AQUACULTURAL WASTES AND EFFLUENTS: THEIR CHARACTERISTICS, REMOVAL, AND BENEFICIAL USES

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Funding Request: $195,000

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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.

Proposed Budgets:

Institution	Principal Investigator(s)	Objec-tive(s)	Year 1	Year 2	Year 3	Total
Iowa State University	Robert C. Summerfelt	1, 2, & 4	$46,056	$36,804	$14,010	$96,870
University of Wisconsin-Madison	Jeffrey A. Malison Douglas J. Reinemann	2	$22,000	$19,000	$19,000	$60,000
University of Wisconsin-Milwaukee	Fred P. Binkowski Steven E. Yeo	3	$12,710	$12,710	$12,710	$38,130
		Totals	**$80,766**	**$68,514**	**$45,720**	**$195,000**

Non-funded Collaborators:

Facility	Collaborator(s)
Loess Hills Aquaculture, Manning, Iowa	Jim Blankman and Chuck Ehlers
University of Wisconsin-Madison	Jae Park
USDA Forest Products Laboratory, Madison, Wisconsin	Roger Rowell and Von Byrd
Odbek Industries, Inc., St. Paul, Minnesota	Todd Rogers and Michael Becker
REM Engineering, LLC, Evansville, Wisconsin	Mark Raabe

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JUSTIFICATION

The world production of fish, crustaceans, and shellfish by aquaculture was 30 million metric tons (MT) in 1997, which was double the 1990 harvest. Aquaculture now accounts for more than 22% of the global food fish supply (New 1997). In the U.S., the 1998 Census of Aquaculture found that sales of aquacultural products increased from $807 to $978 million between 1997 and 1998 (USDA 2000). The expanded market demand for edible fish also pushed up U.S. imports of edible fisheries products by 10% to $9 billion. On the other hand, the production of food fish from capture fisheries has leveled out at less than 60 million MT (New 1997). These statistics certainly indicate that aquaculture is slated for continued growth. Aquaculture, however, has been increasingly criticized for excessive water use; destruction of mangrove forests for shrimp production; waste production and effluent impacts on rivers, lakes, and estuaries; introduction of exotic (non-indigenous) organisms and pathogens; killing of fish-eating birds and mammals; and negative socio-cultural impacts (Pillay 1992). Recently, the use of fish meal in aquaculture feeds has been severely criticized because feeding fish formulated diets with a high percent of fish meal is said to consume more protein than it produces and to encourage excess harvest of pelagic marine fish (anchovy, menhaden, capelin, herring, and sardine), fish that are used by other organisms in the food web (Naylor et al. 1998). Fears about fish meal shortages limiting aquaculture growth have been called the "fish meal trap" (New and Csavas 1995). Although poultry consume 50% of all fish meal produced in the world, aquafeeds consume a further 40% of global fish meal production. Almost 70% of the total amount of fish meal used in aquafeeds is used for salmon, noncarnivorous species, and shrimp (Masser 2000). Estimated values for the proportion of fish meal in shrimp are difficult to ascertain. For example, Naylor et al. (1998) cite sources that indicate that shrimp feed contains 35% and farmed salmon 45% fish meal, respectively, whereas Masser (2000) reports that fish meal is 50% of the feed components for salmon, 30% for trout, and 25% for marine shrimp.

Whether aquaculture reaches its growth potential of 3.7 to 6.0% per year in the next 10 years (FAO 1997) depends on how well producers are able to ameliorate these many issues with best management practices (BMPs) that reduce nutrient, chemical, and biological pollution, and also the consumption of fish meal. In part, these problems are growing pains of a relatively new and rapidly growing industry for which technology and management methods are being developed (Boyd 1999). It seems, however, that society is not so forgiving of aquaculture's shortcomings. Environmentalists are already in the attack mode in the U.S. as evidenced by the 1997 Environmental Defense Fund publication "Murky Waters: Environmental Effects of Aquaculture in the United States" (Goldberg and Triplett 1997). Also, opinion articles in science journals, such as that by Naylor et al. (1998), claim that shrimp and salmon aquaculture consume more fish protein than they produce, thereby depleting fisheries resources. They are said to be net fishery resource "reducers" rather than "producers."

Already, limitations on water supply and environmental issues may constrain continued growth of certain segments of the aquaculture industry in the U.S. and Canada. In the recent NCRAC white paper, Westers (2000) points out that expansion of food fish production in the U.S. in the 1980s was principally due to growth in catfish and trout production on industry-scale farms in Mississippi and Idaho. The catfish industry, however, is in jeopardy due to drawdowns of the once abundant groundwater resources in the Delta region (Tucker 1996) and expansion of the Idaho trout industry is challenged to meet a 40% reduction in phosphorus discharges (Goldberg and Triplett 1997). The image of aquaculture and its future may be in jeopardy unless it deals effectively with environmental issues.

Eutrophication and related problems from fish hatchery effluents have been noted in freshwaters in both the U.S. and Europe, and in marine habitats affected by net pen culture (USEPA 1974; Cowey and Cho 1991; Foy and Rosell 1991; Ketola 1991c; Ketola et al. 1991; Lall 1991; Ketola and Harland 1993; Ketola and Richmond 1994). In the North Central Region (NCR), environmental issues related to aquaculture effluents have already resulted in a mandated closure of a large salmonid netpen enterprise in Minnesota by the state Pollution Control Agency (Axler et al. 1998). Also, phosphorus discharge from the Platte River Fish Hatchery, Beulah, Michigan has been widely cited justification for reducing phosphorus content of fish feeds (Ketola 1991a; Ketola et al. 1991; Ketola and Harland 1993; Ketola and Richmond 1994). Lawsuits by a homeowner association alleged that the Platte River Fish Hatchery caused eutrophication of their lake. This issue involved the Michigan Department of Natural Resources in a rancorous legal turmoil for many years. Similar concerns have been raised nearly everywhere salmonids are cultured (Cowey and Cho 1991; Foy and Rosell 1991; Persson 1991).

The diverse nature of the U.S. aquaculture industry will require an equally diverse array of strategies to deal effectively with environmental issues. The 1998 Census of Aquaculture indicates that U.S. fish production comes from a variety of cultural systems: 63% from ponds for catfish and minnows; 14% from flow through raceways for salmonids; 7% from closed/recycle systems for a variety of fish, but mainly hybrid striped bass and tilapia; 3% from cages and net pens (1%) for salmon; and others (12%). Most farms use groundwater (47.8%) or on-farm surface water (36.1%) sources for water supply. Aquaculture systems also represent various degrees of intensification (weight/unit of culture space), production (weight/yr), and concentration of waste components (solids, phosphorus, nitrogen) in their effluents. The diversity of aquaculture systems also results in a considerable diversity in waste characteristics. Engineering strategies to reduce nutrients in effluent and removal of suspended and dissolved solids will be different for catfish ponds, salmonid raceways, net pen culture, and recycle systems.

The concern by the U.S. Environmental Protection Agency (USEPA) over aquaculture waste in the U.S. is not new. More than 25 years ago, the USEPA sponsored studies to gather information on pollution from trout hatcheries (Hinshaw 1973) and intensive culture of catfish (Summerfelt and Yin 1974). These and other studies placed aquaculture low on the priority list and for this and other reasons, specific effluent guidelines for aquaculture were not developed (Keup 1989). The USEPA put off establishing minimum discharge standards for aquaculture production facilities at that time. Instead, they relied on various provisions of the Clean Water Act to regulate the discharge of wastes from concentrated aquatic animal production facilities under the general National Pollutant Discharge Elimination System (NPDES) permit for point source pollutants. Under the Code of Federal Regulations, concentrated aquatic animal production facilities are considered point sources requiring NPDES permits for discharges into waters of the United States. A permit is required for salmonid hatchery when discharge occurs at least 30 days/yr and more than 9,072 kg (20,000 lb) of aquatic animals/yr are produced, or more than 22,680 kg (50,000 lb) of feed is used during the calendar month of maximum feeding. A permit is required for a warmwater fish culture facility when discharge occurs at least 30 days/yr and more than 45,360 kg (100,000 lb) of aquatic animals/yr are produced (Bastian 1992).

Aquacultural effluents occur when there is overflow from watershed (hill ponds) ponds, and from levee ponds as well when the ponds are drained for harvest or repairs. Aquacultural effluents contain dissolved and suspended solids and the nutrients phosphorus (P) and nitrogen (N) that are derived from fish excretion, feces, and uneaten feed. Nutrients are the cause of eutrophication. The literature concerning aquaculture effluents shows great variability in reported waste loading and their environmental effects. This variability is a reflection of the differences in culture systems; production rates and timing; quantity and quality of source and recipient waters hydraulic retention time; fish species and age; feed types and feeding rates; and management procedures such as cleaning and effluent treatment.

Dilute, but large effluent volumes are discharged from traditional raceway systems used for salmonids (single pass and serial reuse), but they add up to high total daily loads (Westers 2000). Because of the high volume, effluents from raceway culture are extremely difficult to treat (Negroni 2000). Recycle aquaculture systems (RAS) use far less water, often less than 5% of system volume per day, and the effluent is concentrated. Effluents from RAS faculties can be discharged from the culture building to a septic tank, which can be pumped out and applied to fields. Ideally, the effluent will find beneficial use as proposed in Objective 3. Good environmental stewardship requires that aquaculture effluents not have negative impact on the environment.

Recently, in response to accusations and evidence of environmental pollution from aquaculture, both Canadian and U.S. environmental agencies have developed timelines for performance-based standards (effluent limitation guidelines) for aquaculture waste management.

USEPA's effort to develop pollutant controls in the form of nationally applicable discharge standards (known as effluent limitations guidelines and standards) for commercial and public aquatic animal production facilities was announced in the Federal Register Notice, September 14, 2000. This was required by a consent decree from an action filed against USEPA on October 30, 1989 by the Natural

Resources Defense Council, Inc., and Public Citizen, Inc in which they alleged, among other things, that USEPA had failed to comply with section 304(m) of the Clean Water Act. The action by USEPA is the result of a settlement of that action in a consent decree entered on January 31, 1992. The consent decree established a schedule by which USEPA is to propose and take final action for eleven point source categories identified by name in the decree.

The decree also established deadlines for USEPA to complete studies of aquaculture. The last date for USEPA action under the decree, as modified, is June 2004. The decree also required USEPA to establish effluent guidelines. Several effluent guidelines are currently underway to help address siltation and nutrient problems, and, to a lesser extent, pathogens. In the proposed plan, USEPA announced efforts that were initiated in late 1999 to develop new or revised regulations for aquatic animal production (i.e., aquaculture). (USEPA had originally used the term “Aquaculture” to describe this industry. However, they have since recognized that the term “Aquatic Animal Production” better reflects the operations that USEPA expects will be subject to the forthcoming effluent guidelines.) USEPA is discussing the tasks and information necessary to develop an aquatic animal production rule with the Joint Subcommittee on Aquaculture's (JSA's) Aquaculture Effluents Task Force, which consists of representatives from trade associations, academia, federal and state agencies, professional societies, and non-governmental organizations. USEPA has said that it will provide a number of opportunities for further involvement before developing the effluent guideline regulation.

The aquatic animal production industry was first studied by USEPA in 1974 and has operated under guidance issued in 1977. USEPA chose to issue guidance in the late 1970s rather than promulgate a regulation at that time in order to focus resources on other industries that USEPA regarded as higher priorities for the regulation of toxic pollutants. As in the 1998 plan, USEPA's guidance was insufficient for many state permitting efforts; it reflected neither the growth in the industry, nor the significant technological advances that have been made. Several states expressed interest in more current technical assistance and support, including a detailed analysis of the industry, its processes, controls, and financial ability to improve its environmental performance. USEPA's decision to begin developing effluent guidelines for this industry reflects the Agency's commitment to launch the scientific study, data collection, and public involvement necessary to make that happen.

USEPA is conducting a survey that will be used to gather information about the aquaculture industry in order to develop effluent guidelines for this industry. A draft of the proposed USEPA regulations will be released for public comment by June 2002 and final regulations will be released by June 2004. The USEPA draft will be released before the end of the first year of this project (August 31, 2002). Thus, information on aquaculture waste production, treatment methods, and effluent characteristics must be obtained and summarized before formulation of the final regulations. Release of the final regulations nearly coincides with the end of the study (August 31, 2004).

In most cases, the USEPA will delegate the job of enforcing the regulations to state pollution control (environmental quality) agencies. Based on what state agencies already require, effluents will need to be monitored and regulations may specify treatment technologies that are needed to bring the effluents into compliance with USEPA effluent standards. The goal of this project is to provide science-based information that will influence proposed USEPA regulation of aquaculture effluents.

The action by USEPA has prompted a substantial response by the aquaculture community. The JSA, which serves as a federal interagency coordinating group to increase the overall effectiveness and productivity of federal aquaculture research, transfer, and assistance programs, approved the establishment of an Aquaculture Effluents Task Force on September 2, 1999. The mission of the task force is to coordinate, facilitate, review, and provide input of science-based information to assist USEPA in the development of national effluent limitation guidelines and standards for aquaculture facilities in the United States.

There are engineering, fish feed composition, and feeding options for reducing nutrients (N and P), as well as dissolved and solid wastes in aquacultural effluents. Phosphorus in fish hatchery effluents is mainly derived from fish feed, therefore, reducing P content of the feed to only the minimum concentration of available P required for good health of the fish will reduce P content of the effluents. Unless the P in plant phytate is made digestible, the substitution of plant ingredients for fish meal may reduce consumption of fish meal but will increase the release of P. Nitrogen in effluents is derived from metabolism of proteins, which fish mainly excrete through their gills. Thus, protein in the diet must be spared with suitable non-protein sources (i.e., fats and oils). Proper protein to energy ratios and use of highly digestible proteins in the feed can reduce excess nitrogen derived from feeds. Also, both N and P derived from fines (small particles of fish feed) must be reduced by feed manufacturing processes and feed handling. Preventing over-feeding requires proper feeding frequency, calculation of feeding rates based on accurate stock inventory, fish size, water temperature, fish health, and other factors. However, a waste feed controller can reduce the volume of uneaten feed and enhance feed conversions. Engineering design can increase the efficiency of capture of waste feed and feces. Recent development of a dual-drain tank design (Timmons et al. 1998) makes possible a reuse system whereby solids, and most of the P, can be concentrated in only 10% of the flow that can be removed by a microscreen filter (Summerfelt et al. 2000).

