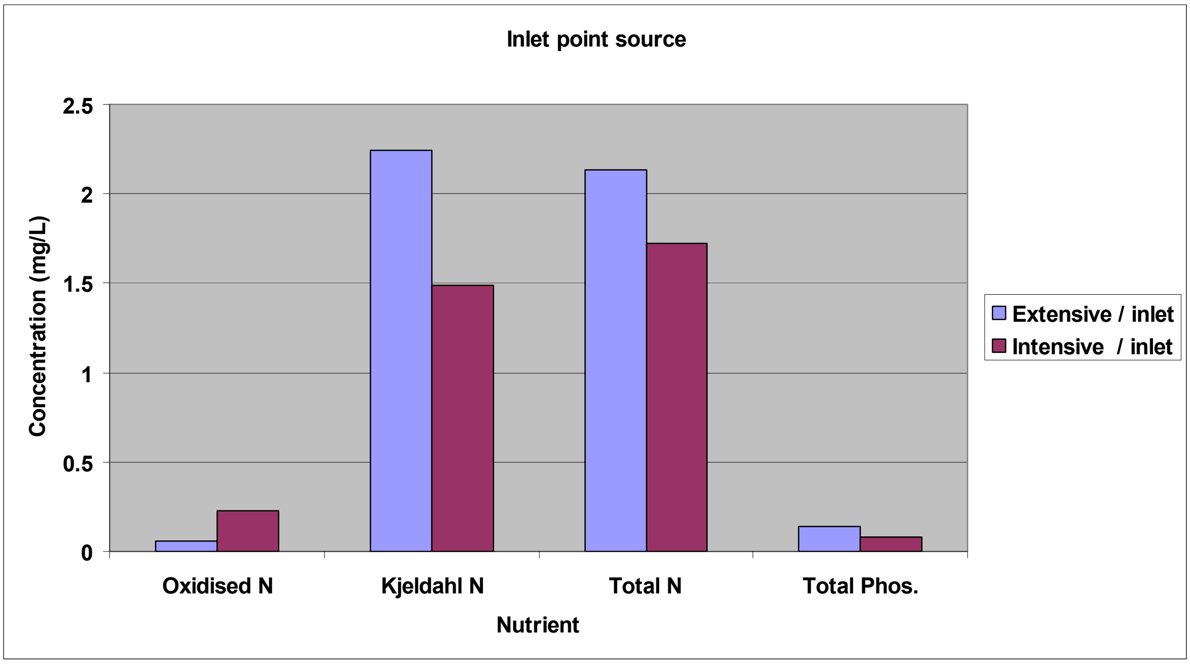

Figure 1. Average nutrient concentrations from inlet water from surveyed farms.

The average concentration of nutrients measured from culture water is presented in Figure 2. Not surprisingly the average concentration of total nitrogen from ponds was elevated compared to inlet waters and the concentration was elevated compared to sewage discharge. Compared to intensive systems, extensive systems tended to be lower in nitrogen and total phosphorous.

