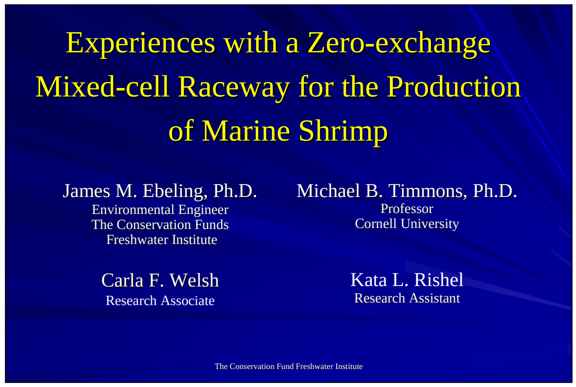
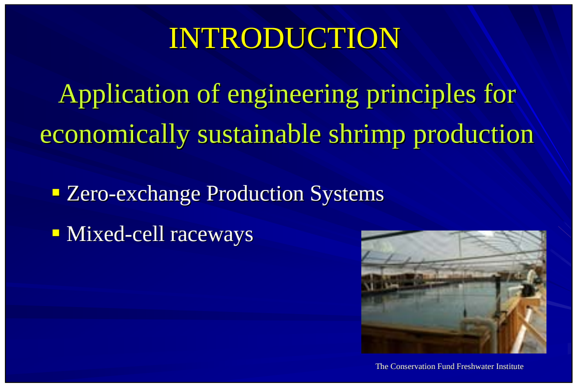


The use of zero-exchange systems has become a viable alternative to traditional pond methods of intensive aquaculture production. Recently, the concept of zero-exchange systems has been applied to indoor tank based production systems for marine shrimp, *Penaeus vannamei*. In addition, raceways have been used for years for the production of a wide range of aquaculture species, but their use has been significantly curtailed by the need for high volumes of high quality water and difficulties treating their effluent discharge. An improvement to the conventional raceway design is to convert the raceways into a series of counter-rotating mixed-cells that act as hydraulically separated round tanks that have the inherent advantage of being self-cleaning. The mixed-cell raceways can then be managed as partial reuse systems or as intensive recirculating systems. Combining these two production concepts, yields a system that is economical to construct, efficient to harvest, has excellent solids management abilities, and high potential product (or biomass) yield.

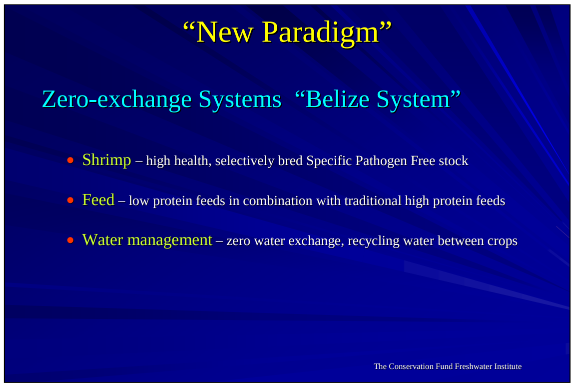


A prototype mixed-cell raceway was constructed at the Conservation Fund Freshwater Institute of structural lumber with an HDPE liner that measured 16.3 m x 5.44 m x 1.22 m. The basic design concept was to operate the raceway as a series of square/octagonal tanks, each having a center drain for continuous removal of solids and sludge. A series of vertical discharge pipes were placed along the raceway sidewalls that directed recycle water through orifice discharges tangentially to the walls to establish the desired rotary circulation. This was then combined with the concept of the 'Cornell double drain system', where 10% to 20% of the total flow into a tank was removed from a center bottom drains and 80 to 90% of the flow was removed from the side drains. Settable wastes and sludge were then removed from the center drains and collected in a settling sump. The systems was stocked with marine shrimp, *Penaeus vannamei* and managed as a zero-exchange low salinity production system for several months. Research was conducted into new methods of maintaining or controlling the dynamics of the water quality of the system through the addition of carbon to stimulate heterotrophic bacterial production. In addition, suspended solids concentration in the production tank was maintained at acceptable levels by controlling the amount and frequency of discharge from the settling tank Basic water quality parameters were routinely measured, including temperature, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, alkalinity, total suspended solids (TSS), and volatile suspended solids (TVS).

The United States appears to have an almost insatiable demand for seafood; most of which is imported from overseas. In 2003, the U.S., imported over $11.1 billion of seafood, $974 million more than in 2002 (Fisheries Statistics & Economics Division, NOAA. The total trade deficit related to seafood trade is $8.0 billion (US Department of Commerce), of which $3.8 billion was for imported shrimp In addition, consumption of shrimp in 2003 reached 4.0 lb per capita, 26% higher than in 2001 (Aquaculture Outlook, LDP-AQS-19, March 12, 2004). Shrimp production accounts for 1/3 of the total economic value of all seafood sold in the US. The shrimp production worldwide totaled 4,168,400 tons in 2000, up slightly from 4,118,900 tons in 1999 (www.foodmarketexchange.com). Production from aquaculture is estimated at 855,500 tons in 2001. This was a 10% increase over the previous year's production but not enough to keep up with the world's growing demand for shrimp. The US wild harvest of shrimp was 158,500 tons in 2002 (2002 is the most recent year that wild domestic harvest data is available). However, the U.S. shrimp catch has remained essentially constant (ignoring annual fluctuations) over the period (1970-1995). The domestic farm-raised shrimp industry (ponds) has been increasing, but price drops have reduced the incentives for new farmers to enter the industry (Aquaculture Outlook, LDP-AQS-19, March 12, 2004).

In the US, marine aquaculture currently accounts for about 1/3 of commercial aquaculture production. However, growth has been constrained due to a variety of reasons, with environmental concerns, permitting processes, and low market prices being dominant. The environmental constraint naturally raises the advantages of recirculating aquaculture system technology, as recirculating systems can eliminate potentially any negative environmental impact from the production operation. Recirculating systems also conserve water, eliminates escapement of cultured animals, and can be site independent. The recycling nature of these systems also permits culture of marine or freshwater species and allows the farms to be located primarily for the benefit of market proximity, as opposed to being sited, based upon the availability of natural resources, such as high volume water (fresh or saline) or open ocean sites. The capability of recirculating systems to be located near markets is a key attribute, as shrimp raised in intensive recirculating systems will need to achieve premium pricing to be economically viable.

For traditional marine aquaculture to increase production, more coastal sites must be found. Appropriate sites are those located in protected areas with abundant access to unpolluted water. However, these same-type sites are also used for other high-profile activities, such as recreational fishing, wildlife protection, and aesthetic enjoyment. As an example, Alaska has prohibited the use of its coastal shoreline for aquaculture, in order to protect their native salmon populations and the associated industries that they support. More and more, other communities and states are following this example. In attempts to circumvent these restrictions, there is considerable interest in developing what is referred to as "off-shore" sites, which are within the 3 to 200 miles offshore zone controlled by the US government. This is a difficult environment, however, and aquaculture in such areas will be subjected to higher capitalization and operating costs, which makes the production of commodity type seafood all but impossible on an economical basis. The practical alternative to these problems is the development of "in-shore" or land based marine aquaculture systems.

