Appendix D

Calculation of Municipal Domestic Wasteload Equivalents

Typical pollutant concentrations and loads associated with municipal domestic wastewater reported by WEF and ASCE (1998) are shown in Table D-1. These estimated daily per capita pollutant load production values are used in the sizing and design of wastewater treatment facilities. Similar values are reported in Metcalf and Eddy, Inc. (1991).

Table D-1

Typical Major Pollutant Composition of Domestic Wastewater

Parameter	Concentration in Domestic Wastewater	Estimated Daily Per Capita Production of Pollutants	Estimated Annual Per Capita Production of Pollutants
BOD_5	400 mg/L	0.17 lb/cap d	62.05 lb/cap year
Total Nitrogen	30 mg/L	0.04 lb/cap d	14.60 lb/cap year
Total Phosphorus	7 mg/L	0.006 lb/cap d	2.19 lb/cap year
Total Suspended Solids	240 mg/L	0.2 lb/cap d	73.00 lb/cap year

The per capita values can be used to estimate annual municipal domestic wasteload equivalents. The equation for this calculation is:

$$\text{Human Equivalents (persons)} = \frac{\text{AAP Facility Load (lb/yr)}}{\text{Human Load (lb/capita yr)}}$$

REFERENCES

Metcalf and Eddy, Inc. 1991. *Wastewater Engineering*: *Treatment, Disposal, and Reuse*, 3d ed., revised by Tchobanoglous, G., and F. Burton., McGraw Hill, Inc., NY.

WEF and ASCE (Water Environment Federation and American Society of Civil Engineers). 1998. *Design of Municipal Wastewater Treatment Plants*, 4th ed., WEF Manual of Practice, Water Environment Federation, Alexandria, VA.

Appendix E

Literature Review for AAP Impacts on Water Quality

Examples of Effluents by Production System Type

Table E1. Examples of Effluents from Cage Systems

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Cornel, G.E. and F.G. Whoriskey. 1993. The effects of rainbow trout (Oncorhynchus mykiss) cage culture on the water quality, zooplankton, benthos, and sediments of Lac du Passage, Quebec. Aquaculture 109: 101-117.	Foreign	Cages	Trout	8 cages, each 9m x 9m x 9m, combined producing 14 metric tons fish per year with feed input of 52,125 kg dry feed/year	After 4 years of operation, water quality was sampled at the farm: 0.09 to 0.011 mg/l PO_4-P, 0.05 to 0.06 mg/l NO_3-N, 0.03 to 0.04 mg/l NH_4-N. Daphnia were less abundant around the farm during the summer. Wild perch, and escaped farm trout hang around outside the net pens to eat waste feed. Bloodworm (*Chironomus*) was the most widespread benthic organism. Bloodworms are a pollution-tolerant species; therefore, their abundance is a negative indicator of water quality. There was low DO around the farm, but nutrient and chlorophyll a levels were small and localized. Sediment available P levels were higher at the farm than at control sites, but the peaks coincided with periods of overfeeding.	 nutrients (other)

Table E2. Examples of Effluents from Flow-Through Systems

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Ruane, R.J., T.Y.J. Chu, and V.E. Vandergriff. 1977. Characterization and treatment of waste discharged from high-density catfish cultures. Water Res. 11: 789-800.	Primary	Flow-Through	Catfish	190 liters/sec	0.07 kg/day/100 kg fish ammonia nitrogen 0.8 kg/day/100 kg fish suspended solids, 0.3 ml/l settleable solids 10,000,000 organisms/100ml water Fecal coliforms	nutrients solids (other)
Westers, H. 2000. Michigan's Platte River State Fish Hatchery Case History, RAS 2000 Conference, Blacksburg, VA	Gray	Flow-Through	Salmon	1200 + 5000 +8500 GPM (three potential sources)	Yearly P loading from Platte River Hatchery: 1990 to1996: 157 kg/yr P. 1990 to 1992: 316 kg/yr P. 1993 to 1996: 96 kg/yr P.	nutrients
Weston, D.P., B. Dixon, and C. Forney. 1998. Fate and Microbial Effects of Aquacultural Drug Residues in the Environment. University of California, Berkeley.		Flow-Through	Sturgeon	unknown	Tetracycline concentrations in sediments downstream of a sturgeon farm were up to 5 ug/g. Oxytetracycline concentrations in sediments beneath net-cage sites are commonly in the 1 to 10 ug/g range. 300 ug/g under a salmon net pen in Norway was the highest oxytetracycline concentration ever recorded in aquaculture sediment.	(other)