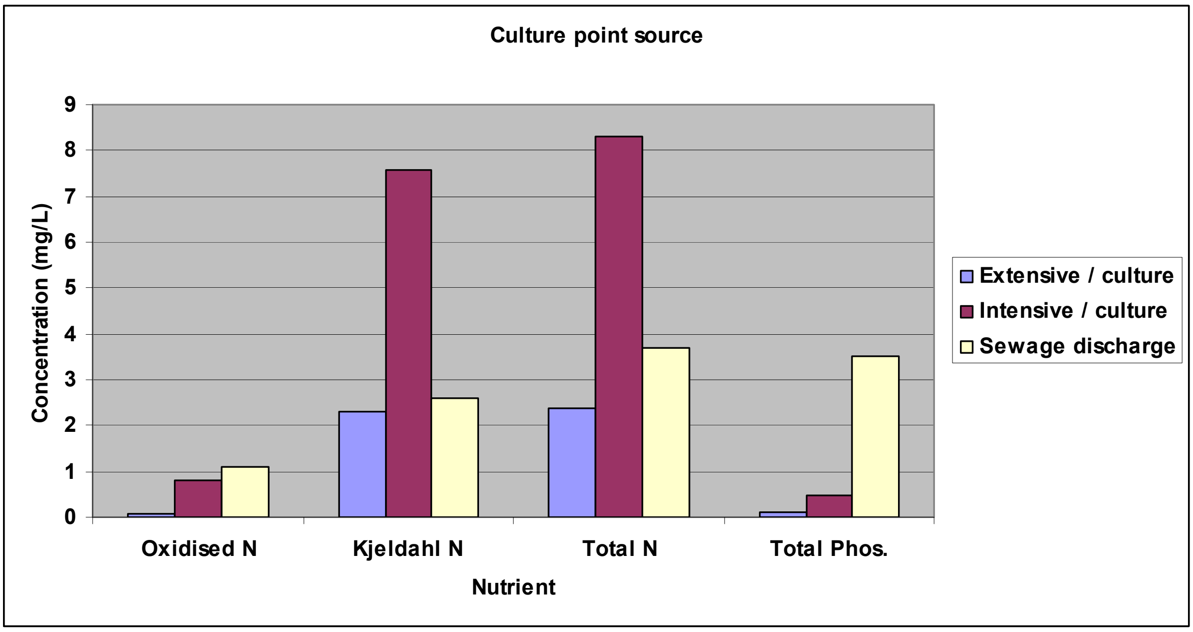

Figure 2. Average nutrient concentrations of culture water from surveyed farms

The average concentration of nutrients measured from waste water is presented in Figure 3. On average, the concentration of nitrogen declined in the waste water point sources measured at the time of this survey and tended to approach the concentration of nutrients (nitrogen and phosphorous) recorded in a typical sample of sewage discharge (Figure 3).

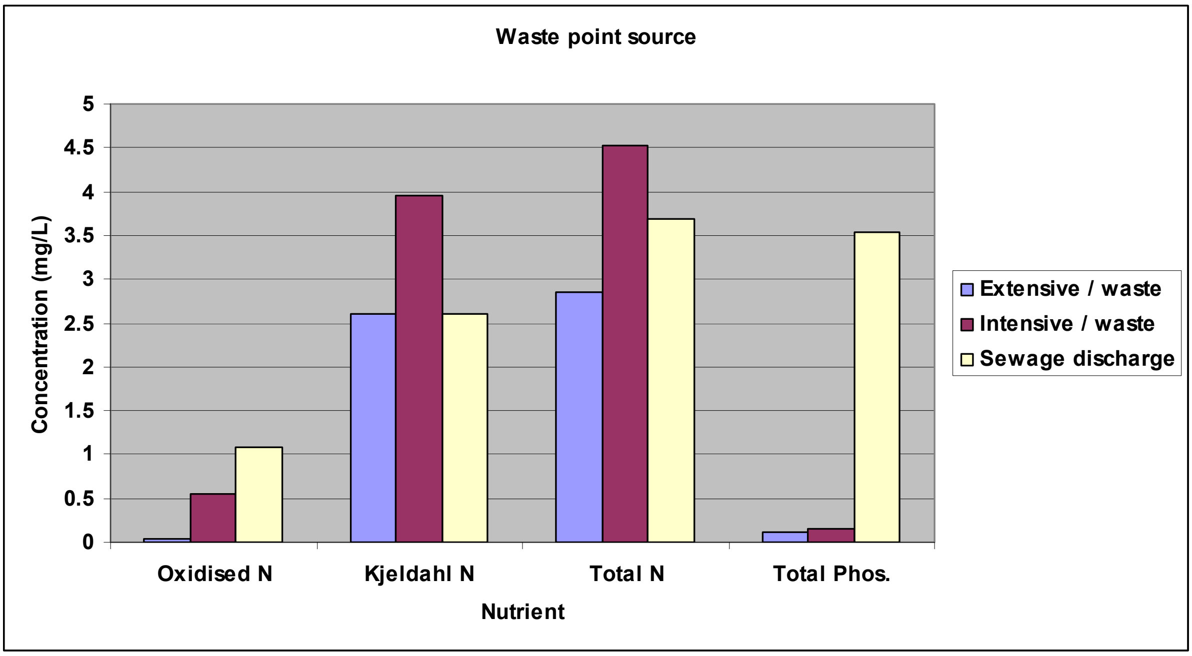

Figure 3. Average nutrient concentrations from waste water from surveyed farms

Little change was recorded between point source nitrogen or phosphorous concentrations in the extensive pond systems indicating these systems were relatively stable at the time of measurement (Table 1).