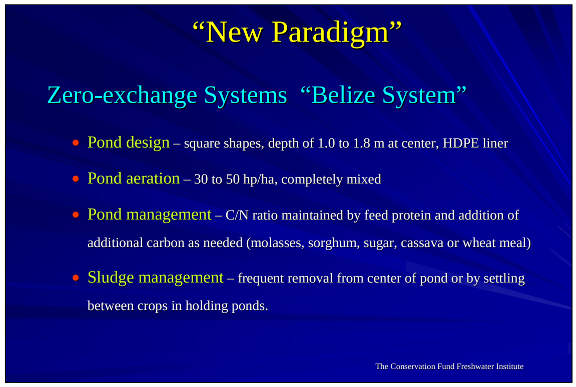


Due to the environmental impact of these nutrient rich discharges and the need for increased biosecurity, Waddell Mariculture Center, among others, researched the concept of reduced or zero-water exchange culture. Waddell Mariculture Center demonstrated that it was possible to obtain high shrimp yields from ponds using minimal exchange of water with high aeration rates. In the mid-90's, this concept with minor modifications was demonstrated at a commercial farm, BAL in Belize, Central America, hence the reference to the 'Belize zero-exchange system'. This system was based on the following concepts:

- Shrimp – high health, selectively bred Specific Pathogen Free stock
- Feed – low protein feeds in combination with traditional high protein feeds
- Water management – zero water exchange, recycling water between crops
- Pond design – square shapes, depth of 1.0 to 1.8 m at center, HDPE liner
- Pond aeration – 30 to 50 hp/ha, completely mixed
- Pond management – C/N ratio maintained by feed protein and addition of additional carbon as needed (molasses, sorghum, sugar, cassava or wheat meal)
- Sludge management – frequent removal from center of pond or by settling between crops in holding ponds.

To prevent the introduction of disease, only disease resistant Specific Pathogen Free (SPR) PL's are stocked in the production pond at densities up to 120 to 200 m2. Recent strains of faster growing shrimp have become available through selective breeding. Feed protein content plays a critical role in maintaining a healthy bacterial population by balancing the carbon to nitrogen ratio. A carbon/nitrogen ratio of 16:1 was found to yield a very health heterotrophic community. This was accomplished by using a grain based feed with a high C/N ratio of 20 to balance the high protein diet used. In addition, molasses (> 40% carbon) was added during initial pond development to stimulate heterotrophic bacterial growth.

During the production cycle, there was no exchange of water except to make-up water loss to evaporation seepage and solids discharge. At harvest, pond water was routed to a settling basin, where the solids quickly settled out and excess nutrients were removed. After one week, the water was recycled back to the production pond and three days later, shrimp stocked out. This was possible because the recycled water had sufficient nutrients and bacterial population that no extensive pond preparations were needed.

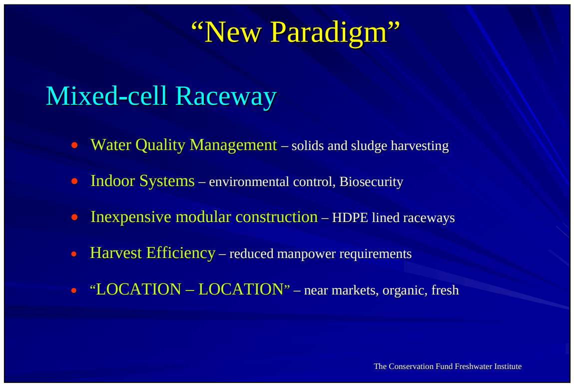


Ponds at Belize Aquaculture were square in shape with an average area of 1.6 ha (4 acres) and deeper compared to traditional shrimp ponds (1.8 m). In addition, each production pond was lined with a 40 ml HDPE liner. The liner was critical to allow the high mixing velocities created by the paddlewheel and aspirator aerators. This mixing action maintained floc in suspension and concentrated sludge in the center of the pond. At production levels of 1.8 to 1.9 kg/m2, approximately 1 hp of paddlewheel aeration was required to maintain dissolved oxygen for the production of 500 – 650 kg of shrimp. Ponds at Belize Aquaculture required 50 hp/ha of aeration. The aerators created a circular motion in the pond with water velocities ranging from 23 cm/s at the outside to 5 cm/s at the center.

These high rates of aeration and mixing are the first major component of a zero-exchange production system. The second is the maintenance of an active heterotrophic bacterial community by controlling the amount of organic loading and the carbon/nitrogen ratio. At sufficiently high stocking densities, there is normally adequate inorganic material (predominately ammonia-nitrogen) to maintain a robust heterotrophic bacterial community. At these high stocking densities, there can be a problem with too high a nitrogen concentration for the available carbon due to the use of high (>30%) protein levels. Belize Aquaculture found that by increasing the carbon/nitrogen ratio in the feed to 16:1 by mixing in a grain based feed (20:1 ratio) the heterotrophic community appeared to be more in balance.

Finally, sludge management is important and consists of primarily removing sludge concentrated in the center of the pond by mixing action. Sludge is very different from the bacterial floc in suspension, consisting of fecal matter and uneaten feed particles. Sludge in the center of the pond is either drained out or pumped out to the drainage canals and eventually to the solids settling pond for treatment and ultimate disposal.

The Belize system, which is a solution to conventional shrimp pond constraints, also suggests the possibility that a recirculating system approach might be used to raise shrimp in an intensive manner. Using an indoor approach would also provide more control over water temperatures and heating costs that might permit a zero-exchange system to produce several crops per year in a moderate climate such as Atlanta GA, where pond systems would be limited by outdoor water temperatures for essentially 6 months of the year. Since maximum shrimp growth rates occur near 86 F (30 C), there are essentially no outdoor sites that have such temperatures year round. Thus, the ability to control water temperatures to optimal temperatures on a year-round basis is a distinct advantage.



The concept of zero-exchange systems is a radical departure from the traditional recirculating aquaculture systems design, which requires expensive waste water treatment and handling equipment and high capital and operational costs. The basic design concept for the intensive zero-exchange production system is to operate multiple mixed-cell raceways as a series of square/octagonal tanks, each having a center drain for continuous removal of solids and sludge. A set of vertical manifold discharge pipes are placed along the raceway sidewalls that direct recycle water through orifice discharges tangentially to the walls to establish the desired rotary circulation. This then converts a conventional plug flow raceway into a series of counter-rotating mixed-cells, each acting as a hydraulically separated round self-cleaning "tank". This is then combined with the concept of the 'Cornell double drain system', where solids are removed from the system by discharging 10 to 20% of the total recirculating flow from the center drains in the middle of each rotating cell. This discharge of settable wastes and sludge are removed from the center drains and collected in a settling sump. This settable wastes and sludge can then be either discharge from the system or recycled to maintain adequate levels of suspended solids in the system.

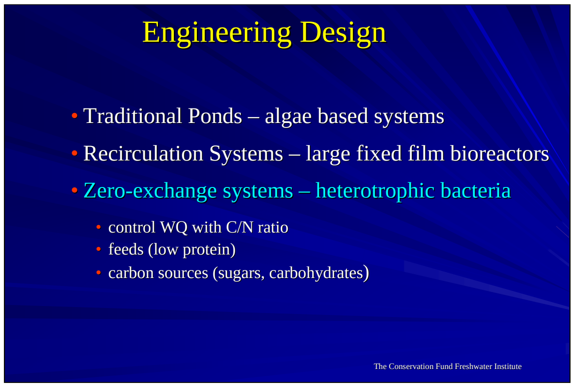
The production raceways are enclosed in a broiler house type insulated building (R-19 in walls). Using an opaque insulated building shell for the production raceways will permit evaporation and associated heat losses to be controlled. Using a covered rearing space will also permit control of light spectrums and day length and providing additional potential for improving the economic performance of shrimp farming, e.g. growth of both the shrimp and the biotic community are affected by light spectrum. Since this production technology incorporates a high level of aeration, the aeration energy will be absorbed by the water column, which significantly reduces the need for supplemental heating, even when placed in a moderate climate, such as Ocean Springs, MS or Atlanta, GA. In addition, vectors for disease transfer are further minimized by enclosing the raceways, eliminating the major cause of poor economic performance in conventional shrimp ponds

