# WASTES/EFFLUENTS[1][7]

Progress Report for the Period
September 1, 2001 to August 31, 2003

**NCRAC FUNDING LEVEL:** $149,280 (September 1, 2001 to August 31, 2003)

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## PROJECT OBJECTIVES

(1) Document the fate of aquaculture waste components (phosphorus, nitrogen, solids) relative to feed input into traditional and newly designed aquaculture systems.

(2) Evaluate the technical and economic feasibility of rapid solids removal/recovery appropriate for new aquaculture facility designs.

(3) Demonstrate economically sound processing methods for beneficial use of aquaculture waste.

(4) Provide workshops and fact sheets that address best management practices (BMPs) for waste control.

## ANTICIPATED BENEFITS

*OBJECTIVE 1*

Traditional flowing water culture systems (i.e., raceways) produce a large volume of effluent with relatively dilute waste concentration, whereas, recycle aquaculture systems produce a small volume of effluent with concentrated wastes, typically rich in organic solids, which gives it a high biochemical oxygen demand (BOD) and nutrients (e.g., nitrogen and phosphorus), which are the cause of eutrophication in surface waters. However, a small volume of concentrated wastes produced in recycle aquaculture systems is easier to treat than a high volume of dilute wastes in effluents from flow-through raceway systems, given that it may be treated by a septic tank system and land application used for disposal of the septic tank sludge.

The results of the study being conducted by researchers at Iowa State University (ISU) at a large state-of-the-art commercial recycle aquaculture system will characterize a unique fish hatchery wastewater and solids disposal system that has no surface discharge to public waters and which produces a by-product with some market value. The facility has a septic tank to capture solids and nutrients from the effluent of the culture system. The information obtained from this system may be used to support the development of best management strategies for the category of recirculating aquaculture facilities to meet the final U.S. Environmental Protection Agency (USEPA) guidelines and standards that are to be issued by June 2004.

*OBJECTIVE 2*

Studies being conducted by ISU at a large state-of-the-art commercial recycle aquaculture system should lead to cost-effective methods for rapid removal of waste feed and fish feces from culture systems to maintain good water quality for the fish, to prevent leaching of nutrients from the solids, and the breakdown of solids to particle sizes smaller than can be efficiently removed by practical filtration.

University of Wisconsin-Madison (UW-Madison) researchers are evaluating the use of natural wood fibers as a filter material for aquaculture. The use of these natural fiber filters will greatly reduce the amount and concentration of organic solids that are discharged into the environment from aquaculture raceways and ponds. The retention of solids by these filters will significantly reduce the amount of nutrients entering the receiving stream, resulting in improved water quality downstream from existing fish culture facilities.

Many natural fibers have fundamental properties that make them ideal for use as a filter material. After minimal processing, the surface area of many fibers is very large per unit area. They are inexpensive, renewable, and biodegradable.

This technology can be integrated into the design of new raceways and ponds. However, it also provides an affordable option to aquaculturists who must reduce the discharge of solids and nutrients from existing raceways and ponds. Disposable natural fiber filters can be made inexpensively from a variety of wood and plant fibers. Thus, the application of natural fiber filters to aquaculture will provide economic opportunities to the agriculture industry to market low value fiber or waste fiber. One additional benefit to this technology is that spent fibers can be composted and used as a soil amendment for agriculture.

*OBJECTIVE 3*

University of Wisconsin-Milwaukee (UW-Milwaukee) researchers at the Great Lakes WATER Institute are evaluating vermiculture and vermicomposting as a beneficial use of biosolids from aquaculture waste. For small-scale recycle aquaculture system operations, typical of some of the systems currently operated in the North Central Region (NCR), integrating these methods with fish production offers an appropriately scaled and on-site means of converting solid waste to salable baitworms and worm castings that could be niche marketed to fishermen or organic gardeners. Future expansion of regional aquaculture requires lowered water usage and reduction of potentially harmful waste discharge. Vermicomposting has the potential to increase the cost effectiveness of recycle aquaculture systems operation by converting the recovered waste solids into beneficial reusable and salable by-products. Used along with aquaponic plant production to recover dissolved nutrients, more fully integrated, sustainable, and cost-effective rearing systems may be developed that will overcome current constraints and allow further industry development.

Worm and worm compost production would not involve the high energy inputs for pumping or lighting that are necessary for integrating aquaponics with recycle aquaculture system operation. Depending on further examination of costs and the marketability of worms and worm-produced by-products, these techniques could provide favorable alternatives to disposal by diversion of aquaculture solids to public sewage treatment facilities that lessens the quality of the sludge through mixture with a variety of municipal and industrial waste. Worm composting provides a superior form of stabilized compost that is more suitable and valuable for potted plant or smaller scale gardening users than liquid septic storage sludge that is now typically spread thinly in outdoor field application situations. Diversion of biosolids to worm composting would lighten the load to on-site septic facilities, reducing the size of septic storage facilities needed, and perhaps increasing the maintenance intervals. Stabilized worm compost can be readily stored compared to liquid sludge and when diverted to gardening and indoor planting uses could assist in avoiding the seasonal climatic limitations on land application.

