State of Connecticut

CT Department of Agriculture

BEST MANAGEMENT PRACTICES FOR FINFISH AQUACULTURE IN CONNECTICUT

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Introduction

Aquaculture is a growing global industry with increasing interest in the State of Connecticut. In Connecticut, finfish have been grown for baitfish, pond and lake stocking, and aquarium ornamentals. Interest in the aquaculture production of food fish is growing and includes integrated multi-trophic systems such as aquaponics. The aquaculture systems vary from earthen ponds to indoor recirculating aquaculture systems (RAS). Continued growth of the industry in Connecticut requires attention to provide guidance for environmental and economic concerns. The environmental considerations that must be managed include water and land use, waste water discharge, and the prevention of the introduction of non-native species and spread of their diseases. Along with environmental concerns, the health and quality of fish intended for human consumption is a priority. The quality of the fish is directly related to the quality of the source water, water quality maintenance and monitoring, biosecurity practices, the facility cleaning and sanitization, and the species specific quality of the feed and feeding practices.

Best management practices (BMP) are designed to provide guidance for new, existing, or expanding aquaculture projects. The guidelines in this document are intended to assist finfish growers in the production of a quality product while preventing or minimizing environmental impacts. Along with these guidelines, growers should know and follow all local, state, and federal policies and regulations that have been identified by the various agencies as pertaining to their aquaculture operation. Best management practices' areas of concern include, but are not limited to, site selection, fish health, water quality monitoring, effluent management, harvest, facility cleaning and sanitization, feed and feeding behavior monitoring, disease control, and drug and chemical management. Each aquaculture venture should use these guidelines to create operation and process specific standard operating procedures (SOP).

One of the first steps in building a successful aquaculture business is creating a business plan. To create a good business plan, research must be done to examine factors such as product, species, pricing, and demand. A market analysis should be completed to determine the demand for different species and products in the region and what price can be obtained. After understanding the market, a fish species should be selected that can be legally imported, raised easily, and a reliable system design can be determined. Once a species and system design are determined, the next step is site selection.

Site Selection

Site selection is an important step in any aquaculture venture. Site evaluation should include an evaluation of the adequacy of water resources and water quality, waste water discharge options, the availability of reliable electrical power, and infrastructure such as roads and airports. Each system design, such as earthen pond flow-through systems and indoor recirculating aquaculture systems, has distinct needs. Outdoor pond sites should be examine for appropriate pond wall slopes, soil composition, depth, site rain runoff and drainage patterns, and topography during the site evaluation. Soil type is critical to water retention and reduces the need for costly liners. Soil quality with proper neutral pH and low organic content will help maintain proper water chemistry without the addition of chemicals and mechanical equipment. Recirculating aquaculture systems must consider the availability of reliable electrical power, biosecurity concerns such as disease exclusion and prevention, and the availability of production water of adequate quality for the intended use as significant factors. Each design element's BMP will be discussed in more detail in subsequent sections.

Best Management Practices

- Site selection should include thorough investigations and testing of the source water reliability, volume, and quality.
- The local or town governments should be contacted to have any plans reviewed, regulatory requirements determined, and permits issued. Some areas that may impact an aquaculture facility include planning and zoning, the building department, inland wetland commissions, and local public health directors.
- Proper treatment and disposal of waste water should be evaluated based on the system design and conform to any local, state, or federal regulations for each site being considered.
- The availability of suitable roads and airports should also be evaluated.

All Production Systems - Best Aquaculture Practices

There are general BMPs that span across all aquaculture system designs. These general BMPs include fish health, biosecurity, disease, aquaculture drugs and chemicals, feed, handling and transport, equipment maintenance, and escapement control.

Fish Health

The health of the fish is the single most important aspect of a productive, profitable, and successful aquaculture facility. However, the quality of the fish's health is governed by almost every factor of the aquaculture facilities' operation. The source of the fish to be cultivated should be sourced from a reputable, disease free facility that provides fish health documentation.

The quality of the source water and continued treatment and monitoring to assure that water quality parameters stay within an optimal range will reduce stress on the animals, optimize growth, and produce high quality marketable fish. Stress can be one of the largest contributors to a fish's susceptibility to disease and can dramatically impact growth. During the stress response, fish channel energy that would be otherwise used for growth, reproduction, or immune response into basic functions vital for survival, such as swimming and respiration. Stress can weaken fish and makes a disease outbreak more likely. Stress can be from many sources including poor water quality, improper or rough handling, poor feed and feeding procedures, improper stocking densities, and predator interactions (mainly outdoor facilities). Other key aspects that minimize disease are biosecurity, frequent and routine mortality collection, and equipment and personnel disinfection. A detailed set of records plays an important part in tracking health and isolating and controlling disease.