Once concentrated and captured, greater integration of aquaculture-rearing systems may be able to promote the beneficial reuse of wastes (Yeo and Binkowski 1999). The objectives of the present proposal are directed to addressing several issues relevant to reducing effluents from aquaculture and finding beneficial uses of waste products.

Fate of Aquaculture Waste Components (Objective 1)

Because of the shortened growing season for pond culture in the NCR, indoor, confinement aquaculture is of considerable interest. Intensive aquaculture in recycle systems is also called closed recirculation tank (USDA 2000). Although only 8.1% of the total fish farms in the U.S. use RAS systems, however, in the NCR the percentage is 16.8%. The Northeastern region was second in use of RAS systems with 14.9% of farms there using RAS systems. In the NCR, all tilapia, most hybrid striped bass, and a considerable portion of yellow perch are cultured in recycle systems. Environmental advantages of RASs are that they are more efficient in water use per weight of product produced than flow-through raceway systems. Also, they produce a small volume of concentrated wastes that are easier to store, collect, and dispose of by land applications, or used for other purposes than serial flow-through hatchery systems (see Objective 3).

Iowa State University will describe the fate of aquaculture waste components (P, N, and solids) relative to feed input in a new, state-of-the-art recirculating aquaculture facility at Loess Hills Aquaculture, Inc., Manning, Iowa (see Figure 1 on page 18). The facility incorporates dual-drain (circular) tanks with external, triple standpipe system, and ultrasonic waste feed control (UWFC). The circular, dual-drain design is managed as a swirl separator. It sends 80-90% of the flow from a sidewall drain directly to the biofilter, and uses the hydraulics of the circular tank to concentrate solids at the center bottom of the tank for quick removal (Timmons et al. 1998; Summerfelt 2000a). The design of these tanks includes an external standpipe with a single inlet and two outlets. The triple standpipe is another swirl separator that captures some of the solids in a settling area that can be flushed to the septic tank with a minimum loss of water. The economic importance of the dual drain is that of reducing the size of the drum filter and rapid concentration of solid waste. With dual drains, only 10-20% of the flow from the culture tank bottom drains will be treated across a drum filter (microscreen filter), a design feature that reduces the size requirement for the drum filter. The waste feed controller is intended to reduce waste feed (a significant portion of solid waste production) and at the same time increase feed efficiency and fish growth.

Rapid Solids Removal/Recovery Appropriate for New Aquaculture Facility Designs (Objective 2)

Solid waste management is essential in order to minimize potential adverse environmental impacts associated with intensive fish culture. Rapid solids removal is essential to reduce leaching of nutrients into the recycle flow, to reduce organic loading on the biofilter, and to reduce biochemical oxygen (BOD) in the culture system.

In flow-through systems (e.g., tanks and raceways), a large portion of the solid waste generated is often removed by periodical sweeping combined with rapid flushing. This method generates a pulse of discharge water that can contain most of the potential pollutants discharged by the system. For example, in a typical 30-min routine cleaning period, 70% of the daily BOD, 75% of the total P, and 10% of the total N can be discharged (Alabaster 1982), and the concentration of total solids discharged can reach as high as 400 mg/L (NCRAC 1994). Settling ponds are one common method of removing solids from the waste stream of flow-through systems, but the discharge can raise the temperature of the receiving waterway, and it can be difficult to incorporate the use of settling ponds in some sites that may be otherwise suitable for flow-through or pond aquaculture.

In pond culture, virtually all of the discharge of solids occurs when ponds are drained for harvest and the concentration of solids discharged increases greatly towards the end of the pond drainage. For example, the concentration of total solids discharged from ponds at the Fairport Fish Hatchery (Iowa) averaged 539 mg/L early during pond draw-down and 1070 mg/L near the end of pond draining (NCRAC 1994a,b). Rivera (1995) reported that the concentration of settleable solids discharged from fingerling ponds at the Wisconsin Department of Natural Resources Lake Mills State Fish Hatchery (Lake Mills, Wisconsin) increased from <0.1 mg/L at the beginning of drawdown to >0.8 mg/L when 90% of the pond was drained, and increased further to >1.6 mg/L when 99% of the pond was drained.

The investigators from Iowa State University (ISU) and the University of Wisconsin-Madison (UW-Madison) propose innovative strategies for rapid solids removal.

<u>ISU</u>

ISU investigators propose to evaluate the relative contribution of the drum filter, triple standpipe, and waste feed controller for rapid solids removal in a new, recycle culture system used for intensive culture of food-size walleye. The system consists of five, 37.9 m^3 (10,000-gal) tanks of the dual-drain design, the operation of which is described by Summerfelt et al. (2000) and Timmons et al. (1998). The proposed research will be the first to report on the performance of this system in a commercial aquaculture facility in the NCR.

The components—P, N, and dissolved, suspended and total solids—of the flow through the culture system will be monitored at several critical control points (see Figure 1 and Table 1 on pages 18 and 19, respectively) to determine the efficiency of each system component. Multiple sample points will be used to demonstrate the relative removal of suspended solids by the microscreen filter, the role of the biofilter in nitrification and dissolved solids removal by heterotrophic microbes, and ozonation for converting nitrites to nitrates. Critical sample points include: (1) the side-wall and center drain effluents from the culture tank, (2) after the drum filter, (3) after the biofilter, (4) in the inflow to the culture tanks, and (5) the effluent from the culture system.

<u>UW-Madison</u>

Investigators at UW-Madison propose to test a variety of natural fibers as filter media for removing the pulsatile release of solid effluents from different types of aquaculture systems. In addition, building and testing a filter box that will use this media to remove solids from the effluent of large-scale raceways and ponds is proposed. It is hypothesized that properly designed natural fiber filters can effectively and inexpensively remove a high percentage of solids from the waste stream of these systems.

Beneficial Use of Aquaculture Waste (Objective 3)

Recycle aquaculture systems consist of components that carry out important unit processes; they must remove suspended solids derived from feed and fecal matter, convert ammonia that is excreted by fish to nitrate, remove CO_2, and add oxygen. Typically, recycle aquaculture reduces water consumption to about 5% of total system volume, a considerable savings in water consumption. Although fish culture in recycle systems reduces the volume of the effluent, the effluent has a higher concentration of biosolids creating disposal situations similar to those dealing with manure from land-based concentrated livestock production operations. The effluent guidelines for aquaculture will apply to wastewater discharges from both the animal production areas and the land application areas at these operations.

Environmental concerns include proper solids handling, drying storage, and land disposal. The recently published Idaho Waste Management Guidelines for Aquaculture Operations (IDEQ 1997) lists odor control, safe and clean solids transport, storage lagoon site selection and design, application techniques, site selection, crop compatibility, hydrogeology, and soil type and depth as considerations for a responsible solids storage and application program. The most important objective of solids utilization, from this regulatory agency perspective, is to insure that constituents harmful to water quality do not leach into ground water or enter surface water. These guidelines are based on the needs of the highly developed trout production in Idaho, and are pertinent to similarly scaled private and public salmonid facilities in the NCR. The waste management needs of the generally small-scale RAS operations and non-traditional species that are currently being attempted in the NCR can be expected to differ from large-scale operations both in the quantities and the management of the biosolids (NCRAC 1994a,b). From a perspective of more integrated or sustainable aquaculture, the objectives for solids utilization should reach beyond guidelines for the avoidance of harm and if possible divert waste to reuse as a valuable resource (Adler et al. 1996; Yeo and Binkowski 1999).

Like other animal manure, biosolids harvested from aquaculture operations can be excellent fertilizer and soil conditioner for agricultural crops, gardens, lawns, trees, and flowerbeds, depending on the siting of the operation. In some situations sludge can be directly land applied as fertilizer (IDEQ 1997). Although applying aquaculture biosolids while wet and immediately tilling into the ground is believed to give the greatest fertilizer value, even dried solids provide humus, conditioning, and increased water retention to the soil. Coordinating application with crop need and the seasonal freezing of the ground in the NCR region complicate this process for this region. Recirculating systems employ rapid solids removal, and produce smaller volumes of more concentrated and probably less degraded or stabilized organic wastes than that harvested periodically from trout hatchery settling ponds and storage lagoons.

Composting offers an alternative to direct land application. Conventional composting is an accelerated biological oxidation of organic matter passing through a thermophilic stage (45–65°C; 113–149°F) where microorganisms (mainly bacteria, fungi, and actinomycetes) liberate heat, carbon dioxide, and water. The heterogeneous organic material is transformed into a homogeneous and stabilized humic-like product through turning or aeration. Conventional composting is conducted by adding high carbon content materials to wastes of high nitrogen content and piling the mixture high enough (approximately 1.22 m [4 ft] in the NCR region) to retain heat to support the thermophilic reaction. To avoid anaerobic conditions and associated odors, these piles must be turned frequently for adequate aeration.

Composting advantages include helping to stabilize the waste material, which reduces odor, BOD, and volume of the waste. Composting produces a useful soil amendment or planting medium that is a slow release fertilizer and increases water holding capacity. The more stabilized finished compost is easier to store and transport for use than raw waste and application can be delayed for better coordination with crop needs. Composting is also suitable for processing dead fish, spoiled feed, and fish processing residues (UWSGI 1992; Fornshell et al. 1998). Composts have a commercial value and can potentially be sold, as well as used as a soil amendment. Compost microflora have been shown to have plant disease suppressive qualities (Adler et al. 1996). Composting may involve expenses for storing wastes and labor for turning the pile. The conventional pile requires considerable bulk in order to retain the heat required for the thermophilic reaction, and in the NCR outdoor composting is subject to reduced activity during the regional cold season.

As an alternative to conventional composting, the use of worms (Edwards and Niederer 1988) in the composting process, termed vermicomposting, offers several advantages that may be appropriate for use by NCR aquaculturists. This technique has been increasingly applied to other organic wastes and livestock manure (Sherman-Huntoon 2000). Vermicomposting is also a biological oxidation and stabilization process of organic material that, in contrast to composting, involves the joint action of earthworms and microorganisms and does not involve a thermophilic stage. The earthworms are the agents of turning fragmentation and aeration consequently avoiding the labor associated with the turning of bulky conventional compost piles. Vermicomposting beds are typically only about 0.45-m (1.5-ft) deep rather than the approximately 1.22 m (4 ft) depth needed for heat retention in conventional composting. Consequently, the space requirements are more modest and the process can be effectively conducted on a scale from small household bins to large institutional waste disposal size. The end products are the worms themselves that have value either as bait or as live fish food, and a highly valued specialty organic fertilizer. There is evidence that worm composting improves the availability of nutrients to plants. Earthworms can break down a wide range of organic wastes and are commercially bred on a large scale in organic wastes for fish bait. Currently other livestock manure is used as feedstock for worms, and there is reason to believe that both recovered aquaculture biosolids in the form of fish manure, unused feed, or fish processing waste could be effectively processed through vermicomposting.

Workshops and Fact Sheets (Objective 4)

This objective is designed to meet the information needs of diverse producer groups by producing authoritative publications and workshops on aquacultural wastes, aquaculture waste management, and regulations regarding aquacultural waste management. Aquacultural producers need up-to-date information on practical strategies for managing aquaculture wastes, current state and federal effluent regulations, monitoring requirements, and hands-on experience with methods for collection of required water quality data. This requires effective communication among research, extension, and commercial aquaculture. The USEPA has delegated regulatory authority to state environmental control agencies that issue discharge permits under NPDES guidelines. The North Central Regional Aquaculture Center (NCRAC) efforts on this project can supplement individual state extension efforts regarding these issues.

The outputs will be: (1) a technical bulletin on the nature of aquacultural wastes; (2) a fact sheet on USEPA and state regulations in the NCR regarding aquaculture effluents and monitoring requirements; (3) a technical bulletin on BMPs for reducing solids and nutrients in aquaculture effluents; and (4) a workshop and/or contribution to sessions on aquacultural waste management for NCRAC or other conferences. All written materials will be made available through the NCRAC web site (http://ag.ansc.purdue.edu/aquanic/ncrac) and distributed to aquaculture specialists, and other Cooperative Extension Service and Sea Grant Advisory Service personnel.

RELATED AND PREVIOUS WORK

Fate of Aquaculture Waste Components (Objective 1)

Most P and N in aquaculture effluents originate from aquafeeds, thus considerable research has been reported on the relationship between the aquacultural wastes and fish feed (Cowey and Cho 1991). Fish produce about 28–32 g (1.0–1.1 oz) of N, and 250–400 g (0.55–0.88 lb) of total suspended solids for every kg (2.2 lb) of feed consumed (Summerfelt et al. 2000). The primary sources of P in fish hatchery effluents are from fish feces and uneaten food. Most (50–80%) of the P in effluents from salmonid hatcheries but only 15% of the total effluent N is found in settleable solids (Heinen et al. 1996). Most of the effluent N is in the inorganic form as ammonia (NH_3 + NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). The fraction of nutrients and organic matter in the dissolved and particulate form are dependent on feed formulation and handling of organic wastes.

A reduction in P content of fish feeds may reduce P concentration in fish hatchery effluents (Ketola 1982; Ketola 1991a,b,c; Ketola et al. 1991; Ketola 1994; and Ketola and Harland 1993). Only 25–30% of the N, P, and organic matter applied as feed was harvested by catfish (Boyd 1985) and similar values have been reported for salmonids (Ramseyer and Garling 1997). Traditional flow-through systems used for salmonid culture export most, if not all, of the burden for water treatment to the receiving water (Westers 2000). Accounting for nutrients in intensive pond culture must include uptake by algae and other organisms, absorption by pond soil, and ammonia exported to the atmosphere. Gross et al. (1999) reported that ammonia (NH_3) volatilization from fish ponds was 3.8% of total ammonia nitrogen (TAN) concentration in water.

The other strategy to reduce nutrients and solids from fish hatchery wastes is in the engineering design (Chen et al. 1993; Timmons et al. 1998; Summerfelt et al. 2000). The focus of this objective is to quantify P, N, (ammonia NH_3 and NH_4^+, nitrite, NO_2^-, and nitrate, NO_3^-), and solids (total suspended solids, TSS, and total dissolved solids, TDS) concentrations before and after critical components (unit processes) of a new recycle aquaculture system (see Figure 1and Table 1 on pages 18 and 19, respectively) and to obtain a mass balance between feed inputs and nutrients in the effluent. Information is sparse on the relative removal/transformation of nutrients at critical control points in a complete recycle system, especially for technology employed in the proposed study.