Discussion

The data provided by this survey provide a useful guide for NSW State and local government agencies in the assessment of new or existing aquaculture developments.

State and local government agencies generally use either the NSW Guideline or the ANZECC 2000 to assess the potential impact of the nutrients within waste waters. However, in discussions with personnel from a number of state and local government agencies there was a perception that the nutrient and suspended loading of aquaculture waste water discharge is as high as the potential loading of nutrients from sewage discharge or intensive animal industries such as dairies and piggeries. The following discussion uses the classification tables within the aforementioned documents to compare the nutrients measured in the on-farm aquaculture waters survey. In addition, this discussion makes comparisons between the nutrients measured in aquaculture waste water to the amount of nutrients released during the practice of fertiliser top dressing or irrigation of pastures on agricultural land.

Comparison of aquaculture waste waters against ANZECC 2000

Excessive quantities of nitrogen and phosphorous applied to irrigated areas can lead to leaching of these nutrients into groundwater and surface water and depending on which nutrient is limiting the stimulation of increased algal growth in surface waters.

ANZECC 2000 provides long-term trigger values (LTV) and short-term trigger values (STV) for nitrogen and phosphorus in irrigation water. These trigger values relate to the recommended nutrient concentration of the irrigated waters and the time span of the irrigation and are based on the significance of the nutrient, the cycling of the nutrient within the environment and the percentage of the nutrient generally removed in harvestable portions of the irrigated pasture or crop (ANZECC 2000). Long term trigger values allow for irrigation of low nutrient waters over a longer time span of up to 100 years while STV values allow for irrigation of high nutrient waters over a much shorter time span of up to 20 years.

These trigger values have been developed to minimise impacts to crop yields, farm infrastructure and off site. ANZECC (2000) recommends that the nitrogen and phosphorus concentrations in irrigation water should be less than their respective recommended trigger values.

Recommended ANZECC 2000 STV and LTV for nitrogen and phosphorous as well as the average total nitrogen and phosphorous values measured in the current survey as well as values for sewage discharge are presented in Table 2.

Table 2: Nitrogen and phosphorus concentrations in aquaculture waste waters, sewage irrigation water and the ANZEC 2000 STV & LTVs.

Water source	Total nitrogen (mg/L)	Total phosphorus (mg/L)
Extensive/waste	2.86	0.11
Intensive/waste	4.52	0.16
Sewage discharge	3.69	3.530
ANZECC 2000 LTV	5	0.05
ANZECC 2000 STV	25 - 125	0.8 - 12

Based on the data in this table the concentration of total nitrogen and phosphorous measured in the waste water at either the extensive or intensive farms is well below the recommended STV values cited for nitrogen and phosphorous by ANZECC 2000. In addition, the measured farm values for total nitrogen are below or similar to the recommended LTV for nitrogen (Table 2). Phosphorous concentration of extensive and intensive waste aquaculture water tended to be slightly higher than recommended STV but within the range recommended for LTV in irrigated waters. The phosphorous concentration of sewage discharge is almost 22 times higher than the phosphorous concentration recorded in the waste water from surveyed aquaculture farms. However, it should be noted that the average level of phosphorus in the discharge irrigation water from the three approved sewage treatment plants was about 70 times the ANZECC 2000 recommended LTV.

This data supports the premise that the waste waters from an extensive or intensive pond based aquaculture farm similar to those surveyed in this study are suitable for long term (up to 100 years) irrigation applications under the ANZECC 2000 guidelines.

Comparison of aquaculture waste waters against NSW guideline

The NSW Guideline provides guidance on the best management practices relating to the management of effluent for irrigation. These guidelines state that water from municipal sewage treatment plants is likely to be low strength, whereas untreated effluent from intensive animal industries is likely to be medium to high strength. Values for low, medium and high strength concentrations are described in Table 3.

Table 3 provides a comparison of the average nitrogen and phosphorus concentrations in the surveyed freshwater ponds to the recommended values cited in the NSW Guideline.

The nitrogen levels measured in the waste water of extensive and intensive freshwater ponds represents only 5.7% and 9.0% respectively of the upper value for a low classification level under the NSW Guideline. Phosphorus levels in the extensive and intensive freshwater pond based aquaculture waste water represented only 1.1% and 1.6% respectively of the upper value for a low classification level under the NSW Guideline.

Table 3: NSW Guideline classification levels and aquaculture waste water nitrogen and phosphorous concentrations.