*OBJECTIVE 4*

On September 12, 2002, the USEPA released proposed rules for effluent limitations guidelines and standards for the concentrated aquatic animal production category under authority of the Clean Water Act. The final USEPA rules are to be released by June 2004. Work from this objective will help producers better understand the proposed rules and provide guidance for development of BMPs.

## PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

*OBJECTIVE 1*

Researchers at ISU have been monitoring the mass balance of nutrient inputs in feed and water and outputs (phosphorus, nitrogen, and solids) from a large state-of-the-art commercial recycle aquaculture system in west-central Iowa (Ehler Enterprises in Manning) for the last two years. This facility has five dual-drain tanks, which have sidewall and center drains. About 78% of the effluent from the tanks leaves via the sidewall drain and goes to a sump and then to the biofilter.

Flow from the center drain passes through an external triple standpipe and then to a drum filter. The drum filter, equipped with a 60-µm mesh microscreen, receives the center drain flow of all five tanks. The triple standpipe is an external cylindrical tank with three standpipes of different heights. The shortest standpipe (11.2 cm; 4.4 in) receives the flow from the center drain of the culture tank. A standpipe of intermediate height sets the height of the water level in the culture tank and overflow into this standpipe flows to the drum filter. The third, tallest, standpipe, never overflows, but when manually pulled once daily for 10 seconds, it drains the accumulated solids from below the shortest standpipe. The triple standpipe functions like a swirl separator to allow rapid removal of heavier solids that settle below the shortest standpipe. These solids are diverted to a septic tank. The overflow from the septic tank effluent goes to a drain field, not directly to a receiving stream. During the first year of study, the septic tank contents were pumped out and land applied, but in the second year the septic tank slurry was transferred to a concrete holding tank (former waste pit of a hog confinement facility) to air dry. The producer found a nursery that bought the dried septic tank solids (dried fish manure) for use as a fertilizer and soil amendment.

Nutrients and solids have been measured in both the recycle system as well as the septic tank. Water quality assurance methods were developed with written procedures, work instructions, and record keeping protocols. Quality control included measurements of concentration recovery of spiked samples (known addition method) for every parameter on every sample date.

Solids accumulation in the septic tank were analyzed from samples of the slurry pumped from the septic tank. Effluent from the septic tank was collected with an autosampler over 3- and 12-h intervals, but because there was not a significant difference between values for 3- and 12-h collections, the 3-h sample is to be used in future samples. Septic tank sludge is collected when the septic tank is drained. The normal schedule for septic tank draining and pump out of sludge was twice per year, but it will be more frequent during the study to provide information on septic tank treatment of the fish hatchery waste. Septic tank sludge (a slurry) is surface applied to 0.8 ha (2.0 acres) of crop land used for soybeans.

From July 22 through August 29, 2002, six sets of samples were obtained to measure inputs of total solids and nutrients from the freshwater supply and the feed, and outputs of solids and nutrients from the culture system to the septic tank, and from the septic tank effluents and solids. In this interval, the fish feed input averaged 16.2 kg/day (35.7 lb/day) (dry weight basis), 1.27 kg (2.80 lb) total nitrogen (TN), and 0.23 kg (0.51 lb) total phosphorus (TP). The combined effluent from the drum filter and the triple standpipe to the septic tank was 9.13 kg/day (20.13 lb/day) total suspended solids (TSS), 0.98 kg/day (2.16 lb/day) TN, and 0.09 kg/day (0.20 lb/day) TP. TP in the effluent to the septic tank was 5.6 g TP/kg of feed per day (0.090 oz/lb), which compares with published values of 5.0B5.9 g TP/kg feed per day (0.080B0.094 oz/lb).

TP leaving the septic tank to the tile drainage field was 3.1 g TP/kg of feed per day (0.05 oz/lb), implying that 55% of the TP input to the septic tank leaves the septic tank in the fluid flow and 45% is retained in the solids portion of the septic tank. There is no other published literature with this information. Including a septic tank in the waste treatment process will reduce TP output to surface water by about half of the output from the culture system.  Because it is well known that phosphorus is strongly attached to soil, the distribution of the septic tank effluent into septic tank drainage tile will eliminate nearly half of the TP effluent problem.

A slurry of septic tank contents that accumulated in the 90-day interval of July through September contained an average of 4,750 mg/L (ppm) TSS and 112 mg/L (ppm) TP.  Based on input and output measurements, an average of 91% of the TSS input to the septic tank was metabolized by the septic tank; only 6% left the septic tank to the septic tank drainage field and 3% was present in the slurry pumped out from the septic tank after the 90-day interval.  The TSS in the effluent from the septic tank to the field tile was 51 mg/L (ppm), comparable to a range of 45B65 mg/L (ppm) for household septic systems.