The intensive zero-exchange system will be environmentally friendly and sustainable. There will be essentially zero impact on the outside environment, since there is no water discharge from the system on any regular basis. Sludge removed from the system is dewatered using the GeoTube technology and the water is then returned to the production system. Dewatered sludge should be low enough in salt content so that it can be used as a soil amendment. The system is designed to be highly sustainable with minimal impact to the environment. The only water used after initially filling the production units is for evaporation losses. In addition, since there is no outside surface waters entering or exiting into the surrounding environment, there is no potential for animal escapement that could impact the natural ecosystem

“New Paradigm”

Sustainable Engineering

- Zero-exchange Production Systems
- Mixed-cell raceways
  - Design and Construction
  - Hydraulic Characterization
  - Water Quality
  - Solids Management



Traditionally, extensive pond aquaculture used photoautotrophic algae based systems to control inorganic nitrogen buildup, 'green-water systems'. In intensive aquaculture production systems, the inorganic ammonia-nitrogen build-up has usually been controlled by using large fixed-cell bioreactors that rely on the nitrification of ammonia-nitrogen to nitrate-nitrogen by *Nitrosomonas* and *Nitrobacter* autotrophic bacteria. The growth of heterotrophic bacteria and the accumulation of organic carbon are minimized through the rapid removal of solids from the system and employing water exchange, although typically only some small fraction of system volume per day, e.g., 10 to 20%. In contrast, it has been demonstrated that for zero-exchange pond production of marine shrimp, the inorganic nitrogen build-up can be controlled by the manipulation of the carbon/nitrogen ratio in such a way to promote the growth of heterotrophic bacteria. As a result, the ammonia-nitrogen is removed from the system through assimilation into microbial biomass. In addition, for some aquaculture species (marine shrimp and tilapia), this bacterial biomass produced in the intensive zero-exchange systems can be an important source of feed protein, reducing the cost of production and thus improving the overall economics.

The justification for intensive zero-exchange systems is based on several specific culture, environmental, and economic factors:

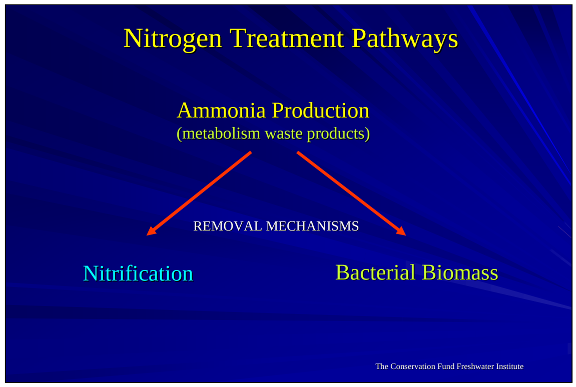
•More stringent environmental regulations limit the discharge of effluent and require more expensive clean-up technologies of the waste flow,

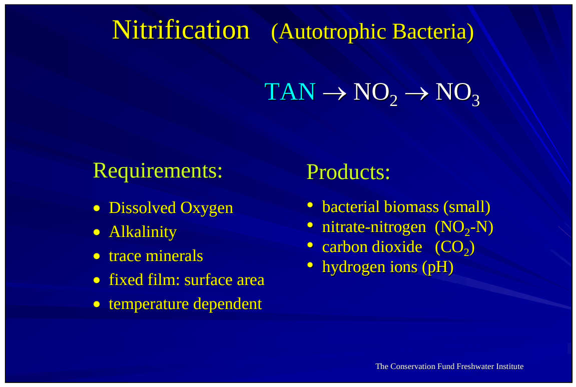
•Increased concerns about biosecurity and introduction of disease through exchange of water,

•More control over water quality during the production cycle, including dissolved oxygen, pH, temperature, carbon dioxide, ammonia-nitrogen and nitrite-nitrogen levels,

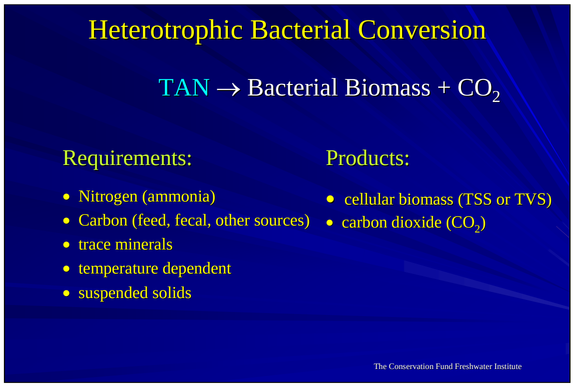
•Reduced operating costs by reducing labor through feed automation, continuous water quality monitoring, and reduced number of production units, through increased density per unit.

More recently, zero-exchange management systems have been developed for large-scale pond production, traditionally photoautotrophic algae based, where carbonaceous substrate is added to the systems to support microbial metabolism. It appears that at high carbon to nitrogen (C/N) ratios, bacteria will assimilate nitrogen, i.e., ammonia, from the water and produce cell protein. In addition, numerous attempts have been made in the last few years to develop this technology for indoor production systems at high densities.

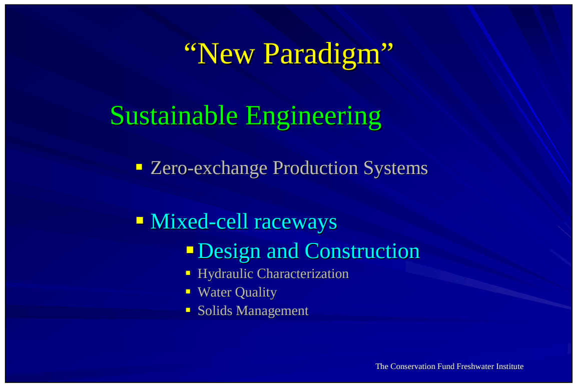

Nitrogen Treatment Pathways
Ammonia Production
(metabolism waste products)
REMOVAL MECHANISMS
Nitrification
Bacterial Biomass
The Conservation Fund Freshwater Institute



Using this stoichiometrically developed relationship, for every g of ammonia-nitrogen converted to nitrate-nitrogen, 4.18 mg of dissolved oxygen, and 7.05 mg of alkalinity is required and 0.20 g of microbial biomass (VSS) and 5.85 gm of CO_2 is produced. It should be noted that both the consumption of oxygen and alkalinity is less than that which normally reported, 4.57 g of O_2 and 7.14 g of alkalinity for every g of ammonia-nitrogen converted (Timmons, et al., 2002), because in this equation some of the ammonia-nitrogen is converted to biomass. Traditionally, this biomass has not been included in the stoichiometric relationship because it is minor in comparison to the other factors.

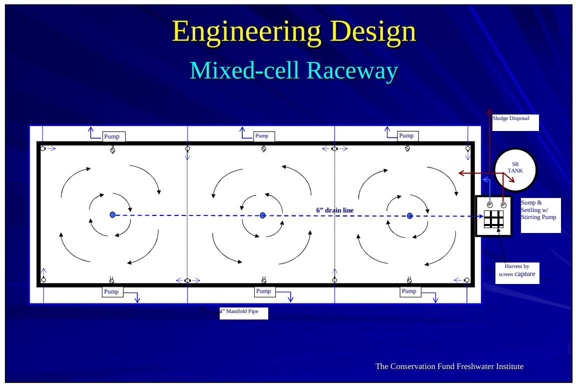


Using this stoichiometry, and for every g of ammonia-nitrogen converted to microbial biomass, 4.89 g of dissolved oxygen, 3.57 g of alkalinity are required and 8.07 g of microbial biomass (VSS) and 9.87 g of CO2 is produced. Note that the oxygen demand is slightly higher, the alkalinity requirement about half and the CO2 production almost 75% greater than the corresponding reaction for nitrification. Most importantly, notice the increase in microbial biomass production, approximately 26 times the mass created from the nitrification process.

