Economic Analysis of an Alternative Fish Raceway System

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ABSTRACT

The costs of purchasing, installing and maintaining the growout facility may represent the biggest investment cost for an aquaculture operation. Therefore, alternative materials that have the potential to maintain or increase productivity while reducing costs can have a large impact on profitability. One such material is high density polyethylene (HDPE). The costs and benefits of purchasing, installing, and operating a 2000 gallon (7560 liter) plastic (HDPE) "U" shaped raceway in West Virginia were estimated and compared to a traditional flat bottom concrete raceway system of similar volume in Pennsylvania. The cost of installing a 2000 gallon (7560 liter) concrete system was estimated using recent quotes from a local concrete tank manufacturer.

Preliminary results indicate that the plastic "U" shaped tanks were less expensive to purchase, install, and operate than the comparable concrete system. This provides medium and small sized aquaculture operations with an adaptable product that lowers the cost of fish production, provides flexibility with design changes, and allows for a resale value due to the mobility of the lightweight tank. Other benefits include lower labor requirements for waste management. The solid removal manifold in the plastic tank allowed for efficient tank cleaning to occur, which ultimately helps lower operating costs and increase profitability.

The study has implications for small- and medium-scale aquaculture operations in West Virginia and surrounding states with similar resource endowments. The increased adoption of new materials such as HDPE will lead to increased aquaculture production and industry growth, with corresponding statewide economic development benefits.

INTRODUCTION

Traditionally trout have been raised for stocking purposes in concrete rectangular raceways due to labor efficiency, ease of handling or harvesting, and the ability to reuse water (Bender, Lukens, & Ricker, 1999; Boardman, Maillard, Nyland, Flick, & Libey, 1998). The large-scale production facilities operated by state and federal agencies are responsible for stocking large areas for public recreational fishing.

Within the past decade a number of public hatcheries have come under increased pressure to reduce waste discharges as well as to reduce the cost of production (Ewart, Hankins, & Bullock, 1995; Flemlin, Sugiura, & Ferraris, 2003; Hulbert, 2000). This pressure has resulted in the closing of some hatcheries, reduced production in other hatcheries (Hulbert, 2000; Westers, 2000), and the purchase of trout from private producers to reduce the cost of stocking public waters used for recreational fishing.

Private trout producers usually have smaller water sources than the larger public facilities and therefore have less production. As more states turn to private suppliers for stocking public streams for recreational fishing, there is a growing recreational market for private trout producers. This creates more demand for developing small to moderate flowing water sources suitable for trout production.

The main objective of this study was to compare the costs and growth rates of trout in the alternative “U” shaped plastic tanks to the traditional concrete raceway system. Due to the coal mining industry, West Virginia has dozens of biosecure free flowing water sources that can be used for small scale fish production. Economies of scale usually imply a higher cost of production for smaller producers, making it difficult to compete with larger operations. This study uses a small mine water discharge site to determine if there is a way for smaller producers to reduce their costs by using a “U” shaped plastic tank for fish production.

METHODS

Five 30 foot sections of 60 inch diameter HDPE pipe were cut in half longitudinally to create 10 tanks each with a volume of 2000 gallons. The pipe has a ribbed exterior and a smooth interior providing a double hull to protect against leaks. End caps were heat welded on each end and each discharge side had a 36 inch wide weir notch on the end plate and a hole cut at the bottom to allow for the hydraulic pressure to push the solids into a 3 inch perforated pipe when a waste valve was opened for cleaning. Nine tanks were intended to be placed into the ground approximately 18-24 inches deep with a 3 foot drop between each tank. Improper installation by the contractor caused stability problems with the tanks that were set on the ground rather than in the ground.