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Boardman, G.D., V. Mallard, J. Nyland, G.J. Flick, and G.S. Libey. 1998. Final Report: The Characterization, Treatment and Improvement of Aquacultural Effluents. Virginia Polytechnic Institute and State University. October 23, 1998.		Flow-Through	Trout	Farm A - 2.70 to 4.05 m^3/min Farm B - 11.2 to 24.8 m^3/min Farm C - 25.6 to 28.9 m^3/min	-Farm A outlet: 0.5 to 0.6 mg/l NH_3-N Farm B outlet: 0.45 mg/l NH_3-N Farm C outlet: 0.02 to 0.17 mg/l NH_3-N -Farm A outlet: 0.8 to 6 mg/l TSS, 0 to 0.04 ml/l suspended solids Farm B outlet: 1.5 to 7.5 mg/l TSS, 0.01 to 0.08 ml/l suspended solids Farm C outlet: 4.1 to 62 mg/l TSS, 0.04 to 0.08 ml/l suspended solids - Farm A outlet: 0.96 to 1.9 mg/l BOD_5, 1.5 to 2.4 mg/l DOC Farm B outlet: 0.6 to 2.4 mg/l BOD_5, 1.2 to 3.1 mg/l DOC Farm C outlet:, 0.5 to 1.8 mg/l BOD_5, 1.5 to 3.8 mg/l DOC	nutrients solids organic enrichment
Brannon, E.L. no date. Fish Farm Effluent Quality. Idaho.		Flow-Through	Trout	unknown, from groundwater source	Post-settling effluent: 0.074 mg/l total P, 0.054 mg/l orthophosphate, .040 mg/l ammonia, 4.980 mg/l NO_2-N + NO_3-N. <0.02 ml/l settleable solids, 3.0 mg/l suspended solids	nutrients solids
Jensen, J.B. No date. Environmental Regulation of Fresh Water Fish Farms in Denmark. Danish National Agency of Environmental Protection. 11 pp.	Foreign	Flow-Through	Trout	not specified	In 1985, pelleted feed was made mandatory. Mandatory improvements in feed quality were phased in 1989-1992. Total Danish fish farm effluent in 1987 was approximately 5,000 t BOD_5/year, 2,200 t nitrogen/year, and 400 t phosphorus/year.	(other)
JRB Associates. 1984. Development of Effluent Limitations for Idaho Fish Hatcheries. July 23, 1984.		Flow-Through	Trout	Flow 22 to 30 cfs	JRB study: 0.72 to 1.64 pounds TSS/ 100 pounds fish. Pisces effluent:, 92 to 150 mg/l TSS, 4,880 to 11,370 kg/day TSS, trace ml/l settleable solids.	solids
Kendra, W. 1991. Quality of salmonid hatchery effluents during a summer low-flow season. Trans. Am. Fish Soc. 120:43-51	Primary	Flow-Through	Trout	0.06 to 0.41 m^3/sec	Yakima Trout Hatchery: - normal operations: 0.43 mg/l TKN, 0.22 mg/l total P - during cleaning: 1.7 mg/l TKN, 4.0 mg/l total P - normal operations: 1 mg/l total suspended solids, 0 mg/l total volatile suspended solids, <0.1 ml/l settleable solids - during cleaning: 88 mg/l total suspended solids, 69 mg/l total volatile suspended solids, and 2.5 ml/l settleable solids. - normal operations: 6 mg/l COD, 3 mg/l BOD_5. - during cleaning: 130 mg/l COD, 32 mg/l BOD_5.	nutrients solids organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Niemi, M., and I. Taipalinen. 1982. Faecal indicator bacteria at fish farms. Hydrobiologia 76(1982):171-175.	Foreign	Flow-Through	Trout	2.6 m^3/sec	Fecal streptococci in effluent 0.18 to 0.37 ml -1, g-1, total coliforms 5.2 to 8.0 ml -1, g -1, fecal coliforms 0.48 to 1.2 ml-1, g-1.	(other)
Piedrahita, R.H. 1994. Managing Environmental Impacts in Aquaculture. Bull. Natl. Res. Inst. Aquaculture, Suppl. 1:13-20. 1994.		Flow-Through	Trout	22.6 m^3/sec	-Fish waste solids were analyzed at 4.13 mg/l N, 2.15 mg/l P, and 88% moisture.	nutrients
Rennert, B. 1994. Water pollution by a land-based trout farm. J. Appl. Ichthyol. 10(1994):373-378.	Foreign	Flow-Through	Trout	110 l/sec with additional 240 1/sec recycled	-Effluent values: 0.02 mg/l NO_2-N, 0.96 mg/l NO_3-N, 0.64 mg/l NH_4-N, 0.21 mg/l PO_4-P. Nitrogen loading rate was 465 g N per tone of fish per day. Phosphorus loading rate was 155 g P per tone of fish per day in water, and also an additional 2.07 g P per ton of fish per day that is in suspended solids that are flushed from the raceways once per day -Effluent values: 0.03 mg/l suspended matter. Nitrogen loading rate was 465 g N per metric ton of fish per day. Additional loadings of 30 liters or suspended matter per metric ton of fish per day. - Effluent values: 4.2 mg/l COD. Additional loadings of 3100 g COD per metric ton of fish per day were also observed.	nutrients solids organic enrichment
Selong, J.H. and L.A. Helfrich. 1998. Impacts of trout culture effluent on water quality and biotic communities in Virginia headwater streams. The Progressive Fish-Culturist 35(7): 247-262.	Primary	Flow-Through	Trout	0.27 to 1.24 m^3/sec	0.3 to 1.0 mg/l total ammonia-N for trout farm A; highest ammonia concentrations occurred during low flow conditions in fall.	nutrients benthic degradation

Table E3. Examples of Effluents from Other Types of Production Systems: Gator Pens

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Pardue, J.H., R.D. DeLaune, W.H. Patrick, Jr., and J.A. Nyman. 1994. Treatment of alligator farm wastewater using land application. Aquacult. Eng. 13(1994) 129-145.	Primary	Gator Pens	Alligators	hypothetical 6000 m^3/year	Data from alligator farm effluent: 10.9 mg/l total P, 77.5 mg/l NH_3, 4.6 mg/l NO_3-N, 153.4 mg/l TKN	nutrients
					379 mg/l total solids, 219 mg/l volatile solids	solids
					452 mg/l BOD	organic enrichment