The TN content entering the septic tank averaged 0.98 kg/day (0.035 oz/day) and the output in the effluent from the septic tank averaged 0.80 kg/day (0.028 oz/day), indicating that 82% the nitrogen entering the septic tank leaves in the effluent to the field tile.

Research in Year 2 was divided into four intervals for data compilation and analysis: interval 1, 61 days (October 10-December 10, 2002), interval 2, 160 days (December 10, 2002-May 21, 2003), interval 3, 27 days (May 21-June 17, 2003), and interval 4, 28 days (June 17-July 15, 2003). Only data from interval 4 is included because the septic tank was drained at the beginning and end of that interval, which allowed for calculation of mass balance of nutrients and solids.  In this interval, the operator was carrying out polyculture of hybrid striped bass, largemouth bass, rainbow trout, and walleye (two tanks).  Standing stock of fish averaged 4,654 kg (10,239 lb), of which 36% was rainbow trout, 35% walleye, 20% hybrid striped bass, and 9% largemouth bass. Feeding rate varied by species; it was much lower for trout and walleye because they were ready for market, but the average for all species was 3% of the body weight per day.

The culture system consisted of five culture tanks, each 39.2 $m^3$ (10,356 gal), which comprised 78.5% of total system volume (250.0 $m^3$; 66,043 gal), and other system componentsCtriple standpipes, sidewall drains, drum filter, sump, biofilter, degassing tower, low head oxygenator, and all of the supply and drain pipesCmade up 21.5% of total system volume.  Total volume of a recycle aquaculture system (tanks and other) is about 1.3× the volume of the culture tanks.

In interval 4, the average daily inflow (3.41 Lpm; 0.9 gpm) provided the culture tanks with an exchange of 0.9 tank volume per hour, which was sufficient to maintain suitable water quality.  In this interval, daily water use was 2.0% of total system volume, which is considerably less than the 5B10% reported in the literature for most recycle systems.  Daily inflow was only that needed to replace water lossCoften called make-up waterCto backwash the drum filter and flush the triple standpipes.  The major sources of water loss (85.6% of total) were from the drum filter backwash (54.9%), and the triple standpipe (30.2%).  Other sources of water loss were from evaporation and several miscellaneous sources.

Nutrient inputs (nitrogen and phosphorus) expressed in mass per day, were from nutrient content of the inflowing water and fish feed. Nutrients and solids were measured in the effluent from the culture building to the septic tank, effluent (output) of the septic tank to the septic tank drainage field, from samples of the slurry pumped from the septic tank, and of the dried matter from the septic tank slurry.

The inflowing water added 0.0043 kg/day (0.15 oz/day) TN and 0.0026 kg/day (0.09 oz/day) TP, which is quite trivial relative to the nitrogen and phosphorus added in the feed; inflowing water added 0.3% of nitrogen and 0.8% of phosphorus compared with the feed. These inputs were subtracted from nutrient outputs to the septic tank to isolate nutrient inputs from the feed. The nitrogen content of the dry weight of the three kinds of feed utilized was 8.1%. The average daily input of feed (all tanks combined) was 13.6 kg/day dry weight (30.0 lb/day). The nitrogen addition from the feed was 1.6 kg/day (3.5 lb/day) for interval 4. Nitrogen (kg dry weight per day) in the effluent from the culture building to the septic tank (0.59 kg/day; 1.3 lb/day) was 36.7% of the nitrogen in the feed. Total nitrogen in the septic tank effluent going to the septic tank drainage field was 17.9 g/kg (ppt) feed fed, or 15% of the nitrogen fed. Based upon the concentration of nitrogen in the effluent from the septic tank, the septic tank removed 59.1% of the nitrogen inputs.

The TN content entering the septic tank averaged 0.59 kg/day (1.3 lb/day) and the output in the effluent from the septic tank averaged 0.24 kg/day (0.5 lb/day), indicating that 40.9% of the nitrogen entering the septic tank leaves in the effluent to the field tile, but it also means that 59.1% was removed during residence in the septic tank.

At the end of interval 4, the septic tank was pumped out and the slurry was analyzed for TN, TP, BOD, and TSS. The results were 828.7 mg/L (ppm) nitrogen, 343.9 mg/L (ppm) phosphorus, 1,060 mg $O_2$/L (ppm) BOD, and 13,700 mg/L (ppm) TSS. The slurry was dried in an empty concrete tank for 28 days. The dried sludge contained 12.8% moisture, 3.16% nitrogen, and 4.8% phosphorus. The dried sludge (dried fish manure) was sold to a nursery.