Nutrient	Low (mg/L)	Medium (mg/L)	High (mg/L)	Extensive Aquaculture waste water (mg/L)	Intensive Aquaculture waste water (mg/L)
Nitrogen	<50	50 - 100	>100	2.86	4.52
Phosphorus	<10	10 - 20	>20	0.11	0.16

These comparisons indicate that the total concentration of nitrogen and phosphorous in waste water from typical freshwater aquaculture ponds is well below the lowest values cited in the NSW Guidelines and is much lower than the medium or high strength concentrations of nitrogen and phosphorous normally associated with the waste waters from intensive animal industries.

Comparison of aquaculture waste waters with agricultural pasture fertiliser applications

The quantity of water and fertiliser used on an area of pasture or lucerne will vary depending on the particular management regimes being employed and the local weather, soil type, topography and irrigation regimes being employed at each site. For example Griffiths et al. (2007) recommend an application rate of about 20kg N ha^{-1} and 20kg P ha^{-1} at the time of establishing a pasture (seeding). Once the pasture has established an annual fertiliser, top dressing of about 150-200kg N ha^{-1} and 50kg P ha^{-1} is recommended.

To undertake a comparison between the potential nutrient levels applied by irrigating with aquaculture waste water and the level of nutrients applied as agricultural fertiliser it is first necessary to calculate the irrigation requirements for the specific site, paddock or region. Once the irrigation requirements are known then the quantity of nutrients applied via the irrigated aquaculture waste waters can be calculated. Documents prepared for the NSW Water Use Efficiency Advisory Unit indicate the theoretical irrigation requirements for pasture and lucerne in the NSW Mid-Coast Region (including Hunter & Central Coast) range from 4.5-7.5 ML ha^{-1}. while in the Murrumbidgee Region requirements range from 6-8 ML ha^{-1} (Hope 2003, Hope and Wright 2003). These theoretical irrigation volumes have been used to calculate the potential nitrogen and phosphorus loads which may be applied to an area of one hectare for both intensive and extensive aquaculture farm types.

Table 4 outlines the respective quantity of nutrients that may be applied by using aquaculture waste waters, sewage works discharge waters and waters with nutrient levels as outlined in the ANZECC LTV & STV. The data indicates that the application of freshwater pond based aquaculture waste waters would represent less than 25% of the nitrogen and less than 3% of the phosphorus application rates generally applied through agricultural top dressing fertilisation practices.

It should also be noted that where used, the application of the nitrogen and phosphorus via the aquaculture waste waters is as a solution which ensures the nutrients are readily available for plant uptake. Applications are also undertaken over numerous events and not in 1-3 large broadcast applications of fertilisers as occur with agricultural practices. Therefore, the application of the nutrients via aquaculture waste waters is less likely to cause leaching and runoff of large quantity of nutrients in storm events.

Conclusion

This survey of the nitrogen and phosphorus concentrations within pond based aquaculture waste water indicated that the average nutrient values of the aquaculture waters surveyed were acceptable in relation to the long-term trigger (LTV) values in irrigation water under ANZECC 2000. The aquaculture waste water nutrient levels would also be classified as low under the NSW Guideline and represents less than 25% of the nitrogen and less than 3% of the phosphorus application rates generally applied through agricultural fertilisation of irrigated pasture or lucerne in the Mid-Coast and Murrumbidgee Regions.

Table 4 Comparison of N & P loads from aquaculture waste waters, agricultural fertiliser rates & waters applied at ANZECC 2000 STV & LTV (Kg/Ha.)

Location/comparison	Waste water source	N lower	N upper	P lower	P upper
Hunter & Central Coast (H&CC)	Extensive Aquaculture	12.87	21.45	0.50	0.83
Hunter & Central Coast	Intensive Aquaculture	20.34	33.9	0.72	1.20
Murrumbidgee Region	Extensive Aquaculture	17.16	22.88	0.66	0.88
Murrumbidgee Region	Intensive Aquaculture	27.12	36.16	0.96	1.28
Hunter & Central Coast	Sewage Discharge	16.59	27.65	15.89	26.48
Murrumbidgee Region	Sewage discharge	22.12	29.5	21.18	28.24
ANZECC LTV (H&CC)		22.5	37.5	0.225	0.375
ANZECC STV (H&CC)		125- 625	187.5 – 937.5	3.6 - 54	6 - 90
ANZECC LTV Murrumbidgee		30	40	0.23	0.38
ANZECC STV Murrumbidgee		150-750	200-1,000	4.8-72	6.4-96

In comparison to three sewage treatment works that are currently approved to irrigate to pastures, the aquaculture waste waters were found on average to have similar nitrogen levels but contained only 4% of the phosphorus levels.