Table E4. Examples of Effluents from Net Pens

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Hargrave, B.T., Phillips, G.A., Doucette, L.I., White, M.J., Milligan, T.G., Wildish, D.J., and R.E. Cranston. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. Water, Air and Soil Pollution 99: 641-650.	Foreign	Net Pens	Salmon	11 farms and 11 reference sites. Farm production varied from 40,000 to 320,000 tons of fish per year.	Sediment cores were collected under farms and at reference sites and analyzed at a lab. The authors do not report specific data values for specific farms or control sites. The most sensitive variables for finding differences between farms and reference sites were total sulfide, benthic O_2 uptake, benthic CO_2 release, and redox potential. The polychaete Capitella sp. can tolerate total sulfide concentrations up to 2 mM. Total sulfide concentrations above 2 mM are toxic to larvae and prevent settlement. No Capitella sp. were observed at any of the farm sites. All of the farms had total sulfide over 180 uM, with a maximum of 6 to 7mM. All but one of the reference sites had total sulfide under 200 uM. Redox potential at all but three of the farms was under +100 mV. Redox potential at all but two of the reference sites was over +100 mV. Mean values for total sediment O2 uptake was 175 percent higher at the farms than reference sites. Mean values for total sediment CO2 release was 355 percent higher at farms than reference sites. Measurements of modal grain size pore water salinity, SO_4, and sediment water content were not significantly different between farms and reference sites.	benthic degradation

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Holmer, M. 1991. Impacts of Aquaculture on Surrounding Sediments: Generation of Organic-Rich Sediments. In Aquaculture and the Environment: Reviews of the International Conference Aquaculture Europe 91, European Aquaculture Society, Dublin, Ireland, June 10-12, 1991, pp. 155-175.	Foreign	Net Pens	Salmon	not specified	One farm, seasonal variation 34 to 41 mmol per m2 per day SOU. Six farms, annual mean 86 to 446 mmol per m2 per day SOU. One farm, seasonal variation 60 to 230 mmol per m2 per day SOU. CO2 production in sediment metabolism was related to food input with an r2 = 0.975. Oxygen uptake in sediments increased sharply with sediment thickness up to 10 cm, and then gradually leveled out. Antibiotic resistant bacteria were found in sediments from antibiotic feeds. Zinc from feed, and copper from antifouling agents have been measured in fish farm sediments. Sedimentation rates under mussel rafts were three times the sedimentation rates at control sites. - Zinc from feed, and copper from antifouling agents have been measured in fish farm sediments. Sedimentation rates under mussel rafts were three times the sedimentation rates at control sites.	benthic degradation (other)
Johnsen, R.I., O. Grahl-Nielsen, and B.T. Lunestad. 1993. Environmental distribution of organic waste from a marine fish farm. Aquaculture 118(3-4): 229-244.		Net Pens	Salmon	N/A	Researchers collected sediment under a working farm and at control sites. Feed, feces and sediment were analyzed to screen fatty acids that might be used as chemical markers for organic sediment enrichment caused by fish farms. Pristane is one of the compounds investigated. Anoxic sediments beneath fish farms gave off H_2S smell. Beneath the farm, divers observed a fine white blanket of what was likely elemental sulfur and sulphur-oxidizing bacteria (Beggiatoa) on the sediment surface. The authors used multivariate statistics to show differences between pristine concentrations in farm sediments and control sediments. Fatty acids and/or pristane show promise as fish farm sediment markers.	benthic degradation

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Kaspar, H.F., G.H. Hall, and A.J. Holland. 1988. Effects of sea cage salmon farming on sediment nitrification and dissimilatory nitrate reduction. Aquaculture 70(4): 333-344.	Foreign	Net Pens	Salmon	N/A	Sediment cores and gas bubbles from sediment were collected beneath a working salmon farm in New Zealand. At site 1 (the site beneath the center of a cage at a water depth of 13 m): 14.3 to 34.3 mmol/m^2 NH_4+, 1.4 to 5.3 mol/m^2 Organic N, 0.4 to 3.6 mol/m^2 Total P, 1.4 to 3.1 N:P ratio.	nutrients
					- Gas evolving from sediment at site 1 consisted of 64 percent methane, 5 percent carbon dioxide, 2 percent water vapor, 7 percent air, and 22 percent unknown. The unknown portion probably contained H_2S, because the divers could smell it. In situ nitrification rates were <0.1 to 0.3 mmol N/m^2 per day. Denitrification at the sites was determined not to be a significant nitrogen removal mechanism. Nitrification / Denitrification was not occurring because the sediments lacked oxygen to supply the nitrification step. Beneath the net pens, divers observed black colored sediments covered by a *Beggiatoa*-like bacterial mat that smelled like H_2S and was bubbling off methane.	benthic degradation
Milewski, I., J. Harvey, and B. Buerkle. 1997. After the Goldrush: Salmon Aquaculture in New Brunswick. In Murky Waters: Environmental Effects of Aquaculture in the U.S, ed. R. Goldberg and T. Triplett, pp. 131-152. The Environmental Defense Fund, New York.	Gray	Net Pens	Salmon	N/A	In one study, 8.3 ha out of 34.6 ha salmon farms investigated were classified as heavily degraded. Heavy degradation includes bubbling gas, the absence of fish and sediment-dwelling organisms, accumulations of fish feed and feces not dispersed by a tidal cycle, and bacterial mats. Areas less impacted would have no organisms other than worms tolerant of low DO.	benthic degradation