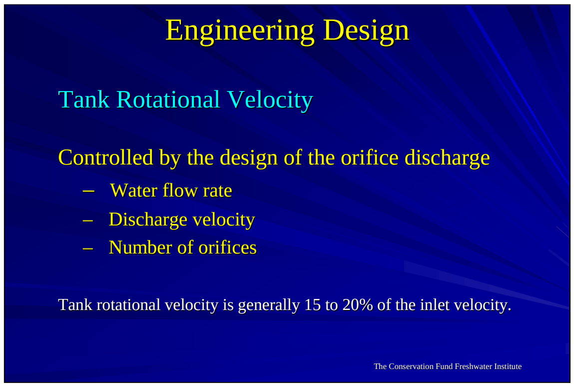


Recently, the concept of zero-exchange systems has been applied to indoor tank based production systems for marine shrimp, *Penaeus vannamei*. In addition, raceways have been used for years for the production of a wide range of aquaculture species, but their use has been significantly curtailed by the need for high volumes of high quality water and difficulties treating their effluent discharge. An improvement to the conventional raceway design is to convert the raceways into a series of counter-rotating mixed-cells that act as hydraulically separated round tanks that have the inherent advantage of being self-cleaning. The mixed-cell raceways can then be managed as partial reuse systems or as intensive recirculating systems. Combining these two production concepts, yields a system that is economical to construct, efficient to harvest, has excellent solids management abilities, and high potential product (or biomass) yield.

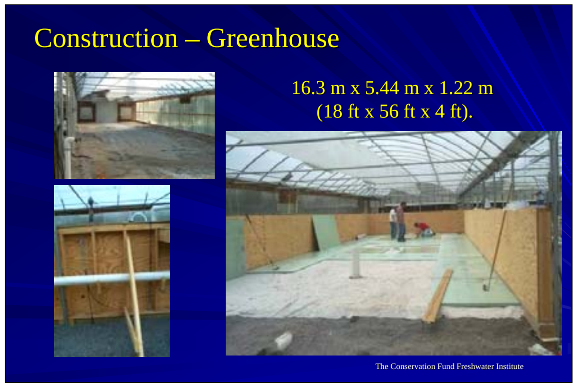
A prototype mixed-cell raceway was constructed at the Conservation Fund Freshwater Institute of structural lumber with an HDPE liner that measured 16.3 m x 5.44 m x 1.22 m. The basic design concept was to operate the raceway as a series of square/octagonal tanks, each having a center drain for continuous removal of solids and sludge. A series of vertical discharge pipes were placed along the raceway sidewalls that directed recycle water through orifice discharges tangentially to the walls to establish the desired rotary circulation. This was then combined with the concept of the 'Cornell double drain system', where 10% to 20% of the total flow into a tank was removed from a center bottom drains and 80 to 90% of the flow was removed from the side drains. Settable wastes and sludge were then removed from the center drains and collected in a settling sump. The systems was stocked with marine shrimp, *Penaeus vannamei* and managed as a zero-exchange low salinity production system for several months. Research was conducted into new methods of maintaining or controlling the dynamics of the water quality of the system through the addition of carbon to stimulate heterotrophic bacterial production. In addition, suspended solids concentration in the production tank was maintained at acceptable levels by controlling the amount and frequency of discharge from the settling tank Basic water quality parameters were routinely measured, including temperature, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, alkalinity, total suspended solids (TSS), and volatile suspended solids (TVS).



The mixed-cell raceway acts as a series of hydraulically separated round tanks. The basic design concept of the mixed-cell raceway (Watten, et al., 2000) is to operate it as a series of adjacent counter rotating square/octagonal tanks, each having a center drain for continuous removal of solids and sludge, Figure 1. A prototype raceway was constructed in one bay of an existing greenhouse at The Conservation Fund's Freshwater Institute with approximated dimensions of 16.3 m x 5.44 m x 1.22 m (54 ft x 18 ft x 4 ft), which created three mixed-cells. Each cell received water from four vertical manifolds (downlegs) extending to the raceway floor and located in the corners of each cell and at the intersection between adjacent cells (Figure 2); four of the manifolds supply water to two cells concurrently. Water is pumped through several orifice discharges (or jet ports) from each of the downleg pipes to establish rotary circulation in the cell, with adjacent cells rotating in opposite directions. Each cell had a bottom drain located at the center of the cell connected to a drain line, which discharged solids and sludge to a settling sump. A small fraction of the total recirculated flow, e.g., 10 to 20%, is withdrawn from this sump and returned to the raceway, creating a “Cornell” dual drain system.



The rotational velocity in the cells can be controlled by the design of the orifice discharges, either by increasing the flow rate, the discharge velocity, or the total number of orifices. Paul, et al. (1991) reported that for a tank the rotational velocity is roughly proportional to the velocity through the openings in the water inlet structure. Timmons, et al. (1998) indicated that this proportionality constant between tank rotational velocity is generally 15 to 20% of the inlet velocity.



Due to construction limitations imposed by the greenhouse, the mixed cell raceway was constructed as an above ground tank the width of one bay, with approximate dimensions of 16.3 m x 5.44 m x 1.22 m (18 ft x 56 ft x 4 ft). Sidewall modules (1.22m 2.44m) were prefabricated of 2x6 construction studs on 24” spacing and covered with ½” plywood sheeting. These sidewall modules were then supported on a 6x6 treated wood beam ‘foundation’ and connected together with ½” lag bolts. In addition, a top plate was used to provide additional rigidity to the sidewall modules. Normally such a tank would be constructed below grade, allowing for structural support of the walls with backfill material. To provide this structural support, a series of polypropylene-impregnated wire rope were run across the top of the tank at five equally spaced intervals and also below the tank. In addition, a single cable was strung the length of the tank top and a second one below the insulated floor. These cables were secured into the sidewall top plates and the 6x6 treated wood beam foundation with eyebolts and forged galvanized steel hook and eye turnbuckles to allow adjusting and tightening. These proved quite adequate, but only after several failed attempts with lighter gauge materials. The message here is to never underestimate the structural requirements and the large pressures exerted by a tank of water.

The floor of the raceway was covered with approximately 5 cm of fine sand and graded to provide a slight slope to the three center drains. To minimize heat loss through the sidewalls, these were insulated with 2.54cm x 1.22m x 2.44m foam insulation board. To minimize heat loss through the ground, the outside perimeter of the floor was covered with 5.0cm x 1.22m x 2.44m insulation board and the center strip of the floor with 2.54cm x 1.22m x 2.44m insulation board. The tank was lined with a 20 ml high density cross laminated polyethylene (HDPE) raceway liner from Permalon, Reef Industries, Inc.