Rapid Solids Removal/Recovery Appropriate for New Aquaculture Facility Designs (Objective 2)

ISU

The focus of this objective is to evaluate new technology that has been incorporated into the construction of a recycle system at Loess Hills Aquaculture, Inc., Manning, Iowa. The company has invested in state-of-the-art technology that will be both effective for fish culture as well as appropriate technology for rapid solids removal and disposal. Projects of this type can be instrumental in ensuring that many aquaculture practices develop in an environmentally sustainable way.

Traditional sedimentation as a waste capture technology may result in considerable leaching of nutrients, and rough handling of wastes by pumping will break fecal matter, uneaten food, and feed fines into smaller fractions that are not removed by microscreen filtration. The proposed project will describe effectiveness of a new RAS facility that uses new engineering strategies to quickly remove solids and which produces a small volume of effluent (3–5% of total system volume per day). Rapid solids removal is accomplished by use of circular tanks that function like a swirl separator, quickly moving feces and waste feed to a central drain by the rotational velocity of the current and radial flow that moves settleable solids along the tank bottom to the center drain (tea-cup effect). Only about 5–20% of the effluent from the center drain is required to flush settleable solids from the tank bottom (Summerfelt et al. 2000). The solids leaving the tank are briefly sorted by an external triple standpipe that also functions like a swirl separator. Summerfelt et al. (2000) and Timmons et al. (1998) have described experimental dual-drain recycle systems with this design. This type of dual-drain culture tank is now used at three sites in Ohio and at the Loess Hills Aquaculture facility in Manning, Iowa (Timmons and Summerfelt 2000).

The Loess Hills Aquaculture system will also be equipped with a waste feed controller (WFC), a hydroacoustic detection device that can distinguish between fish feces and fish feed. Hydroacoustics for detection of waste feed were first used in Norway as a means for demand feeding and food intake for salmon in sea cages (Juell 1991; Juell et al. 1993). On the other hand, the application of analogous hydroacoustical systems to regulate feeding for the purpose of reducing pollution from waste feeds has received more emphasis in the United States. Durant et al. (1995), Summerfelt et al. 1995), Derrow et al. (1996), and Tsukuda et al. (2000) describe a hydroacoustic system that detects feed within the drain pipe of fish culture tanks.

UW-Madison

In nature, wood and plant fibers often effectively trap sediment and solids in runoff, a process commonly associated with the filtration capacity of wetlands. Based on this knowledge, over 10 years ago scientists from the USDA Forest Products Laboratory, Madison, Wisconsin (USDA-FPL) and the UW-Madison began conducting studies testing the use of modified and unmodified natural fibers as a media for water filtration to remove compounds including particulates, heavy metals, pesticides, and nutrients. As a result of this research, fiber filters are now being used in the city of Madison to remove pollutants from storm water runoff into the Madison lakes.

More recently, a pilot study was conducted from 1997-1999 on the application of natural fibers to a small recirculation fish culture system. A variety of wood and plant fibers were used as separate media for the removal of settleable and suspended solids, and for the biofiltration of nitrogenous wastes. This study demonstrated that the extensive surface area of natural fibers makes them fundamentally favorable both for removing solids and as a biofilter.

Beginning in January 2000, a team of investigators including scientists from the UW-Madison Aquaculture Program, the UW-Madison Departments of Biological Systems Engineering and Civil and Environmental Engineering, the USDA-FPL, Odbek Industries, Inc., St. Paul, Minnesota, and REM Engineering, LLC, Evansville, Wisconsin has been conducting a project funded by the Energy Center of Wisconsin. The team has expertise in aquaculture, aquacultural and environmental engineering, wood fiber chemistry and engineering, and fiber manufacture. One objective of the project is to test the feasibility of using natural fiber filters to remove solids from yellow perch recycle systems. The fiber material being used for this project is being refined at the USDA-FPL. Odbek Industries, Inc. and REM Engineering, LLC, private companies involved in the design and manufacture of non-woven fibers and fabrics, are providing expertise in the design and manufacture of the fiber mats.

The fish culture systems for this project each consist of one 3,000-L (793-gal) round fiberglass fish tank connected to two filter boxes. The first filter box contains vertically mounted fiber mats for the removal of solids. The second box contains vertically mounted filters containing sphagnum moss, which act as a biofilter for the system. The water flow through the systems averages more than 4,500 L/h (1,189 gal/h).

The project team has achieved very favorable results to date. As much as 1.1 kg (2.4 lb) of feed is being fed daily to 1,300 fish in one of the systems. By using only four fiber filters having a total area of <3 m^2 (32.3 ft^2) to remove solids, total suspended solids have not risen above 1.5 mg/L in the system. The filters are showing an extremely high capacity to remove solids, and are only changed on an average of every three weeks. The filter furthest upstream tends to clog first because it is exposed to the highest concentration of solids.

Further tests are currently being conducted to determine the maximum daily feeding rate achievable for the systems. Different types and designs of fiber mats are being used to determine the optimum condition for maximizing the removal of suspended solids, while at the same time permitting high flow rates by minimizing frictional losses.

The technical information being generated in these studies is providing an excellent foundation upon which to investigate how solids filtration using natural fiber media can be applied to flow-though and pond aquaculture systems. Presently, it is anticipated that changes will be required in the design of the filtration system and filter mats, based on parameters such as flow rate, particle size, and solids concentration. Use of the same natural materials with various alterations is proposed to improve its effectiveness for application to flow-though and pond aquaculture systems. Investigations will be conducted to: (1) evaluate a variety of suitable fibers; (2) preprocess filter material to increase surface area; (3) modify the fiber surface to increase performance; and (4) test different manufacturing techniques for the production of fiber mats.

Beneficial Use of Aquaculture Waste (Objective 3)

Land application to cropland has become the easiest and most widely adopted technique to recycle nutrients from settling ponds. Properly applied, this technique safely disposes of waste while providing crop fertilization and improving or maintaining soil structure. The nutrient characteristics and fertilizer value of fish manure (Mudrak 1981;Yarris 1981; Smith 1985; Willet and Jacobsen 1986; Olson 1992a,b,c; Westerman et al. 1993; Axler et al. 1997; Naylor et al. 1999) have been found to depend on the source materials, the methods of collection and storage, and the methods of land application. Based on 1991 trout production levels of 23 million kg (50.6 million lb) for the U.S., it has been estimated (Westerman et al. 1993) that about 10 million kg (22 million lb) of fecal solids are available and should be removed from raceway waters before they are discharged. Solids samples showed substantial variation between farms and between types of manure management on the same farm. Age of storage of the trout manure influenced the quality. With regard to heavy metal content, zinc levels have been found to be slightly high, but not high enough to be limiting to land application.

The IDEQ (1997) has recently published guidelines for removal and land application of aquaculture waste that are especially appropriate for large scale salmonid type operations. The amount of wastes generated from even a large aquaculture facility, however, when properly applied has the potential to benefit only a relatively small amount of cropland. Forty hectares (one hundred acres) of land are adequate to accommodate biosolids produced by a properly operated aquaculture facility with a swimming inventory of 0.45 million kg (1.0 million lb), feeding 6,804 kg (15,000 lb) of feed per day (IDEQ 1997).

To avoid environmental damage, land application of aquaculture waste slurry should take into account site conditions, timing of application, application rates, crop type, crop uptake capacity, crop rotation, and land availability for application (IDEQ 1997). For the typically smaller NCR operation, compared to the example above holding 0.45 million kg (1.0 million lb), the potential nutrient benefit of cropland applied aquaculture waste is generally too small to provide incentive for incorporation into field crop management planning. Smaller scaled alternatives may be more appropriate beneficial use. For smaller scaled horticultural, landscape or gardening application further processing and stabilization of raw waste by composting is probably justifiable for handling, storage, and marketing reasons. Williams and Starr (1990; 1995) pointed out important constraints on the regional utilization of fish waste. Surface land application of this material can present undesirable odor conditions. Also, during regional winter conditions, when the soil surface is frozen, application of the waste will not allow it to incorporate into the soil and consequently creates problems with loss through spring runoff. The alternative of storing this material for later disposal presents formidable economic constraints. Williams and Starr (1995) reported Michigan Department of Natural Resources (MDNR) estimated costs for constructing fish waste storage facilities for State of Michigan fish hatcheries range from \$79–\$132/m^3 (\$0.30–\$0.50/gal) as compared with estimated costs of \$13–\$19/m^3 (\$0.05–\$0.07/gal) for land application with subsurface injection. At those rates, an aquaculture facility producing 45,360 kg (100,000 lb) of fish per year would have to spend up to \$75,000 for a waste storage facility and up to \$15,000 per year in disposal costs.

Recycle systems have greatly reduced consumption compared with traditional flow-through hatcheries, but they still use 200 m^3 (52,840 gal) to over 20,000 m^3 (5,284,000 gal) of water per MT (2,205 lb) of fish production. Typical effluent flows from RAS systems can range from 90–28,000 L/day (24–7,397 gal/day) (NCRAC 1994). From these volumes of discharge, solids can be effectively separated and concentrated by the clarifying devices (e.g., drum filter). Depending on site conditions at specific locations, the solids that are removed by the clarifier can be diverted to settling ponds, septic systems, or public sewage treatment works. Each of these options involves waste costs that often have not been explicitly detailed in available examples of aquaculture enterprise budgets. The RAS system budgeting tool by Dunning et al (1998) lists only a \$5,000 cost for an initial settling pond. Costs of domestic septic systems range from several thousand to over ten thousand dollars depending on the expected flow capacity and soil conditions, but a septic system specifically designed for an RAS system would likely be roughly comparable in cost to a larger scale domestic system. Periodic pumping and land application of sludge from a settling pond or septic tank adds additional operating costs, but it is a chore familiar to confinement hog production. Frequency of removal and cost will depend on the size and design capacity of the facilities. In an urban site, disposal may require flushing waste to a municipal sewage treatment system. As an example, the city of Milwaukee, Wisconsin has a rate for the metropolitan sewage district based on flow and concentration of the waste. They have a base charge of \$0.12/m^3 (\$0.45/1,000 gal) for clear water and \$0.22/m^3 (\$0.83/1,000 gal) when concentrations of TSS and BOD are typical of domestic sewage. Gempesaw et al. (1993) estimated the waste disposal costs for an RAS would be \$42/1,000 kg (MT) of fish produced but costs per MT of fish produced will depend on fish production per unit of effluent.

Settled fish waste is generally in the form of slurry that is around 95% water. Although a high water content can be beneficial for direct land application, dewatering of the sludge is needed to alleviate space when further storage is required. Williams and Starr (1990; 1995) studied the dewatering of fish production waste using a filter press system. Fly ash, agricultural lime, diatomaceous earth or perlite can be used as a filter cake material to reduced the moisture content; the filter cake retained 95% of the N, P, and BOD, while reducing the moisture content of the waste by about 35%.

Preliminary attempts to assess the utility of the filter cake material as a fertilizer for plant growth (Willliams and Starr 1995) were not very promising. Although the filter cake contained nutrients, the amount present or its availability did not compare to similar volumes of inorganic fertilizer, causing decreased growth rates. The fine particle size of the filter cake may have decreased pore space of the growth media, reducing growth rate. The high pH of the agricultural lime aided filter cake material may also have been detrimental at the incorporation rates used.

Composting offers another potential approach to convert recovered aquaculture biosolids (Adler et al. 1996) to a usable soil amendment. Conventional composting has been used for processing dead fish, spoiled feed, and fish processing wastes (Fornshell et al. 1998; UWSGI 1992). Laboratory and field trials of trout manure composting indicate that trout manure becomes stable compost quickly, but at a low rate, as indicated by elevated temperature (Rynk et al. 1998a). This apparently contradictory result may have been due to low organic matter levels due to partial decomposition during settling and storage and the presence if inorganic sediment in the sludge.

Vermicomposting has the potential to convert aquaculture waste into commercially valuable by-products, the vermicompost and the worms. Vermicomposting may be a more suitable stabilization technique for fish manure, which has high moisture content, than conventional composting, which requires greater amounts of dry amendments. Earthworms require a moist aerobic environment at cool to moderate temperatures; they do poorly in anoxic conditions and in materials with high concentrations of ammonia and salts. At the University of Idaho some initial attempts (Rynk et al. 1998b) have been made to evaluate the suitability of trout manure as a feedstock for vermicomposting. Generally, the projects suggested that both composting and vermicomposting can beneficially recycle residues from aquaculture production, and that economic and environmental conditions of a specific farm will determine whether such processing is worth the effort (Buyuksonmez et al. 1998; Rynk et al. 1998b). Results of these vermiculture trials were conflicting, yet promising. Although worms grew poorly in small experimental containers, they thrived in larger holding bins containing the same materials. Generally, the worms performed better in aged fish manure, and fresh manure was usually intolerable to the worms. A period of acclimation appeared to be necessary before the worms would grow and reproduce.

<u>Uses and Value of Vermicompost</u>

Worm casting compost is sold retail as bagged organic specialty fertilizer from $0.97–$2.18/kg ($0.44–$0.99/lb); the variation is related to quantity. Bulk worm castings are sold from $47–$131/m^3 ($36–$100/yd^3). The final product of organic waste worked by earthworms is usually a finely divided peat like material with excellent structure, porosity, aeration, drainage, and moisture holding capacity (Edwards 1982; Edwards and Burrows 1988). Nutrient content differs depending on the parent material. However, worm compost produced from a variety of animal manures has been shown to often have higher levels of most nutrients than commercial plant growth medium (compost) to which inorganic nutrients had been added, except for magnesium, which was often deficient (Edwards and Burrows 1988). An important feature is that during the processing of wastes by earthworms, many of the nutrients they contain are changed to forms more readily taken up by plants, such as nitrate, soluble P, and exchangeable potassium, calcium, and magnesium (Edwards and Burrows 1988). A wide range of plants, including many vegetables, bedding plants, flowers, and ornamental shrubs have been successfully grown in worm-worked wastes both undiluted and mixes of 3:1 or 1:1 ratios of worm-worked waste to peat, pine bark, or Kettering loam (Edwards and Burrows 1988). Seedling emergence tests of tomatoes, cabbage, radishes, and ornamentals tended to be as good or better than in a commercial growth medium, and much better than in composted animal wastes with no earthworms (Edwards and Burrows 1988). Potential commercial markets for worm-worked animal wastes vary from country to country and so do the economic returns (Edwards and Burrows 1988). In general, for the high-value market, the product must be produced to within relatively small tolerances, as a standard material varying little in consistency or nutrient content. For such a product, uniform sources of organic wastes must be available, and the mixture and additives must be in constant proportions. Batch analysis would be needed to ensure standardization of the product. As the product is produced with lower technology and with more variable wastes its value decreases but so does the cost of production processing and packaging (Edwards and Burrows 1988).