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Mazzola, A., S. Mirto, and R. Danovaro. 1999. Initial fish-farm impact on meiofaunal assemblages in coastal sediments of the Western Mediterranean. Mar. Poll. Bull. 38(12): 1126-1133.	Foreign	Net Pens	Sea Bream	N/A(cultured fish biomass varied from about 18,000 - 30,000 kg fish during the year)	Sampling of sediment chemistry and meiofauna started when the cages were stocked and continued for six months. After six weeks the sediments were suboxic. Chemical parameters included 2.3 to 8.2 ug/g Chlorophyll-a at the control, and 1.3 to 15.4 ug/g Chlorophyll-a at the cage. 1617 to 3304 ug/g Proteins at the control, and 1677 to 6740 ug/g Proteins at the cage. 503 to 2814 ug/g sedimentary carbohydrates at the control, and 628 to 5690 ug/g sedimentary carbohydrates at the cage. 331 to 2096 ug/g Lipids at the control, and 848 to 3096 ug/g Lipids at the cage. No significant differences were found between control and cage for biopolymeric carbon. Redox potential discontinuity (RPD) depth is the depth at which sediment turns brown to black. 1.4 to 2.9 cm RPD at the control, and 0 to 1.1 cm RPD at the cage. Meiofaunal organisms were extracted from sediment cores. Copepods and ostracods significantly decreased in farm sediments. Kinorhynchs were extremely sensitive to farm reducing sediments and disappeared almost completely from the farms. Polychaete densities were the same at cages and controls. Nematodes are usually tolerant of reducing conditions in sediment, but did show some effects at the farm sites. The nematode to copepod ratio has been used in the literature to detect pollution. In this study, the ratio did not reliably point to pollution effects at either cage or control.	benthic degradation
Gale, P. 1999. Appendix 9. Water Quality Impacts from Aquaculture Cage Operations in the LaCloche/North Channel of Lake Huron. In Addressing Concerns for Water Quality Impacts from Large-Scale Great Lakes Aquaculture: A Roundtable. Habitat Advisory Board of the Great Lakes	Foreign	Net Pens	Trout	N/A	Water quality monitoring at Grassy Bay site: 6 to 10 ug/l total phosphorus. Near the pens, researchers observed 16 to 26 ug/l total P in September, and 40 ug/l total P in October. Anoxic conditions in the hypolimnion can result in the release of P from the sediments. Historic P concentration in that part of the lake is 5 ug/l total P.	nutrients

Table E5. Examples of Effluents from Ponds

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Boyd et al. 2000. Environmental Assessment of Channel Catfish Farming in Alabama, Auburn University, Department of Fisheries and Allied Aquaculture, Auburn, AL.		Ponds	Catfish		-Average effluent concentrations during precipitation overflow events: 0.12 mg/l soluble reactive P, 0.68 mg/l total P, 0.86 mg/l NO3-N, 1.20 mg/l total ammonia N, 3.42 mg/l total N. -Average effluent concentrations during partial drawdown events: 0.01 mg/l soluble reactive P, 0.25 mg/l total P, 0.69 mg/l NO3-N, 1.13 mg/l total ammonia N, 5.68 mg/l total N. -Average effluent concentrations during final pond drawdown: 0.06 mg/l soluble reactive P, 1.59 mg/l total P, 0.14 mg/l NO3-N, 1.37 mg/l total ammonia N, 9.58 mg/l total N	nutrients
					-Average effluent concentrations during precipitation overflow events: 81 mg/l TSS. -Average effluent concentrations during partial draw down events: 69 mg/l TSS. -Average effluent concentrations during final pond draw down: 1027 mg/l TSS	solids
					-Average effluent concentrations during precipitation overflow events: 11.0 mg/l. -Average effluent concentrations during partial draw down events: 9.42 mg/l BOD_5. - Average effluent concentrations during final pond draw down: 31.8 mg/l BOD_5	organic enrichment
Boyd, C.E. 1978. Effluents from catfish ponds during fish harvest. Journal of Environmental Quality 7(1):59-62.	Primary	Ponds	Catfish	0.53 to 5.02 ha with depths of 1.5 to 1.8 m	Mean effluent parameters during seining phase of harvest (Over half of the total settleable matter and orthophosphate was lost during the seining phase.): 59 ug/l soluble orthophosphate, 0.49 mg/l total P, 2.34 mg/l total NH_3, 0.14 mg/l NO_3-N.	nutrients
					28.5-ml/l settleable matter	solids
					28.9 mg/l BOD, 342 mg/l COD	organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Huggett, D.B., D. Schlenk and B.R. Griffin. 2001. Toxicity of copper in an oxic stream sediment receiving aquaculture effluent. Chemosphere 44: 361-367.	Primary	Ponds	Catfish	Nine-10,000 fish/ha ponds were treated with a total of 45 kg of dispersed copper over 3 years, drained after harvest into a nearby stream	*Hyallea azteca* and *Typha latifolia* were exposed to sediments collected upstream, at outflow, and downstream from catfish ponds medicated with copper. No significant loss was observed in the upstream or outflow samples. *H. azteca* did suffer significant mortality in the downstream sample. However, because copper levels in all 3 locations were similar to each other and to those from ponds where copper was not used, it was determined the use of copper in this study did not negatively impact the receiving stream. Bulk sediment copper concentrations in the samples were: Upstream: 29 mg Cu/kg dry weight Outfall: 31 mg Cu/kg dry weight Downstream: 25 mg Cu/kg dry weight	
Schwartz, M.F., and C.E. Boyd. 1994a. Channel catfish pond effluents. Prog. Fish Cult. 56: 273-281.	Primary	Ponds	Catfish	Unknown	-Production water values: 0 to 1.85 mg/l total P, 0 to 0.074 mg/l soluble reactive P, 0.58 to 14.04 mg/l TKN, 0.008 to 8.071 mg/l TAN, 0 to 6.661 mg/l NO_3-N. -Production water values: 0 to 1.8 ml/l settleable solids, 5.2 to 336.7 mg/l suspended solids, 0.02 to 221.0 mg/l volatile solids. - Production water values: 1.9 to 35.54 mg/l BOD_5	nutrients solids organic enrichment
Shireman, J.V., and C.E. Cichra. 1994. Evaluation of aquaculture effluents. Aquaculture 123(1994): 55-68.	Primary	Ponds	Catfish	0.4 hectare by 1.5 m deep = 6,000 m^3 (1 acre pond)	At Schuler Fish Farm, production water ranges: 0.050 to 0.350 mg/l NH_4-N, 0.030 to 0.280 mg/l NO_3-N, 0.000 to 0.007 mg/l NO_2-N, 0.8 to 4.9 mg/l Total N, 0.148 to 0.238 mg/l Total P 4.3 to 63.4 mg/l TSS, 2.7 to 39.4 mg/l VSS, 1.6 to 29.3 mg/l FSS 4 to 16 mg/l CBOD 1,400 to 160,000 number/100ml Fecal coliforms	nutrients solids organic enrichment (other)

