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aquacultural engineering

Aquacultural Engineering 32 (2005) 303–323

www.elsevier.com/locate/aqua-online

The economic impact of proposed effluent treatment options for production of trout *Oncorhynchus mykiss* in flow-through systems

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Received 20 April 2004; accepted 13 July 2004

Abstract

The United States Environmental Protection Agency has considered several treatment options for flow-through systems in its Effluent Limitation Guidelines rulemaking effort on aquaculture. However, the economic effects of treating effluents can impose high costs on aquaculture businesses, depending upon the treatment option selected. Survey data from trout farmers in North Carolina and Idaho were used to develop enterprise budgets, a spreadsheet-based risk analysis, and mathematical programming models of medium-sized trout farms in North Carolina (68,182 kg/yr) and Idaho (90,909 kg/yr) and large trout farms in Idaho (1,136,364 kg/yr). These analyses were used to examine the effect of imposing five different effluent treatment options on the net returns of farms raising trout in raceways. Budget analyses showed that the trout farm scenarios considered were generally profitable, although the medium-sized farms exhibited low levels of profitability. All five proposed effluent treatment options resulted in negative net returns for the medium-sized farms in both North Carolina and Idaho. The large farm scenario showed positive net returns after adding costs associated with the affluent treatment options considered, but the risk of generating positive net returns decreased from 82–84% to 10–11%. Thus, financial risk increased considerably when treatment

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0144-8609/$ – see front matter
doi:10.1016/j.aquaeng.2004.07.001

options were imposed. The mixed-integer mathematical programming model demonstrated sensitivities to the level of credit reserves both for operating and investment capital. The effluent treatment options imposed on the models were not economically feasible at the levels of capital available on most trout farms. Subsequent runs of the model used investment capital requirements of treatment options at 50% of the original estimates. The models showed that imposing effluent treatment options forced farms to substitute production units for treatment facilities. This results from a combination of: 1) the additional capital requirements of the treatment options; 2) limited availability of credit reserves; and 3) competing uses for land in trout farming areas that put upward pressure on land prices. Many of the proposed treatment options included substantial investment capital requirements that increased annual fixed costs. Limited availability of investment capital prevented the farm expansion that would be needed to spread the increased fixed costs; hence, the models were forced to remove units from production to meet treatment constraints. Net returns decreased because farms were forced to operate at inefficient levels.

Keywords: Trout; Economics; Effluents

1. Introduction

According to the 1998 Census of Aquaculture (NASS, 2000), the U.S. trout industry consists of 561 farming operations located in 42 states. Most of the trout are produced in flow-through concrete raceways; however, earthen ponds continue to be used by some farmers. The majority of the farms are small, family-operated businesses with average sales per farm of $129,185 nationally. Eighty-one percent of the trout farms in the U.S. have sales of less than $100,000 annually. However, there are a few (108) large trout farming operations. These constitute about 19% of all trout farming operations but over 85% of total sales. Idaho is the leading trout producing state with 70–75% of domestic production (NASS, 2003). North Carolina ranks second in the United States and accounts for 8% and 10% of total U.S. production and sales, respectively. Twenty-one (37%) of the 57 commercial trout farms in production in North Carolina in 2002 were located in Transylvania County with a reported production of approximately 816,000 kg of trout.

The United States Environmental Protection Agency (EPA) began to review aquaculture for consideration in the Effluent Limitation Guidelines (ELG) program in 1998. The ELG rulemaking effort considers economically achievable, technology-based standards for incorporation into effluent rules. EPA outlined three potential regulatory options for flow-through systems in the proposal that was published in 2002 (USEPA, 2002) (Table 1). Option 1 included quiescent zones, sedimentation basins, best management practices (BMP's), and compliance monitoring for total suspended solids (TSS). Option 2 included a drug and chemical BMP plan in addition to the other treatment options in Option 1. Option 3 included solids polishing (removal) with microscreen filters and weekly compliance monitoring for total phosphorus in addition to the Option 2 provisions. EPA proposed Options 1, 2, and 3 for large flow-through facilities with annual production above 215,909 kg (475,000 lb) of trout, but proposed only Option 1 for medium facilities with an annual production between 45,455 kg/yr (100,000 lb/yr) and 215,909 kg/yr

Table 1
Treatment options proposed by EPA for flow-through systems

Treatment option	Specific components included

Option 1	Quiescent zones
	Sedimentation basins
	Best management practices (BMP)
	  Feed management BMP
	  Solids control BMP
	Compliance monitoring for total suspended solids

Option 2	All components of Option 1 Drug and chemical BMP plan
Option 3	All components of Option 2 Solids polishing with microscreen filters Weekly compliance monitoring for total phosphorus
Option A	Primary settling BMP plan for facility BMP plan for drugs and chemicals BMP plan for escape prevention Reporting INADs/extra label drug use
Option B	All components of Option A BMP plan for solids control or Solids polishing with microscreen filter

(475,000 lb/yr). No treatment options were proposed for facilities producing less than 45,455 kg/yr (100,000 lb/yr) because it was evident that these farms could not afford additional treatment of effluents as proposed by EPA.

EPA published a Notice of Data Availability (NODA) on December 29, 2003. In the NODA, two additional options (Options A and B) were included for consideration. Options A and B restructured the combinations previously divided into Options 1, 2, and 3 and added BMP plans for escape prevention in addition to reporting requirements for Investigational New Animal Drugs (INADs) (Table 1).

Quiescent zones (considered in regulatory Options 1 and A) are settling areas for solids in the lower (outflow) portion of tanks. Fish are excluded from quiescent zones with a screen on the upstream side of the zone to prevent disturbance of settled solids. Quiescent zones are typically cleaned with a vacuum hose attached to the drain outlet. Vacuumed solids are then transferred to a sedimentation basin. After settling, accumulated solids are removed periodically from the settling basins with a vacuum tank or a front-end loader and disposed of through land application. Solids control BMP plans (considered under Options 1, 2, 3, and B) would require the farm manager to incorporate a series of site-specific activities to limit the release of solids from the farms. These activities include specification of feeding methods, description of proper pollution control technologies and equipment, proper operation and maintenance of equipment, a cleaning schedule, training of personnel, and record keeping. Compliance monitoring for TSS requires labor and material for weekly monitoring. An 8-h composite water sample would be collected and delivered to a laboratory for analysis.