The weighted average phosphorus content of the three kinds of feed was 1.64% of dry weight. The phosphorus added from the fish feed was 0.32 kg/day (0.71 lb/day) for interval 4. Total phosphorus (mass dry weight per day) in the effluent from the culture building to the septic tank (0.28 kg/day; 0.62 lb/day) was 86% of the phosphorus in the feed. Total phosphorus in the septic tank effluent to the septic tank drainage field was 0.13 kg/day (0.29 lb/day). The inputs of total phosphorus to the drainage field were 46.8% of total phosphorus entering the septic tank. Based on the concentration of phosphorus entering (0.28 kg/day; 0.62 lb/day) and leaving the septic tank (0.13 kg/day; 0.29 lb/day), the septic tank removed 53.2% of the phosphorus inputs to the tank. The TP content of the 4.54 $m^3$ (1,200 gal) of slurry pumped from the septic tank after a 28-day culture interval was 1.56 kg (3.44 lb). The slurry was dried (now a fish manure) in a separate tank and analyzed for TP. The TP was 48 g/kg (ppt) dry weight.

The monthly average TSS output from the culture building to the septic tank was 517 mg/L (ppm), which was 17.2☟ the proposed 30 mg/L (ppm) TSS monthly average requirements for a recirculating system with more than 45,300 kg (100,000 lb) production. The septic tank removed 81% of the received TSS input to the tank. Only 19% of the TSS entering the septic tank left the septic tank effluent to the septic tank drainage field. The TSS in the effluent from the septic tank to the field tile was 240 mg/L (ppm), much higher than the USEPA proposed 30 mg/L (ppm) limit. Paradoxically, the proposed USEPA TSS limit is about half that of the range in TSS of 45B65 mg/L (ppm) for household septic systems.

*OBJECTIVE 2*

ISU researchers measured rapid solids removal from the culture tank effluent by the triple standpipe and drum filter. The dual-drain tank design had two discharges; 78% from the sidewall drain and 22% from the center drain. The center drain carried most of the suspended solids from the culture tank to the triple standpipe from which most of the flow went to the drum filter. A small flow of heavy solids was diverted to the septic tank by manually pulling the triple standpipe for 10 seconds daily.

The drum filter removed 26% (1.62 kg/day; 3.57 lb/day) and the triple standpipe removed 74% (4.53 kg/day; 9.99 lb/day) of the total quantity of solids (TSS) in the effluent from the center drain of the culture tank. The drum filer removed 55% (0.32 kg/day; 0.71 lb/day) of the TN, but only 38% (0.11 kg/day; 0.24 lb/day) of TP. Conversely, the triple standpipe removed 62% (0.18 kg/day; 0.40 lb/day) of TP but 45% (0.27 kg/day; 0.59 lb/day) of TN. Most of the TP was associated with the solids, but less so for TN. In the 10 seconds the triple standpipe was being drained, it removed solids stored below the shortest standpipe as well as some solids that are deposited in the lateral pipe from the center drain of the culture tank to the triple standpipe. The storage of solids in the bottom standpipe accounted for 96.2% of the concentration of TSS in the effluent of the triple standpipe, 56% of the TN, and 84.3% of the TP. Thus, accumulated solids in the drainpipe from the center drain were minimal, demonstrating that the triple standpipe reduces the load on the drum filter.

The goal of UW-Madison studies is to evaluate the feasibility of using wood fiber filters to capture solids from raceway and pond effluents. Prior to designing the fiber filters, information on the particle size of solids in raceway and pond effluents was needed. The particle size of three types of effluents was characterized as follows. The first was effluent from fingerling production ponds at the Lake Mills State Fish Hatchery (LMSFH). The effluent from the final 5% of the water was sampled during pond draining, because previous studies have shown that this portion of the effluent contains the highest concentration of solids. The second effluent characterized was from coho salmon production raceways at the LMSFH collected during Asweep” cleaning (a commonly used method to clean raceways). And the third was effluent from coho salmon production raceways at the LMSFH collected during Apump@ cleaning (another commonly used method to clean raceways).

A small-scale filter box (designed for a flow rate of 4.0-6.0 Lpm [1.1B1.6 gpm]) was designed and built by UW-Madison researchers and engineers from the U.S. Department of Agriculture Forest Products Laboratory (FPL). This box was designed to accept 4B6 filters in a series flow design.

Initial studies focused on flow dynamics, i.e., to minimize problems related to overflow and filter bypass. Once these problems were resolved, a set of graded Nytex7 screens was installed to measure particle size and distribution. The results indicate that pond effluent contained a higher percentage of small particles than raceway effluent. Approximately 60% of solids from pond effluent, and 75% of solids from Aswept" or Apumped" raceway effluent were retained by a 75 µm screen. According to FPL engineers, these data suggested that it should be possible to design wood fiber filters to retain a high percentage of solids and at the same time permit high flow rates through the filters.

Three types of fiber filters were then manufactured: Arandom," made from 28% kenaf, 28% jute, 28% flax, 10% aspen, and 6% binder; ADW I," made from 90% juniper and 10% binder; and ADW II," made from 65% juniper, 15% aspen, 10% alfalfa, and 10% binder. Preliminary studies showed that all three filter types were effective at retaining solids from aquaculture effluents. In repeated tests using pond effluent (which contains smaller particles, in general, than raceway effluent), three random and DW I filters in a series retained more than 70% of the solids.