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Tucker, C. S., S.K. Kingsbury, J.W. Pote, and C.L. Wax. 1996. Effects of water management practices on discharge of nutrients and organic matter from channel catfish (Ictalurus punctatus) ponds.	Primary	Ponds	Catfish	Ponds averaged 7 ha in area and 1.25 m in depth; water was supplied by wells pumping from an aquifer; periodic additions of well water were made to replace evaporation; overflow occurred only during periods of excessive rainfall.	Predicted discharge (kg ha^{-1} of pond surface) of selected parameters in overflow from levee-type ponds, in an average year, under two management scenarios **(1) With no water storage potential:** total nitrogen: Spring 14.7; Summer 12.4; Autumn 15.2; Winter 17.2 ; total phosphorus: Spring 1.0; Summer 0.9; Autumn 0.7; Winter 1.1; chemical oxygen demand (as O_2) Spring 223; Summer 172; Autumn 165; Winter 245; biochemical oxygen demand (as O_2) Spring 45; Summer 41; Autumn 25; Winter 42. **(2) With 7.5-cm water storage potential:** total nitrogen: Spring 4.2; Summer 1.0; Autumn 2.0; Winter 10.1; total phosphorus: Spring 0.3; Summer 0.1; Autumn 0.2; Winter 0.7; chemical oxygen demand (as O_2) Spring 64; Summer 14; Autumn 22; Winter 143; biochemical oxygen demand (as O_2) Spring 13; Summer 3; Autumn 3; Winter 25.	
Tucker, C.S. no date. Quality of potential effluents from channel catfish culture ponds		Ponds	Catfish	Unknown, but stocked at 17,000 fish / ha	Production water values for August: 3.9 to 9.9 mg/l total N, 0.06 to 1.79 mg/l total ammonia, 0 to 0.15 mg/l NO_3-N, 0 to 0.08 mg/l NO_2-N, 0.45 to 1.13 mg/l total P, 0.01 to 0.06 mg/l soluble phosphorus. 64 to 200 mg/l COD	nutrients organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Tucker, C.S., and S.W. Lloyd. 1985. Water Quality in Streams and Channel Catfish (Ictalurus punctatus) Ponds in West-Central Mississippi. Technical Bulletin 129. Mississippi Agricultural & Forestry Experiment Station, Mississippi.	Secondary	Ponds	Catfish	pond volumes 20,000 to 80,000 m^3, stocked at 10,000 to 20,000 fish per hectare	-Mean production water values for spring: 0.072 mg/l soluble reactive phosphorus, 0.560 mg/l total P, 0.934 mg/l total ammonia, 0.053 mg/l NO_2-N + NO_3-N, 4.41 mg/l total N. -Mean production water values for summer: 0.159 mg/l soluble reactive phosphorus, 0.855 mg/l total P, 0.416 mg/l total ammonia, 0.235 mg/l NO_2-N + NO_3-N, 5.55 mg/l total N. -Mean production water values for spring: 481 mg/l total solids, 149 mg/l total volatile solids. -Mean production water values for summer: 500 mg/l total solids, 162 mg/l total volatile solids. -Mean production water values for spring: 61 mg/l COD. -Mean production water values for summer: 97 mg/l COD	nutrients solids organic enrichment
Smydra, T.M. 1994. Characterization and effects of aquacultural effluents from two Iowa hatcheries. Master's thesis, Iowa State University, Ames, Iowa.	Primary	Ponds	Catfish, Walleye, Largemouth Bass	Unknown and variable	0.10 to 0.49 kg/day soluble reactive P, 0.13 to 0.41 kg/day NO_2-N, 0.29 to 11.68 kg/day ammonia-N, 0.00 to 0.0378 kg/day un-ionized ammonia, 0.95 to 10.11 kg/day Total N 22.8 to 549.9 kg/day TSS 3.38 to 20.11 kg/day $CBOD_5$	nutrients solids organic enrichment
Tucker, C.S. 1998a. Characterization and Management of Effluents from Aquaculture Ponds in the Southeastern United States. July 1998. SRAC Final Project No. 600. Southern Regional Aquaculture Center.	Gray	Ponds	Crawfish	2.2 to 23.6 ha commercial ponds	Mean values for effluents during draining period (Effluent quality is poorest during the summer drainage period. Ponds with native vegetation generally have lower concentrations of nutrients and solids than ponds with rice or sorghum-sudan grass): 0.139 mg/l soluble reactive P, 0.614 mg/l total P, 0.353 mg/l total ammonia N, 0.009 mg/l NO_2-N, 0.040 mg/l NO_3-N. 607 mg/l total solids, 109 mg/l total volatile solids. 61.3 mg/l COD, 11.6 mg/l BOD	nutrients solids organic enrichment
Dierberg, F.E., and W. Kiattisimkul. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. Environ. Manage. 20(5): 649-666.	Foreign	Ponds	Shrimp	N/A	Effluent loading per 4 month cycle from shrimp grow out ponds stocked at 50-60 shrimp per m2: 0.71 kg/ha NO_2-N, 2.7 kg/ha NO_3-N, 18.4 kg/ha TAN, 178 kg/ha total N, 2.0 kg/ha SRP, 15.7 kg/ha total P 6,650 kg/ha TSS. 474 kg/ha BOD_5.	nutrients solids organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Hopkins, J.S., C.L. Browdy, R.D. Hamilton II, and J.A. Heffernan III. 1995. The effect of low-rate sand filtration and modified feed management on effluent quality, pond water quality and production of intensive shrimp ponds. Estuaries 18(1A): 116-123.	Primary	Ponds	Shrimp	1300 m^3 ponds, one pond had 5% daily water exchange	Effluent from daily water exchange passed through a sand filter before discharge: 0.08 to 2.86 mg/l TAN, <0.01 to 0.65 mg/l NO_2-N, <0.01 to 0.06 mg/l NO_3-N, 0.07 to 0.90 mg/l reactive orthophosphate, 0.5 to 2.9 mg/l Total P, 2.8 to 15.9 mg/l Kjeldahl N, <0.1 to 19.5 mg/l dissolved Kjeldahl N 18 to 347 mg/l suspended solids, 14 to 143 mg/l volatile solids 5.7 to 43.0 mg/l	nutrients solids organic enrichment
Hopkins, J.S., J.D. Holloway, P.A. Sandifer, and C.L. Browdy. No date. Results of Recent Controlled Comparisons of Intensive Shrimp Ponds Operated With and Without Water Exchange. Waddell Mariculture Center, Bluffton, South Carolina.	Gray	Ponds	Shrimp	0.25 ha lined ponds, 1.3 to 1.5 m deep (about 3,500 m^3) that did not use water exchange	Feeding at 136 kg/ha feed per day with a 20% protein feed, production water values were: 0.2 mg/l TAN, 2.8 mg/l NO_3-N, 0.3 mg/l NO_2-N, 4.0 mg/l TKN, 1.2 mg/l Total P, 0.4 mg/l Reactive orthophosphate 93.3 mg/l TSS, 46.2 mg/l organic suspended solids 15.7 mg/l BOD, 16.5 mg/l total organic carbon.	nutrients solids organic enrichment