EPA proposed a drug and chemical BMP plan for Options 2, 3, and A to document the use of drugs and chemicals. Each farm manager would be required to develop a BMP plan that presents a series of site-specific activities to control the inadvertent spillage or release of drugs and chemicals.

Microscreen filters are included in Options 3 and B to achieve additional solids removal with wastewater treatment technology. The microscreen filters would be used to reduce solids discharged from sedimentation basin effluents. Filters would consist of a fine screen (60–90 μm) fitted to a rotating drum and equipped with an automatic backwash system that removes collected solids.

While there have been a number of studies on effluent treatments in aquaculture, few studies have focused on the economic feasibility of the specific effluent treatment options proposed by EPA. Engle and Valderrama (2003) showed that settling basins were not economically feasible for use in pond aquaculture. Wui and Engle (2004), using a mixed integer linear programming model, found that the only feasible treatment alternatives for hybrid striped bass effluents were not draining and not flushing ponds. However, the production risks of not flushing or draining hybrid striped bass ponds have not been thoroughly investigated. Engle and Valderrama (in review) showed, with a mathematical programming model, that implementation of BMPs on shrimp farms can result in changes in net revenue. The net revenue changes were both positive and negative and resulted from changes in production practices, cash flow, and increased costs of financing shrimp production. Analyses of both the farm-level and local economic impacts are important to evaluate the overall effect of imposing additional treatment technologies on aquaculture farms.

Kaliba et al. (2004) developed an IMPLAN analysis of the economic impact of the trout industry. The trout industry in Transylvania County, North Carolina, generated about $9 million in economic output, created 201 jobs, generated $3 million in labor income, and $0.9 million in tax revenue in 2002. This economic activity is particularly important in a county like Transylvania County, where economic prosperity depends upon locally available jobs and diversification of economic activities.

The objective of the current study was to evaluate the economic feasibility of the proposed effluent treatment options for trout flow-through systems. The analyses focused on trout farms in Idaho and North Carolina that produce more than 45,455 kg/yr (100,000 lb/yr).

2. Materials and methods

Surveys of trout farms in Transylvania County, North Carolina, and Idaho were conducted in 2003. Survey data were collected from 13 of the 21 farms (62%) in Transylvania County, NC and 8 of the 26 trout farms in Idaho. The questionnaire solicited information on resource inputs and production levels for 2002. These included trout marketing, sales, and variable costs. Variable cost data collected included: transportation costs, labor costs, chemical and oxygen costs, disease and treatment costs, electricity, fuel and lubricant costs, stocking and feeding costs, waste management and effluent monitoring costs, repair and maintenance costs, and overhead costs. Items included in the overhead cost were: telephone, farm insurance, legal, accounting, office supplies and consumables, interest on capital, land lease costs, and nets, boots, waders and other miscellaneous purchases. Base farm scenarios were developed that included: 1) medium-sized farm in North Carolina producing 68,182 kg/yr (150,000 lb/yr); 2) medium-sized farm in Idaho (90,909 kg/yr; 200,000 lb/yr); and 3) large-sized farm in Idaho (1,136,364 kg/yr; 2,500,000 lb/yr). These base scenarios were selected by choosing the most commonly observed farm sizes in the survey data within the production level categories for which EPA proposed treatment options. Different management practices used in Idaho as opposed to North Carolina required development of separate base scenarios. No large farm scenario was analyzed for North Carolina because there were no farms operating in Transylvania County in 2003 with production levels greater than 215,909 kg/yr (475,000 lb/yr).

Enterprise budgeting techniques (Kay and Edwards, 1999) were used to evaluate the effect of imposing effluent treatment options proposed by EPA on the trout farm size scenarios selected. Enterprise budgets were developed first without the proposed treatment options. Production characteristics, management practices, and prices from the survey results were used to develop estimates of annual costs and returns using standard budgeting techniques (Kay and Edwards, 1999). Costs associated with the treatment options proposed by EPA were added to the budgets and changes in net returns were then measured. Additional scenarios were developed to reflect both farm businesses with no land financing costs and those with land financing costs.

Both “low” and “high” cost scenarios were developed to account for the range of implementation costs resulting from variation in site-specific conditions. For example, compliance monitoring of TSS can be accomplished either by hand or by purchasing an automatic composite sampler. Installation of quiescent zones may or may not result in reduced production depending upon tank configuration. Similarly, construction of offline settling ponds may require destruction of existing tanks if no additional level land is available. For Option 1, the low-cost scenario included: solids control BMP plan, compliance monitoring of TSS done by automatic composite sampler, quiescent zones without negative effect on production, offline settling pond constructed without having to destroy tanks and emptied with a vacuum tank, and no additional land purchased for disposal of solids.

The high-cost scenarios for Option 1 included: solids control BMP plan, compliance monitoring of TSS done by hand, quiescent zones that proportionally reduce production, replacing existing tanks with offline settling ponds because no extra land was available, offline settling pond emptied with a front-end loader, and additional land purchased for disposal of the solids. No site-specific variation in costs was considered for Option 2 because no evidence for such variation was found. Thus, no distinction was made in the analysis of Option 2 for low or high cost variations.

For Option 3, the low-cost scenarios were based on EPA’s cost assumptions (EPA, 2002) while the high-cost scenarios were based on comments of the Flow-Through Subgroup of the Joint Subcommittee on Aquaculture’s Aquaculture Effluents Task Force related to cost variations observed in the trout industry (AETF, 2003). Option A included primary settling, BMP plans for drugs and chemicals, and escape prevention, and reporting for INADs and extra label drug use. Option B included those items in A in addition to either a BMP plan for solids control or solids polishing with a microscreen filter. Both EPA and AETF estimates of costs associated with microscreens were included.