Findings on flow rates through the filters have shown that fiber filters can be practically designed to accommodate flow rates typically associated with pump cleaning of large scale raceways (60B200 Lpm; 16B53 gpm). Fiber filters capable of effectively removing solids from pond effluent can be designed, but the large surface area required to permit the extremely high flow rates associated with pond draining (>1,500 Lpm; 396 gpm) may make the application of fiber filters for pond effluent less feasible than for raceway effluent. Therefore, the remainder of the research will focus on the retention of solids from raceway effluents. Construction of a large-scale filter box capable of handling flows of 60B200 Lpm (16B53 gpm) has been recently completed.

*OBJECTIVE 3*
UW-Milwaukee scientists investigated processing methods for beneficial use of aquaculture waste. Their work is categorized into two sub-objectives.

Sub-objective A: One component of their research is to recover and partially dewater biosolids from intensive yellow perch aquaculture for use as a feedstock for vermicomposting using red worms and warmer-temperature tolerant Acultured" nightcrawlers. Back-flushed waste solids from a bead filter/clarifier of UW-Milwaukee=s 25-$m^3$ (6,604-gal) recycle aquaculture system, and to a lesser extent, some solids from a 3.3-$m^3$ (872-gal) circular flow-through tank of yellow perch fingerlings was obtained for use as worm food. A graduated conical-bottomed 560-L (148-gal) tank was used to separate the solids by settling from the remaining wastewater. The daily amount of sludge recovered from the bead filter varied widely with a mean volume of 48 L (13 gal), a range of 254 L (67 gal), and a modal value of 57 L (15 gal).

From January through October 8, 2002, about 973 kg (2,145 lb) dried weight of commercial fish feed was used to feed the perch in the recycle aquaculture system. During that same period, an accumulated total of 9.6 $m^3$ (2,536 gal) of settled sludge material (336 kg [741 lb] dried weight) was recovered from the bead filter back washings. This recovered sludge is about equivalent to 35% of the dried weight of the fish food (973 kg; 2,145 lb) used to grow out the approximately

10,000 perch fingerlings in the recycle aquaculture system during the 259-day period of operation. The bead filter sludge also contained some microbial floc and possibly small amounts of sand from the biofilter. In mid-December 2002 the recycle aquaculture system was restocked with perch fingerlings for another grow-out cycle (257 days of operation through August 31, 2003). During this period biosolids from the bead clarifier were again recovered. In this time period, a total of 14.4 $m^3$ (3,813 gal) of settled sludge was collected which was potentially available for use as worm food. This recovered amount was again equivalent to 35% of the dry weight of the fish food (1,460 kg; 3,219 lb) used during that period.

Sub-objective B: This component of the research is to propagate worm stocks using continuous composting bins utilizing bead filter sludge as food. Seed stocks were obtained of two species of earthworms with recognized potential for vermicomposting of organic materials: Acultured" nightcrawlers, *Eudrilus eugeniae*, (about 400 totaling 0.384 kg [0.847 lb]) and red worms, *Eisenia foetida*, (about 500 totaling 0.081 kg [0.179 lb]). In January 2002, these worm stocks were introduced into separate commercial continuous-vermicomposting bins. The surface area of each bin was 0.66 $m^2$ (7.10 $ft^2$) and contained 75 kg (165 lb) of initial bedding material that ranged in depth between 10B20 cm (3.9B7.9 in). Draining the sludge through the worm bedding dewatered the bead filter sludge. The majority of the solids from the bead filter sludge were retained in the upper layer of worm bedding and excess water dripped by gravity through the bed and collected in a drip pan. Feedings of settled sludge were measured volumetrically and poured from a 3.0-L (0.8-gal) graduated pitcher. Sludge feedings were applied in thin layers to cover only a portion of the bedding surface to insure that the worms could find a refuge from extreme conditions. Additional food was added when the previously added material had been worked over by the worm stocks. Accumulation of unused food was avoided to prevent anaerobic conditions, odor problems, and adversely high temperature conditions in the beds.

Worm populations in the bins were sampled at 2, 9, 14, and 23 weeks after stocking. Both species of worms prospered when fed the yellow perch recycle aquaculture system bead filter backwash sludge. Reproduction and cocoon deposition were observed in the first few weeks. The estimated worm initial stocking density (% by weight) in the bedding was 0.1% for the red worms and 0.5% for the nightcrawlers. The red worm bin population tended to increase steadily over the 23-week period both in terms of percent worms by weight (0.1B2.6%) and estimated number of worms (500 to ~13,000) in the bin. The nightcrawlers fluctuated in percent worm density by weight (range 0.5B6.4%). Nightcrawler density increased to 4.6% due to rapid initial growth, but then decreased as the larger older individuals died off gradually through the first nine weeks and were replaced by an abundant cohort of young worms after 42B48 days. In the nine-week sample, worm density by weight (1.9%) was less than half of what it was at two weeks, while the estimated number of worms in the bin had gone from an original 400 to approximately 12,000. By 14 weeks, the nightcrawler bin had regained high worm density by weight (6.4%) and estimated numbers appeared to remain around 13,000. However, by 23 weeks the worm sizes were mixed and not as clearly dominated by a single cohort in both numbers (~4,000) and density by weight (1.8%). Variation between samples on a given sampling date was high and handpicking subsamples was laborious. It is difficult to obtain accurate inventory of worm stocks in continuous batch culture in order to predict of the numbers of harvestable bait-size worms.