Lopez-Ivich, M.A. 1996. Characterization of effluents from three commercial aquaculture facilities in South Texas. Master's thesis, Texas A&M University, Corpus Christi, Texas.	Primary	Ponds	Shrimp	Taiwan Shrimp Village, sampling point TV3 (located at the end of the discharge canal running along eastern border of facility) - 63,961 m^3/day Harlington Shrimp Farm sampling point H2 (located before the last gate of the farm’s discharge canal) - 193,562 m^3/day Southern Star Farm sampling point SS2 (located in front of the last gate of the farm’s discharge canal) - 12,748 m^3/day	-TV3 effluent sampling point: 1.14 mg/l NH_4-N, 0.23 mg/l NO_2-N, 0.45 mg/l NO_3-N, 0.45 mg/l Total P, 0.23 mg/l Total reactive P -H2 effluent sampling point: 0.04 mg/l NH_4-N, 0.01 mg/l NO_2-N, 0.65 mg/l NO_3-N, 0.15 mg/l Total P, 0.01 mg/l Total reactive P -SS2 effluent sampling point: 0.44 mg/l NH_4-N, 0.12 mg/l NO_2-N, 0.34 mg/l NO_3-N, 0.34 mg/l Total P, 0.11 mg/l Total reactive P -TV3 effluent sampling point: 99.46 mg/l TSS, 0.29 ml/l settleable solids -H2 effluent sampling point: 95.08 mg/l TSS, 0.14 ml/l settleable solids -SS2 effluent sampling point: 71.46 mg/l TSS, 0.12 ml/l settleable solids -TV3 effluent sampling point: 3.56 mg/l $CBOD_5$ H2 effluent sampling point: 9.16 mg/l $CBOD_5$ SS2 effluent sampling point: 3.93 mg/l $CBOD_5$	nutrients solids organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Martin, J., Y. Veran, O. Guelorget, and D. Pham. 1998. Shrimp rearing: Stocking density, growth, impact on sediment, waste output and their relationships studied through the nitrogen. Aquaculture. 164(1998):135-149.	Foreign	Ponds	Shrimp	ponds 1370 to 1520 m^2 by 1.3 m deep, with 10% daily water exchange	Data from shrimp pond stocked at 15 shrimp per m^2: 1460 m^2 pond area, 79.0 percent survival area, 19.9 g final body weight, 346 kg final biomass, 546.5 kg total feed, 1.58 FCR: 0.10 to 0.74 mg/l nitrogen, 10.5 +/- 6.0 ug/l NH_4-N, 2.7 +/-6.6 ug/l NO_2-N + NO_3-N, 127.7 +/- 40.7 ug/l organic N, 72 to 240 ug/l total soluble N.	nutrients
Samocha, T.M., and A.L. Lawrence. 1995. Shrimp farms' effluent waters: environmental impact and potential treatment methods. Water Effluent and Quality, With Special Emphasis on Finfish and Shrimp Aquaculture. U.S.-Japan Cooperative Program in Natural Resources, Corpus Christi, Texas.	Gray	Ponds	Shrimp	378,540 m^3/day permitted average discharge flow	Effluent from main discharge to county canal: 0.39 to 0.66 mg/l total P, 0.15 to 0.37 mg/l reactive P, 0 to 7 mg/l NH_3-N. 58 to 203 mg/l TSS. Effluent from one pond while draining for harvest: 41 to 652 mg/l TSS, and 37 to 49 mg/l VSS. 1.7 to 5.0 mg/l $CBOD_5$.	nutrients solids organic enrichment
Teichert-Coddington, D.R., D.B. Rouse, A. Potts, and C.E. Boyd. 1999. Treatment of Harvest Discharge from Intensive Shrimp Ponds by Settling. Aquacult. Eng. 19(1999): 147-161.	Primary	Ponds	Shrimp	888 m^3, during last month of culture, 25 to 30 percent of water exchanged per week	During draining, mean values for effluent when pond is drained from full capacity to empty: 0.53 to 1.67 mg/L Total P, 1.57 to 4.15 mg/l Total N, 0.59 to 2.40 mg/l TAN 0.4 21.5 ml/l settleable solids, 181 to 2788 mg/l total solids, 88 to 563 mg/l volatile solids. 30.6 to 44.3 mg/l BOD	nutrients solids organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Ziemann, D.A. 1991. Effluent Mixing Zones - Theory and Practice	Gray	Ponds	Shrimp	Pacific Sea Farms - 2.7 to 4.5 mgd Oceanic Institute - 0.032 to 0.058 mgd	-Pacific Sea Farms effluent: 90 to 330 ug/l NO_3-N + NO_2-N, 150 to 1280 ug/l NH_4-N, 1110 to 3930 ug/l Total N, 270 to 1030 ug/l Total P. Loadings Pacific Sea Farms effluent: 2.7 to 4.5 mgd flow, 0.9 to 5 kg/day NO_3-N + NO_2-N, 1.5 to 20.4 kg/day NH_4-N, 17.6 to 61 kg/day Total N, 2.8 to 13.6 kg/day Total P. -Oceanic Institute effluent: 0 to 548 ug/l NO_3-N + NO_2-N, 3 to 1534 ug/l NH_4-N, 80 to 3055 ug/l Total N, 15 to 712 ug/l Total P. Loadings Oceanic Institute effluent: 0.032 to 0.058 mgd flow, 0.000 to 0.100 kg/day NO_3-N + NO_2-N, 0.001 to 0.277 kg/day NH_4-N, 0.020 to 0.600 kg/day Total N, 0.003 to 0.140 kg/day Total P. - Pacific Sea Farms effluent: 16 to 36 mg/l TSS. Loadings Pacific Sea Farms effluent: 197 to 565 kg/day TSS. -Oceanic Institute effluent: 13 to 102 mg/l TSS. Loadings Oceanic Institute effluent: 2.8 to 17 kg/day TSS. - Pacific Sea Farms effluent: 4 to 10 mg/l BOD. Loadings Pacific Sea Farms effluent 63 to 157 kg/day BOD. -Oceanic Institute effluent: 7 to 15 mg/l BOD. Loadings Oceanic Institute effluent: 1.1 to 2.8 kg/day BOD.	nutrients solids organic enrichment
Tucker, C.S. 1998a. Characterization and Management of Effluents from Aquaculture Ponds in the Southeastern United States. July 1998. SRAC Final Project No. 600. Southern Regional Aquaculture Center.	Gray	Ponds, Freshwater And Saltwater	Hybrid Striped Bass	Commercial ponds of unknown size	Production water mean values 7.1 mg/l Kjeldahl Nitrogen, 0.95 mg/l total ammonia, 0.07 mg/l NO_2-N, 0.36 mg/l NO_3-N, 0.31 mg/l total P, 0.02 mg/l soluble reactive P. 49 mg/l suspended solids, 29 mg/l volatile suspended solids. 11.5 mg/l BOD.	nutrients solids organic enrichment
Seok, K., S. Leonard, C.E. Boyd, and M.F. Schwartz. 1995. Water quality in annually drained and undrained channel catfish ponds over a three-year period. The Progressive Fish-Culturist 57:52-58.	Primary	Ponds, Levee	Catfish	400 to 600 m^2 with average depth 1m is about 400 to 600 m^3 (about 1/10 acre pond)	Ranges for effluents from draining ponds during October harvest: 1.65 to 14.45 mg/l Kjeldahl nitrogen, 0.34 to 3.70 mg/l TAN, 0.004 to 0.065 mg/l NO_3-N. 0.007 to 0.17 mg/l NO_2-N, 0.231 to 3.302 mg/l Total P 47 to 1948 mg/l TSS, 1.1 to 10.0 ml/l settleable solids. 30.0 to 54.4 mg/l BOD.	nutrients solids organic enrichment