In November of 2006 one group of 4 inch rainbow trout fingerlings were stocked into a series of 2,000 gallon “U” shaped plastic tanks at a density of about 4 fish per cubic foot. The plastic tanks were located in a remote area of southern West Virginia that had a reliable high quality mine water discharge. A chain link fence surrounded the tanks and three electrified wires around the fence were used to minimize external variables (wildlife intrusion). The cohorts of this group, from the same hatchery, were stocked at similar densities into a concrete flat bottomed tank of similar volume at a commercial trout hatchery. Both of these sites had a history of normal trout growth from previous production cycles with flows ranging between 100 to 200 gallons per minute resulting in acceptable exchange rates.

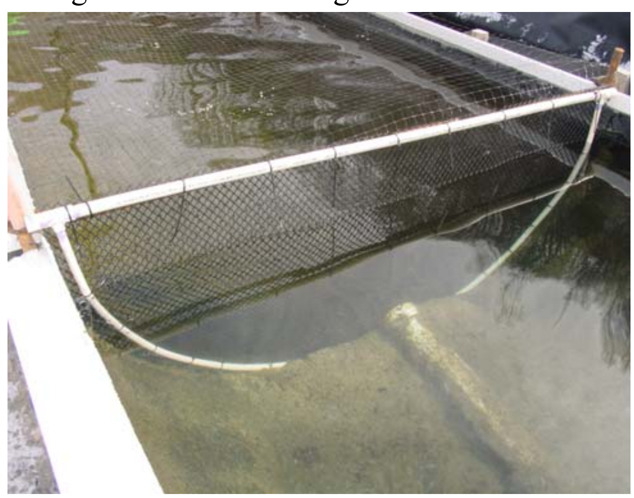
Both groups were fed a high protein (42%), high fat (16%) commercial trout diet throughout the 31 week production cycle. Every six weeks random samples of 50 fish were taken for macroscopic health checks and average weights. Demand feeders were used at both sites and initially nylon netting was used to deter aerial predators. The cost of purchasing, installing, and cleaning the custom plastic tanks during the study was compared to the estimated cost of purchasing, installing, and cleaning precast concrete tanks as well as poured concrete tanks. Businesses that specialize in building concrete tanks provided recent quotes for this cost estimate.

The annual labor cost for cleaning the plastic and concrete tanks was determined by using an average of five cleanings taken over the last five months of the study. Growth data were collected every six weeks from a random sample of at least 50 fish from both systems, using an Ohaus bench scale. As the trout approached marketable size, fin condition was recorded using a scale from 0 (perfect) to 5 (> 90% missing or eroded) for each of the 7 rayed fins. This meant that each fish had a potential score of between 0 and 35. A photographic key, developed by Hoyle (2007), for each of the fins, was used as a reference during the fin condition data collection.

Water quality was monitored in the plastic tanks using a YSI 600XLM sonde that recorded temperature, pH, oxygen and conductivity every hour. A YSI oxygen meter was used for temperature and oxygen readings from the concrete system. A certified analytical laboratory analyzed water samples from both sites for anions and cations in order to identify any parameters that were outside the accepted range for growing rainbow trout. A layout of the "U" shaped plastic tank system is shown in Figure 1 (below left). The concentrated solids in the settling zone are shown in Figure 2 (below right).

Figure 1 Plastic research tanks

Figure 2 Concentrating solid waste



RESULTS

Critical water quality parameters remained stable at both sites for the majority of this study. Water temperatures remained between 10 and 15 degrees Celsius at both sites. Water chemistry analysis from both sites showed that all measured parameters were within the tolerance range of trout (Table 1). The water quality monitoring that was done at each site showed that the concrete tank had one low oxygen event during the last week in May (week 28), which resulted in the precautionary removal of 400 trout (40%) from the system. The plastic tanks had two low oxygen events in the lower tanks, one in May and one in June, due to the intrusion of a bear which managed to divert the water from the lower tanks. The upper two tanks were unaffected by this diversion of water which is why these tanks were used for the biological data (growth, fin condition, mortality).

Table 1.
Water Chemistry Data From the Two Water Sources.