From January through September 2002, the worms were fed a total of 837 L (221 gal) of sludge. Individual feedings were generally in 3.0 L (0.8 gal) increments and varied from 0B18 L (0B4.8 gal) per bin on a given date. Following the harvest of the perch at the end of September 2002, through mid-December 2002, the recycle aquaculture system was idle and the worm colonies were maintained using Purina worm chow. Once the 2003 perch production cycle of the UW-Milwaukee recycle aquaculture system was restarted in late December 2002 through October 2003, the worm bins were again maintained by feeding bead filter sludge. In that period, a total of 495 L (130 gal) of sludge was fed to the worms in the continuous compost bins.

The amount of recovered sludge from the recycle aquaculture system proved to be far greater than the capacity of these composters to accept the waste without creating undesirable bedding conditions and odor problems. Observation of the worms feeding on a thin layer of sludge (3B6 L) applied to each bin (0.66 $m^2$ or 7.10 $ft^2$) and covered with a light covering of soil, indicated that when sufficient worm stocks are present the food layer could be worked over in 3B4 days at which time more sludge could be applied. Applying sludge at a rate similar to that used for these composting bins (approximately 4.5B9 L/$m^2$ [0.11B0.22 gal/$ft^2$] at 4-day intervals), a worm bed of 25B50 $m^2$ (269B538 $ft^2$) could be readily supported at the modal level of sludge production.

Although the continuous vermicompost bins with mixed generations of worms would be suitable for compost production and waste recycling, for vermiculture of appropriately sized baitworms an approach that separates cohorts of worms by age and size would insure better inventory control, and avoid problems with trying to separate harvestable worms from the numerous smaller sized worms. At a commercial vermiculture operation in Racine, Wisconsin cultured nightcrawlers are grown in plastic pails (approximately10.0 L [2.6 gal] capacity) with ventilation holes punched into the upper rim. At about two-week intervals the worms are separated from the cocoons and fed a formulated commercial diet. Use of modular bins and a cohort separation management strategy is advantageous for inventory control in an operation intending to produce predictable numbers of harvestable bait-sized worms. Under UW-Milwaukee conditions, the smaller sized bed of the modular pails tended to dry more easily and required closer monitoring than the larger continuous composting beds. Perhaps a hybrid rearing scheme using the continuous composting bed as the principle waste processing method and using the modular bins to achieve the final rapid growth and fattening of worms (from the continuous composters where growth is slowed due to high density) to bait size with several weeks growth under less dense conditions would be most advantageous for recycle aquaculture waste recycling.

In the summer of 2002 UW-Milwaukee researchers compared bead filter sludge as a foodstuff for vermicomposting/vermiculture to a commercial worm diet. The influence of the addition of hardwood sawdust and shredded paper as worm bedding additives were also examined. This research was done with the assistance of an undergraduate participant in the National Science Foundation AResearch Experience for Undergraduates" program from July through August 2002; an experiment was conducted using ventilated commercial production pails. Three worm feeding treatments (no supplemental feeding, commercial worm food, and bead filter sludge) were combined with three types of bedding (Ablack peat" soil alone [9.0 L; 2.4 gal]; black peat [6.0 L; 1.6 gal] plus sawdust [3.0 L; 0.8 gal]; and black peat [6.0 L; 1.6 gal] plus shredded paper [3.0 L;

0.8 gal]). Each treatment combination was assigned to a commercial production worm pail and 20.0 g (0.7 oz) (about 50 African nightcrawlers, or 70 red worms) batches of each worm species were randomly assigned to each of the nine pails. The treatment array was replicated three times on successive dates resulting in triplicate pails for each of the nine treatment combinations for each worm species (27 pails total for each species). Food treatments consisted of either 3.0 L (0.8 gal) of sludge, 29 g (1.0 oz) of commercial worm food followed by 3.0 L (0.8 gal) of recycle aquaculture system water, or no food followed by 3.0 L (0.8 gal) of recycle aquaculture system water. The amount of commercial food fed to the worms (29 g; 1.0 oz) approximated the equivalent dried solids in 3.0 L (0.8 gal) of biosolids sludge. Growth and survival in each pail was evaluated at two and four weeks.

Yellow perch recycle aquaculture system bead filter backwash sludge was found to be a suitable feedstock for both Acultured" nightcrawlers and red worms. Buckets of nightcrawlers fed bead filter sludge increased 489% in overall mass with a 96% survival after four weeks. After four weeks, the weight of red worms fed bead filter sludge increased 224% with 73% survival. Between the second and fourth week several buckets of both sludge fed and commercial food fed red worms experienced some mortality.