Since production characteristics, costs, and prices vary through time and from farm to farm, a stochastic Monte Carlo simulation model was used to assess the effect of variations in budget parameters on net returns. The enterprise budgets developed were based on typical farm values observed in the survey data. Crystal Ball®[1] (Decisioneering Inc., Denver, Colorado), an add-on program to Microsoft Excel, was used to substitute probability distributions for the single values used in the enterprise budget worksheets. Triangular distributions characterized by a most likely, a minimum, and a maximum value were used for most assumptions. The model generated stochastic fluctuations in selected variables and calculated the probability of achieving positive net returns. Simulations of 1000 iterations per scenario were run.

The enterprise budgets were used to construct mixed integer programming models (Dantzig, 1991; Anderson et al., 2004) for North Carolina farms with capacity to produce 68,182 kg/yr (150,000 lb/yr) and for Idaho farms with capacities of both 90,909 kg/yr (200,000 lb/yr) and 1,136,364 kg/yr (2,500,000 lb/yr). The objective function of the model was to maximize net returns above variable costs. Constraints included supply and demand balances for foodsize trout and for purchased inputs. The North Carolina model included production and sales activities for both food trout and recreational trout sales because the survey data showed different prices and market constraints for sales to the recreational market in North Carolina. The Idaho survey data showed foodfish sales only. Resource availability constraints and non-negativity constraints were included. Effluent treatment option constraints were integer variables including each component of the proposed options. The model was formulated by aggregating all equations so that the model maximizes net returns above variable costs after imposing the various treatment options subject to constraints including integer variable constraints (Meredith et al., 2002).

3. Results and discussion

The response rate of the structured questionnaire in Transylvania County in North Carolina was 81%. Farms had a median production level of 66,000 kg/yr, ranging from 1000–204,500 kg/yr (Table 2). Median market price of food trout was $2.42/kg ($1.10/lb). Major expenses on trout farms were the variable costs of fingerlings, feed, labor, management, and fixed depreciation costs. Fingerlings cost $0.07 each, but ranged from $0.07–$0.17 depending upon the size purchased. Feed conversion ratios ranged from 1.04–1.55 with a median of 1.20. Feed prices ranged from $0.66–$0.79/kg with a median price of $0.70/kg. Depreciation costs ranged from $6,000–$18,000/farm.

Farmers interviewed in Idaho had a median production of 1.2 million kg/yr, ranging from 27,000 kg/yr to 1.7 million kg/yr. Idaho trout farmers purchased eggs instead of fingerlings, at a median cost of $0.015 each. Feed conversion ratios were similar, but Idaho feed costs were slightly lower than in North Carolina. Depreciation costs per farm increased with the larger farm sizes in Idaho.

[1] Use of a particular brand name does not imply endorsement.

Table 2
Selected results of surveys of trout farms in Transylvania County, North Carolina and Idaho

Item	Unit	North Carolina		Idaho	
		Median	Range	Median	Range
Farm size	kg/yr	66,000	1,000–204,500	1,200,000	27,000–1,700,000
Market price food trout	$/kg	2.42	2.33–3.04	1.76	1.54–1.83
Seed cost[a]	$ each	0.07	0.07–0.17	0.015	0.015–0.02
Feed					
FCR[b]		1.20	1.04–1.55	1.20	1.20–1.55
Price	$/kg	0.70	0.66–0.79	0.64	0.62–0.66
Labor[c]	h	1,680	1,470–2,100	1,400	1,400–2,400
Management	h	720	630–1,800	600	600–3,600
Depreciation	$	12,000	6,000–18,000	16,000	8,000–24,000

[a] North Carolina farmers mostly purchased fingerlings while Idaho farmers purchased eggs.
[b] Adapted from EPA's detailed survey aggregated values.
[c] Labor costs include both paid labor and unpaid (family) labor.

3.1. Enterprise budget and risk analysis

The enterprise budget analysis showed that gross revenue for similar sizes of production units is lower in Idaho than in North Carolina (Table 3). Differences in products, target markets, market channels, and positioning of trout products in the respective states result in lower prices received by farmers in Idaho as compared to those received by trout farmers in North Carolina.

The greatest expense in trout farming in both states is feed (Table 4). Feed represented 40% of total variable costs (TVC) and 36% of total costs (TC) of trout farming in North Carolina. On the relatively larger trout farm sizes modeled for Idaho, feed represented from 52–57% of TVC and from 44–50% of TC. Labor was the next highest cost on the farm in NC (14% of TC) and on the medium farm in Idaho (11% of TC). Depreciation was the second-greatest cost (11% of TC) on the larger farm in Idaho. For the NC farms, other cost shares include: management (11% of TC), fingerlings (8% of TC), depreciation (8% of TC), interest on operating capital (7% of TC), and oxygen (6% of TC).

All representative farms modeled showed positive net returns after accounting for both cash and non-cash expenses (Table 3). Overall net returns were highest on the larger farm in Idaho and were followed by the NC farm. The lowest returns modeled were those of the medium-sized Idaho farm.

Breakeven prices above total costs ($BEP_{\text{Total Costs}}$) ranged from \$1.51–\$2.29/kg (\$0.69–\$1.04/lb), with the NC farm model exhibiting the highest $BEP_{\text{Total Cost}}$ (Table 3). However, given the higher market prices in NC, the higher $BEP_{\text{Total Cost}}$ does not by itself reflect lower profitability.

The enterprise budgets included all unpaid family labor and management. The majority of medium-sized farms are family-operated businesses in which the majority of labor and management is from unpaid family members. The value of this resource is especially large in proportion to overall costs and revenue on smaller farm sizes. Assigning a dollar value to the number of hours worked by the family members indicates that net returns from the enterprise, while positive, are low even without considering the costs of effluent treatment.