			Plastic			Concrete	
			Dates			Dates	
		12/14/2006	2/7/2007	6/13/2007	11/2/2006	2/26/2007	6/15/2007
Analyte	units						
pH			7.26			6.67	
SO4	mg/l	337	324	345	7.36	12.7	7.11
Hardness	mg/l			464		29.3	20.54
F	mg/l	<.088	0.092	0.093	0.13	<0.08	<.008
Cl	mg/l	2.9	5	5	10.72	10.77	10.16
NO2	mg/l	<.03	<.009	<.009	<0.03	<.009	<.009
NO3	mg/l	15.35	0.881	1.063	2.92	0.26	0.576
NH3	mg/l			0.0233	0.0025		0.02
PO4	mg/l	<.158	<.051	<.051	<.158	<.051	0.26
Al	mg/l	<.1	<0.1	<.1	<.1	<0.1	<.1
Ca	mg/l	100.19	83.16	104.68	6.04		4.91
Mg	mg/l	50.47	42.38	48.55	2.52		2.28
Fe	mg/l	<.1	0.23	<.1	<.1		<.1
Mn	mg/l	<.1	<.1	0.14	<.1		<.1
Zn	mg/l			0.021	<.1		0.016
TSS	mg/l					2	
Conduc.	uS/cm	925				134	

Annual Maintenance / Cleaning costs:

Assuming labor costs of $10/hr. and that cleaning occured every 5 days (73 times per year), an average of 5 cleanings during the study resulted in 25 minutes per cleaning for 9 plastic tanks. This translates into 3.4 hours per tank per year or $34/tank/year. The concrete tank used a pump to remove the solids from the flat bottom. The average cleaning of the settling zone (4 feet long by 4 feet wide) in this tank required 6.75 minutes. This translates into 8.2 hours per tank per year or $82/tank/year (Table 2). The purchase price for 10 precast concrete tanks was $45,850. The same number of poured concrete tanks cost $33,110 and ten plastic tanks cost $24,507. Installation costs were significantly higher for the precast tanks due to the need for a heavy crane to lift the tanks into place.

Table 2.
Cost comparison for 2,000 gallon concrete and plastic tank system (10 tanks)

	Purchase Price	Install / Prep. $	Cleaning	Total Cost	% precast
Concrete precast	45,850	6,000	820	52,670	100%
Concrete poured	33,110	4,000	820	37,930	72%
Plastic (HDPE)	24,507	3,000	304	27,811	53%

Growth, fin condition, and mortality data are presented based on the average of the top two plastic tanks compared to the concrete tank. After 30 weeks the final weights were averaged from a random sample of at least 50 fish from the approximately 1000 fish stocked in each tank. The trout in the concrete tank showed better growth but higher mortality (2.20 gm / day growth and 5.6 % mortality) than those in the plastic tanks (1.75 gm./day growth and 3.96 % mortality, see Table 3).

Table 3.
Growth, fin condition, and mortality from concrete and plastic tank system

			Growth rate			
	volume (m^3)	gm. Gain	gm / day	fin cond.	% mortality	culture days
Concrete	7.84	484.50	2.20	7.93*	5.62	220
Plastic	7.57	382.89	1.75	8.08*	3.96	219

*$\alpha < 0.05$

A one way ANOVA was performed on the fin condition data using total scores. When the trout from the two plastic tanks were compared to the trout in the concrete tank, the ANOVA procedure showed there was no significant difference ($\alpha < 0.05$) of fin erosion comparing the two trout populations.

Using the data collected from this research, enterprise budgets were developed for a representative small farm, using the new plastic tanks, assuming annual production of 20,000 and 50,000 pounds (Tables 4 and 5). The enterprise budget included costs for a chain link fence and an emergency pump. The interest rates were set at 10% and depreciation for the initial investment was 5% per year.

Enterprise budgets require various assumptions to be made. The financial assumptions included an annual interest rate at 10% and annual depreciation of 5% on the investment. Biological assumptions include: a flow rate of 150 to 200 gallons per minute gravity flow for the 20K production system (one line of tanks) and 600 to 800 gallons per minute (four lines of tanks) for the 50K system; a three foot drop between each level of production; concentration of un-ionized ammonia below 0.03 mg/l; and a stocking rate of 1000 fingerlings per tank with a 5% mortality. With 48 weeks of production per tank per year and an average growth rate of 2.1 grams per day, each tank was assumed to produce approximately 1,476 pounds per year. Further details are provided in Miller (2008).