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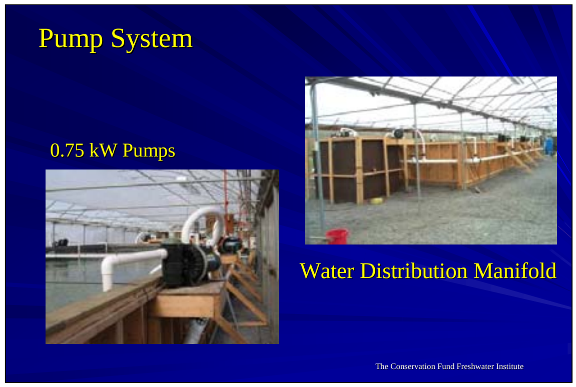
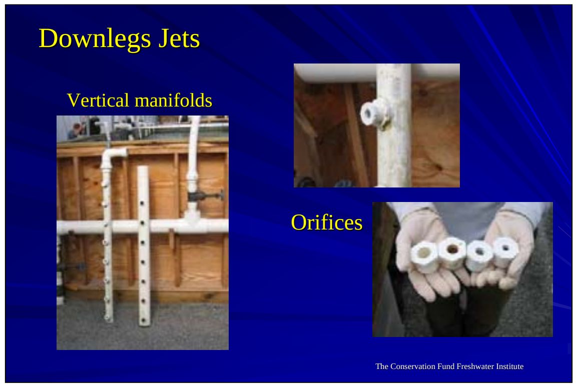
A 15.24 cm (6 in) drainline with three discharge drains (tee fittings) centered on each of the three cells was buried along the longitudinal axis of the tank. A standard flange socket fitting was modified by boring out the center to allow either standpipe or screened inlet and installed on each of the three tee fittings. A concentric ring of PVC sheet materials was used to secure the liner to the flange flat surface to provide a water tight seal at the three drains. The three drains discharged into a 1.83m x 1.83m x 1.83m (6 ft x 6 ft x 6 ft) fiberglass sump tank. The sump tank had both a standpipe for water level control and a drainline to flush the system. The sump tank was intended to fulfill several roles, including solids management by acting as a solids settling basin, water level set point with the standpipe and harvesting basin by flushing the production tank through a screened harvesting cage.

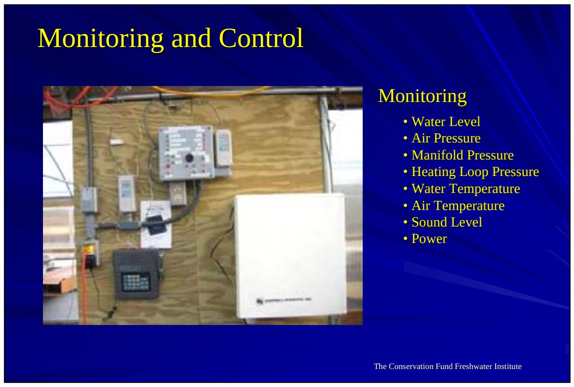


Eight 0.75 kW pumps (1hp) were installed along the outside walls on platforms and discharged into a 10cm (4 in) schedule 40 PVC manifold that encircled the raceway. These pumps were used as a cost saving measure, since they were free. Although in retrospect, they simulated a dual-drain system, where most of the recycled water is removed from the top sides of a tank and only a small fraction is removed from the center drains. Two of the pumps were located on the sump collection tank, while the remaining six were placed equal distant along the length of the tank outside walls. The suction lines with check valves were located approximately at mid-depth in the tanks. The pump discharges were connected to the manifold with a 5.08cm (2 in) flexible hose with a bronze gate valve to control flow and a clear plastic manometer to measure downleg back pressure.

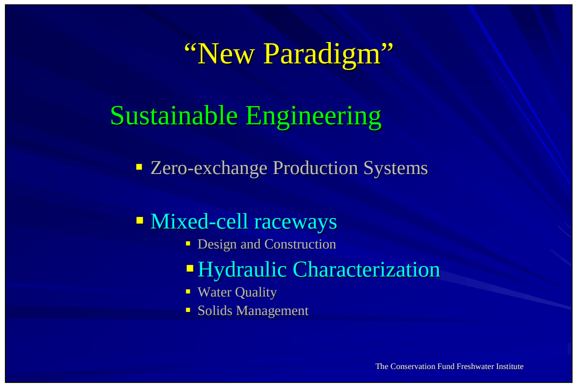


Each hydraulically separated cell created within the tank measured approximately 5.44 m x 5.44m (18ft x 18ft) as determined by the downleg placements. Four 5.08cm (2 in) downlegs with seven orifices were placed in the four corners of the tank and four 7.62cm (3 in) discharge pipes were located along the sidewalls, dividing the tank into three equal cells. Two of the 7.62cm (3 in) downlegs had 14 orifices; seven discharging along each edge of the wall and the other two discharge downlegs had 7 orifices each. The downlegs were constructed of either 5.0 cm (2 in) or 7.62 cm (3 in) PVC schedule 40 pipe. The orifice opening were constructed by welding a threaded bushing 3.18 cm by 2.54 cm (1 ¼ x 1 in), allowing a 2.54 cm (1 in) threaded plug to be inserted. This allowed for easy modifications of the orifice sizes and plugging of unused orifice openings.

Temperature was maintained using a standard swimming pool propane heater and three aluminum heat exchangers located in the tank. A small circulation pump forced water around a closed loop from the heater to the heat exchangers. A simple thermostat control on the propane heater was used to maintain temperature at a set point of 86 Degrees F.



A monitoring and control system has been designed, constructed, and installed as shown above. The system monitors tank water level, pressure (flow) in the injection manifold, air pressure for the air stones, and flow in the heating system. In addition, it monitors sound level in the immediate area, production water temperature, greenhouse temperature, and power. It can call out to four phone numbers, which currently are my office, my home and a pager that I carry with me at all times. There is also a temperature controller for the propane heating system that will control the production tank temperature. The large enclosure contains a Campbell Scientific data acquisition system that could be used to monitoring water quality parameters and system environmental parameters at various locations in the production system, greenhouse, and other locations.



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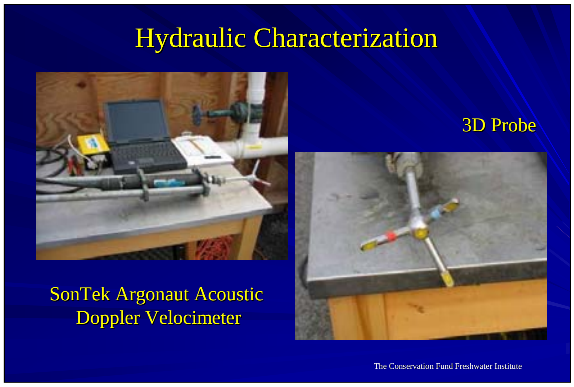
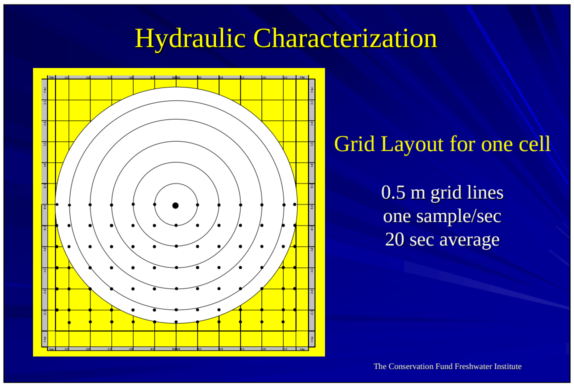
A prototype mixed-cell raceway was constructed at the Conservation Fund Freshwater Institute of structural lumber with an HDPE liner that measured 16.3 m x 5.44 m x 1.22 m. The basic design concept was to operate the raceway as a series of square/octagonal tanks, each having a center drain for continuous removal of solids and sludge. A series of vertical discharge pipes were placed along the raceway sidewalls that directed recycle water through orifice discharges tangentially to the walls to establish the desired rotary circulation. This was then combined with the concept of the 'Cornell double drain system', where 10% to 20% of the total flow into a tank was removed from a center bottom drains and 80 to 90% of the flow was removed from the side drains. Settable wastes and sludge were then removed from the center drains and collected in a settling sump. The systems was stocked with marine shrimp, *Penaeus vannamei* and managed as a zero-exchange low salinity production system for several months. Research was conducted into new methods of maintaining or controlling the dynamics of the water quality of the system through the addition of carbon to stimulate heterotrophic bacterial production. In addition, suspended solids concentration in the production tank was maintained at acceptable levels by controlling the amount and frequency of discharge from the settling tank Basic water quality parameters were routinely measured, including temperature, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, alkalinity, total suspended solids (TSS), and volatile suspended solids (TVS).