Reference	Source Category	System	Species	Flow Or Volume	Parameter Data	Pollutant
Boyd, C.E. and T. Dhendup. 1995. Quality of Potential Effluents from the Hypolimnia of Watershed Ponds Used in Aquaculture. *The Progressive Fish-Culturist* 57:59-63. 1995.		Ponds, Watershed	Catfish	9,400 to 66,900 m^3 pond volume	Measurements taken July to September, -TAN 0.34 to 3.59 mg/l; NO_2-N 0.0 to 0.15 mg/l - BOD_5 8.5 to 20.6 mg/l	nutrients organic enrichment
Schwartz, M.F., and C.E. Boyd. 1994b. Effluent quality during harvest of channel catfish from watershed ponds. The Progressive Fish Culturist 56:25-32.	Primary	Ponds, Watershed	Catfish	0.92 to 1.32 hectare by 1.37 to 1.73 m deep, (ballpark 18,000 m^3)	Effluent loadings discharged per hectare of pond: 2.95 kg/ha TAN, 77.8 kg/ha TKN, 0.03 kg/ha NO_2-N, 3.95 kg/ha NO_3-N, 0.17 kg/ha soluble reactive P, 3.23 kg/ha Total P. Loadings discharged per metric ton (MT) of fish in pond: 0.74 kg/MT TAN, 18.6 kg/MT TKN, 0.01 kg/MT NO2-N, 0.95 kg/MT NO_3-N, 0.04 kg/MT soluble reactive P, 0.78 kg/MT Total P 9,362 kg/ha settleable solids. Loadings discharged per metric ton (MT) of fish in pond: 2,302 kg/MT settleable solids. 164 kg/ha BOD. Loadings discharged per metric ton (MT) of fish in pond: 39.3 kg/MT BOD.	nutrients solids organic enrichment