<u>Uses and Value of Harvested Worms</u>

Several species of worms that are suitable for composting of organic waste are also bred commercially on a large scale for fish bait. *Eisenia foetida*, commonly called a red worm, is the most commonly bred species used both for composting and fish bait on a large commercial scale. It is a rapidly reproducing worm, smaller sized, about 0.45 g (about 1,000/lb), with habits and tolerances well suited for vermicomposting. As bait red worms do not command as high a price ($13–$18/1,000) as the larger Canadian night crawler ($31–$56/1,000). The Canadian nightcrawler doesn't do well under culture conditions and doesn't tolerate composting conditions. There are larger, about 0.65 g (about 700/lb), temperate and tropical worms that vary in temperature tolerance, reproductive rate, etc., that are also suitable for mass culturing and can command a more premium bait price ($31–$56/1,000). Unlike the Canadian nightcrawler they do not require refrigeration, making them ideal for shipping and ease of handling as fish bait. These are sold under a variety of trade names such as African nightcrawler, cultured nightcrawler, and European nightcrawler. The large but not very prolific *Dendrobaena veneta* and the large tropical *Eudrilus eugeniae* have been considered suitable candidates for vermicomposting.

In addition to having marketable value as bait, earthworms are suitable fish food and the nutrient spectrum of worm tissues has excellent potential for animal feed (Edwards and Niederer 1988). Overall, their composition doesn't differ greatly from that of many vertebrate tissues. Like meat and fish, worm tissue is about 60% protein. The essential amino acid profile of worm tissue is very adequate for good animal feed, and contains a preponderance of long-chain fatty acids, has an excellent range of vitamins, is rich in niacin and is an unusual source of vitamin B_{12} (Edwards and Niederer 1988). Potentially, earthworm protein could be a substitute for fish meal (Hilton 1983) in animal diets, but they are not currently mass cultured and harvested on a large enough scale to make this a practical reality. If they cannot be marketed as bait, excess worms from an on-site vermicomposting operation could possibly be directly fed to fish stocks, thereby recovering some of the cost (40–60% of the running cost of intensive fish farming) already expended on fish feed. In experimental trials five species of earthworm (*Allolobophora longa, Lumbricus terrestris, Eisenia foetida, Dendrobaena veneta*, and *Dendrodrilus subrubricundus*) have been evaluated as food for rainbow trout (Stafford and Tacon 1988). Fish fed solely on frozen slices of these earthworms (except for *E. foetida*) achieved growth rates and food utilization efficiency comparable to fish fed a control fish meal based diet. Carcass lipid content of trout fed the frozen earthworm diets had lower lipid and higher moisture content that those fed control diets, probably due to lower lipid content of the worm diets. An apparent problem with acceptability of *E. foetida* (the most widely used vermicompost species) to trout seemed to be from a foul smelling yellow coelomic fluid that it ejects as a defense mechanism in response to unfavorable stimuli (Gerard 1964; Edwards and Lofty 1977). Pretreatment of *E. foetida* by blanching or by freeze-drying overcame this difficulty in subsequent trials (Stafford and Tacon 1988).

Some evidence from these trials suggested that levels of lead and zinc increased somewhat in the carcass of fish fed solely on frozen slices of earthworm compared to control diet. However, at lower levels of inclusion (up to 30% of dried *E. foetida* meal) no significant linear relationship emerged between levels of heavy metals in the fish carcass and increasing dietary inclusion of dried *E. foetida* meal. No indication of a toxic effect of earthworm diets on rainbow trout was found (Stafford and Tacon 1988).

<u>Estimating Potential Revenues of Vermiculture Composting of Aquaculture Waste Operation</u>

Production of a MT of fish at a food conversion rate of 1.2–1.5 would result in production of 1.25 –1.75 MT (2,756–3,859 lb) of sludge with 80–95% moisture. To be used as worm bedding, the moisture content needs be lowered to approximately 40–50% moisture, which can be done by partial drainage and drying, and then adding an equal weight of shredded paper or other bedding material. About 2.5–3.5 MT of bedding for vermicomposting can be produced per MT of fish production. Assuming a 10% weight reduction (Fieldson 1988) and a 25% volume reduction during the vermicomposting process, the anticipated yield of product containing worms and compost would be 2.25 and 3.15 MT (@ 53% moisture). This product contains approximately 95% (2.1–3.0 MT or 1.0–1.4 MT dried) vermicompost and approximately 5% (0.11–0.16 MT wet weight) worms. The estimated retail value of the vermicompost @ $968–$2,178/MT ($.44–$0.99/lb) would be approximately $968–$3,050 for each ton of fish production. Assuming the worms are redworms that weigh approximately 0.45 g (1,000/lb) and have a value of $13–$18/1,000 the number of worms that could be expected to be produced from the wastes of a ton of fish production (244,000–355,000) would have a retail value of $3,172–$6,390. Assuming the higher value ($31–$56/1,000) of larger worms weighing approximately 0.65 g (700/lb), the retail value of worms expected to be produced from the wastes of a ton of fish production (169,000–246,000) would be $5,239–$13,776.

These estimates of production costs and values are only a rough approximation per MT of product output, but they do not include rates of population growth and the time required to process the compost. The costs and labor involved in such production have not been determined.

These estimates are intended to illustrate the possibility that either the worms or the compost produced from what is now the solid waste of a ton of fish production could have a value comparable, perhaps greater, than the $4,400–$6,600 value of a MT of yellow perch @ $4.41–$6.61/kg ($2.00–$3.00/lb) in the round. Investigating the feasibility of vermicomposting, and the associated costs of such an enterprise, are proposed. The solids from a recycle aquaculture facility might generate potential revenues rather than an expense for waste disposal.

Workshops and Fact Sheets (Objective 4)

ISU

NCRAC has printed a technical bulletin on current laws that are applicable to the production and marketing of aquaculture productions in the states served by NCRAC (Thomas et al. 1990). That publication, however, focused on licensing, permits, and fish and game regulations for the species of fish that may be cultured or transported; it did not contain the information on state or federal environmental (i.e., pollution control regulations.

ANTICIPATED BENEFITS

Fate of Aquaculture Waste Components (Objective 1)

ISU

The results of the present study in a large (189.5-m^3 [50,000-gal] culture tank capacity) commercial recycle system will add to what has been found from laboratory studies about the relationship between feed consumption and waste production in laboratory environments. This information will provide factual perspective on the contribution of each unit process to the breakdown and removal of solids and the chemical form of the nutrients (e.g., protein-N to ammonia, ammonia to nitrites, and nitrites to nitrates).

Rapid Solids Removal/Recovery Appropriate for New Aquaculture Facility Designs (Objective 2)

ISU

Rapid solids removal is important for proper functioning of a recycle system because excessive solids mechanically clog a biofilter and provide food for heterotrophic microorganisms in the biofilter. The latter displace the nitrifying bacteria needed for conversion of ammonia to nitrates. Rapid solids removal is essential to prevent breakdown of solids to particle sizes smaller than can be efficiently removed by a microscreen filter. Organic solids have a high BOD and they are important sources of N and P pollutants. Of course, suspended solids have negative impact on fish health.

The proposed study will utilize two strategies for quickly removing the solids, first with the dual-drain tank design with external triple-standpipe drain, and secondly, with a WFC, which distinguishes fish feces from fish feed, that shuts off the feeder when fish have been fed to satiation (Summerfelt et al. 1995). The WFC is also of value to efficient feeding of fish.

UW-Madison

The use of filtration systems 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.

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. The cost of the raw material is very inexpensive because the technology is ideally suited to the use of waste and by-product materials.

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.

Beneficial Use of Aquaculture Waste (Objective 3)

Future expansion of regional aquaculture requires lowered water usage and reduction of potentially harmful waste discharge. Development of cost effective recirculating rearing systems that are integrated for effective rapid solids removal and dissolved nutrient recovery are necessary to avoid the environmental regulatory and public image problems currently constraining industry growth. Vermicomposting has the potential to increase both the cost effectiveness of an RAS production system by converting the recovered solids that these systems produce into beneficial reusable and salable byproducts. 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.

Workshops and Fact Sheets (Objective 4)

Science-based information is the basis for rational decision making. Producers, regulators, and researchers need information on aquaculture wastes and effluent characteristics relative to feed and feeding. A detailed literature search of computerized databases will be summarized. Findings of the current and other studies can provide guidance for development of BMPs. Information will be distributed as hard copy in fact sheets and technical bulletins, made available electronically via NCRAC's Web site, and presented at conferences and workshops.

PROGRESS TO DATE

Characterization of aquaculture effluents from four types of production system was the title of a previous NCRAC Work Group (Yeo 1994). The objectives of that Work Group were:

1. Characterize aquaculture effluents from four types of aquaculture production systems: pond culture, flow-through culture (raceway), cage culture, and recirculating systems.
2. Generate a data base from these four types of production systems to help promote a reasonable choice of effluent discharge regulations by government agencies.

The Work Group characterized aquaculture effluents with regard to water quality parameters and production characteristics of 11 case studies from four major types of aquaculture production systems that are used in the NCR. The current project differs from the previous NCRAC study in that the focus of the current study is to obtain a characterization of waste components (P, N, and solids) relative to feed input in a newly constructed aquaculture system that makes use of two new technologies, a dual-drain tank and a hydroacoustic WFC (Objective 1).

The second objective of the present study is to "Evaluate the technical and economic feasibility of rapid solids removal/recovery appropriate for new aquaculture facility designs." The ISU project will be carried out at a commercial facility that has dual-drain tanks to separate effluent from the culture tank into a small flow containing most of the solids to a drum filter and the larger flow to a fluidized bed sand filter. Because of the split flow, the design reduces the cost for solids removal and at the same time it provides for rapid solids removal. In addition, a hydroacoustic WFC will be added to the external standpipe to monitor waste feed and to regulate feeding. The University of Wisconsin-Madison plans to evaluate an innovative design for a biofilter using mats formed with wood fibers.

Objective 3 (UW-Milwaukee), to "Demonstrate economically sound processing methods for beneficial use of aquaculture waste," is the first NCRAC research and development effort to make useful applications for aquaculture wastes.

Objective 4, to "Provide workshops and fact sheets that address best management practices (BMPs) for waste control," will summarize science-based information on waste production, capture, and effective waste capture and disposal methods. This information is needed to guide the development of rigorous but practical standards for environmental protection. Information on N, P, and organic matter production of samples of operating fish farms are needed to help decide nutrient input and control strategies for dealing with aquaculture effluents.

Although NCRAC has fostered the development of many technical bulletins and fact sheets, as well as sponsored four conferences (in 1991, 1995, 1997, and 1999), to this point neither technical bulletins nor fact sheets have been prepared on BMPs for waste control, nor is there a fact sheet or technical bulletin on the NPDES regulatory process for discharge of aquacultural wastes. The products of this objective will be technical bulletins and fact sheets describing BMPs for aquacultural waste, and a description of USEPA guidelines for aquacultural effluents. The budget for the third year includes expenses for a producer-oriented conference or workshop on effluent problems and regulations.

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.

PROCEDURES

Fate of Aquaculture Waste Components and Rapid Solids Removal/Recovery (Objectives 1 & 2)

ISU

ISU proposes to study both Objectives 1 and 2 together in the same culture system (Loess Hills Aquaculture) because data collection for both objectives can be done simultaneously. Objective 1 involves description of the fate of nutrients in feeds, that is, their utilization by fish and elimination in waste feed, feces, and dissolved solids. Objective 2 is an evaluation of a new culture tank design which has a dual-drain system (a side-wall and center drain) that facilitates rapid solids removal by shunting 80% of flow from the side drain directly to the biofilter and 20% of the flow from the center drain to a drum filter where the solids are rapidly removed. The system also involves another new technology, that is, an electronic waste feed controller to prevent over-feeding and enhance feeding efficiency and fish growth.

Two tanks are to be equipped with timer-controlled feeders and three tanks with WFC. The hydraulics of the culture tanks move uneaten feed down the center drain of the culture tank to the external triple standpipe where the WFC sensor in the shorter standpipe of the triple standpipe system is able to discriminate between feed and feces by a sensitivity adjustment. The WFC turns off the feeder when the sensor detects feed (Figure 1). When fish eat most of the feed as fed, the feeder continues to run, and it is not turned off until the fish have fed to satiation and pellets start down the center drain. Effective functioning depends on a slow feeding rate, that is, over a 20–30 min interval.

Water quality monitoring will be done from October 2001 through August 2003, which will represent a production cycle from fingerlings to harvest. The facility was completed in April 2001; it will be stocked with the first cohort of walleye fingerlings July 2001. As designed, the system uses less than 5% of system volume in freshwater each day and the only effluent to leave the culture building will go to a septic tank (site 24, Figure 1). The sludge will be periodically removed from the septic tank for field application; liquids from the septic tank are continuously discharged to the septic tank tile field that lies up slope of a field used for raising corn and/or soybeans.