Table 3
Annual costs and returns for base scenarios, trout production, North Carolina and Idaho

Description	Unit	North Carolina			Idaho				
					Medium farm			Large farm	
		Unit price	Quantity	Total value	Unit price	Quantity	Total value	Quantity	Total value
Gross revenue	kg	2.42	68,182	165,000	1.76	90,909	160,000	1,136,363	2,000,000
Variable costs									
Fingerlings	each	0.07	187,500	13,125	0.015[a]	500,000	7,500	6,250,000	93,750
Production feed	kg	0.704	79,179	55,742	0.638	106,909	68,208	1,336,363	852,600
Medicated feed	kg	0.92	1,623	1,493	1.10	2,182	2,400	27,273	30,000
Chemicals									
Oxygen	Total	9,000	1	9,000	620	1	620	12.5	7,750
Salt	Metric ton	136.4	2.045	279	110	2.73	300	27.273	3,000
Vaccines	Total	1,125	1	1,125	27,500	0	0	1	27,500
Others	Total	900	1	900	1,200	1	1,200	7.5	9,000
Energy	Total	3,000	1	3,000	4,000	1	4,000	12.5	50,000
Labor	h	13.56	1,680	22,781	12.39	1,400	17,346	12,600	156,114
Management	h	25	720	18,000	25	600	15,000	5,400	135,000
Office supplies	Total	200	1	200	200	1	200	8	1,600
Nets, boots	Total	300	1	300	400	1	400	7.5	3,000
Repairs/maint.	Total	3,750	1	3,750	5,000	1	5,000	1.9	9,500
Interest on operating capital		0.08	129,695	10,376	0.08	122,174	9,773.92	1,378,814	110,305
Total variable costs				140,071			131,948		1,489,119
Fixed costs									
Telephone	Total	785	1	785	785	1	785	2	1,600
Legal/accounting	Total	750	1	750	3,000	1	3,000	4	12,000
Insurance	Total	2,000	1	2,000	620	1	620	12.9	8,000
Licenses/taxes	Total	750	1	750	2,000	1	2,000	7.5	15,000
Int. real estate	Total								
Depreciation	Total	12,000	1	12,000	16,000	1	16,000	11.9	190,000
Total fixed costs				16,285			22,405		226,600

Total costs		156,356	154,353	1,715,719
Net returns		8,644	5,647	284,281
Breakeven price				
Above total variable cost	$/kg	2.05	1.45	1.31
Above total cost	$/kg	2.29	1.70	1.51
Breakeven yield				
Above total variable costs	kg	57,881	74,970	846,090
Above total costs	kg	64,610	87,701	974,840

[a] Price of eggs purchased.

Table 4
Percentage of costs of major expense items for North Carolina and Idaho trout farms

Item	North Carolina		Idaho			
			Medium farm		Large farm	
	% TVC[a]	% TC[b]	% TVC	% TC	% TVC	% TC
Feed	40	36	52	44	57	50
Labor	16	14	13	11	10	9
Management	13	11	11	10	9	8
Fingerlings	8	8	–	–	–	–
Depreciation	9	8	12	10	13	11
Int. on operating capital	7	7	7	6	7	6
Oxygen	6	6	<1	<1	<1	<1
Eggs	–	–	6	5	6	6

[a] Total variable costs.
[b] Total costs.

The treatment options proposed by EPA require varying combinations of labor, management, capital (charged as annual depreciation), and operating and maintenance (O and M) costs (Table 5). Quiescent zones require land and capital costs associated with the structure and vacuum components for removal of sediments. Likewise, an offline

Table 5
Estimated annual costs of proposed treatment options by farm size and location

Treatment option/items	Unit	Medium-sized farms		Large-sized farm
		NC	ID	ID
Primary settling				
Quiescent zones				
Land	$	1,114	1,815	27,224
Depreciation	$/yr	2,227	2,474	28,029
Vacuum components	$/yr	500	500	500
Total labor time	h/yr	307	511	7,666
Offline settling pond w/front-end loader				
Depreciation of OSP	$	3,117	3,124	17,900
Land for field application	$	150,000	22,000	275,000
O & M costs	$/yr	6,597	6,597	6,597
Total labor time	h/yr	232	232	584
Offline settling pond w/vacuum tank				
Depreciation of OSP	$	4,167	4,174	18,950
Land for field application	$	150,000	22,000	275,000
O & M costs	$/yr	1,207	1,207	1,207
Total labor time	h/yr	232	232	584
BMP plans				
Drug & chemical plan				
First year only				
Total management time	h	56	56	56

Table 5 (*Contined*)

Treatment option/items	Unit	Medium-sized farms		Large-sized farm
		NC	ID	ID
Total labor time	h	8	8	8
Every year				
Total management time	h/yr	1	1	1
Total labor time	h/yr	1	1	1
Solids control plan				
First year only				
Total management time	h/yr	80	80	80
Total labor time	h/yr	16	16	16
Every year				
Total management time	h/yr	12	12	12
Total labor time	h/yr	12	12	12
BMP plan for escape prevention				
Total management time	h	57	57	57
Total labor time	h	9	9	9
INAD reporting				
Total management time	h	27	27	27
Total labor time	h	92	92	92
Compliance monitoring				
Labor				
Total management time	h/yr	12	12	12
Total labor time	h/yr	192	192	192
Other costs	$/yr	4,008	4,008	4,008
Composite sampler				
Water quality sampler depreciation	$/yr	250	250	250
Total management time	h/yr	12	12	12
Total labor time	h/yr	108	108	108
Other costs	$/yr	4,008	4,008	4,008
Weekly monitoring	$/yr	5,928	5,928	5,928
Solids polishing				
Microscreens-AETF				
Depreciation	$	9,140	9,140	45,700
O & M costs	$	4,300	4,300	21,500
Microscreens-EPA				
Depreciation	$	805	805	1,682
O & M costs	$	1,411	766	766
Total labor time	h/yr	26	26	26

settling pond requires capital for the structure, land for field application and O and M costs. The offline settling pond will require either a front-end loader or a vacuum tank for proper operation. The drug and chemical BMP requires only labor and management time with a much higher time requirement the first year. The solids control BMP plan requires only labor and management time with a greater quantity of time required the first year. Compliance monitoring also requires labor and management if the monitoring is done

Table 6
Net returns and probability of achieving positive net returns after imposing various effluent treatment options, Monte Carlo simulation risk analysis