Additional Literature for Review

Alanärä, A., Bergheim, A., Cripps, S.J., Eliassen, R., Kristiansen., 1994. An integrated approach to aquaculture wastewater management. *J. Appl. Ichthyol*. 10, 389.

Bergheim, A., Åsgård, T., 1996. Waste production from aquaculture. In: Baird, D.J., Beveridge, M.C.M., Kelly, L.A., Muir, J.F. (Eds.), Aquaculture and Water Resource Management. Blackwell, Oxford, pp. 50-80.

Beveridge, M.C.M., Phillips, M.J. and Clarke, R.M., 1991. A quantitative and qualitative assessment of wastes from aquatic animal production. In: D.E. Brune and J.R. Tomasso (Editors), Aquaculture and Water Quality. World Aquaculture Society, Baton Rouge, LA. pp. 506 – 533.

Boaventura, R., A.M. Pedro, S. Coimbra and E. Lencastre. 1997. Trout farm effluents: characterization and impact on the receiving streams. *Environmental Pollution*. 95(3): 379 – 387.

Boersen, G., Westers, H., 1986. Waste solids control in hatchery raceways. *Prog. Fish. Cult.* 48, 151-154.

Boyd, C. E. 2000. Shrimp farm effluent during draining for harvest. *Global Aquaculture Advocate*, 3(4): 26 – 27.

Costa-Pierce, B.A., 1996. Environmental impacts of nutrients from aquaculture: towards the evolution of sustainable aquaculture systems: In: Baird, D.J., Beveridge, M.C.M., Kelly, L.A., Muir, J.F. (Eds.), Aquaculture and Water Resource Management. Blackwell, Oxford, pp. 81-113.

Cripps, S.J., Kelly, L.A., 1996. Reductions in wastes from Aquaculture. In Baird, D.J., Beveridge, M.C.M., Kelly, L.A., Muir, J.F. (Eds.), Aquaculture and Water Resource Management. Blackwell, Oxford, pp. 166-201.

Einen, O., Holmefjord, I., sgård, T., Talbot, C., 1995. Auditing nutrient discharges from fish farms: theoretical and practical considerations. *Aquacult*. Res. 26, 701 – 713.

Enell, M., Lof, J., 1983. Environmental impact of aquaculture: sediment and nutrient loadings from fish cage culture farming. *Vatten* 39, 364 – 375.

Gowen, R.J. & Bradbury, N.B. 1987. The ecological impact of salmonid farming in coastal waters: a review. *Oceanogr. Mar. Biol. Ann. Rev*. 25: 563 – 575.

Handy, R.D. and M.G. Poxton. 1993. Nitrogen pollution in mariculture: toxicity and excretion of nitrogenous compounds by marine fish. *Rev. Fish Biol. Fish*. 3: 205 – 241.

Heinen, J.M., J.A. Hankins and P.R. Adler. 1996. Water quality and waste production in a recirculating trout-culture system with feeding of a higher-energy or lower-energy diet. *Aquat. Res*. 27: 699 – 710.

Jory, D.E. 1997. Status of marine shrimp farming. *Aquaculture Magazine* 26: 39 – 46.

Muir, J. F., 1982. Recirculated water systems in aquaculture. In: J.F. Muir and R.J. Roberts (Editors), Recent Advances in Aquaculture. Westview Press, Boulder, CO, pp. 357 – 447.

Screenivasan A. 1995. Pollution from industrial shrimp culture: A serious environmental threat. *Fish. Chimes*. 15(5): 19 – 20.

Steward, J.E. 1997. Environmental Effects of Aquaculture. *World Aquacult*. 28 (1): 47 – 52.

Summerfelt, S.T., 1998. An integrated approach to aquaculture waste management in flowing water systems. In: Libey, G.S., Timmons, M.B. (Eds.), Proceedings of the Second international Conference on Recirculating Aquaculture, 16 – 19 July 1998, Roanoke, USA, pp. 87 – 97.

Tomasso, J.R., ed. 2002. *Aquaculture and the Environment in the United States*. U.S. Aquaculture Society, a Chapter of the World Aquaculture Society, Baton Rouge, Louisiana.

Tovar, A., Moreno, C., Mánuel-Vez, M.P. and García-Vargas, M. 2000. Environmental impacts of intensive aquaculture in marine waters. *Water Research* 34(1): 334 – 342.

Uhlmann, D., 1979. BOD removal rates of waste stabilization ponds as a function of loading, retention time, temperature and hydraulic pattern. *Water Res*., 13: 193 – 200.

Williams, M.J. In: J.E. Bardach (Ed.), Sustainable Aquaculture, J.E. Bardach, Ed. (Wiley, New York, 1997), pp. 15-51; R.J. Goldburg and T. Triplett, Murky Waters: Environmental Effects of Aquaculture in the United States (Environmental Defense Fund, New York, 1997).

Wu, R.S.S. 1995. The environmental impact of marine fish culture: towards a sustainable future. *Mar. Pollut. Bull*. 31, 4 – 12.