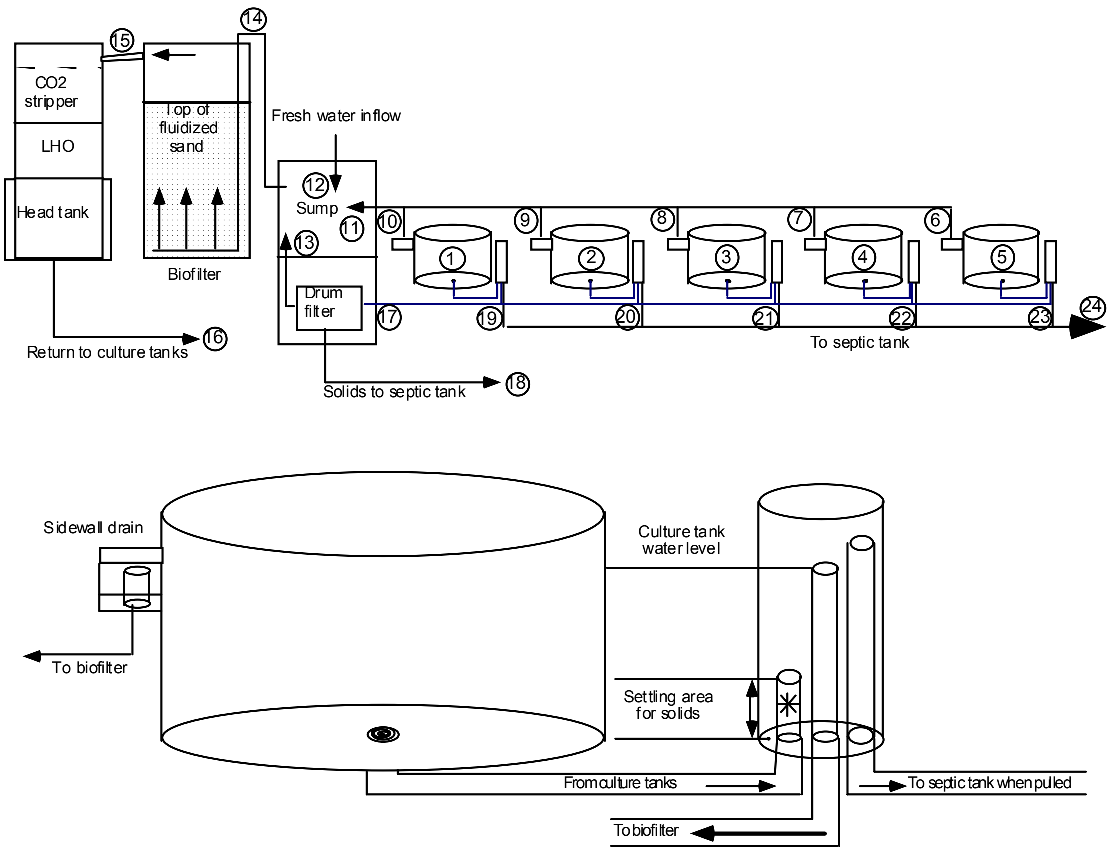
Thirteen chemical variables and water temperature will be monitored once monthly from October 2001 through August 31, 2003 (Table 1). Twenty-nine sample sites have been identified in the recycle system (Figure 1). The water quality from sample sites within the system are to be used to describe performance of different system components, and to provide information on rapid solids removal, mass balance of nutrient input and output. The characterization of the effluent from the culture building will be obtained from analysis of samples from site 24, and characterization of the effluent from the septic tank and the septic tank sludge are sites outside of the culture building; they are not shown in Figure 1.

Proximate analysis (protein, fat, moisture, ash, and N and P) will be done on a sample of fish and feed. A composite sample of 10 fish will be collected at the initiation of the study, and at six-month intervals during the production cycle, whenever fish are harvested, but specifically by August 2003. Nutrient content (N and P) of the inlet water will be done once monthly to characterize inputs of N and P to the system. Nutrient inputs to the culture system include nutrients in the inlet water, fish stocked, and fish feed. Outputs of nutrients include the N and P content of the effluent leaving the culture system (site 24), N and P of fish removed from the system for harvest, or occurrences of large mortalities. Samples of septic tank discharge (liquid) and the septic tank sludge will be used to characterize the treated hatchery effluent that goes to the environment. On occasions when there is an effluent from the fluidized sand filter (biofilm floc), samples will be examined for N, P, TSS, TDS, and BOD.

Monitoring of water quality parameters listed in Table 1 will follow procedures given in Standard Methods (SM), 20th edition (APHA 1998). Dissolved oxygen concentrations and temperature will be measured with a YSI Model 95 oxygen meter with thermister thermometer. The pH will be determined electrometrically with a portable pH meter. Carbon dioxide will be calculated from pH-alkalinity relationship, and alkalinity by titration. TDS will be done by SM 2540 C (sample is filtered and the filtrate is evaporated dried to constant weight at 180°C [356°F]) and TSS by SM 2540 D. Both dissolved and suspended forms of phosphorus will be determined. Filtration through a 0.45-μm-pore-diameter membrane filter will be used to separate dissolved and suspended solids for P analysis. The persulfate digestion method will be used as the preliminary step for P determination of dissolved and suspended samples. A high range (1 to 20 mg P/L) colorimetric method SM 4500-P will be used to determine the P-content of the solids and a low range (0.01 to 6 mg P/L) colorimetric method (4500-P E) will be used for dissolved samples. BOD will be done by the traditional 5-day BOD test (SM 5210 B). Several forms of nitrogen will be determined; they are TAN, nitrate, nitrite, organic nitrogen, and total nitrogen. The later will be determined by SM 4500-N C (persulfate method).

A diel sampling, around the clock at 4-h intervals will be conducted once monthly to measure temperature, DO, pH, TAN, BOD, TDS, dissolved and suspended P and N at four sites: freshwater inflow (site 12), discharge from drum filter (site 18), effluent from culture system to septic tank (site 24), and return flow from the LHO to the culture tanks (site 16). The additional samples represented by the diel sampling are not included in the total number of samples given in Table 1.

Quality assurance (QA)/Quality control (QC) procedures will be undertaken. QA will include a manual with written procedures, work instructions and record keeping protocols. QC will include use of certified standards for each analysis to check correctness, reagent blank, and at least four laboratory-fortified blanks using certified standards, method detection limit determination, and initial and ongoing assessment of precision and accuracy for laboratory personnel.



✳ Samples at this site from each culture tank (samples 25-29)

Figure 1. Schematic of Loess Hills Aquaculture recycle system-showing location of water quality sample sites 1 through 29. The water quality variables that are sampled at each site are given in Table 1.

Table 1. Water quality variables and sample sites for once monthly measurement for 24 months in Years 1 and 2. In addition, once per month diel samples will be collected every 4-h for 24-h of select variables (designated with *) at sites 12, 16, 18, and 24.

Water Quality Variables														
Sample Site	O_2	CO_2	O_3	pH	TAN	NO_2^-	NO_3^-	Alk	P-part	P-sol	TDS	TSS	BOD	Total
1	X	X		X	X	X	X	X			X	X	X	10
2	X	X		X	X	X	X	X			X	X	X	10
3	X	X		X	X	X	X	X			X	X	X	10
4	X	X		X	X	X	X	X			X	X	X	10
5	X	X		X	X	X	X	X			X	X	X	10
6	X	X		X	X	X	X	X			X	X	X	10
7	X	X		X	X	X	X	X			X	X	X	10
8	X	X		X	X	X	X	X			X	X	X	10
9	X	X		X	X	X	X	X			X	X	X	10
10	X	X		X	X	X	X	X			X	X	X	10
11					X	X	X				X	X	X	6
12	X*	X		X*	X*	X*	X*	X	X*	X*	X*	X*	X*	12*
13					X	X	X				X	X	X	6
14	X	X		X	X	X	X	X			X	X	X	10
15	X	X		X	X	X	X	X			X	X	X	10*
16	X*	X	X	X*	X*	X*	X*	X	X*	X*	X*	X*	X*	13
17					X	X	X				X	X	X	6
18	X*			X*	X*	X*	X*		X*	X*	X*	X*	X*	10*
19					X	X	X				X	X	X	6
20					X	X	X				X	X	X	6
21					X	X	X				X	X	X	6
22					X	X	X				X	X	X	6
23					X	X	X				X	X	X	6
24	X*			X*	X*	X*	X*		X*	X*	X*	X*	X*	10*
25					X	X	X				X	X	X	6
26					X	X	X				X	X	X	6
27					X	X	X				X	X	X	6
28					X	X	X				X	X	X	6
29					X	X	X				X	X	X	6
Total	16	14	1	16	29	29	29	14	4	4	29	29	29	243

Rapid Solids Removal/Recovery Appropriate for New Aquaculture Facility Designs (Objective 2)

<u>UW-Madison</u>

Fiber Filters: Researchers will evaluate selected wood and agro-based plant products for their suitability as biofilters and suspended solids filters. Selection of candidate filters will be based on cost (with preference given to waste and by-product fibers), surface area, biodegradeability, fiber length, and their modification potential. Odbek Industries, Inc., using an air-laid process, will fabricate processed fiber into filter mats. This process is inexpensive and provides flexibility in design and a high degree of uniformity of the resulting mat. Parameters that will be considered in the design of the filters are contact time, flow rate, and concentration of the wastes.

Preprocessing of the fiber material consists of creating individual fiber strands of similar length through the use of a fiberizer. The fiber material is then manufactured into a thin mat using an air-laid process. The resulting mat contains overlapping fibers held in place using a bonding agent. The thickness, weight, and porosity of the fiber can be varied in the production process.

Various modifications of the fiber will be investigated for the enhancement of the solids removal. The modifications may be conducted as part of the preprocessing of the fiber or may be applied to the fiber after manufacture of the filter. For example, in a current study it has been observed that a film of heterotrophic bacteria on the surface of the fiber may improve the retention and removal of solids. The fibers will also be exposed to various dry and wet chemical processes as well as physical modification techniques and manufacturing processes. The objective is to increase solids removal while retaining high hydraulic conductivity. Processing of the fiber will be conducted at the USDA-FPL and both the USDA-FPL and Odbek Industries, Inc. will manufacture the fiber mats. Chemical modifications, including oxidation, chemical substitution, and cold plasma reactions will be tested for their potential to increase the attraction between inorganic and organic particles and the fiber surface. Physical modifications, including techniques to increase internal porosity, will be tested for their potential to increase surface area, maximize fiber length, and maintain uniformity. Different manufacturing processes will be compared to produce high quality fiber mats with low basis weight and high porosity, while minimizing production costs. Laboratory measurements will include surface area, fiber length, sorption potential, and decomposition rates. Measurements during manufacturing of fiber mats will include basis weight, amount and type of binder required, and uniformity of the mat.

The design of the filter mats must address two forces that act counter to each other—specifically that the capture of solids reduces the porosity and the hydraulic conductivity of the fiber. Filter media must achieve both efficient solids removal, while at the same time maintaining a minimum flow rate required for efficient operation of both types of fish culture systems.

Studies evaluating a wide range of fibers using small-scale flow-through systems is proposed for Year 1. For these studies a small (<1 m^3; 35 ft^3) filter box will be constructed capable of filtering the effluent from 750-L (198-gal) flow-through tanks at the UW-Madison Aquaculture Program's wet laboratory facilities on the UW-Madison campus and at the Lake Mills State Fish Hatchery. The tanks to be used will contain a sufficiently high density of well-fed fish (e.g., 50 kg/m^3 [3.1 lb/ft^3], fed at 1–2%/day) to generate sufficient solid waste needed for the tests. The standard husbandry procedure currently used to remove accumulated solids from these tanks, which is to rapidly (200 L/min [52.8 gal/min] discharge) drain and brush-clean the tanks once weekly, will be used.

The filter box will contain vertically mounted filters aligned in series. At least 10 types of wood and non-wood fibers will be compared for use as filter media. Parameters used in the selection of the candidate fibers will include availability, cost, fiber characteristics, and ease of construction of the fiber into a mat.

The filtration system will be installed and monitored for efficiency in removal of solids. Water samples entering the filter (i.e., raw tank effluent) and discharged from it will be analyzed to determine the quantity, concentration, and particle size of solids. The amount and percentage of solids retained by the filters during tank cleaning will be measured. The practical capacity of the filters to retain solids relative to the degree that they restrict water flow through the filter box will be measured.

Also in Year 1, a large-scale filter box to handle the flow rates and concentration and quantity of solids discharged from commercial scale aquaculture production ponds and raceways will be designed and constructed based on findings of the studies outlined above. The filtration system will be intended for applications to ponds up to 0.5 ha (1.24 acre), typical of the size of many fish ponds in Wisconsin, and flow-through systems having a discharge of as much as 3,800 L/min (1,003 gal/min).

Commercial scale trials will be conducted to remove solids from the effluents of aquaculture raceways and ponds in Years 1 and 2. At least three types of fiber filters will be tested for each of these studies. The studies will be conducted at the Lake Mills State Fish Hatchery which has a set of concrete raceways that discharge at least 3,000 L/min (792 gpm) and 40 production ponds that range in size from 0.02–0.5 ha (0.05–1.24 acre). Depending on time and budget constraints, tests at additional commercial-scale facilities will also be conducted .

For the studies on raceways, tests will be conducted in conjunction with the twice-weekly cleaning that is normally conducted on the Lake Mills raceways and ponds. Each cleaning period lasts approximately 1–2 h, during which at least 90% of the accumulated solids are discharged from the raceways. During cleaning, 100% of the raceway effluent will be passed through the filter box before being discharged. For each test, the filtration system will be installed and monitored for efficiency in removal of solids. Water samples entering the filter (i.e., raw raceway effluent) and discharged from it will be analyzed to determine the quantity, concentration, and particle size of solids. The amount and percentage of solids retained by the filters during raceway cleaning will be measured. The practical capacity of the filters to retain solids relative to the degree that they restrict water flow through the filter box will also be measured.

Studies on ponds will be conducted in conjunction with the drawdowns and fish harvest from fingerling production ponds at the Lake Mills Hatchery. For these tests, the concentration of solids in the effluent of ponds will be monitored throughout pond draining, but the use of fiber filters to remove solids from the effluent will be focused on the last 25% of drawdown, because previous studies have demonstrated that this is when the concentration of solids in the pond effluent increases rapidly (Rivera 1995). Except for the above, the tests on ponds will be similar to those conducted on raceways.

All of the raceway and pond studies will be replicated sufficiently (N = 4–6) to provide for meaningful statistical comparisons. At the end of these studies an economic analysis on the fiber filter will be conducted. This analysis will determine the approximate cost of using this media for solids removal. Cost estimates will be determined for the purchase of each raw material, preprocessing, modifications (if applicable), and the manufacture of the mat. Furthermore, based on data obtained during the field trials, an estimate will be made for the cost of the fiber mats required for the operation of a raceway, and for the draining of a pond.