Treatment strategies	Net returns from North Carolina farm scenario		Net returns from Idaho farm scenarios			
	Medium (68,182 kg/yr)		Medium (90,909 kg/yr)		Large (1,136,363 kg/yr)	
	Most likely ($)	Probability of positive returns (%	Most likely ($)	Probability of positive returns (%)	Most likely ($)	Probability of positive returns (%)
Low-cost scenarios						
Baseline[a]	8,644	46	5,647	2	284,281	84
Option 1[b]	−25,509	0	−33,810	0	43,087	11
Option 2[c]	−27,180	0	−35,469	0	41,427	10
Option 3[d]	−32,320	0	−39,879	0	35,573	10
Option A[e]	−25,954	0	−31,066	0	45,832	11
Option B[f], w/solids control BMP	−28,848	0	−33,924	0	42,974	11
Option B[f], microscreens, EPA	−29,020	0	−33,402	0	42,232	11
Option B[f], microscreens, AETF	−43,776	0	−48,888	0	−43,278	0
High-cost scenarios						
Baseline[g]	6,125	40	3,128	1	271,688	82
Option 1[h]	−55,908	0	−65,142	0	−259,844	0
Option 2[c]	−57,579	0	−66,801	0	−21,503	0
Option 3[i]	−77,474	0	−86,697	0	−352,686	0
Option A[e]	−56,352	0	−62,398	0	−257,098	0
Option B[f], w/solids control BMP	−59,246	0	−65,256	0	−259,958	0
Option B[f], microscreens, EPA	−59,418	0	−64,734	0	−260,700	0
Option B[f], microscreens, AETF	−74,174	0	−80,220	0	−346,208	0

[a] Excluding land financing costs.
[b] Includes: solids control BMP plan, compliance monitoring done by automatic composite sampler, quiescent zones without negative effect on production, offline settling pond constructed without having to destroy tanks and emptied with a vacuum tank, and no additional land purchased for disposal of the solids.
[c] Includes Option 1 plus a drug and chemicals BMP plan.
[d] Includes Options 1 and 2 plus solid polishing with microscreen filters (estimates adapted from USEPA, 2002).
[e] Primary settling, BMP plans for drugs and chemicals, escape prevention, and reporting INAD and extra label drug use.
[f] Includes Option A plus either a BMP plan for solids control or solids polishing with microscreen filter.
[g] Including land financing costs.
[h] Includes: solids control BMP plan, compliance monitoring done by hand, quiescent zones which proportionately reduce production, offline settling pond constructed by having to destroy tanks and emptied with a front-end loader, and additional land purchased for disposal of the solids.
[i] Solids polishing with microscreen filters (AETF, 2003).

by hand. However, if a composite sampler is purchased, additional capital cost is incurred. Solids polishing with a microscreen entails a capital cost. Estimates of the capital cost vary between EPA and the AETF Flow-Through Subgroup, but both estimates are presented (Table 5).

All effluent treatment options resulted in negative net returns for the medium-sized farms in both NC and ID (Table 6). These results showed that none of the treatment options proposed are economically feasible for this farm size. This is the case even in the low-cost scenarios that do not include the cost of purchasing land for waste disposal.

Net returns for the largest farm size considered were still positive after imposing the lowest-cost scenarios for each treatment option. However, while positive, net returns were only $31–38/MT of production. This low level of profitability would generate a return on average investment of less than 4%. Given that opportunity costs of capital in the U.S. are considered to be in the range of 9–12% (Kay and Edwards, 1999; Barry et al., 1995), such a low rate of return is unlikely to be sufficiently attractive for investors. The opportunity costs of using this capital in trout farming are likely to be too great to continue to operate over time. Net returns became negative for all treatment options considered for the large farm under the high-cost scenarios.

The risk analyses resulted in estimates of the probability of each scenario generating positive net returns (Table 6). The estimated probabilities of achieving positive net returns for the North Carolina baseline scenario were 46% for the low-cost scenario and 40% for the high-cost scenario. These probabilities dropped to 2 and 1%, respectively, for the medium-sized farm in Idaho. These relatively low probabilities reflect the low profitability of trout farming on this scale if all family labor and management are charged at full rates. The probability of obtaining positive net returns was highest for the largest farm size in Idaho, 84% for the low-cost base scenario and 82% for the high cost base scenario. These high probabilities of positive net returns likely reflect economies of scale associated with trout farming.

Imposing the various effluent treatment options decreased the probability of generating positive net returns to zero for the medium-sized farms in North Carolina and Idaho as well as for the high-cost scenario on the large Idaho farm. Thus, not only are mean expected net returns estimated to be negative but there is an extremely low probability of these farms surviving the additional costs associated with the proposed treatment alternatives. For the low-cost scenario on the large Idaho farm, the probability of obtaining positive net returns decreased to 11% for Option 1 and to 10–11% for the other options. Thus, even though net returns were still positive after imposing the proposed treatment options, the financial risk increases substantially.

The cost analyses presented in this study include all labor and management costs even if these represent unpaid family labor. However, opportunity costs are real costs when a farm operator is making long-term decisions related to his/her business. If the increased time burdens on labor and management from effluent treatment options become so great that the operator and family have more attractive alternatives, that farmer will choose to do something else with his/her time and the farm may close. Consideration of the effects on unpaid family labor and management is critical to this type of analysis. Inclusion of costs of family labor is the most appropriate way to include this resource in economic analyses (Kay and Edwards, 1994).

3.2. Results of mixed integer programming analysis

3.2.1. Base scenario

Net returns above variable costs in the base scenario of the model for the medium-sized farm in North Carolina were $59,877 (Table 7). Note that these returns do not represent profits because annual fixed costs are not included. Fixed costs are complex to account for in mathematical programming models and objective functions are frequently specified as net returns above variable costs for this reason. However, annual net returns for these treatment options were negative, as shown in Table 6. The mixed-integer programming models were still developed in order to explore additional constraints and limitations imposed by the proposed treatments.