In this experiment, recycle aquaculture system sludge as a worm feedstock was as successful as, or outperformed the commercial worm food. After four weeks, the weight of nightcrawlers fed commercial worm food increased 415% with a 99.8% survival. Red worms fed commercial worm food had a 63% survival rate and a worm biomass increase of 187% after four weeks. The fed worms grew much better than the worms without supplemental feeding; at four weeks unfed nightcrawlers increased only 154% with 100% survival and red worms increased 127% with 97% survival. All substrate types tested were successful in maintaining worm cultures. No differences in worm growth and survival could be attributed to the various substrates. However, preliminary results suggest that the addition of sawdust allows better drainage and drying of the bedding. Addition of sawdust would probably reduce the labor costs required for separation and picking of the worms from the substrate at harvest.

Samples of worms, bedding substances, and composts from both the continuous compost bins and the sludge feeding experiment were freeze-dried for isotope and carbon analysis: nitrogen ratio to characterize the alteration in the biosolids during the vermicomposting process. Preliminary results indicate that the freeze-dried sludge has a nitrogen content of 5.0B5.7 % nitrogen and a carbon to nitrogen ratio (C:N) of 5:1. The freeze dried compost has a nitrogen content of 2B3% and a C:N ratio of 14B15:1.

*OBJECTIVE 4*

A conference was held on October 9, 2003 in Ames, Iowa on the USEPA ADraft Guidance for Aquatic Animal Production Facilities to Assist in Reducing the Discharge of Pollutants" and BMPs. There were eight presentations, including two case studies of state hatchery effluent issues (Michigan and Pennsylvania), an overview of USEPA=s proposed guidelines and standards, presentations on BMPs for ponds, raceways, recycle systems, and a Hazard Analysis Critical Control Points approach to prevent spread of aquatic nuisance species.

**WORK PLANNED**

*OBJECTIVE 1*

ISU researchers finished data collection at the Ehler Enterprises fish farm in August 2003, therefore, work in the last (third) year will focus on data analysis, writing the final report, and preparation of manuscripts for professional journals. The database consists of measurements of TSS, TN, TP, BOD, and other parameters. The results for Objective 1 will focus on mass balance of nutrient inputs and outputs, and evaluation of the role of the septic tank in effluent quality.

*OBJECTIVE 2*

In the last year, ISU researchers will be doing data analysis to compare solids removal by the triple standpipe with the drum filter components of the culture system. Following that, the final report will be prepared and also manuscripts prepared for professional journals. Talks will be prepared for regional and national aquaculture conferences.

In Year 3 UW-Madison researchers will test several filter types in the large-scale (150 and 1,500 Lpm; 40 and 396 gpm) filter boxes, and gather data including flow rates and filter capacity using effluent from commercial scale raceways.

*OBJECTIVE 3*

In Year 3 of the project, UW-Milwaukee researchers will conduct a trial to evaluate the acceptability of worms produced from recycle aquaculture system biosolids sludge as fish food and compare the chemical content of the fish before and after being fed worms. Red worms and cultured nightcrawlers raised on sludge are currently being periodically harvested from the continuous vermicomposting bins and frozen in small batches to support this investigation.

Isotope analyses and C:N ratios will be used to determine if there are any alterations in the biosolids during the vermicomposting process.

*OBJECTIVE 4*

Additional information will be generated that addresses BMPs for waste control.

**IMPACTS**

*OBJECTIVE 1*

ISU researchers are describing nutrient (nitrogen and phosphorus) inputs in water and feed, and nutrient and solids outputs in the effluent of a commercial recycle aquaculture facility that employs a septic tank to capture solids and nutrients from the effluent of the culture system. By using the septic tank and drainage field as recommended by the ISU researchers, there is zero discharge of any fish hatchery effluent to surface water. In addition, a market has been found for the dried fish sludge providing some economic return for the addition of the septic tank.  The system may serve as a model for a best management strategy for waste management for an intensive, closed-system commercial aquaculture facility.

*OBJECTIVE 2*

ISU research has demonstrated design features of a recycle aquaculture system that rapidly removes solids as well as reduces initial facility costs.  The Ehler Enterprise culture system uses dual-drain tanks that allow the operator to set the proportion of flow from the culture tank to sidewall and center drains.  Because most (79%) of the flow from the culture tanks leaves the system via the sidewall drain, the size and cost of the drum filter, a major capital cost, is reduced.  In addition, the findings demonstrate that the triple standpipe reduces the load of solids to the drum filter as well as facilitating rapid solids removal. Efficient solids capture and disposal is important to operating efficiency of the recycle aquaculture system, water quality for the cultured fish, and waste management.

UW-Madison will test the hypothesis that a filtration system using natural fiber filters will greatly reduce the amount and concentration of organic solids that are discharged into the environment from aquaculture raceways and ponds.  The retention of solids by these filters will significantly reduce the amount of nutrients entering the receiving stream, resulting in improved water quality downstream from existing fish culture facilities.