Best Management Practices

- Fish must be obtained from reputable, experienced, disease-free hatcheries.
- Three years of health report (inspections, testing, and certifications of the absence of disease) for each importation should be obtained.
- Imported fish should be inspected for signs of disease, stress, and abnormal behavior prior to introducing them to the system.
- Fish should be quarantined and acclimated with water from the production system to reduce stress prior to introduction into production units.
- Fish should be transported using industry standard stocking densities and water quality parameters for the species being cultured.
- Fish health should be routinely monitored visually for signs of disease, abnormal behavior, and changes to feeding behavior. All observations should be recorded for each production tank or pond. If a disease is suspected or observed, fish health experts should be contacted. Establishing a relationship with fish health experts prior to a disease outbreak will help to expedite diagnosis and treatment.
- Treatment using therapeutic drugs or chemicals should be selected from the approved list provided by the US Food and Drug Administration and administered in the amounts and techniques following the manufacturer's guidelines and label.
- The observations that may indicate disease include:
    - Visible physical changes from normal like scale loss, fin damage, visible parasites, and external injury.
    - Changes in normal behavior including swimming and schooling behavior and increased respiration.
    - Changes in feeding behavior including amount of food consumed and diminished feeding response.
- Fish stress should be reduced by the following:
    - Water quality should be maintained by both physical and biological filtration and the parameters should be monitored regularly, results recorded, and variations from optimal ranges should be corrected.
    - Quality feed that provides adequate nutrition should be used for each species and size of fish being cultured. Proper feeding techniques and amounts should be followed and excess food should be removed in a timely manner.
    - Fish should be handled in such a way that will minimize injury and minimize the time the fish are exposed to overcrowding and out-of-water events.
    - The stocking densities should be appropriate for the species and size being cultured, the type of system, and the type of enclosure being used. A balance should be made between fish health, water quality impacts, and optimal growth rates.

- Fish mortalities should be removed frequently and routinely. Mortalities and any observations should be recorded. Fresh mortalities can be used to diagnose any suspected diseases.
- Equipment management and disinfection practices should be used. Personal gear should be disinfected when moving from one production area to the next and at the end of the day. Equipment such as nets and buckets should be disinfected after use and should not be used in multiple areas. Equipment being used in the quarantine area should not be used in the grow-out area.
- Disinfection mats or shoe dips should be used at the facility entrance and between production areas.
- A plan should be made for animal and pests exclusion, control, and where appropriate, eradication. Many animals, such as mice and birds, carry disease. Any plans that include eradication, especially of birds, may need local, state, and federal permits. The exclusion or eradication of rodents from the facility, including the feed storage area, should be part of any pest control program.
- Fish health records should be logged, retained, and include:
    - Inventory records including the source of the stock, number of fish with the disease, location in the facility such as pond or tank.
    - Tracking of fish that are moved throughout the facility.
    - Mortality records for each pond or tank including the number of mortalities.
    - Any lab work or diagnostics that were completed and there results.
    - Water quality parameters.
    - Medicated feed records including time, amount, and time to harvest.
    - Therapeutant treatment records including which ponds or tanks, time administered, amount or dosage, and time needed until harvest.
    - Records of other actions taken to help mitigate health issues that are not therapeutant drugs or chemicals.
- A biosecurity plan should be created and implemented to control the introduction of disease.

Biosecurity

Biosecurity is the protection of agricultural animals from any type of infectious agent and includes viral, bacterial, fungal, and parasitic. A biosecurity plan is a set of procedures and practices that manages or prevents the introduction of disease causing organisms. In an aquaculture facility, biosecurity can include the exclusion of unwanted plants, fish species, invertebrates, and chemical contaminants. Biosecurity applies to all personnel (staff and management), to all visitors, and equipment.

A biosecurity plan should be created for each site. The plan should include the importation and quarantine of healthy, disease-free stock, testing of the source water, sanitization plan for gear and equipment, exclusion or sanitization of off-site equipment and vehicles, exclusion or sanitization of visitors, adequate feed storage to prevent pest and fungal growth leading to mycotoxin formation, and the exclusion of pet, pests, and livestock from the facility.

Best Management Practices

Facility Grounds

- A sign or placard is posted explaining the biosecurity plan, disease control efforts and the rules of your site. When visitors such as regulators or inspectors must enter, biosecurity procedures should be clearly explained and any necessary equipment provided.
- Premises are maintained in a clean manner. Raceways, pools, screens and hatchery areas are cleaned daily. Facilities should be kept free of clutter and unused or unnecessary equipment.
- The facility can been fenced and gates locked to prevent intruders or predators.
- The water supply is restricted or fenced to prevent contamination.
- The water quality is tested for recommended parameters and maintained.
- The water supply is kept fish-free or double screened to prevent entry of unwanted species to the facility.
- The feed storage area is secure and protected from pests, excessive heat, and moisture. Spoiled or fungal-laden feed should be removed and disposed of properly. Feed spillage should be cleaned up immediately.
- Culture systems are covered with bird netting to prevent predation stress and disease introduction.
- Pets and livestock are not allowed on the site. Ornamental plants are eliminated from buildings where fish or eggs are cultured.
- A rodent control program should be established and pest activity should be monitored.
- Disinfecting footbaths and hand sanitizers are provided at key entry points.
- Public access is controlled. The public and their vehicles are restricted to designated areas. Visitors are escorted through the facility and must follow biosecurity and disinfection procedures.
- Suppliers will be made aware of site procedures in advance. Any supplier visiting several aquaculture sites shall be subject to biosecurity procedures.
- Appropriate local, state and federal agencies (e.g. Bureau of Aquaculture, Department of Energy and Environmental Protection) should be notified in cases of unusual occurrences, such as high escape numbers, high number of fish deaths, and flooding. A list of response actions should be created and appropriate contacts should be readily available.