Beneficial Use of Aquaculture Waste (Objective 3)

This objective has three sub-objectives:

A. Develop methods to recover and partially de-water biosolids from intensive yellow perch aquaculture for use as a feedstock for vermicomposting using red worms and warmer-temperature tolerant cultured nightcrawlers.

B. Construct and demonstrate a continuous-culture style vermicomposter, capable of handling the waste production of a commercial scale RAS for yellow perch grow out, and evaluate the costs of setup and operation.

C. Evaluate the acceptability of worms as fish food and of compost produced from vermicomposting.

University of Wisconsin-Milwaukee (UW-Milwaukee)

Sub-Objective A

In the first year of the project the goal will be to develop suitable methods of partially de-watering and incorporating recovered biosolids from the Great Lakes WATER Institute (GLWI) aquaculture operations into a suitable blend of shredded paper and fish waste to maintain suitable worm culture conditions. Solids recovered from siphoned settled tank waste and from back washing of the RAS bead filter will be recovered for use in the vermicompost trials. The collected solids will be partially de-watered by gravity draining on fine mesh screening. The resulting sludge will be mixed with shredded paper (from on-site recycling collection) to further adjust moisture content to make a suitable feedstock/bedding for the worms.

Worms will be raised in replicated (triplicate) sets of small-scale (about 0.115–0.189 m^3 [30–50 gal]) worm bins. These bins will be set up at GLWI for evaluation of the suitability of yellow perch biosolids for vermicomposting. Initial stocks of red worms and cultured nightcrawlers will be purchased from commercial growers along with some of the aged bedding to which they are accustomed. One set will be stocked with redworms and the other set with cultured nightcrawlers. Waste will be added in a stepped fashion, with an initial target of approximately 0.09 m^2 (1.0 ft^2) of surface area for 0.45 kg (1.0 lb) of waste material. The initial acceptance of the fish waste by the worms will be observed and further addition adjusted toward the target operation level based on these observations.

The length of time required to achieve finished compost and quantitative measurement of the outputs of vermicompost (volume, wet, and dry weight), and the numbers and weight of harvestable worms and worm cocoons produced will be determined. The yield of worms and worm compost will be determined in relation to the quantity of aquaculture solids and bedding materials used. The performance of the two worm types will be compared. The associated costs of labor (as man-hours), energy (for environmental control and preparation of feedstock/bedding), and materials used in the recovery of sludge, initial setup, maintenance, and harvest of the compost and worms will be determined in terms of the unit weight of fish sludge processed.

To characterize the alteration in the biosolids during the vermicomposting process in terms of C:N ratio, and macro and micronutrient content, samples of compost and worms before and after composting will be prepared for macro and micro nutrient analysis at the University of Wisconsin Soil and Plant Analysis Lab by inductively coupled plasma analysis with optical emission spectrometry.

Sub-Objectives B and C

A larger continuous-culture type vermiculture bin for a full-scale demonstration for its capacity to handle commercial RAS production facility quantities of recovered biosolids and yellow perch processing waste will be constructed and tested in Years 2 and 3. The associated costs of labor, energy (for environmental control and preparation of feedstock/bedding), and materials used in the recovery of sludge, initial setup, maintenance, and harvest of the compost and worms will be determined in terms of the unit weight of fish sludge processed. Typical prices for vermicompost and worms from worm farm operations will be used to estimate the value of the end products on a unit weight of waste sludge basis. This system will provide a model for regional aquaculturists to utilize vermicomposting to beneficially utilize recovered aquaculture biosolids. Results of the demonstration of this system will be condensed for submission as a NCRAC fact sheet or technical bulletin.

Worms produced by vermiculture will be preliminarily evaluated as a food for yellow perch. Replicated groups of sub-market sized yellow perch in flow through aquaria supplied with 18–20°C (64.4–68°F) dechlorinated water from a common head tank will be offered either a commercial diet (control) or (suitably treated for acceptance) vermicompost reared worms either alone or as a partial substitute for commercial diet (depending on worm production achieved during the above trials). Acceptance of the worms by the fish, growth, and food conversion of yellow perch over a 3–4 week period would be compared between groups. Samples of worms and fish from this trial will be prepared for heavy metal analysis at the University of Wisconsin Soil and Plant Analysis Lab using inductively coupled plasma analysis with optical emission spectrometry.

The vermicompost and small scaled worm bins used in Sub-Objectives A and B will be made available to the Vocational Agriculture/Aquaculture program at Freedom High School, Freedom, Wisconsin for possible cooperative student projects, utilizing these resources for further evaluation of vermicompost as a planting medium and the use of vermicompost to handle aquaculture waste.

Workshops and Fact Sheets (Objective 4)

ISU

The project will develop and implement aquaculture educational programs and prepare fact sheets that will be available on-line through the NCRAC web site. The products of this project will serve to enhance information transfer, provide solid information resources, and clarify research needs.

A fact sheet that describes characteristics of aquacultural wastes and a bulletin describing BMPs for different aquaculture systems will be developed; a session will be presented on Aquacultural Waste Management for a regional NCRAC conference. All written materials will be made available through the AquaNic Web site (http://ag.ansc.purdue.edu/aquanic/ncrac) and AquaNic Web contents distributed to aquaculture specialists and other Cooperative Extension Service and Sea Grant Advisory Service personnel per NCRAC Publications Policy.

A comprehensive, scientific database (i.e., pertinent reference materials) on the characteristics of aquacultural effluents from ponds, flow-through (serial and single-pass), and recycle systems, including information on nutrient capture relative to nutrient inputs in feed will be developed in Year 1. This information will be used to develop a response to the USEPA regulations on aquaculture effluents. Presumably, a main component of the USEPA regulations will be a requirement for monitoring protocols.

Regulations by USEPA and state regulatory agencies in the NCR that are concerned with aquaculture effluents will be summarized in Year 2.

A workshop or conference symposium will be held on BMPs for reducing nutrients and solid waste in aquaculture effluents.

The goal of this project is to provide science-based information that the aquaculture industry can use to meet proposed USEPA regulation of aquaculture effluents in Year 3.

FACILITIES

Fate of Aquaculture Waste Components (Objective 1)

Researchers at ISU will work with Loess Hills Aquaculture, Ehler Enterprises, a non-funded collaborator that has a new recycle facility in Manning, Iowa. The facility is scheduled for completion by spring 2001. It will be a state-of-the-art recycle system for raising walleye to food size. It is modeled after a nearby system of the same size that is owned and operated by J. Fernading, who began operation in April 2000. Both systems contain five, 37.9-m^3 (10,000-gal) tanks, each with space for five more tanks. Both systems use a dual-drain tank design, which minimizes the volume of effluent water from the culture tank that needs filtration to remove suspended solids. The components of the culture system are culture tanks, microscreen drum filter, degassing column to remove CO_2, low head oxygenator for adding oxygen and ozone, and fluidized-sand biofilters. A WFC will be installed in three of the five tanks at the site.

Rapid Solids Removal/Recovery Appropriate for New Aquaculture Facility Designs (Objective2)

ISU

The facility is described above. In addition to the use of a dual-drain tank, the proposal includes installation of three WFCs in the producer's tanks that are designed to reduce waste feed. The WFCs, called the UltraEye waste feed controller (CultureTools, Monkton, Vermont), are the same type described by Tsukuda et al. (2000). They are the third generation of devices first described by Summerfelt et al. (1995). The improvements in the new version are in sensitivity for differentiation between uneaten feed and feces, and a feed controller, thus eliminating the need for a separate timer for the feeder.

UW-Madison

The UW-Madison has facilities both on-campus and at the Lake Mills State Fish Hatchery. The campus facility has a well-equipped analytical laboratory and a wet laboratory with numerous circular fiberglass tanks (110–3,000-L [29.1–792.5-gal]) and ample supplies of carbon-filtered water, which can be maintained at 5–25 ± 1°C by water heaters or chillers. The Lake Mills facility has 40 ponds ranging in size from 0.02–0.5 ha (0.05–1.24 acre), all of which have high-volume lake water inputs. The Lake Mills facility also has over 100 tanks (110–3,000-L [29.1–792.5-gal]) and three water sources (dechlorinated city water, high capacity well, and lake water). The raceway facility at Lake Mills consists of a set of two concrete raceways 0.5-m deep × 2.0-m wide × 100-m long (1.6-ft deep × 6.6-ft wide × 328.1-ft long) in series. The raceways are provided with >3,000 L/min (792 gpm) of well water, and are used to raise over 100,000 coho salmon fingerlings.

USDA

The USDA-FPL is the foremost government research institution for the study of wood and wood products. It contains a highly trained staff of scientists and engineers, all of which are accessible for this project. The USDA-FPL has an extensive analytical laboratory, mechanical equipment for the processing of wood into fiber, and workshops for the construction of the filtration boxes and associated systems.

Odbek Industries, Inc.

Odbek Industries, Inc. is an industrial producer of non-woven fabric materials. The company was established in 1988 and is located in St. Paul, Minnesota. The owners are Todd Rogers and Michael Becker, formerly employed by the 3M Corporation in St. Paul. Machinery to be used in this project was originally purchased from 3M for the production of air-laden, non-woven mats. This process will be used in the manufacture of filters for this project. Odbek also has expertise in the use of a variety of binders for non-woven mats. Design characteristics for the binder will be developed based upon criteria established for the design of the lignocellulosic mats.

Beneficial Use of Aquaculture Waste (Objective 3)

UW-Milwaukee

The University of Wisconsin Great Lakes WATER Institute has both flow-through and recirculating aquaculture facilities. Automated dechlorination systems with a current total capacity of approximately

2,270-Lpm (600 gal/min), supply dechlorinated Milwaukee municipal tapwater (derived from Lake Michigan) for the fish culture facilities. Portions of this supply are heated or refrigerated to supply hot water, ambient cold water, and refrigerated water to the fish rearing tanks. A commercially-scaled RAS system currently configured with a single 26,500-L (7,000-gal) rearing tank, a floating bead clarifier, a fluidized bed biofilter, and foam fractionator are available to demonstrate yellow perch grow out. Additional flow-through rearing tanks ranging in size from large 2.44 m (8 ft) diameter circular (about 18), 1.22 m (4 ft) diameter circular, to banks of smaller rectangular fiberglass and all glass aquaria are available to support fish culture investigations.

GLWI has sufficient analytical laboratories and shop facilities to support a wide variety of aquatic research investigations.

Workshops and Fact Sheets (Objective 4)

<u>ISU</u>

ISU has a hotel (Memorial Union Hotel), and an abundance of conference facilities in both the Memorial Union and the Scheman Center for Continuing Education. The university is geographically located to conveniently serve clients from throughout the NCR. To conduct summaries of wastes and effluent characteristics of aquaculture, the university has extensive database services in the ISU library with Ethernet connections to faculty offices. There are modern services for publication and printing. The extension liaison for the project and associate director of NCRAC is located at ISU.

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PROJECT LEADERS

State	Name/Institution	Area of Specialization
Iowa	Robert C. Summerfelt Iowa State University	Fish Culture/Physiology/Nutrition/Diseases
Wisconsin	Fred P. Binkowski University of Wisconsin-Milwaukee	Fish Culture/Feeding Strategies
	Jeffrey A. Malison University of Wisconsin-Madison	Aquaculture/Physiology
	Douglas J. Reinemann University of Wisconsin-Madison	Biological Systems/Engineering
	Steven E. Yeo University of Wisconsin-Milwaukee	Fish Culture

PARTICIPATING INSTITUTIONS AND PRINCIPAL INVESTIGATORS

Iowa State University (ISU)
Robert C. Summerfelt

University of Wisconsin-Madison (UW-Madison)
Jeffrey A. Malison
Douglas J. Reinemann

University of Wisconsin-Milwaukee (UW-Milwaukee)
Fred P. Binkowski
Steven E. Yeo

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
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BUDGET

ORGANIZATION AND ADDRESS
Office of Sponsored Programs Administration
Iowa State University
221 Beardshear Hall, Ames, IA 500ll

USDA AWARD NO. Year 1: Objectives 1, 2, & 4

Duration Proposed Months: 12
Duration Awarded Months: ________

PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S)
Robert C. Summerfelt

	CSREES FUNDED WORK MONTHS Calendar	Academic	Summer	FUNDS REQUESTED BY PROPOSER	FUNDS APPROVED BY CSREES (If Different)
A. Salaries and Wages 1. No. of Senior Personnel					$
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. ___ Graduate Students					
d. 1 Prebaccalaureate Students				$2,520	
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$19,300	
Total Salaries and Wages →				$21,820	
B. Fringe Benefits (If charged as Direct Costs)				$5,632	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$27,452	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$13,019	
F. Travel 1. Domestic (Including Canada)				$5,205	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($95), Fax ($95), Postage ($95), Photocopying ($95)				$380	
J. Total Direct Costs (C through I) →				$46,056	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$46,056	
M. Other →					
N. Total Amount of This Request →				$46,056	$
O. Cost Sharing (If Required Provide Details)	$299,480				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

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BUDGET

ORGANIZATION AND ADDRESS Office of Sponsored Programs Administration Iowa State University 221 Beardshear Hall, Ames, IA 500ll				**USDA AWARD NO.** Year 2: Objectives 1, 2, & 4	
				Duration Proposed Months: 12	Duration Awarded Months: ________
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Robert C. Summerfelt				**FUNDS REQUESTED BY PROPOSER**	**FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages 1. No. of Senior Personnel	**CSREES FUNDED WORK MONTHS**				$
	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. ___ Graduate Students					
d. 1 Prebaccalaureate Students				$2,520	
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$20,072	
Total Salaries and Wages →				$22,592	
B. Fringe Benefits (If charged as Direct Costs)				$5,857	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$28,449	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$1,720	
F. Travel 1. Domestic (Including Canada)				$5,205	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($80), Fax ($80), Postage ($80), Photocopying ($80), Proximate analysis ($1,110)				$1,430	
J. Total Direct Costs (C through I) →				$36,804	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$36,804	
M. Other →					
N. Total Amount of This Request →				$36,804	$
O. Cost Sharing (If Required Provide Details)	$122,934				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

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BUDGET

ORGANIZATION AND ADDRESS Office of Sponsored Programs Administration Iowa State University 221 Beardshear Hall, Ames, IA 500ll				**USDA AWARD NO.** Year 3: Objectives 1, 2, & 4	
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Robert C. Summerfelt				Duration Proposed Months: 12 **FUNDS REQUESTED BY PROPOSER**	Duration Awarded Months: ________ **FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages	**CSREES FUNDED WORK MONTHS**				$
1. No. of Senior Personnel	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. ___ Graduate Students					
d. 1 Prebaccalaureate Students				$700	
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$3,292	
Total Salaries and Wages →				$3,992	
B. Fringe Benefits (If charged as Direct Costs)				$961	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$4,953	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$670	
F. Travel 1. Domestic (Including Canada)				$6,987	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($350), Fax ($350), Postage ($350), Photocopying ($350)				$1,400	
J. Total Direct Costs (C through I) →				$14,010	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$14,010	
M. Other →					
N. Total Amount of This Request →				$14,010	$
O. Cost Sharing (If Required Provide Details)	$127,673				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

BUDGET EXPLANATION FOR IOWA STATE UNIVERSITY

(Summerfelt)

Objectives 1, 2, and 4

A. Salaries and Wages. Years 1 and 2: A research associate (74% FTE) will be involved with data collection, data analysis and entry, and to serve as a liaison for the PI and personnel from Loess Hills Aquaculture, Inc. for Objectives 1 and 2; a prebaccalaureate student hourly employee will conduct a literature search of database references, maintain files, conduct library searches, and make photocopies for Objective 4. Year 3: A research associate (70% FTE for 2 months) will finish data analysis and assist PI in preparation of manuscripts and reports for Objectives 1 and 2; a prebaccalaureate student hourly employee will conduct a literature search of database references, maintain files, conduct library searches, and make photocopies for Objective 4.