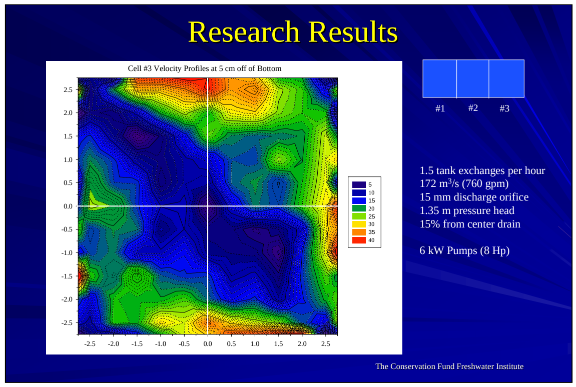


A SonTek Argonaut Acoustic Doppler Velocimeter from Yellow Springs Instruments was utilized in this study to measure speed and direction within the hydraulically separated cells. The SonTek velocity meter is a single-point, 3D Doppler current meter designed for shallow water flow monitoring. Water velocity is measured via the Doppler shift in frequency of sound from a moving object, in this case small particulate mater in water current. A transmitter generates a short pulse of sound from an acoustic transmitter that travels along the beam axis. As it passes through the sampling volume, sound is reflected in all directions and received by three acoustic receivers, which convert the reflected signals into Cartesian (XYZ) velocities (both speed and direction). The sampling volume is approximately a cylinder 0.6cm in diameter and 0.9 cm long. The system samples 10 times a second with short ‘pings’ of sound and the user can specify averaging intervals to produce a mean velocity profile.

The SonTek probe assembly was mounted on an aluminum beam supported above the width of the raceway, which allowed the probe to be easily moved across the tank width. The probe was lowered into the tank to the specified depths of 23cm, 60cm, and 100cm, along a 0.5m grid system.

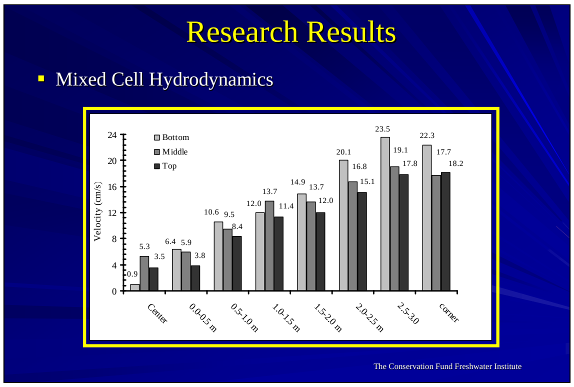


Measurements were taken at all three depths for the measurement of the system at full flow simulating a traditional raceway structure. Measurements were taken only at the 60cm and 100cm depths for the floor mixing zone representation. Measurements were taken for a one minute averaging interval at each of grid points and the values averaged for a numerical value used to plot the results. The data collected form the SonTek system was downloaded into Microsoft Excel for processing and contour graphing of the velocities was accomplished with Sigma Plot.

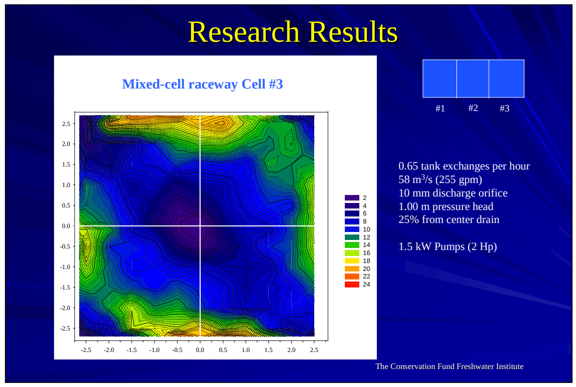


For this design analysis, a water exchange rate of 1.5 exchanges per hour was chosen for all trials, which would correspond to a moderate fish biomass density, e.g. 30 to 50 kg/m3. As constructed, the mixed-cell raceway had a volume of 108 m3 (28,500 gallons), using a water depth of 1.22 m (4 ft). At 1.5 water exchanges per hour, the required total flow rate was 172 m3/s (760 gpm). This included a withdrawal rate from the center drains of 25 m3/s (110 gpm), or 15% of the total flow, i.e., a "Cornell" dual drain system.

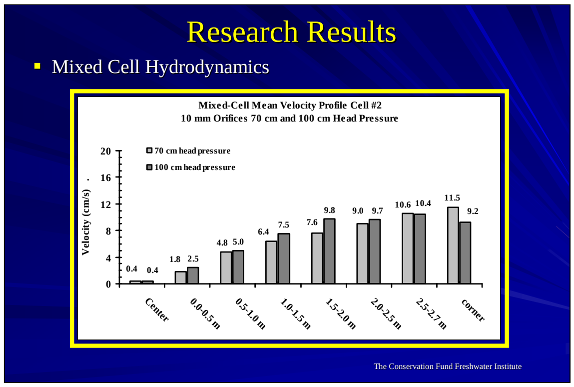
The above figure shows the contour plot for cell #3 (end cell) at velocity intervals of 5 cm/sec for 15 mm discharge orifices and a pressure head of 1.35 m (53 in). Relatively high scouring velocities are seen at the outside perimeter of the cell and significantly lower velocities near the center of the cell. As in Trial 1, the plumes from each of the vertical manifolds are obvious in each corner as is the extremely low velocities near the center of the cell.



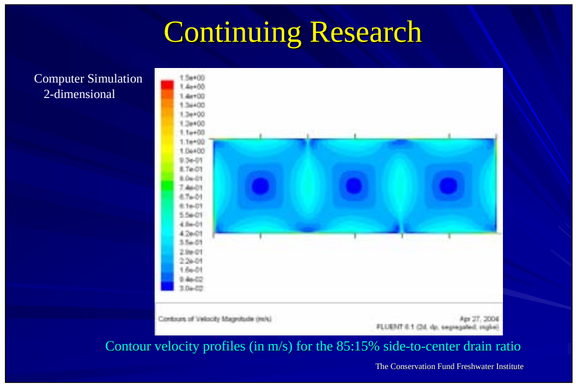
The above was created by averaging the velocities in an annular ring 0.5 m wide starting at the center. This graph shows the almost linear velocity profile as a function of distance from the center drain. Note the high rotational velocity at the outer sections of the raceway and in the corners, providing for good solids removal.



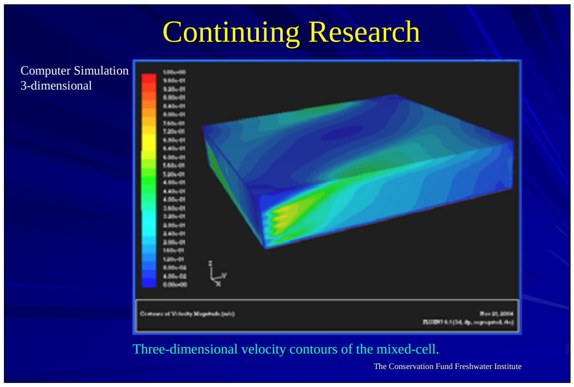
Mixed-cell raceway Cell #3   10 mm orifice diameter, 100 cm Pressure head, approximately 255 gpm, 64 gpm center drains, 25%.   0.65 tank exchanges per hour or about 1.5 hour for one tank exchange. Two pumps at 1 hp each were used to provide the flow rate of 255 gpm.