Management Practices

- Appropriately trained personnel are assigned to important duties.
- Workers have clean outer garments. Clothing such as rain gear, boots, and gloves should be provided. All rain gear, boots, and gloves should be sanitized after each use or when moving from one production area to another.

- Stressful conditions, such as overcrowding or poor water quality, are eliminated.
- Fish are taken off feed one to two days prior to handling, grading, shipping, etc.
- All incoming fish are properly inspected, certified, and quarantined.
- When cleaning, handling or feeding, proper flow from the youngest fish which are attended to first to the diseased fish which are attended to last. In flow-through systems, start upstream and work downstream.
- Work flow should proceed from areas of highest biosecurity concerns, like the hatchery, to areas of lower biosecurity concerns.
- All mortalities are removed and properly disposed of daily, in accordance to local and state regulations. Records are maintained of daily mortality. Fresh mortalities may be used or sent to a veterinarian for disease identification.
- Appropriate vaccines are used where possible.
- Double screens are placed at the end of every run, raceway or pond to prevent escapement and keep fish from moving from one tank to another.
- When possible in RASs, raceways and ponds are disinfected between each lot of fish.
- Only appropriate disinfection products are to be used and the application and rinsing should follow the manufacturer's instructions and label.
- Full or partial facility fallowing practices should be done to help eliminate disease.
- Cleaning and mortality records should be maintained.
- Personal or facility vehicles are not driven to facilities known to be infected with fish pathogens. Any exposed vehicle is washed and sanitized, with care taken to remove any mud or water. Wash water should not enter the production water.
- Personnel should avoid visiting facilities known to be infected with fish pathogens. No soil or water is transferred from these facilities.

Equipment

- No equipment from off-site is used on the premises.
- Separate sets of equipment, such as waders, nets, buckets, etc., are used at each site.
- Equipment is stored in a well maintained area, free of pests.
- Equipment is cleaned and sanitized daily or after each use.
- Any vehicle exposed to a site containing prohibited pathogens is cleaned and sanitized before entering the premises.

Fish Disease

Even when implementing a biosecurity plan and using the best management practices, an aquaculture facility may still contract disease. The impact, especially financially, can be severe if not quickly diagnosed and mitigation implemented. Depending on the system design, disease can spread rapidly throughout the facility.

Potential diseases, and the symptoms of those diseases should be known for the species of fish being cultured. The pathways of introduction of those pathogens should be identified and procedure should be implemented to mitigate that introduction point. Quarantine procedures should be established for the facility prior to any outbreak.

When a potential disease is detected, the symptoms should be investigated to help identify the pathogen. Live fish showing signs or fresh mortalities should be examined by a trained professional. Because disease often results from a stress event 10-14 days prior, good fish health record keeping, daily observation recording, and water monitoring records can aid in the diagnosis and control of the disease. Vigilant monitoring and early detection is key to good management of disease emergencies.

Best Management Practices

- Potential disease for the species of fish being cultured should be identified, as well as the symptoms, pathways for infection, and treatment.
- The disease should be identified through sample collection and examination of fish health records.
- All ponds should be identified that have the symptoms of the disease. Movement tracking records should be consulted to determine other potential areas of infection within the facility.
- Following the pre-established quarantine plan, individual fish or ponds should be isolated and quarantined.
- A qualified veterinarian or fish pathologist should be consulted and provided with samples collected using methods established by the fish health professional.
- Appropriate treatment for disease should be selected using the list of FDA approved therapeutic drugs or chemicals.
- All therapeutic drugs should be administered using the manufacturer's dosing and holding times.
- All actions should be recorded and harvest times for the treated fish should be followed.
- The movement of fish through the facility should be halted and all equipment associated with the infected fish should be sanitized.
- Live infected fish should not be released into the environment. Infected mortalities should be disposed of properly to prevent the infection of wild fish populations.
- Disinfection of infected tank water shall be performed prior to discharge.
- Disinfection of empty ponds or tanks associated with the disease should be performed before introducing other fish.
- Nutritional requirements for particular species should be identified and proper feed should be used accordingly. Fresh, high quality feed should be used.
- To reduce stress, water quality should be monitored and maintained.

Aquaculture Drugs and Chemicals

A good health management goal is the maintenance of healthy and productive fish populations without the use of therapeutic drugs or chemicals. Unfortunately, the use of drugs and chemicals may be needed to combat or prevent disease, to maintain good water quality, and to reduce fish stress. The use of drugs and chemicals introduces potential contaminants into a food product. Because of possible contamination into the food supply, the US Food and Drug Administration strictly regulates the use of drugs and chemicals by the aquaculture industry (GuidanceComplianceEnforcement/PoliciesProceduresManual/UCM046931.pdf). It is imperative that the aquaculture facilities only use products that are approved for aquaculture use, as specified on the label, and for the intended use.