Table 4.

20,000 pound per year trout farm – Plastic Tanks Enterprise Budget

(a) Construction	Unit	price /unit $	# units	Total $	% Total
Site Preparation	dollar			3000	5%
Water diversion	dollar			500	1%
Plastic tank (2000 gallon)	tank	2,450	14	34300	55%
Emergency pump / pipe		1,100	1	1100	2%
Screens (1 per tank)	each	22	14	308	0%
Chain link fence (option)	foot	20	1000	20000	32%
sub-total				59208	95%
Equipment					
Demand feeder (installed)	each	200	14	2800	4%
Net , gloves, boots		250	1	250	0%
sub-total				3050	5%
Total initial investment				$62,258	100%

(b) Maintenance	Unit	price /unit $	# units	Total $	% Total
Annual sales					
Recreational market	lb.	2.5	15,000	37500	83%
Food market	lb.	1.5	5,000	7500	17%
Total Sales	lb. or dollar		20,000	45000	100%
Variable Costs					
fingerlings (3")	each	0.21	14,000	2940	11%
Feed (FCR=1.2:1)	lb.	0.4	24,000	9600	36%
Electricity	month	10	12	120	0%
Labor (8 hours/week)	hour	10	416	4160	16%
Interest on operating capital	dollar	0.1	16820	1682	6%
Delivery Costs	mile	0.5	1000	500	2%
Total Variable costs				19002	72%
Fixed Costs					
Interest on Ave. Ann. Inv.	percent	10%	31129	3113	12%
Property taxes	percent	2%	62258	1245	5%
Repairs and depreciation	percent	5%	62258	3113	12%
Total Fixed Costs				7471	28%
Total Costs				26473	100%
	Total cost / pound produced	$1.32			
	Returns to land & operator's mgmt.			$18,527	

Table 5.

50,000 pound per year trout farm – Plastic Tanks Enterprise Budget

(a) Construction	Unit	price /unit $	# units	Total $	% Total
Site Preparation	dollar			6000	5%
Water diversion	dollar			2000	2%
Plastic tank (2000 gallon)	tank	2,450	36	88200	72%
Emergency pump / pipe		2,750	1	2750	2%
Screens (1 per tank)	each	22	36	792	1%
Chain link fence (option)	foot	20	750	15000	12%
sub-total				114742	94%
Equipment					
Demand feeder (installed)	each	200	36	7200	6%
Net , gloves, boots		250	3	750	1%
sub-total				7950	6%
Total initial investment				$122,692	100%

(b) Maintenance	Unit	price/unit $	# units	Total $	% Total
Annual sales					
Recreational market	lb.	2.5	37,500	93750	83%
Food market	lb.	1.5	12,500	18750	17%
Total Sales	lb. or dollar		50,000	112500	0%
Variable Costs					
fingerlings (3")	each	0.21	36,000	7560	12%
Feed (FCR=1.2:1)	lb.	0.4	60,000	24000	40%
Electricity	month	25	12	300	0%
Waste discharge fee	dollar	0.01	50,000	500	1%
Labor (16 hours/week)	hour	10	832	8320	14%
Interest on operating capital	dollar	0.1	40680	4068	7%
Delivery Costs	mile	0.5	2500	1250	2%
Total Variable costs				45998	76%
Fixed Costs					
Interest on Ave. Ann. Inv.	percent	10%	61346	6135	10%
Property taxes	percent	2%	122692	2454	4%
Repairs and depreciation	percent	5%	122692	6135	10%
Total Fixed Costs				14723	24%
Total Costs				$60,721	100%
	Total cost / pound produced	$1.21			
	Returns to land &operator's mgmt.			$51,779	

Using information from the enterprise budgets, a capital budgeting (benefit-cost) analysis was conducted. The Net Present Value (NPV) is relatively large, which is a positive trait for investing in a project. Assuming a 10-year planning horizon and the two production scenarios, the NPV is shown for the 20,000 and 50,000 lb. production scenarios at three different interest rates (Table 6). The internal rate of return over the same 10 year period is shown for both production levels in Table 7.