B. Fringe Benefits. Annual costs: The ISU fringe benefit rate for research associates is 29.18%.

E. Materials and Supplies. Year 1: 5 screw/auger feeders with spreaders @ $450/each ($2,250); 5, 40 kg hoppers @ $110/each ($550); timer and AC to DC converter ($544); 3 waste feed sensors and controllers @ $985/each ($2,955); 3 RS-485 LAN interface @ $45 ($135); network software and RS-485 protocol converter ($200); HACH DR/2010 spectrophotometer with pour-through cell ($1,825); analytical balance for TSS and TDS ($1,100); BOD incubator ($1,900); reagents and standards ($580); glassware such as beakers, graduate cylinders, sample bottles, etc. ($580); and general office supplies such as paper, toner, pens, file folders ($400). Year 2: Reagents and standards ($850); other supplies such as filters, BOD accessories, reagents, glassware for acid persulfate digestion, and cuvettes for P analysis ($470); and general office supplies such as paper, toner, pens, file folders ($400). Year 3: General office supplies such as paper, toner, pens, file folders ($670).

F. Travel. Years 1 and 2: $2,160 for mileage costs from ISU campus to research site near Manning, Iowa and return—total round-trip distance is 200 miles (27 trips @ $0.40/mile), $625 for meals for 24 days of travel from ISU campus to research site @ $26/day, $720 for lodging for 12 overnight stays at research site @ $60/night; $1,700 for transportation, lodging, and meal expenses for the PI to attend a regional and/or national conference, destination(s) to be determined. Year 3: $6,000 for travel, lodging, and meal expenses for speakers invited for a symposium/conference/workshop on aquacultural effluents, location to be determined; $987 for transportation, lodging, and meal expenses for the PI to present results at a regional and/or national aquaculture conference(s), destination(s) to be determined.

I. All Other Direct Costs. Year 1: Telephone ($95), fax ($95), postage ($95), and photocopying ($95). Year 2: Telephone ($80), fax ($80), postage ($80), photocopying ($80), and proximate analysis of 15 fish and feed from a commercial laboratory @ $74/sample ($1,110). Year 3: Telephone ($350), fax ($350), postage ($350), and photocopying ($350).

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
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BUDGET

ORGANIZATION AND ADDRESS Board of Regents University of Wisconsin System 750 University Ave., Madison, WI 53706				**USDA AWARD NO.** Year 1: Objective 2	
				Duration Proposed Months: 12	Duration Awarded Months: ________
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Jeffrey A. Malison and Douglas J. Reinemann				**FUNDS REQUESTED BY PROPOSER**	**FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages	**CSREES FUNDED WORK MONTHS**				$
1. No. of Senior Personnel	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. 1 Graduate Students				$10,000	
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$2,000	
Total Salaries and Wages →				$12,000	
B. Fringe Benefits (If charged as Direct Costs)				$2,000	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$14,000	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$7,000	
F. Travel 1. Domestic (Including Canada)				$840	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($75), Fax ($25), Photocopying ($60)				$160	
J. Total Direct Costs (C through I) →				$22,000	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$22,000	
M. Other →					
N. Total Amount of This Request →				$22,000	$
O. Cost Sharing (If Required Provide Details)	$68,240				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
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BUDGET

ORGANIZATION AND ADDRESS
Board of Regents
University of Wisconsin System
750 University Ave., Madison, WI 53706

USDA AWARD NO. Year 2: Objective 2

Duration Proposed Months: 12 — **FUNDS REQUESTED BY PROPOSER**

Duration Awarded Months: ________ — **FUNDS APPROVED BY CSREES** (If Different)

PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S)
Jeffrey A. Malison and Douglas J. Reinemann

	CSREES FUNDED WORK MONTHS: Calendar	Academic	Summer	Funds Requested by Proposer	Funds Approved by CSREES (If Different)
A. Salaries and Wages					$
1. No. of Senior Personnel					
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty)					
a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. 1 Graduate Students				$10,000	
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$2,000	
Total Salaries and Wages →				$12,000	
B. Fringe Benefits (If charged as Direct Costs)				$2,000	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$14,000	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$4,000	
F. Travel 1. Domestic (Including Canada)				$840	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($75), Fax ($25), Photocopying ($60)				$160	
J. Total Direct Costs (C through I) →				$19,000	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$19,000	
M. Other →					
N. Total Amount of This Request →				$19,000	$
O. Cost Sharing (If Required Provide Details)	$69,278				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
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BUDGET

ORGANIZATION AND ADDRESS Board of Regents University of Wisconsin System 750 University Ave., Madison, WI 53706				**USDA AWARD NO.** Year 3: Objective 2	
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Jeffrey A. Malison and Douglas J. Reinemann				Duration Proposed Months: 12 **FUNDS REQUESTED BY PROPOSER**	Duration Awarded Months: ____ **FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages	**CSREES FUNDED WORK MONTHS**				$
1. No. of Senior Personnel	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. ___ Other Professional					
c. 1 Graduate Students				$10,000	
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. 1 Technical, Shop and Other				$2,000	
Total Salaries and Wages →				$12,000	
B. Fringe Benefits (If charged as Direct Costs)				$2,000	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$14,000	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies				$4,000	
F. Travel 1. Domestic (Including Canada)				$840	
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.) Telephone ($75), Fax ($25), Photocopying ($60)				$160	
J. Total Direct Costs (C through I) →				$19,000	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$19,000	
M. Other →					
N. Total Amount of This Request →				$19,000	$
O. Cost Sharing (If Required Provide Details)	$71,385				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

BUDGET EXPLANATION FOR THE UNIVERSITY OF WISCONSIN-MADISON

(Malison and Reinemann)

Objective 2

A. Salaries and Wages. Annual costs: Approximately 60% of the annual salary of one graduate student and 6% of the annual salary of one technician whose responsibilities will be to construct filters, conduct tests, and analyze data.

B. Fringe Benefits. Annual costs: The UW-Madison fringe benefit rate for graduate students is 13.5% and for technicians is 32.5%.

E. Materials and Supplies. Year 1: $7,000 for raw materials and components such as containers, filter cages, baffles, and piping to construct filtration systems. Years 2 and 3: $4,000 for materials to maintain and refine filtration systems.

F. Travel. Annual costs: $840 for 50 trips annually from the UW-Madison campus to the research site at the Lake Mills State Fish Hatchery (60 miles each @ $0.28/mile).

I. All Other Direct Costs. Annual costs: Telephone ($75), fax ($25), and photocopying ($60).

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
Expires 5/31/98

BUDGET

ORGANIZATION AND ADDRESS Great Lakes WATER Institute University of Wisconsin-Milwaukee 600 E. Greenfield Ave., Milwaukee, WI 53204				**USDA AWARD NO.** Year 1: Objective 3	
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Fred P. Binkowski and Steven E. Yeo				Duration Proposed Months: 12 **FUNDS REQUESTED BY PROPOSER**	Duration Awarded Months: ________ **FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages 1. No. of Senior Personnel	**CSREES FUNDED WORK MONTHS**				$
	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. _1_ Other Professional	3.0			$9,593	
c. ___ Graduate Students					
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. ___ Technical, Shop and Other					
Total Salaries and Wages →				$9,593	
B. Fringe Benefits (If charged as Direct Costs)				$3,117	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$12,710	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies					
F. Travel 1. Domestic (Including Canada)					
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.)					
J. Total Direct Costs (C through I) →				$12,710	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$12,710	
M. Other →					
N. Total Amount of This Request →				$12,710	$
O. Cost Sharing (If Required Provide Details)	$12,072				

NOTE: Signatures required only for Revised Budget   This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
Expires 5/31/98

BUDGET

ORGANIZATION AND ADDRESS Great Lakes WATER Institute University of Wisconsin-Milwaukee 600 E. Greenfield Ave., Milwaukee, WI 53204				**USDA AWARD NO.** Year 2: Objective 3	
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Fred P. Binkowski and Steven E. Yeo				Duration Proposed Months: 12 **FUNDS REQUESTED BY PROPOSER**	Duration Awarded Months: ________ **FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages	**CSREES FUNDED WORK MONTHS**				$
1. No. of Senior Personnel	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. 1 Other Professional	3.0			$9,593	
c. ___ Graduate Students					
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. ___ Technical, Shop and Other					
Total Salaries and Wages →				$9,593	
B. Fringe Benefits (If charged as Direct Costs)				$3,117	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$12,710	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies					
F. Travel 1. Domestic (Including Canada)					
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.)					
J. Total Direct Costs (C through I) →				$12,710	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$12,710	
M. Other →					
N. Total Amount of This Request →				$12,710	$
O. Cost Sharing (If Required Provide Details)	$12,199				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

UNITED STATES DEPARTMENT OF AGRICULTURE
COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE

OMB Approved 0524-0022
Expires 5/31/98

BUDGET

ORGANIZATION AND ADDRESS Great Lakes WATER Institute University of Wisconsin-Milwaukee 600 E. Greenfield Ave., Milwaukee, WI 53204				**USDA AWARD NO.** Year 3: Objective 3	
PRINCIPAL INVESTIGATOR(S)/PROJECT DIRECTOR(S) Fred P. Binkowski and Steven E. Yeo				Duration Proposed Months: 12 **FUNDS REQUESTED BY PROPOSER**	Duration Awarded Months: ________ **FUNDS APPROVED BY CSREES** (If Different)
A. Salaries and Wages	**CSREES FUNDED WORK MONTHS**				$
1. No. of Senior Personnel	Calendar	Academic	Summer		
a. ___ (Co)-PI(s)/PD(s)					
b. ___ Senior Associates					
2. No. of Other Personnel (Non-Faculty) a. ___ Research Associates-Postdoctorates					
b. _1_ Other Professional	3.0			$9,593	
c. ___ Graduate Students					
d. ___ Prebaccalaureate Students					
e. ___ Secretarial-Clerical					
f. ___ Technical, Shop and Other					
Total Salaries and Wages →				$9,593	
B. Fringe Benefits (If charged as Direct Costs)				$3,117	
C. Total Salaries, Wages, and Fringe Benefits (A plus B) →				$12,710	
D. Nonexpendable Equipment (Attach supporting data. List items and dollar amounts for **each** item.)					
E. Materials and Supplies					
F. Travel 1. Domestic (Including Canada)					
2. Foreign (List destination and amount for each trip.)					
G. Publication Costs/Page Charges					
H. Computer (ADPE) Costs					
I. All Other Direct Costs (Attach supporting data. List items and dollar amounts. Details of subcontracts, including work statements and budget, should be explained in full in proposal.)					
J. Total Direct Costs (C through I) →				$12,710	
K. Indirect Costs If Applicable (Specify rate(s) and base(s) for on/off campus activity. Where both are involved, identify itemized costs in on/off campus bases.)					
L. Total Direct and Indirect Costs (J plus K) →				$12,710	
M. Other →					
N. Total Amount of This Request →				$12,710	$
O. Cost Sharing (If Required Provide Details)	$12,230				

NOTE: Signatures required only for Revised Budget — This is Revision No. →

NAME AND TITLE (Type or print)	**SIGNATURE**	**DATE**
Principal Investigator/Project Director		
Authorized Organizational Representative		

Form CSREES-55 (6/95)

BUDGET EXPLANATION FOR THE UNIVERSITY OF WISCONSIN-MILWAUKEE

(Binkowski and Yeo)

Objective 3

A. Salaries and Wages. Annual costs: An academic staff associate researcher (24% FTE) will assist the PI with all technical aspects associated with the setup, conduct, and reporting of all investigations of vermicomposting and its by-products for beneficial reuse of yellow perch culture solid waste.