Best Management Practices

- A diagnosis of the problem(s) should be obtained from a licensed pathologist or veterinarian before any treatment.
- Professional advice should be sought if there is any doubt as to when or how to use regulated products.
- Regulated products must be used only for those species and indications listed on the label, unless extra-label use is specifically prescribed by a licensed veterinarian.
- Product labels should be read and directions followed carefully.
- Proper dosage, amount, or concentration for the species and/or specific condition should be used. Proper application times and rinsing procedure should be known and followed.
- A small portion of the afflicted population should be treated prior to treating the entire population to ensure efficacy and safety of treatment.
- Use the correct method and route of application or administration, whether by spraying aquatic vegetation, water treatment (ponds, tanks, or immersion), injection, or oral administration (medicated feed).
- Withdrawal times should be calculated accurately, documented, and followed.
- Treated populations or stocks should be clearly identified.
- Antibiotic drugs or medicated feed for disease prevention should not be used unless they are specifically approved for that use.
- Medicated feed should be kept separate from non-medicated feed and properly labeled.
- Keep and maintain accurate records.
- Environmental impacts of discharging treated water should be mitigated.
- When the product is for human consumption, a Hazard Analysis and Critical Control Point (HACCP) program that provides guidelines for preventing tissue residue violations and for producing high-quality, wholesome products shall be implemented.
- Requirements concerning personal safety measures and proper procedures for farm workers and pesticide applicators that handle or apply regulated products should be followed.

- Economic consequences, both short- and long-term, of treatment should be considered before using a regulated product (Sometimes the best approach is to let the disease run its course).

IT IS THE USER'S RESPONSIBILITY TO KNOW WHETHER A PARTICULAR PRODUCT IS APPROVED FOR AN INTENDED USE IN AQUACULTURE AND TO USE THE PRODUCT AS APPROVED.

Feed

A high quality feed is critical to producing a quality fish for market and reducing the amount of waste produced by optimizing growth of the fish per unit of food. It is important to obtain feed from a reputable manufacturer for the species and size or life stage of the fish being produced. Because feed is manufactured specifically for a limited number of species of cultured fish, the feed that best meets the nutritional needs of the cultivated species should be used. By using a feed based on the species' nutritional needs, the overall health of the fish and water quality will be maintained.

Industry standard feed conversion rates are available and should be utilized to determine species and size specific feeding rates. Smaller and younger fish need more feed as a percentage of their body weight. Regular sampling to determine the growth rates should be performed and feeding adjusted accordingly.

The type and amount of feed should be calculated for each tank and allocated over time. Feeding should be done over the span of a day and not at a single feeding. Do not over-feed the fish. Over-feeding can have a negative impact on water quality and increase stress on the fish. Careful attention to feeding can reduce excess feed accumulation that can impact water quality. Uneaten feed should be removed regularly. Daily feeding records should be maintained and include time of feeding, amount feed, type and size of the feed, and feeding activity. During feeding, observations should be made to identify any potential health issues.

Best Management Practices

- Feed should be purchased from a reputable manufacturer.
- Only fresh, high-quality feed should be utilized based on the nutritional requirements of the particular species being cultured.
- The quantities of feed purchased should be based on feeding rates and the manufacturer's recommended shelf life.
- Inventory and tracking records should be kept on feed including lot numbers, type and size of feed, quantities, location, and expiration dates.

- Feed should be stored in a dry, cool, and pest-proof area. Feed should not be stored longer than manufacture's recommended time period. Wet, moldy, contaminated, or old feed should be discarded.
- Industry standard feeding rates should be used based on species specific developmental stages. Feeding rates should also be adjusted according to fish feeding behavior to avoid either over or underfeeding.
- Daily records of the amount of feed fed, time of feeding, and behavior of fish should be maintained. While feeding, fish health observations should be conducted.
- Growth rate and feed conversion monitoring should be done routinely and feed size and amount adjusted for growth.
- Water quality should be monitored and feeding reduced or suspended when water quality is poor.
- Feed amounts should be calculated based on the food conversion rate, amount of fish or biomass per tank or pond, and on the type of automated feeder (if any). Spilled feed should be cleaned up daily.

Transportation and Handling

Fish will need to be transported to and from the aquaculture facility. Appropriate hauling tanks, water quality, and stocking densities should be used to reduce fish stress and transport mortalities. Hauling tank size and construction should be determined for each species and specific developmental stage being transported. Hauling densities should be adjusted based on tank size, species, life stage, water quality, and outdoor environmental factors. Mechanical aeration and supplemental oxygen can be used to increase the stocking densities.

Prior to shipping, fish should be segregated and removed from feed for several days to allow waste to be purged. Purging will help maintain water quality in the hauling tanks and reduce fish stress.

Best Management Practices

- Industry standard equipment should be used for species and life stage specific transport needs.
- As part of a biosecurity plan, hauling equipment, including tanks and nets, should be cleaned, disinfected, and rinsed before use.
- Fish should not be fed for three to four feedings (1-2 days) before transport to allow for purging.
- Out-of-water times should be minimized as much as possible during movement from the culture area to the hauling tank.
- Proper aeration or oxygenation systems should be employed during transportation.
- Backup systems are desirable should a failure occur.
- Industry standard hauling densities should be adjusted for environmental factors, fish size, and behavior.

- Transport water temperatures should be adjusted before transferring fish to minimize temperature related stress.