Table 6

Net Present Value (NPV) for three different interest rates over 10 years, 20,000 and 50,000 lb. production systems.

Cost of Capital	NPV – 20,000 lbs./yr.	NPV – 50,000 lbs./yr.
7%	$103,005	$322,590
10%	$82,980	$266,836
13%	$66,614	$221,318

Table 7

Internal Rate of Return (IRR) over 10 years, 20,000 and 50,000 lb. production systems.

Time Period	Internal Rate of Return -20K	Internal Rate of Return-50K
10 years	36%	39%

DISCUSSION

For the 20,000 pound scenario a single series of tanks was chosen to accommodate flows as low as 200 gpm. If more water is available (at least 400 gpm), a paired series of parallel tanks would be possible which would reduce the fence requirement as well as the threats from oxygen or ammonia issues that arise with multiple water reuse in raceways. The 50,000 pound scenario uses estimates for labor and land preparation based on the expense data collected during the research. The water flow (farm design) changes from a single series of tanks (20,000 lbs./yr.) to four parallel series of tanks with nine levels for the 50,000 lbs./yr. design. Each series of tanks would require up to 200 gpm.

The purchase price of precast tanks was highest. Installation was also higher due to the need for a heavy crane ($2,000/day) to lift the tanks into place. The poured tanks require the rental of a concrete pump, on the recommendation of two concrete contractors, for pouring the walls. The land preparation for the plastic tanks was slightly less than the flat bottomed concrete tanks because the plastic tanks require a narrower leveled pad due to the “U” shaped nature of the tank. Variations in land preparation will depend on each site.

What is not known at this point is the useable life span of the plastic tanks. If the plastic tanks have a shorter life span then concrete tanks, then the depreciation costs would be higher for the plastic tanks. The HDPE material is extremely resistant to weathering and it is expected that a properly installed tank, with welded strips on each side to protect the open ribs, will last for at least 10-20 years, and possibly as long as concrete tanks.

Ultraviolet radiation would be expected to make the tanks less resilient over time. The manufacturer of the tanks provided ample documentation from the transportation departments of various states showing the expected useful life of HDPE to be about the same as reinforced concrete products (50 years).

The difference in growth rates was likely due to the increased stress and reduced access to feed due to the predator problem in the plastic tanks. In an effort to reduce the smell of fish feed, which was drawing black bears to the plastic tanks, daily hand feeding began on April 26th. Prior to that, feed was placed in the demand feeders every other day and the caretaker noted if the feeder was empty. The concrete system did not have a predator problem and the demand feeder consistently contained feed. This resulted in improved access to trout feed for the concrete system.

There are many considerations to take into account when deciding between the two materials used in this study. A list of these considerations is shown in Table 8.

Table 8
Comparisons between concrete and plastic (HDPE)

CONSIDERATIONS	CONCRETE	PLASTIC (HDPE)
Purchase Cost	Higher	Lower
Tank weight	36,000 lbs.	760 lbs.
Site Prep. Cost	Higher	Lower
Vulnerability	Low	Moderate
Installation	Critical	Critical
Easily Modified	No	Yes
Useful Life	20 years	20 years?
Waste Removal	Slower	Faster
Growth / Mortality	Normal	Normal
Flexibility	None	Some
Production volume	2000 gallons	2000 gallons
Size restrictions	Customized	60 inch diameter
Outside use	Internal rebar	Recommended 20” in ground
Inside use	Internal rebar	HDPE cross supports
Resale or Transfer	More difficult	Less difficult

Waste removal

Assuming labor costs at $10/hr. and that cleaning occurs every five days (73 times per year), an average of five cleanings during the study resulted in 25 minutes per cleaning for nine plastic tanks. This translates into 3.4 hours per tank per year or $34/tank/year. The concrete tank used a pump to remove the solids from the flat bottom. The average cleaning of the settling zone (four feet long by four feet wide) in this tank required 6.75 minutes. This translates into 8.2 hours per tank per year or $82/tank/year. For illustration, the labor savings for a ten tank system cleaned every day for the 20 year estimated life span of the tanks amounts to $48,000. The budgets use a more realistic cleaning schedule of every 5 days.