In the base scenario, all tanks on the NC farm were in production with 26 used for foodfish trout production and 4 used to produce trout for the recreational market. Of the total operating capital required ($140,000), $75,000 was equity capital (retained earnings) and the remaining $65,000 was borrowed at an interest rate of 8%. The investment borrowing level used in the model was $90,000, equaling the assumed level of equity capital in the business. The additional $90,000 of credit reserve specified in the model was not needed in the base scenario and remained unused. Available family labor alone was not sufficient to meet all labor and management requirements on the farm; thus, the model also selected hiring part-time labor to fulfill all labor requirements. Baseline farms were economically feasible even with no owner equity in operating capital. Without owner equity, net returns would be reduced by the amount of the interest charged on all operating capital, or $6000, for total net returns of $53,877. Varying levels of interest on operating capital affected the overall level of net returns but did not result in changes in the basic farm production plan.

The base scenario model was particularly sensitive to the level of credit reserves both for operating and investment capital. Reductions in total available operating capital (equity capital plus borrowing capacity) resulted in reducing the number of tanks in production and a consequent reduction in net returns above variable costs of $5455 from the scenario in which 100% of the operating capital was borrowed (Table 7). This sensitivity to availability of operating capital (regardless of whether equity or borrowed) is important because the maximum amount of operating capital (for either a line of credit or a standard loan) is frequently set as a percentage of the value of the crop. For example, if a farmer were required to take tank space out of production for quiescent zone development, total production is reduced, and the operating capital borrowing capacity is also reduced. This factor may not be critical if land adjacent to the farm is available for purchase at prices that are economically feasible. However, we suggest that trout farms often are located in areas with high demand for competing uses that put upward pressure on land prices. As total operating capital decreased, tanks were dropped out of production: from $140,000 to $129,000, four tanks were dropped out of production, followed by five more as total operating capital decreased to $119,000 and four more with each additional decrease of $20,000 in operating capital. Net returns would decrease by approximately $6000 for each $20,000 decrease in operating capital, depending upon the ratio of equity to borrowed operating capital. The decrease in net returns resulted from increased interest costs.

Table 7
Results of NC base model at different levels of operating capital, considering both equity and borrowing capacity

Scenario/total available capital (equity + borrowed) ($)	Equity capital ($)	Borrowed capital ($)	Net returns ($)	Foodfish tanks (no.)	Recreational fish production tanks (no.)
Base					
$140,000	75,000	65,000	59,877	26	4
No equity, full borrowing capacity					
$140,000	0	140,000	53,877	26	4
Low equity, reduced borrowing capacity					
$139,000	4,000	135,000	48,422	22	4
Base equity, reduced borrowing capacity					
$129,000	75,000	54,000	54,102	22	4
$119,000	75,000	44,000	47,514	17	4
$99,000	75,000	24,000	40,925	13	4
$79,000	75,000	4,000	33,137	9	4

Investment capital constraints in the model included both equity capital that could be used for investment and borrowed investment capital. Sensitivity analyses were developed in which: (1) additional land was assumed to be available; (2) investment capital borrowing capacity was assumed to be $90,000; and (3) operating capital borrowing capacity was assumed to increase with the addition of any new tanks. The assumed $90,000 of borrowing capacity in investment capital was based on the assumption that the land and tanks were owned and served as collateral. Thus, the borrowing capacity would be equal to the value of the land and tanks. Under these assumptions, the model constructed 12 new tanks that would be financed through borrowed capital. Net returns would increase to $63,794 from the additional production generated. Labor needs were met in the model by hiring additional part-time labor.

Both land prices and tank construction costs affected the farm's ability to add to the physical plant of the business. If the farm did not have land available for construction of new tanks, no new tanks would be constructed even with adequate levels of borrowing capacity. This occurred because the average land purchase price specified in the model of $25,000 was too high for expansion to be feasible. Land prices had to drop to less than $13,000/acre for expansion to be feasible (Table 8). At a land price of $12,500, 16 new tanks would be constructed that, after debt-servicing charges, would increase net returns above variable costs to $67,179. Land prices of $6,000 or less would allow construction of 20 new tanks for net returns above variable costs of $70,204. A 40% decrease in tank construction costs resulted in further increases in farm capacity through additional construction of new tanks and net returns above variable costs of $76,401–$77,841, depending upon land price. However, increasing tank construction costs to $2,917 had no effect on construction of new tanks.

3.2.2. *With effluent treatment options*

The mixed integer programming models were not feasible under any proposed effluent treatment options when full costs of quiescent zones and offline settling basins were used in the model (Table 9). Construction of off-line settling basins required higher levels of capital investment than is likely to be available for trout farms in NC. Lenders often impose a cap that limits the total amount of lending to a particular farm; some lenders base this cap on a percentage of the value of the crop inventory. The model could not find a feasible solution when credit reserves were specified in the model at levels commonly used by rural

Table 8
Investment capital, if no land is available on the farm and operating capital increases with the number of new tanks

Land cost ($)	Tank cost ($)	New tanks built (no.)	Net returns ($)
Base			
$25,000[a]	2,333	0	59,877
12,500	2,333	16	67,179
6,000	2,333	20	70,204
6,000	1,750	24	77,841
12,500	2,917	16	67,493
12,500	1,750	24	76,401

Tank construction cost is reduced by 40% in these cases.

[a] Land costs were observed to range from $12,500–125,000/ha ($5,000–$50,000/ac) in the NC survey.

Table 9
Effect on net returns of varying investment costs of primary settling structures

Estimated cost of primary settling structures (%)	Investment capital		Net returns above variable costs
	Equity	Borrowed	
100	Infeasible	Infeasible	Infeasible
75	$90,000	$82,075	$12,295
50	$90,000	$90,000	$33,971

banks for aquaculture loans. Since aquaculture is viewed as a high-risk activity in areas that are primarily row-crop areas, the standards used for evaluating aquaculture loans may differ from those used in other forms of agriculture. Moreover, banks in some states will not use swimming fish inventory as collateral for loans.

For the model to produce a feasible solution, either the costs of designing and installing quiescent zones and offline settling basins had to be reduced to less than 75% of the estimated cost or the level of borrowing capacity would have to exceed the value of existing facilities. This would require farms to use personal collateral other than the land and tanks themselves. At 75% of estimated costs of constructing quiescent zones and offline settling basins, only eight tanks were in production and net returns above variable costs were only $12,295 (Table 9). Farms that do not account for all unpaid family labor or sunk costs in equipment and facilities may be able to construct facilities at lower cash costs. Subsequent runs of the model were developed using quiescent zone and offline settling basin investment capital requirements of 50% of the estimated cost.