The above was created by averaging the velocities in an annular ring 0.5 m wide starting at the center. This graph shows the almost linear velocity profile as a function of distance from the center drain for two different pressure heads, 70 and 100 cm. These correspond to about 0.5 and 0.65 tank exchanges per hour. Very low, but excellent for marine shrimp production to provide adequate dissolved oxygen to the system using Speece cones and liquid oxygen injection. Only two 1 hp pump were required to provide the necessary 200 gpm to 250 gpm low rate.



A numerical simulation of the hydraulics of a Mixed-Cell Raceway (MCR) was performed using Computational Fluid Dynamics (CFD), a computational technology that allows modeling of fluid flows for any given geometry by solving the fundamental governing equations of fluid dynamics. A two-dimensional CFD simulation was conducted using a k-ϵ turbulence model in a segregated solution scheme using a 17,000-cell triangular-pave grid of the MCR. Simulations were conducted for three different tank-drainage conditions. Results of the vector and contour plots revealed good agreement between the CFD simulations and the field data in describing the fluid flow characteristics of the raceway, but it was not accurate in predicting the magnitude of the velocities.

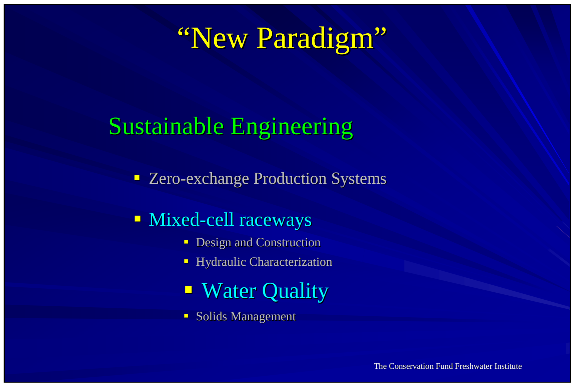


A structured three-dimensional grid model of one mixed-cell of the MCR composed of 250000 hexahedral elements was constructed and the simulations were conducted using the Realizable k-ε turbulence model. From the results of the CFD simulations, average cell rotational velocities, radial velocity profiles, and velocity contour and vector plots were generated for different water depths.

As observed in experimental trials conducted by the authors, predicted velocity contours and vectors plots revealed the development of a strong rotational flow in the mixed-cell and lower velocity zones at the center and corners of the cell. Also, a linear trend of rotational velocities from the cell center to its circumferential perimeter was described.

A good agreement between the experimental and predicted vector and contour plots was observed. Average rotational velocities at the bottom (95 cm depth), middle (50 cm depth), and surface (20 cm depth) of the mixed-cell (1-m water depth) were 17.2, 14.9, and 13.7 cm/s, respectively. According to these results, an overall error of 4% (96% agreement) was calculated between the experimental and predicted data.

Simulations of aquaculture-like particles trajectories revealed that roughly 100% of particles larger than 500 µm were settleable and can be removed within the mixed-cell in less than 15 min. Nearly 100% of the 100-µm particles released can be removed within the first 30 min, but only half of them was settleable, as they were removed by the bottom-center drain of the mixed-cell. Particles below 100 µm do not settle well; only 50% of the released particles was removed, mainly through the upper-side drains of the mixed-cell.



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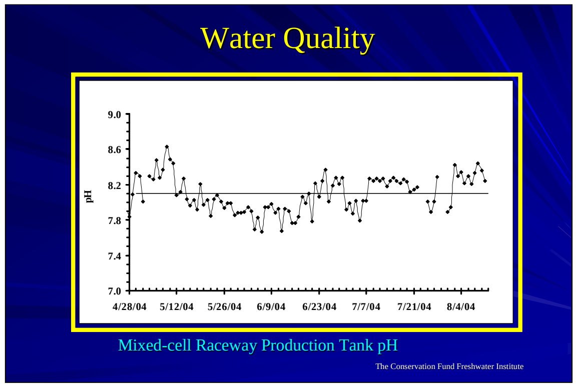
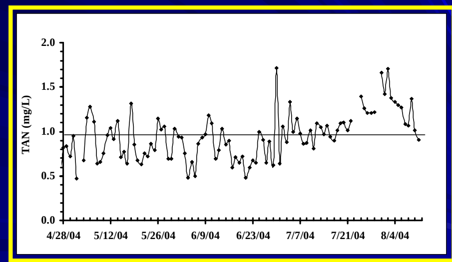
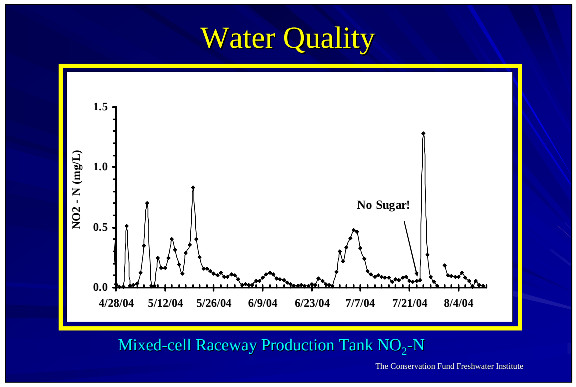

Water Quality
9.0
8.6
8.2
7.8
7.4
7.0
pH
4/28/04
5/12/04
5/26/04
6/9/04
6/23/04
7/7/04
7/21/04
8/4/04
Mixed-cell Raceway Production Tank pH
The Conservation Fund Freshwater Institute

Water Quality

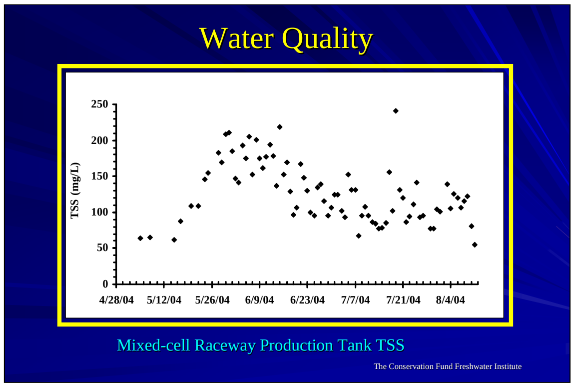


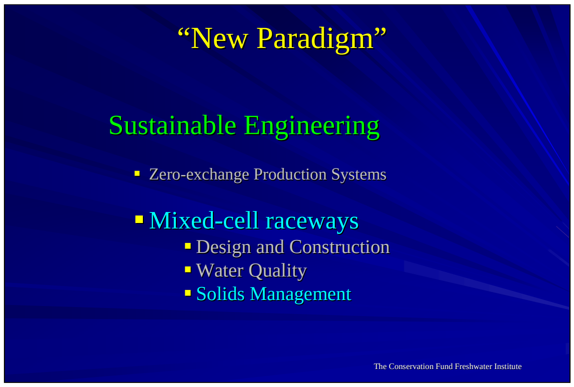
Mixed-cell Raceway Production Tank TAN

The Conservation Fund Freshwater Institute



Water Quality
NO2 - N (mg/L)
1.5
1.0
0.5
0.0
No Sugar!
4/28/04
5/12/04
5/26/04
6/9/04
6/23/04
7/7/04
7/21/04
8/4/04
Mixed-cell Raceway Production Tank NO_2-N
The Conservation Fund Freshwater Institute