Equipment Maintenance

All aquaculture systems need reliable and affordable equipment to operate; some equipment used in RAS are very technical, costly, and sophisticated. Even the best equipment will require regular maintenance to help prevent break downs. Properly trained staff, a regular maintenance plan, adherence to manufacturer recommendations, and stocking of replacements parts will help prevent down time and reduce fish stress and mortality. Appropriate maintenance schedules should be adopted and recorded.

Best Management Practices

- The most reliable and affordable equipment should be selected.
- Using equipment from a well-established manufacturer will aid in support and troubleshooting.
- All manuals should be reviewed during installation and retained for easy access.
- A maintenance log should be developed to document equipment purchase, installation, maintenance, and repair.
- A regular maintenance plan should be implemented that includes inspections on all equipment and maintenance scheduled when worn components are discovered.
- The maintenance plan should also include backup systems for essential components such as generators, pumps, and aerators. Spare parts should be kept in stock.
- Contingency plans should be drafted for possible equipment maintenance and failures.
- All personnel should be knowledgeable of normal equipment operation, contingency plans, contact names and phone numbers, and location of relevant materials should a disruption occurs.

Fish Escapement Control

The control of fish and their diseases from escaping a facility should be a high priority for both environmental and economic reasons. Escapement prevention methods shall be utilized to prevent the escape of eggs, larvae, fish, and disease from land-based ponds and recirculating aquaculture systems. Escapement prevention is especially critical for shore-based facilities discharging to state waters. Non-native and aquaculture modified genetic strains shall be prevented from escapement. Escapees can have environmental consequences for entire ecosystems. Escapees can alter the native genetic structure, compete for limited resources such as food and habitat, breed uncontrolled by predators, and introduce disease. The species and aquaculture strains imported into CT will be evaluated by the CT Department of Energy and Environmental Protection to determine if an import permit can be issued.

A containment plan should be created and be part of the design and standard operating procedure. The plan should include regular monitoring and emergency implementation. Methods of prevention include double screening, micro-filtration, ultra-violet treatment, ozone treatment, chlorine treatment (with subsequent chlorine removal), and stock characteristics such as triploid or mono-sex, essentially achieving functional sterility.

Cage systems pose a unique challenge due to their submerged condition and direct contact with the environment. Cage systems placed in ponds and lakes will be limited to native fish species. Cages are enclosures made out of corrosion resistant (heavy plastic, heavy nylon, stainless steel or aluminum) and anti-fouling materials that prevent fish from leaving the enclosure but allows water to move freely through the mesh. Cages should be well constructed, well moored, regularly inspected, and repaired. Standard operating procedures should be determined for the handling and transfer of fish from boats to and from the cage structure.

If escapement from any facility occurs, the Bureau of Aquaculture should be notified. Information about the escapement should include the operation name, location, species, and number of fish. The reason for the fish escapement should be investigated and future prevention determined.

Best Management Practices

- As part of the initial system design, fish and disease escapement equipment, methods, and procedures should be established.
- An escapement contingency plan should be created and staff should be trained.
- Escapement prevention monitoring should be conducted regularly.
- If escapement occurs, the regulatory agency should be contacted with the operator name, location, species, and number of fish.
- Equipment should be maintained to prevent escapement including cage structures.
- Cages should be well constructed, well moored, regularly inspected, and repaired.
- Standard operating procedures should be determined for the handling and transfer of fish from boats to and from the cage structure.
- Ponds with outlets, including ponds, lakes, rivers or streams, must have escapement mitigation devices such as screens or gates. Depending on the species of fish, anti-jump-out netting may be required.

System Design

Recirculating Aquaculture System

Recirculating aquaculture systems (RAS) are designed to circulate, condition, and remove waste while minimizing water use and reducing the need for waste water discharge. Complete reuse and the elimination of waste water discharge is a goal for RAS design. The accumulation of waste and deteriorated water chemistry requires regular waste water discharge and water replenishment. In recirculating aquaculture systems, water quality, including temperature, salinity, pH, and oxygen concentrations, can be controlled and allows for higher stocking densities. Water quality is further enhanced by treating fish excretions with a biological filter, transforming and reducing ammonia to less toxic forms, and removing solid waste by utilizing filters and settling tanks. The indoor aspect, reduced water usage, and reduced waste water discharge allows aquaculture to exist in areas previous not considered.

The complexity, knowledge, and the higher cost needed to design and operate RAS may supersede the advantages of the system. The system design includes culture tanks, circulating pumps, filters for suspended solids, settling tanks, and biofilters. Other mechanical systems can include aeration and oxygen systems, CO_2 removal, protein skimmers, water heating and cooling systems, and disinfections systems. Disinfection systems, such as UV and ozone are critical to keeping disease under control.

When considering RAS, several factors need to be examined; the source water, waste water discharge, and overall culture system design layout with the inclusion of filtration, backup, disinfection, and escapement mitigation systems.