Table 10 presents results of the mixed integer programming models for the medium-sized farm scenario in North Carolina when the various effluent treatment options were forced into the models using the 50% level of estimated construction costs of quiescent zones and offline settling basins. Net returns above variable costs decreased dramatically (43–56%) for Options 1, 2, A, and B with a solids control BMP. The model could not identify a mathematically feasible way to comply with either Options 3 or B with microscreen filters.

Forcing treatment Option 1 into the model resulted in dropping four tanks out of production. Less operating capital was borrowed because fewer tanks were in production,

Table 10
Effect on net returns of imposing various effluent treatment options on the medium-sized farm in North Carolina

Scenarios/treatment options		Tanks in production			Capital borrowed	
	Net returns ($)	Foodfish (no.)	Recreational (no.)	Labor hired (h)	Operating ($)	Investment ($)
Base scenario	59,877	26	4	1,500	65,000	0
Option 1	33,971	22	4	495	51,088	85,549
Option 2	26,358	22	4	504	58,024	85,549
Option 3	Infeasible		–	–	–	–
Option A	32,859	22	4	577	51,088	85,549
Option B w/solids control BMP	26,145	22	4	934	53,008	83,049
Option B w/microscreens, EPA estimates	Infeasible		–	–	–	–

but an additional $85,549 of investment capital was borrowed. The additional investment capital was required primarily for primary settling units.

A BMP plan for drugs and chemicals was added to the model to evaluate the impact of imposing Option 2 on medium-sized trout farms in North Carolina (Table 10). The solution was similar to that for Option 1 with slightly lower net returns above variable costs ($26,358), a reduction of $7613 that accounted for the increased variable costs, interest on operating capital, and increased hours of part-time labor hired.

The use of microscreens for solids polishing and weekly compliance monitoring requirements were added to the Option 2 model to evaluate farm-level effects of Option 3. The model could not produce a mathematically feasible solution when Option 3 was imposed for either the EPA or the AETF cost estimates.

Net returns above variable costs of $32,859 (45% decrease from the base scenario) were obtained when Option A was imposed on the model (Table 10). Total operating capital borrowed was $51,088. Total investment capital borrowed was $85,549. Part-time labor was hired for 577 h. Since the driving factor in the model results was the amount of investment capital required for the quiescent and settling basins, results of the sensitivity analyses were similar to those discussed earlier.

Option B with a solids control BMP plan resulted in net returns above variable costs of $26,145 (Table 10). Option B with microscreen filters was not mathematically feasible. Negative net returns above variable costs were obtained even with the EPA estimates of microscreen costs.

Fig. 1 presents net returns above variable costs for the proposed treatment options for the two Idaho farm scenarios. Overall, trends were similar to those found for the NC farm scenarios. For the medium-sized farm, net returns above variable costs decreased to very low levels for proposed treatment Option 1. Option 2 was similar. Option 3 generated negative net returns above variable costs (for both EPA and AETF cost estimates) for the medium-sized farm. Option A resulted in net returns above variable costs of a similar magnitude to those of Options 1 and 2. None of the Option B treatment options were feasible.

On the large Idaho farm, net returns above variable costs were positive, but at levels 74–84% lower than pre-treatment levels for Options 1, 2, and A. Options 3 and B (with EPA estimates) were still positive, but at a lower level. Options 3 (with AETF estimates), B (with BMP for solids control), and B (with AETF estimates) were all negative.

Investment capital limited the farm's ability to implement the proposed treatment options. Part of the need for additional investment capital is for the land costs associated with disposal of wastes from off-line settling basins. Alternatives to purchasing land for waste disposal may include land application on fields not owned by the farm or possibly the sale of material as a soil amendment for gardeners or landscapers. In this study, the analyses were run at 50% of the estimated investment capital requirements and additional sensitivities were run at much lower levels of investment capital. At the lowest levels, the investment cost approximated rent levels commonly charged in areas near trout farms in NC and ID. The results of the study were robust across this wide range of investment capital levels. Individual farmers may be able to develop relationships with other farms that reduce the costs associated with land disposal. However, many of the trout farming areas have high demand for competing uses that have increased the value of land, its rent, and may decrease

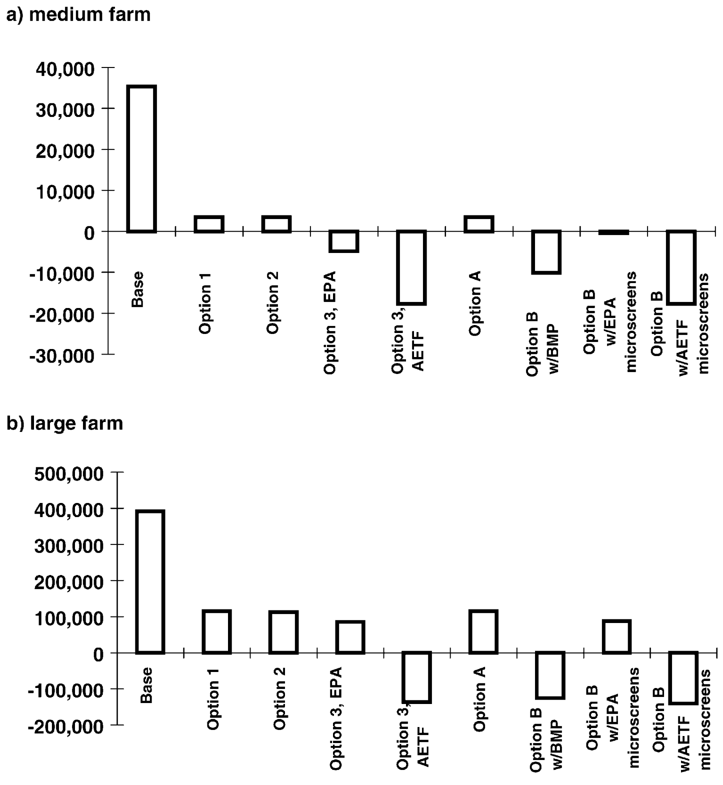

Fig. 1. Net returns above variable costs for proposed treatment options for two Idaho farm scenarios.

the number of opportunities for low-cost land application of waste products. It is not known as to whether a marketable product could be developed from the waste products. There likely would be additional research and development costs to develop appropriate packaging, storage, and transportation logistics with such a product that would result in some increase in investment capital. Limits on investment capital borrowing resulted in reducing the number of tanks in production. Imposing effluent treatment technologies forces farms to operate at less efficient levels.