*OBJECTIVE 3*

UW-Milwaukee scientists have demonstrated that fish waste sludge equivalent to approximately 35% of the weight of the food used to produce perch in recirculating systems is potentially a viable feedstock for worm culture.  This can be beneficial to aquaculture, especially recycle aquaculture systems, because vermicomposting can potentially decrease the amount of waste released by converting it to salable worms and organic compost to defray some of the high operating expense of recycle aquaculture system rearing.

These investigations are still incomplete and UW-Milwaukee researchers are unaware of any applications of this technique for aquaculture waste recovery in the region.  However, in discussions with several Wisconsin recirculating system operators at the state aquaculture conference, several expressed interest in vermicomposting on a trial basis.

*OBJECTIVE 4*

The goal of the research in Objectives 1, 2, and 3 is to provide options for waste management and use of wastes as a valuable by-product feedstuff for worm culture.  Results from those activities and findings from other studies will provide commercial operators with information on environmental regulations and the best available technologies needed to meet those regulations.

## PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED

See the Appendix for a cumulative output for all NCRAC-funded Wastes/Effluents activities.

**SUPPORT**

| YEARS | NCRAC-USDA FUNDING | OTHER SUPPORT | | | | | TOTAL SUPPORT |
|---|---|---|---|---|---|---|---|
| | | UNIVERSITY | INDUSTRY | OTHER FEDERAL | OTHER | TOTAL | |
| 2001-02 | $80,766 | $58,752 | $299,980 | $21,060 | | $379,792 | $460,558 |
| 2002-03 | $68,514 | $59,059 | $123,434 | $21,918 | | $204,411 | $272,925 |
| **TOTAL** | $149,280 | $117,811 | $423,414 | $42,978 | | $584,203 | $733,483 |

## WASTES/EFFLUENTS

***Publication in Print***

Rosati, R., P.D. O=Rourke, K. Tudor, and R.D. Henry. 1993. Performance of a raceway and vertical screen filter while growing *Tilapia nilotica* under commercial conditions. Pages 303-214 *in* J-K. Wang, editor. Techniques for modern aquaculture. Publication No. P-0293, American Society of Agricultural Engineering, St. Joseph, Michigan.

***Manuscript***

Maher, J.P., I.R. Adelman, and J.N. Connor. In preparation. Suspended solids in recirculating aquaculture systems and their effect on growth of tilapia (*Oreochromis niloticus*) and bluegill (*Lepomis macrochirus*). North American Journal of Aquaculture.

***Papers Presented***

Hinrichs, D., J. Webb, R. Rosati, and P. Foley. 1994. Effluent characterization from the production of *Oreochromis niloticus* in a modified Red Ewald-style recirculating system. 25th Annual Meeting of the World Aquaculture Society, New Orleans, Louisiana, January 12-18, 1994.

Raabe, J.K., and S.E. Yeo. 2002. Vermicomposting and vermiculture as a beneficial use for aquaculture waste. National Science Foundation Research Experience for Undergraduates, Milwaukee, Wisconsin, August 16, 2002.

Rosati, R., D. Hinrichs, and J. Webb. 1994. Biofilter performance during the production of *Oreochromis niloticus* in a modified Red Ewald-style recirculating system. 124th Annual Meeting of the American Fisheries Society, Halifax, Nova Scotia, August 21-25, 1994.

Rosati, R., P.D. O=Rourke, K. Tudor, and R.D. Henry. 1993. Performance of a raceway and vertical screen filter while growing *Tilapia nilotica* under commercial conditions. Techniques for Modern Aquaculture, Special Session at the Annual Meeting of the American Society of Agricultural Engineering, Spokane, Washington, June 21-23, 1993.

Rosati, R., J. Webb, D. Hinrichs, and P. Foley. 1993. Characteristics of the effluent from a recirculating aquaculture system. U.S. Chapter of the World Aquaculture Society, Hilton Head, South Carolina, January 27-30, 1993.

Smydra, T.M., and J.E. Morris. 1994. Characterization of aquaculture effluents from two Iowa hatcheries. Iowa Chapter, American Fisheries Society, Council Bluffs, Iowa, February 15-16, 1994.

Smydra, T.M., and J.E. Morris. 1994. Characterization of aquaculture effluents. 56th Midwest Fish and Wildlife Conference, Indianapolis, Indiana, December 4-7, 1994.

Yeo, S.E. 2003. Vermiculture and vermicomposting for recycling perch culture biosolids from recirculating aquaculture systems. 32nd Meeting of the Wisconsin Chapter of the American Fisheries Society, Madison, Wisconsin, January 14-16, 2003.

Yeo, S.E. 2003. Vermiculture and vermicomposting for recycling perch culture biosolids from recirculating aquaculture systems, Michgan Aquaculture Association, Cadillac, Michigan, February 12-14, 2003.

Yeo, S.E. 2003. Vermiculture and vermicomposting for recycling perch culture biosolids from recirculating aquaculture systems, 10th Annual Wisconsin Aquaculture Conference, Stevens Point, Wisconsin, March 13-15, 2003.