The source water for recirculating systems may be well water, ground water, municipal water, or seawater. Well, ground, and sea water should all be tested and treated for contaminants prior to pumping into the system. Municipal water is treated with chlorine and fluorine and may require treatment or filtering prior to use in the system. There may be added cost associated with a municipal water source. Seawater can potentially contain microorganisms, chemicals, and human and agricultural waste. Treatment of seawater should be performed to filter and disinfect any potential contaminants. Ultra violet disinfection can be used on incoming water to treat for biological pathogens and should be considered as part of a biosecurity plan. When utilizing saline water, permits will be required to mitigate navigational interference of intake and discharge piping and dredging needed to install the pipes. Salt water shall not be discharged to freshwater environments.

Despite the reduced water use and waste water generation associated with RAS, waste water will still need to be considered. A system design should include plans that adequately treat and properly dispose of all waste water generated throughout the system and take into account how tanks are flushed, drained, and disinfected. The type and quality of the waste water will be influenced by the type of filtration used, stocking densities, quality of the food, and when in the cycle the water is discharged. When a tank is drained or flushed to remove solid waste or for cleaning, the effluent should be treated to settle out the solids, filtered, and disinfected with UV or Ozone before being discharged. Aquaculture cleaning disinfectants should not go through the bio filter. Based on the amount, type, quality, and discharge location, a determination of the treatment of the waste water shall be made by the CT Department of Energy and Environmental Protect (DEEP) and Bureau of Aquaculture. If the facility is located where municipal sewers are available, sewers can be used for the discharge of waste water. The aquaculture operator should contact the municipal authority to determine if this option is feasible, the limitations on the amount that can be discharged daily, and the cost. Disinfection of the effluent may still be required if non-native species are being cultured in order to eliminate any pathogens escaping the facility. Aquaponics can be utilized to treat production water through plants to further reduce the nutrients and provides a second marketable crop. Aquaponics usage does not eliminate the evaluation needed by regulatory agencies of the effluent discharge.

The system design is critical to the success of any RAS facility. The design should be based on the fish being cultured, the source water, the biosecurity plan, the treatment and discharge of waste water during daily activities, back-up equipment, and escapement mitigation. Many aquaculture suppliers have system designers to aid in the system design that best achieves BMP goals. The order of placement of the suspended solids filtration, the bio filter, and UV disinfecting equipment is critical and should follow standard industry practices. Biosecurity should be part of any RAS facility design including filtering and disinfection of the source water, tank quarantine and isolation, and facility layout. Consideration should be made to having multiple small recirculating systems with several tanks, pumps, and filters instead of one large systems. The cost of the multiple small systems may initially be higher, but it may help in isolating disease, maintaining water chemistry, and minimize the loss of product and profits. After contacting the appropriate local, state, and federal agencies, waste water treatment and discharge should be part of the overall site selection and system design. Escapement mitigation is an important consideration during the system design as well as during the daily operation of the facility. The design should have adequate screening to prevent escapement of fish species. When non-native fish species and genetically altered strains, along with their parasites or pathogens, are being cultured, double screening on outlet pipes, successive micro-filters, and disinfection equipment such as UV and Ozone will be used to prevent escapement.

Best Management Practices

System Design

- The complexity of the RAS system requires ongoing maintenance with levels of backup.
- Staff should be fully trained in the operation of the system and understand emergency procedures.
- The system critical areas should be computer monitored and alarm systems should be installed. Critical areas that should be monitored include pump pressure, water flow, tank water levels, temperature, pH, and dissolved oxygen.
- Power failure back-up generators and/or oxygen is necessary to prevent product loss.
- UV or ozone filtration should be utilized to prevent disease and disease escapement.
- Indoor systems require additional lighting.
- CO_2 stripping may be required to maintain pH without adding buffering chemicals.
- High quality feed and proper feed management should be employed to reduce waste generation.

Production and Waste Water

- Filtration systems (solids removal and biological filter) should be maintained and monitored on a regular basis.
- Species-specific industry standard water quality parameters should be determined and maintained.
- Flow from the biofilter to the tanks should be adequate.
- Solids should be collected regularly and properly disposed. Solids collection can be accomplished through tank designed collection and flushing, settling tanks, and filters.

- During the site investigation, water source testing should be conducted to determine if parasites, pathogens, disease, or other environmental contaminates are present.
- Special consideration should be given to determining the species of fish to be cultured with an emphasis on high tolerance to water quality fluctuations and the ability to grow rapidly in high stocking densities.
- Water quality data should be monitored and recorded daily. Important industry standard water quality parameters include ammonia, nitrite, nitrate, alkalinity, pH, dissolved oxygen, turbidity, and temperature.

Pond Aquaculture

Earthen pond aquaculture is one of the oldest fish production methods. Pond types can include natural ponds, constructed ponds dug out of a flat area, or dammed waterways that filled an area. The constructed earthen pond type of system is utilized in CT producing fish for stocking and baitfish. Ponds range from three to eight feet deep and from 1/16th of an acre to more than an acre depending on the size of the operation and size of the fish being cultured. The construction of the pond should follow the guidelines described in the US Department of Agriculture National Resources Conservation Services Handbook 590 "Ponds – Planning, Design, and Construction". Pond size is determined by the species of fish, size in the fish's lifecycle, and the availability of land and water. Each site should be fully evaluated prior to pond construction. Important aspects to consider are soil type, rain run-off patterns, slope or topographic characteristics, water sources, and water discharge options. Professional design plans can be obtained for the construction of ponds. Proper slopes of the banks and bottom must be maintained for proper function and drainage. The proper placement and construction of drainage monks (pond outlet structure) are important. The slope of the bottom and placement of the monk should allow the pond to entirely drain.