4. Conclusions

Trout farming has been a profitable aquaculture business in the U.S., particularly in Idaho and North Carolina. Results of the enterprise budget analysis showed that proposed effluent treatment options result in negative net returns for medium-sized farms in both North Carolina and Idaho. Under higher-cost scenarios, even the largest farm size considered became unprofitable after imposing treatment options. The risk analysis showed very low probabilities of generating positive net returns after imposing treatment options for all farm sizes and cost levels. The mixed integer programming models further demonstrated that proposed treatment options will not be economically feasible for trout farms in North Carolina and Idaho. The primary factor that influenced model results was the capacity to borrow operating and investment capital. Specific components of borrowing capacity are defined differently by different banks, but typically are based on a firm's balance sheet. Collateral used frequently includes the value of land and raceways, equipment, and in some cases, may include swimming inventory. The borrowing capacity levels used in the model were based on the values of these components obtained from the survey, but sensitivity analyses showed that the results were robust over a wide range of values. Limits to the borrowing capacity of both operating and investment capital were the primary factors. The models showed that the high land prices in areas adjacent to trout farms prevent their expansion. If additional production area is taken out of production in order to add effluent treatment technologies, then the operating capital borrowing capacity is reduced; yet, investment capital borrowing would need to increase.

Some farms had incorporated some of the treatment options proposed by EPA prior to the consideration of new guidelines. It is likely that these farms were able to do so because additional land at affordable prices was available or because sunk costs on older farms do not generate cash expenses. This would allow these farms to expand production to offset the increased fixed costs associated with treatment, particularly if non-cash expenses were not taken into consideration. However, sunk costs in capital goods will eventually need to be replaced and economic analyses must consider long-run effects.

This study further documented the relatively high levels of financial risk on trout farms. The proposed regulations considered in this analysis required additional investment capital that further increased financial risk. While some fish farmers successfully manage around relatively high levels of financial risk, at some point the risk becomes greater than the operator's ability or willingness to accept. The farm then shuts down.

Limits to borrowing capacity forced farms to take tanks out of production. The budget analysis showed that larger farms can manage the expense of treating effluents better than smaller farms, but imposing these regulations forces farms to reduce production due to limited capacity to borrow additional funds. Thus, these proposed regulations create a paradox for farmers in that the increased investment capital required for compliance increases economies of scale and incentives to expand farm size. However, since the additional investment is not generating additional production, it uses up borrowing capacity and causes farmers to reduce production potential. Thus, farms are forced to operate at inefficient levels.

Overall, the proposed regulations pose serious economic challenges to trout farms, increase financial risk on farms, and increase economies of scale and barriers to entry. Limitations on borrowing capacity may force existing farms to substitute treatment facilities for production units and, thus, operate at inefficient levels.

Acknowledgments

The authors thank the trout farmers in Idaho and North Carolina who participated in the survey interviews. This material is based upon work supported by the USDA Cooperative

State Research, Education and Extension Innovation Fund grant (Agreement No. 00-38859-9235) administered by Mississippi State University.

References

AETF (Technical Subgroups of the Aquaculture Effluents Task Force). 2003. Comment Package from the Joint Subcommittee on Aquaculture, Aquaculture Effluents Task Force in Reference to: 40 CFR Part 451 Docket number W-02-01 Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category: Proposed Rule.

Anderson, D.R., Sweeney, D.J., Williams, T.A., 2004. Quantitative Methods for Business, South-Western Publishers, OH.

Barry, P.J., Ellinger, P.N., Hopkin, J.A., Baker, C.B., 1995. Financial Management in Agriculture, Interstate Publishers Inc., Danville, IL.

Dantzig, G.B., 1991. Linear Programming and Extensions, Princeton University Press, Princeton, NJ.

Engle, C., Valderrama, D., 2003. Farm-level costs of settling basins on commercial catfish farms. Aquaculture Eng. 28, 1–29.

Engle, C., Valderrama, D., in review. Economic effects of implementing selected components of Best Management Practices (BMPs) for Semi-Intensive Shrimp Farms in Nicaragua. Aquaculture Econ. Manag.

Kaliba, A., Engle, C.R., Pomerleau, S., Hinshaw, J.M., Sloan, D., 2004. The economic impact of the trout, *Oncorhynchus mykiss*, industry on Transylvania County, North Carolina. J. Appl. Aquaculture 15 (1–2).

Kay, R.D., Edwards, W.M., 1999. Farm Management, Fourth ed. McGraw-Hill, NY.

Meredith, J.R., Shafer, S.M., Turban, E., 2002. Quantitative Business Modeling, South-Western Publishers, OH.

NASS (National Agricultural Statistical Services) 2003. Trout Production. Fact Finder for Agriculture, Aq 2 (2-03), US Department of Agriculture, Washington, DC.

NASS (National Agricultural Statistical Services) 2000. 1998 Census of Aquaculture. US Department of Agriculture, Washington, DC.

USEPA (US Environmental Protection Agency) 2002. Development Document for Proposed Effluent Limitations Guidelines and Standards for the Concentrated Aquatic Animal Production Industry Point Source Category. US Environmental Protection Agency. EPA-821-R-02-016.

Wui, Y., Engle, C., 2004. A mixed integer programming analysis of effluent treatment options proposed for pond production of hybrid striped bass, *Morone chrysops* × *M. saxatilis*. J. Appl. Aquaculture 15 (1–2).