B. Fringe Benefits. Annual costs: The UW-Milwaukee fringe benefit rate of an associate researcher is 32.5%.

BUDGET SUMMARY FOR EACH PARTICIPATING INSTITUTION

Year 1

	ISU	UW-Madison	UW-Milwaukee	TOTALS
Salaries and Wages	$21,820	$12,000	$9,593	$43,413
Fringe Benefits	$5,632	$2,000	$3,117	$10,749
Total Salaries, Wages and Fringe Benefits	$27,452	$14,000	$12,710	$54,162
Nonexpendable Equipment	$0	$0	$0	$0
Materials and Supplies	$13,019	$7,000	$0	$20,019
Travel	$5,205	$840	$0	$6,045
All Other Direct Costs	$380	$160	$0	$540
TOTAL PROJECT COSTS	$46,056	$22,000	$12,710	$80,766

Year 2

	ISU	UW-Madison	UW-Milwaukee	TOTALS
Salaries and Wages	$22,592	$12,000	$9,593	$44,185
Fringe Benefits	$5,857	$2,000	$3,117	$10,974
Total Salaries, Wages and Fringe Benefits	$28,449	$14,000	$12,710	$55,159
Nonexpendable Equipment	$0	$0	$0	$0
Materials and Supplies	$1,720	$4,000	$0	$5,720
Travel	$5,205	$840	$0	$6,045
All Other Direct Costs	$1,430	$160	$0	$1,590
TOTAL PROJECT COSTS	$36,804	$19,000	$12,710	$68,514

Year 3

	ISU	UW-Madison	UW-Milwaukee	TOTALS
Salaries and Wages	$3,992	$12,000	$9,593	$25,585
Fringe Benefits	$961	$2,000	$3,117	$6,078
Total Salaries, Wages and Fringe Benefits	$4,953	$14,000	$12,710	$31,663
Nonexpendable Equipment	$0	$0	$0	$0
Materials and Supplies	$670	$4,000	$0	$4,670
Travel	$6,987	$840	$0	$7,827
All Other Direct Costs	$1,400	$160	$0	$1,560
TOTAL PROJECT COSTS	$14,010	$19,000	$12,710	$45,720

RESOURCE COMMITMENT FROM INSTITUTIONS[1]

Year 1

Participant	Source of Match and/or Cost Sharing				Total
	University	Industry	Federal	Other	
ISU	$14,500	$284,980[a]			$299,480
UW-Madison	$32,180	$15,000[b]	$21,060[c]		$68,240
UW-Milwaukee	$12,072				$12,072
Totals	$58,752	$299,980	$21,060	$0	$379,792

[a]Loess Hills Aquaculture, Inc.
[b]Odbek Industries, Inc. ($10,000), REM Engineering, LLC ($5,000)
[c]USDA Forest Products Laboratory

Year 2

Participant	Source of Match and/or Cost Sharing				Total
	University	Industry	Federal	Other	
ISU	$14,500	$108,434[a]			$122,934
UW-Madison	$32,360	$15,000[b]	$21,918[c]		$69,278
UW-Milwaukee	$12,199				$12,199
Totals	$59,059	$123,434	$21,918	$0	$204,411

[a]Loess Hills Aquaculture, Inc.
[b]Odbek Industries, Inc. ($10,000), REM Engineering, LLC ($5,000)
[c]USDA Forest Products Laboratory

Year 3

Participant	Source of Match and/or Cost Sharing				Total
	University	Industry	Federal	Other	
ISU	$14,500	$113,173[a]			$127,673
UW-Madison	$34,010	$15,000[b]	$22,375[c]		$71,385
UW-Milwaukee	$12,230				$12,230
Totals	$60,740	$128,173	$22,375	$0	$211,288

[a]Loess Hills Aquaculture, Inc.
[b]Odbek Industries, Inc. ($10,000), REM Engineering, LLC ($5,000)
[c]USDA Forest Products Laboratory

[1]Because cost sharing is not a legal requirement, participants are not required to provide or maintain documentation of such a commitment.

SCHEDULE FOR COMPLETION OF OBJECTIVES

Objective 1: Initiated in Year 1, completed in Year 3.

Objective 2: Initiated in Year 1, completed in Year 3.

Objective 3: Initiated in Year 1, completed in Year 3.

Objective 4: Initiated in Year 1, completed in Year 3.

LIST OF PRINCIPAL INVESTIGATORS

Fred P. Binkowski, University of Wisconsin-Milwaukee

Jeffrey A. Malison, University of Wisconsin-Madison

Douglas J. Reinemann, University of Wisconsin-Madison

Robert C. Summerfelt, Iowa State University

Steven E. Yeo, University of Wisconsin-Milwaukee

VITA

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EDUCATION

B.S. University of Wisconsin-Milwaukee, 1971, Zoology
M.S. University of Wisconsin-Milwaukee, 1974, Zoology (Fisheries Biology)

POSITIONS

Director (1993-present), Aquaculture Center, University of Wisconsin System, UWS/UWM Great Lakes WATER Institute

Senior Scientist (1991-present), Associate Scientist (1987-1990), Senior Fisheries Biologist (1984-1986), Associate Fisheries Biologist (1981-1983), and Assistant Fisheries Biologist (1978-1980), Center for Great Lakes Studies, University of Wisconsin Great Lakes Research Facility

Research Specialist (Fisheries)(1975-1978), Department of Zoology, University of Wisconsin-Milwaukee

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS

American Fisheries Society, Early Life History and Fish Culture Sections
U.S. Aquaculture Society
World Aquaculture Society

SELECTED PUBLICATIONS

Letcher, B.H., J.A. Rice, L.B. Crowder, and F.P. Binkowski. 1997. Size- and species-dependent variability in consumption and growth rates of larvae and juveniles of three freshwater fishes. Canadian Journal of Fisheries and Aquatic Sciences 54:405-414.

Letcher, B.H., J.A. Rice, L.B. Crowder, and F.P. Binkowski. 1996. Size-dependent effects of continuous and intermittent feeding on starvation time and mass loss in starving yellow perch larvae and juveniles. Transactions of the American Fisheries Society 125:14-26.

Binkowski, F.P., and L.G. Rudstam. 1994. The maximum daily ration of Great Lakes bloater. Transactions of the American Fisheries Society 123:335-343.

Rudstam, L.G., F.P. Binkowski, and M.A. Miller. 1994. A bioenergetics model for analysis of food consumption patterns by bloater in Lake Michigan. Transactions of the American Fisheries Society 123:344-357.

Binkowski, F.P., J.J. Sedmack, and S.O. Jolly. 1993. An evaluation of *Pfaffia* yeast as a pigment source for salmonids. Aquaculture Magazine, March/April 1993:1-4.

Sommer, C.V., F.P. Binkowski, M.A. Schalk, and J.M. Bartos. 1986. Stress factors that can affect studies of drug metabolism in fish. Veterinary and Human Toxicology 28 (Supplement 1):45-54.

Binkowski, F.P., and S.I. Doroshov, editors. 1985. Proceedings of North American sturgeons: biology and aquaculture potential. Kluwer Academic/Plenum Publishers, New York.

VITA

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EDUCATION

B.S. University of Wisconsin-Stevens Point, 1976, Biology
M.S. University of Wisconsin-Madison, 1980, Endocrinology-Reproductive Physiology
Ph.D. University of Wisconsin-Madison, 1985, Endocrinology-Reproductive Physiology

POSITIONS

Director (1995-present), Assistant Director (1990-1995), and Associate Researcher (1987-1990), University of Wisconsin Aquaculture Program, University of Wisconsin-Madison

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS

American Association for the Advancement of Sciences
American Fisheries Society
Wisconsin Aquaculture Association
Wisconsin Aquaculture Industry Advisory Council
World Aquaculture Society

SELECTED PUBLICATIONS

Weil, L.S., T.P. Barry, and J.A. Malison. In press. Fast growth in rainbow trout is correlated with a rapid decrease in post-stress cortisol concentrations. Aquaculture.

Head, A.B., and J.A. Malison. 2000. Effects of lighting spectrum and disturbance level on the growth and stress responses of yellow perch (*Perca flavescens*). Journal of the World Aquaculture Society 31:73-80.

Ko, K., J.A. Malison, and J.D. Reed. 1999. Effect of genistein on the growth and reproductive function of male and female yellow perch *Perca flavescens*. Journal of the World Aquaculture Society 30:73-79.

Procarione, L.S., T.P. Barry, and J.A. Malison. 1999. Effects of high rearing densities and loading rates on the growth and stress responses of juvenile rainbow trout. North American Journal of Aquaculture 61:91-96.

Malison, J.A., L.S. Procarione, T.B. Kayes, J.F. Hansen, and J.A. Held. 1998. Induction of out-of-season spawning in walleye (*Stizostedion vitreum*). Aquaculture 163:151-161.

Malison, J.A., J.A. Held, L.S. Procarione, and M.A.R. Garcia-Abiado. 1998. The production of monosex female populations of walleye (*Stizostedion vitreum*) using intersex broodstock. Progressive Fish-Culturist 60:20-24.

Barry, T.P., Riebe, J., Parrish, J.J., and J.A. Malison. 1997. Effects of 17a,20b-dihydroxy-4-pregnen-3-one on cortisol production by rainbow trout interrenal tissue. General and Comparative Endocrinology 107: 172-181.

VITA

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EDUCATION

B.S. University of Wisconsin-Madison, 1980, Agricultural Engineering
M.S. University of Wisconsin-Madison, 1983, Agricultural Engineering
Ph.D. Cornell University, 1987, Agricultural Engineering

POSITIONS

Associate Professor (1995-present), University of Wisconsin-Madison

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS

American Society of Agricultural Engineers; Information and Electrical Technologies Division, Committee; Institute of Biological Engineering, Charter Member
Energy Analysis and Policy Program, Energy Center of Wisconsin, Research Advisory Council
Institute for Environmental Studies, Affiliate Faculty Member

SELECTED PUBLICATIONS

Reinemann, D.J., J.Y. Parlange, and M.B. Timmons. 1990. Theory of small diameter air-lift pumps. International Journal of Multiphase Flow 16(1):113-122.

Reinemann, D.J., and M.B. Timmons. 1989. Predicting oxygen transfer and total dissolved gas pressure in air-lift pumping. Aquacultural Engineering 8:29-46.

Reinemann, D.J., and M.B. Timmons. 1989. Design of air-lift pumping and aeration systems. Cornell University Extension Bulletin No. 455.

Reinemann, D.J., and M.B. Timmons. 1989. Thermal environment of intensive aquaculture structures. Cornell University Extension Bulletin No. 456.

Reinemann, D.J., and M.B. Timmons. 1988. Design of air-lift pumps for aquacultural applications. ASAE Paper No. 88-4549, Presented at the Winter Meeting of the American Society of Agricultural Engineers, December 13-16, 1988, Chicago, Illinois.

VITA

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EDUCATION

B. S. University of Wisconsin-Stevens Point, 1957, Biology
M. S. Southern Illinois University, 1959, Zoology
Ph.D. Southern Illinois University, 1964, Zoology

POSITIONS

Professor (1976-present), Department of Animal Ecology, Iowa State University
Associate Director (1988-1990), North Central Regional Aquaculture Center
Chairman (1976-85), Department of Animal Ecology, Iowa State University
Leader (1966-76), Oklahoma Cooperative Fishery Research Unit, Oklahoma State University
Assistant Professor (1964-66), Department of Zoology, Kansas State University
Temporary teaching positions at Utah State University (winter quarter 1983); Oregon Institute of Marine Biology (Summer 1975); Southern Illinois University (summer 1975).

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS

American Fisheries Society
American Institute of Fishery Research Biologists (Fellow)
Aquacultural Engineering Society
Iowa Academy of Sciences (Distinguished Fellow)
World Aquaculture Society
Sigma XI, Phi Kappa Phi, Gamma Sigma Delta

SELECTED PUBLICATIONS

Summerfelt, R.C. 2000. Walleye. Pages 970-985 *in* R. R. Stickney, editor. Encyclopedia of aquaculture, John Wiley & Sons, Inc., New York.

Phillips, T.A., R.C. Summerfelt, and R.D. Clayton. 1998. Feeding frequency effects on water quality and growth of walleye fingerlings in intensive culture. Progressive Fish-Culturist 60:1-8.

Summerfelt, R.C., editor. 1996. Walleye culture manual. NCRAC Culture Series #101, NCRAC Publications Office, Iowa State University, Ames.

Forsberg, J.A., and R.C. Summerfelt. 1992. Ammonia excretion of fingerling walleye fed two formulated diets. Progressive Fish-Culturist 54:45-48.

Summerfelt, R.C. 1981. Practice and prospects of fish farming for food production. Pages 81-120 *in* D.C. Beitz, editor. Proceedings of the International Symposium on Animal Products in Human Nutrition. Nutrition Foundation Monograph Series, Academic Press, New York.

Muncy, R.J., G.J. Atchison, R.V. Bulkley, B.W. Menzel, L.G. Perry, and R.C. Summerfelt. 1979. Effects of suspended solids and sediment on reproduction and early life of warmwater fishes: A review. U.S. Environmental Protection Agency, Ecological Research Series. EPA-600/3-79-042.

Summerfelt, R.C., and S.C. Yin. 1974. Paunch manure as a feed supplement in channel catfish farming. U.S. Environmental Protection Agency, Environmental Protection Technology Series. EPA-660/2-74-046.

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EDUCATION

B.S. University of Connecticut, 1971, Fishery Biology
M.S. University Wisconsin-Milwaukee, 1978, Zoology

POSITIONS

Researcher (1993-present), Aquaculture Center, University of Wisconsin System, UWS/UWM Great Lakes WATER Institute

Fisheries Research Specialist (1983-1993), Center for Great Lakes Studies, University of Wisconsin-Great Lakes Research Facility

Fish Biologist-Aquarist (1979-1983), Medical College of Wisconsin-NIEHS Aquatic Biomedical Research Center.

Assistant Curator of Fishes (1974-1978), Milwaukee Public Museum

SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS

American Fisheries Society; President of Wisconsin Chapter 1985-1986.

SELECTED PUBLICATIONS

Yeo, S.E., and F.P. Binkowski. 1999. Beneficial utilization of aquaculture effluents and solids. Report submitted to NCRAC, Michigan State University, East Lansing, Michigan.

Yeo, S.E. and F.P. Binkowski, editors. 1994. Characterization of aquaculture effluents from four types of production systems. Appendix A. Tabulated database of aquaculture effluent characteristics. Appendix B: Bibliography concerned with aquaculture effluents in various production systems. Report submitted to NCRAC, Michigan State University, East Lansing, Michigan.

Dabrowski, K., D.A. Culver, C.L. Brooks, A.C. Voss, H. Sprecher, F.P. Binkowski, S.E. Yeo, and A.M. Balogun. 1993. Biochemical aspects of the early life history of yellow perch (*Perca flavescens*). Pages 531-539 *In* Proceedings of the International Fish Nutrition Symposium, Biarritz, France, June 25-27, 1991.

Luecke, C., J.A. Rice, L.B. Crowder, S.E. Yeo, and F.P.Binkowski. 1990. Recruitment mechanisms of bloater in Lake Michigan: an analysis of the predatory gauntlet. Canadian Journal of Fisheries and Aquatic Sciences 47(3):524-532.

Melancon, M.J., S.E. Yeo, and J.J. Lech. 1987. Induction of hepatic microsomal monoxygenase activity in fish by exposure to river water. Environmental Toxicology and Chemistry 6:127-135.