Research undertaken by Smith *et al* (1996) into the losses of nitrogen through volatilisation following irrigation of pasture at Wagga Wagga with urban sewage effluent found losses to the atmosphere of up to 25% of the applied nitrogen. The ANZECC 2000 also indicates that between 0 and 80% of the nitrogen within irrigation water may be lost through volatilisation and denitrification.

Based on the data collected during this survey, the nitrogen and phosphorus levels within the waste water from a pond based aquaculture farm where used for irrigation are unlikely to cause a significant impact on the environment.

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Overview of the nitrogen and phosphorus balance within aquaculture ponds.

Introduction
In natural aquatic systems including farm dams nitrogen and phosphorus inflows are rapidly assimilated by phytoplankton and aquatic vegetation communities. The phytoplankton communities are then consumed by zooplankton and then by macro-invertebrates that in turn are consumed by the fish, birds, amphibians and reptiles.

This natural process is also employed to maintain water quality within aquaculture farms and is especially important in discharge water reservoirs. The natural processes assist in treating the discharged water so that it can be reused back through the aquaculture culture ponds.

Calculation of nutrients from a fish farm
To provide details of the potential ***maximum*** available nutrients from the aquaculture facility culturing 4 tonne of Silver perch the following calculations have been made based on the following assumptions:

1. All fish growth is due to formulated feeds and there is no contribution of feed from natural ecosystem within aquaculture ponds,
2. The discharge treatment reservoir is being bypassed with wastes from fish going straight onto pastures. Therefore, there is no calculations of the removal of nutrients through natural processes in the discharge reservoir.
3. Natural aquatic processes are not impacting on discharge levels of nutrients in culture ponds (ie discharged direct from fish onto adjoining lands.)
4. There are no natural gaseous discharges from the culture water to the atmosphere. (Ammonia volatilization results in a net loss of nitrogen).

The food conversion ratio for silver perch is on average about 2:1 therefore for every tonne of fish produced two tonnes of feed is required.

Silver perch manufactured feed generally consists of 35% protein and 2% phosphorus. In calculating the quantity of nitrogen within protein a conversion factor of 6.25 is generally accepted. Also only a quarter of the nitrogen and phosphorus within the feed is utilised by the fish with the remainder being lost to the environment. The following calculations have been done for both the average and maximum potential production.

Nitrogen
To produce 4 tonne of fish 8 tonne of manufactured feed is required, therefore :

8 tonne of feed = 8,000kg @ 35% protein = 2,800 kg of protein
2,800 kg of protein divided by 6.25 = 448kg nitrogen.
448 X 0.75 = 336 kg of nitrogen entering the culture water.

Phosphorous
To produce 4 tonne of fish 8 tonne of manufactured feed is required. Fish feed generally includes about 2% phosphorous and again only about ¼ of this is utilised by the fish, therefore:-

8,000kg @ 2% phosphorous = 160 kg phosphorous in the feed,
160 kg phosphorus X 0.75 = 120 kg of phosphorous entering the culture water.

Comparison to agricultural fertilisation levels of pasture
Fertiliser applications for pasture growth vary depending on soil types and crops being grown. However, an application of 150kg/ha of super phosphate and 60 kg/ha of urea is generally classed as a light top dressing for pasture growth.

It should be noted that the nutrients in the fish pond discharge water are totally soluble and more readily available for plant use than solid agricultural fertilizers.

Therefore, if the area available for irrigation is 4 hectares then the respective nutrient levels per hectare would be:-

Nitrogen

Maximum 336/4 = 84 kg /ha

Phosphorus

Maximum 120/4 =30 kg / ha.

In conclusion, the nutrient levels of the discharge water (with the above assumptions applied) are equal to a light dressing of nitrogen or a poor application of phosphorus.

It should be noted that irrigation of the discharge water over the 4 ha would occur, if required, over a period of time, unlike the agricultural practise of single application of fertiliser. Therefore, the chance of nutrient run off is far less with irrigated fish culture pond discharge water.