The design of a complete system of ponds can incorporate aspects of the recirculating aquaculture system to maximize the water usage by pumping the water back to the top of a gravity fed system. Many of the design parameters of RAS can be implemented in a pond system.

The species of fish that can be grown in outdoor ponds will be limited to native species of fish including trout, largemouth bass, smallmouth bass, mummichogs, and bluegills or sunfish. Escapement prevention in outdoor ponds must be accomplished using screening and grates. The difficulties of escapement prevention make non-native species less suitable for earthen pond production. Similarly, disinfection of effluent prior to release are more difficult to achieve and makes non-native disease escapement prevention problematic.

As with any aquaculture design, water sources and waste water discharge must be investigated and incorporated into any pond system design. Water source quality is similar to other aquaculture systems. However, ponds can be supplied with several sources of water including springs, streams or other surface waters, and wells; each of which have varying temperatures and water quality. Without aeration or circulators, ponds can stratify and oxygen levels towards the bottom can get below the optimal levels. Aerators and circulators may be needed to prevent mortality.

Waste water amounts and quality must be determined and proper treatment options will be determined by the CT DEEP. The stocking densities of earthen ponds are much less than RAS, making the waste water less concentrated. Waste water treatment options include earthen settling ponds, seasonal agricultural field application following local, state, and federal regulations and best management practices, constructed wetlands, and designed septic systems.

Disease prevention and treatment are considerably more challenging in outdoor earthen ponds. Many of the animals and birds that prey on the fish are also carriers of disease that can impact fish health. Complete netting over every pond can be expensive and time consuming to maintain. Scare tactics have limited success. Noise and visual anti-predation scare techniques should be altered to maximize effectiveness.

Best Management Practices

Site Selection and Construction

- A complete survey including topography and soil mapping should be conducted at each site being considered for pond construction.
- Pond should have a rectangular shape to facilitate seining.
- Ponds should not be constructed in flood-prone areas, salt marshes, or other ecologically sensitive areas.
- Pond site selection should exclude locations where lives and/or property may be endangered should an embankment fail
- Construction of ponds should not alter natural water flows necessary to maintain surrounding habitats.
- To prevent pond contamination, ponds should not be subject to agricultural run-off or accessible to livestock.
- A soil mixture of sand, silt, and clay is most suitable to resist erosion and seepage. Plastic liners or clay may be used.
- Waste water discharge and treatment should be evaluated by regulatory agencies. After approval, the use of constructed wetlands or a settling basin to reduce effluent nutrients may be considered.
- Ponds being used year-round, should maintain pond depths of at least eight feet to prevent freezing or utilize agitation equipment.
- Constructed pond bottoms should be smooth and with adequate slope to allow complete drainage, to minimize growth of aquatic vegetation, and to facilitate harvest.
- Recommended slopes of the banks for ponds should be 2:1. Steeper slopes can be considered because they will discourage predation by wading birds, but can complicate harvest.
- Entry points should be incorporated into the design to facilitate harvest.

- A drain system should be installed to permit the pond to be fully drained. The drain should be designed to prevent accidental draining and seepage. The drainage system should allow for maintenance at a range of water levels.
- Pond inlets and outlets should be double screened to prevent fish escape and impede entry by predators and competing species.
- Mechanical aeration or other critical equipment that require electricity should have a backup system available.
- Ponds can be drained or dredged and should be initiated in the fall following harvest and allowed to dry out completely for several months (fallowing). The dredged material consisting of decomposed fish, fecal matter, and decomposed feed should be disposed of properly or properly composted for agricultural purposes.
- In general, fish should be over-wintered only in ponds that have a depth of eight feet or more. Allowing ponds to be lightly stocked through the winter months will improve survival. It is recommended that ponds used to over-winter fish be aerated to prevent ice from forming and the accumulation of light snow.
- Ponds with outlets, including rivers or streams, must have escapement mitigation devices such as screens or gates. Depending on the species of fish, anti-jump-out netting may be required.

Production and Waste Water

- An initial test of the water source should be conducted to determine it is free of contaminants, including parasites, pathogens, disease or any other environmental impurities. If the results indicate problems, suitable remedial actions must be initiated to correct water quality issues.
- To reduce the generation of waste and degraded water quality, proper feed management should be employed including record keeping. Over feeding should be avoided and uneaten feed should be removed regularly.
- Ponds should be sited away from organic debris that can adversely impact water quality such as leaf litter.
- Routine testing of water quality parameters including ammonia, nitrite, alkalinity, pH, dissolved oxygen, turbidity, temperature, and total hardness should be done at specific intervals. Records of water testing results should be maintained on standardized data sheets. Dissolved oxygen is the most critical water quality parameter and should be monitored regularly. Emergency or supplemental aeration should be turned-on if oxygen values are anticipated to fall below optimal. Night time aeration maybe needed during the summer months to increase oxygen when the phytoplankton's shift to respiration and produce CO^2.
- Annual water usage should be determined by regularly monitoring the amount of water inflow and discharge.
- Water flow should be regulated to meet industry standard water quality requirements for the species being cultured. In general, water flow reduces nutrient load in the pond, increasing production capacity. Increased water flow can reduce water temperature in the summer and reduce ice formation in the winter.