Water Quality
TSS (mg/L)
250
200
150
100
50
0
4/28/04
5/12/04
5/26/04
6/9/04
6/23/04
7/7/04
7/21/04
8/4/04
Mixed-cell Raceway Production Tank TSS
The Conservation Fund Freshwater Institute



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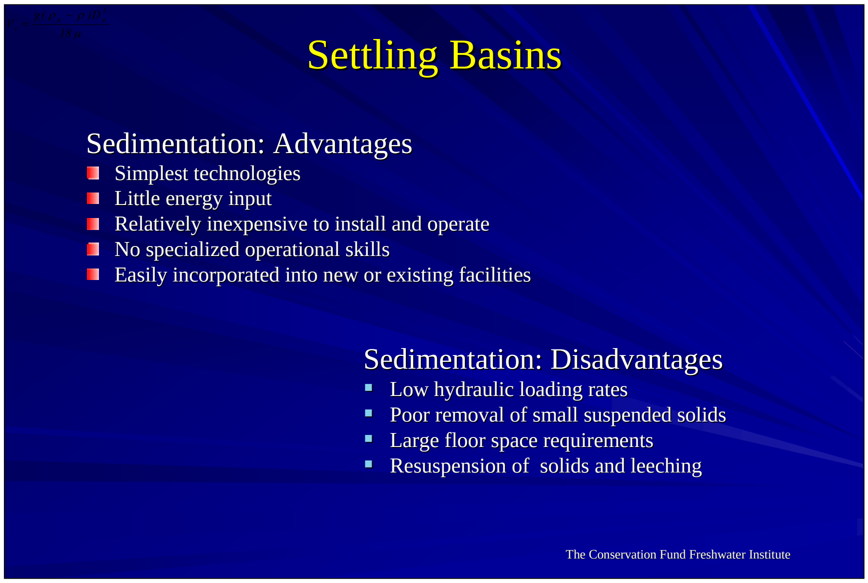
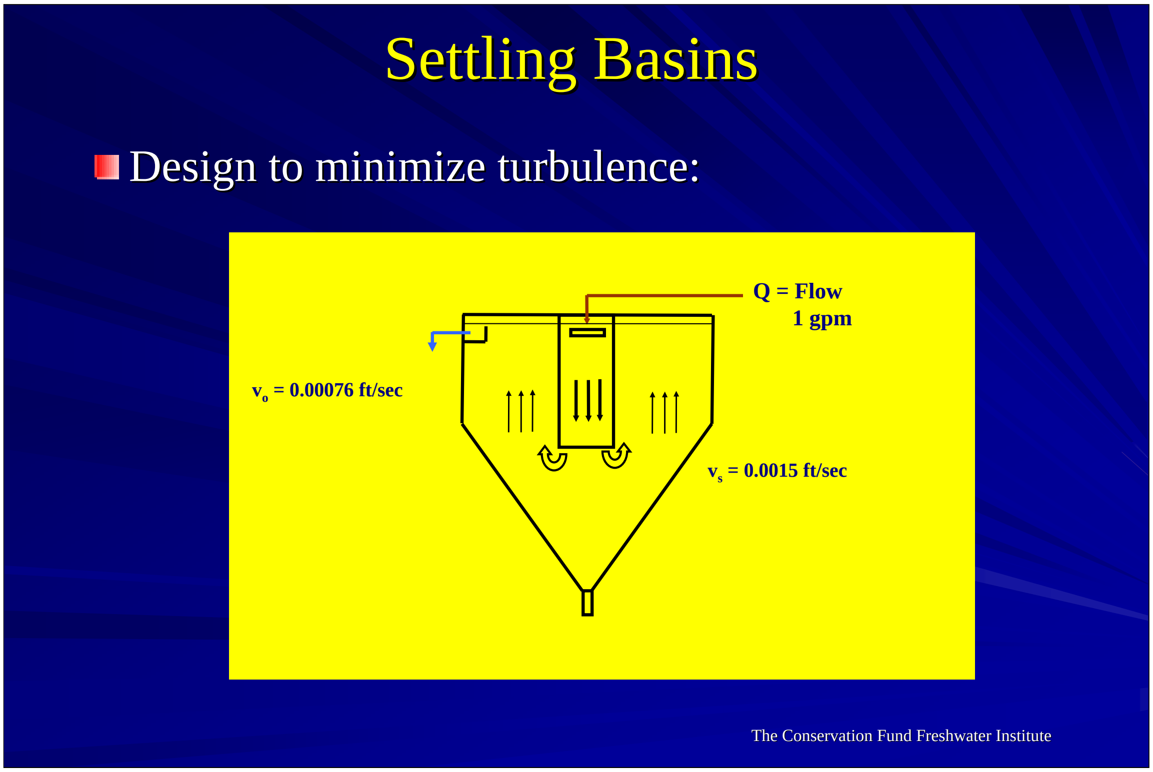


Settling basins are very effective if properly configured and operated. Sedimentation, i.e., gravity separation, is one of the simplest of technologies available to control particulate solids in process water and wastewater. Sedimentation basins require little energy input, are relatively inexpensive to install and operate, require no specialized operational skills, and can be easily incorporated into both new and existing facilities.

The disadvantages of sedimentation are low hydraulic loading rates and poor removal efficiency of small suspended solids (<100 µm). Also, they require additional floor space for their incorporation in comparison to microscreen filters. Innovative uses of vertical space over the settling bed or placing the settling bed in less expensive space can reduce this cost considerably.

Another potentially serious disadvantage is that settled manure remains in the system until the settling basin is cleaned. This condition is one of the major concerns in their use. Dissolution of nutrients and the resuspension of solids that have settled and collected on the bottom of settling basins can markedly reduce the expected performance of these clarifiers (Cripps and Kelly, 1996). Henderson and Bromage (1988) estimated that settling ponds could capture an estimated 97% of their solids loading if resuspension of settled solids was not a factor. They suggest that settling basins are not effective in removing TSS when inlet concentrations are <10 mg/L or attaining effluent concentrations of <6 mg/L. Eliminating resuspension of TSS is difficult at best in most settling basins. Thus, settling basins will generally require further TSS treatment to meet the stringent removal criteria necessary to achieve mandated levels of TSS.



All continuous flow settling basins are conceptually divided into four zones according to function, see above. The inlet zone serves to uniformly distribute the suspension over the entire cross-section of the basin. Sedimentation occurs in the settling zone and, upon removal from the water column, the solids accumulate in the sludge zone. The clarified liquid is generally collected over the entire cross-section of the basin at the outlet zone and is discharged. Under ideal conditions (no mixing or turbulence), required retention time is the time required for a particle that starts at the top of the inlet zone and settles to the floor of the basin at or before the junction of the outlet zone. The key parameter for the design of settling basins is the volumetric flow of water per unit surface area of the basin or overflow rate (V_o).

Any particle with a settling velocity (V_s) greater than the overflow rate (V_o) will settle out of suspension. Other particles, for which $V_s < V_o$, will be removed in the ratio V_s/V_o, depending upon their vertical position in the tank at the inlet.

Settling Basins

6 ft x 6 ft x 6 ft fiberglass tank

The Conservation Fund Freshwater Institute

Conclusions

- Mixed-cell raceways have significant potential as growout and production systems
- velocity profiles suggest that systems can be designed with both low and high exchange rates
- Solids management is straight forward and easy
- Construction costs are moderate
- Space utilization is maximized

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Opinions, conclusions, and recommendations are of the authors
and do not necessarily reflect the view of the USDA.

All experimental protocols involving live animals were in compliance
with Animal Welfare Act (9CFR) and have been
approved by the Freshwater Institute Animal Care and Use Committee.

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Questions

The Conservation Fund Freshwater Institute