A waste removal fee was added to the variable costs for the 50,000 pound per year operation because it is unlikely that an operation of that size would be able to remain environmentally sustainable without some waste removal expense. The waste removal system for the plastic tanks was a simple and fast process. Taking advantage of the "U" shape and the smooth plastic material, an 18 inch squeegee was used to move the solid waste toward the 3 inch diameter manifold pipe that ran along the lowest portion of the settling zone. The ¾ inch openings in the lower portion of the manifold pipe allowed the accumulated solids to exit through the pipe, due to head pressure from water in the tank, when an external valve was opened. This process avoided siphoning and pumping, which added to the variable cost. The cost of the plastic tank system included the 3 inch valves and the manifold pipes for solids removal. To accommodate freezing conditions an internal gate valve should be used.

The difference in solid waste removal, as described, resulted in lower labor costs for the plastic tank system. There is however an inherent added risk that is not found with the pumping or siphon waste removal system used in concrete tanks. The risk is that the caretaker may forget to shut the valve that removes the solids from the bottom of the tank. An open valve with a 3 inch drain will divert much more water from the system then a siphon or pump using a hose that does not exceed 2 inches in diameter.

From November until May the water quality remained within the accepted parameters for trout at both of the sites. Growth and survival were normal for the plastic tanks until the intrusion of black bears became in issue. The bear intrusion caused the trout in the plastic tanks to jump out of the tank which made it difficult to determine which tank they originated from. The fish feed appeared to be the bear's target as many feeders were found strewn about the site, some needing repairs. Efforts to repair the fence were unsuccessful as a corner pole set in concrete was eventually bent over and the concrete base was shattered. On May 1st a 250 pound male black bear was trapped inside the research site and removed from the region. Two nights later another bear had breached the fence. The problem was rectified by properly grounding the fence and testing the current along the entire fence.

CONCLUSIONS

- The plastic tanks used in this research appear to be suitable for quarantine, fingerlings, and growout, with flow-through or recirculating systems. Development of improved screens and crowding systems is warranted.
- These plastic tanks are presently limited to a maximum diameter of 60 inches. Concrete tanks can be made nearly any size or shape. Although extremely resilient, the plastic tanks should be partially set into the ground (18" to 24") for stability. If used indoors on a hard floor, cross-braces or footings will be required for the plastic tanks.

- Total cost of the plastic tank system was estimated to be approximately 53% of a precast concrete system and 74% of a poured concrete system for similar production volume. Net present value and the internal rate of return are favorable for the plastic tanks based on our analysis.
- The equipment and skills used to install the plastic tanks are more commonly available than for concrete tanks. It is conceivable that the grower can install these tanks with relative ease. The modular nature and durability of the tanks allows them to be moved and reset as needed.
- The time required to clean the plastic tanks was 41% of the labor required to clean the flat bottomed concrete tanks. This is attributed to the design of the quiescent zone. Labor savings were estimated to be $9,600 over the expected 20 year life span of a ten tank system if cleaned every 5 days.
- There was no significant difference between the concrete and plastic tanks regarding fin condition of the trout.

The advantages of the "U" shaped plastic tank include lower purchase and installation costs, easy modifications, transportability, which allows for resale value, and reduced labor for cleaning. The disadvantages of the new tank include a life span that has yet to be determined, and like concrete tanks, if installation is not done properly, poor performance may result. Since the initial research improvements have been made to the valve placement for solid removal and the design of the screens for improved strength, which could result in added cost savings over time.

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