- After gaining approval of the regulatory agency to discharge, effluent should be treated and monitored to prevent impacts on the surrounding environment.
- When the pH is not within the optimal range, and water exchange is minimal, sodium bicarbonate can be added to help achieve neutral pH or lime may be added to acidic soils in the watershed to increase pH.
- Pesticides usage should be avoided in the pond and watershed area. If pesticides are used, they should be used according to state regulations and label instructions must be followed.
- Aeration and circulation systems can be implemented to increase production capacity, reduce mortality, decrease stratification, and prevent winter-kill.

Marine Aquaculture

To date, marine aquaculture in Connecticut has been mainly limited to shellfish. Saltwater finfish aquaculture, as practiced in Connecticut, includes land-based systems with inlet pipes drawing marine waters into the systems. Cage systems may be used in the marine environment to contain and grow out native fish species in the future. Because of the potential to impede navigation and impact water quality, finfish aquaculture in the marine environment will be evaluated similarly to shellfish aquaculture. Various local, state, and federal agencies will evaluate the proposed location and system design.

Best Management Practices

- The native species of fish to be cultured should be determined.
- A suitable location with adequate depth and current should be selected.
- System design should be completed and a detailed diagram created.
- All local, state, and federal applications should be completed and submitted with all the necessary information.
- Cage structures should be made of rust-proof and anti-fouling material.
- Cages should be well-constructed and appropriately moored.
- Standard operating procedures (SOPs) should be created for feeding, repair and maintenance, and handling and transport.
- The mesh size of the cage should be small enough to prevent escapement of the cultured species and to prevent predator entrance into the cage, while allowing water to flow freely.
- Each cage should have a cover to prevent escapement, bird predation, and shading of the fish from the sun.

Flow Through Systems

Flow through system aquaculture depends on large volumes of high quality water that continuously flows through the entire system. Very little water conditioning and filtering occurs. Not only should the source water be tested for quality, particular attention should be focused on the volume and replenishment rate of any aquifer, pond, or lake being used. Flow through systems located on the coastline that use marine waters for their source must treat the incoming water to eliminate parasites and contaminants. Water permits may be required depending on the type and quantity of source water being consumed. Shoreline based inlet and outlet piping will require permitting for their location and may require associated marker buoys.

Flow through systems should be designed to utilize gravity and minimize the need for mechanical pumping. Aeration should be achieved through inlet pipe design and require very little additional mechanical aeration. When designing the system, a plan to treat the effluent should be formulated that adequately removes solid fish waste, uneaten feed, and nitrogen (ammonia). Settling ponds and constructed wetlands may be utilized to treat the effluent. Indoor and marine land-based systems will require some treatment of the effluent including settling ponds and nitrogen filtering. The layout of the ponds and tanks including the piping should allow for quarantine isolation, cleaning, and shutdown bypasses. Escapement devices should be part of any system design. Fish movement from pond to pond (or tank to tank) and escapement with the effluent should be prevented. This is especially true when non-native species are being cultured. The flow rate and length of the system should be calculated to eliminate the buildup of toxic water chemistry.

One of the advantages of a flow through system is that the water quality will remain within optimal ranges with only a few exceptions. The water quality may deteriorate towards the end of the system and the length of the system should be considered in the design process. Dissolved oxygen must be monitored especially towards the end of the system where it can drop below optimal levels. Oxygen can be consumed quickly when stocking densities are high. Stocking densities should be monitored and follow industry standards for each species of fish, the volume of water of the tanks or ponds, and rate of flow through those tanks or ponds. Ammonia may build to levels that can stress fish, reduce growth, and promote disease. Water quality parameters should be monitored and recorded daily.

Best Management Practices

System Design

- Local and state agencies should be consulted and any applicable permits obtained prior to facility construction.
- System should be designed based on the quality and volume of the water source, site features and limitations, production goals, and time available for operation and maintenance.
- Water flow rate adjustments, pond isolation, and bypass features should be part of the system design.
- Appropriate means of waste collection, treatment, and discharge shall be planned and integrated into the system.
- Pond enclosures should be constructed to deter predators and unwanted debris from entering system.
- System should be designed to facilitate passive aeration and removal of concentrated solids.

Waste Management

- High quality feed and proper feed management should be employed to reduce waste generation.
- All waste outlets should be screened to limit fish escape or invasion by unwanted fish.
- Properly designed settling ponds should be established in accordance with state and federal regulations.
- Waste products must be effectively collected and removed.
- Sumps/waste collection areas should be drained daily in culture tanks to remove settled solids.

Water Management

- An initial test of the water source should be conducted to determine it is free of contaminants, including parasites, pathogens, disease or any other environmental impurities. If the testing results determine any problems, suitable remedial actions must be initiated to correct water quality issues.
- For the species being cultured, water flow should be regulated to meet industry standard water quality requirements.
- Water withdrawal and discharge should be monitored in compliance with local, state, and federal regulations.