Inherently Safer Aquacultural Work

Hierarchical Hazard Controls

By Melvin L. Myers, Robert M. Durborow and Henry P. Cole

IN BRIEF
- The hierarchy of controls is a tool for use in evaluating the effectiveness of inherently safer technologies.
- Fish farmers are innovative in creating inherently safer interventions for occupational safety.
- Many farmer-generated innovations have been found to eliminate occupational hazards and, thus, eliminate risks.

Melvin L. Myers, M.P.A., is associate professor of preventive medicine and environmental health at the Southeast Center for Agricultural Health and Injury Prevention, University of Kentucky College of Public Health, and adjunct associate professor for occupational and environmental health policy, Emory University, Rollins School of Public Health. He holds a B.S. in Agricultural Engineering from University of Idaho and an M.P.A. from Indiana University.

Robert M. Durborow, Ph.D., is state extension specialist for aquaculture, aquaculture program, at Kentucky State University. He holds an A.B. in Biology from Lafayette College, an M.S. in Fisheries Biology from Louisiana State University, and a Ph.D. in Fisheries and Allied Aquacultures from Auburn University.

Henry P. Cole, Ed.M., Ed.D., is professor of preventive medicine and environmental health at the Southeast Center for Agricultural Health and Injury Prevention, University of Kentucky College of Public Health, and emeritus professor of educational psychology at the University of Kentucky College of Education. He holds a B.S. in Chemistry from Nasson College, and an Ed.M. in Teaching of Chemistry and an Ed.D. in Educational Psychology and Science Education from the State University of New York at Buffalo.

In January 2011, a trout farm manager in Kentucky lost his life when he became entangled in a power-take-off connected to a posthole digger ("Green County man," 2011). He was constructing a fence on the farm. Later, in May 2011, an experienced diver drowned while tending fish cages offshore under about 120 ft of water for a large aquaculture farm in Hawaii (Shikina, 2011). OSHA is investigating that fatality.

These fatalities are but two examples of the many varied dangers associated with fish farming. The first was a fish farm manager working onshore, while the second victim was an employee of a mariculture operation working offshore. Even hobby farmers are taking up aquaculture (Morgan, 2011). The myriad of dangers within this emerging sector demand countermeasures to reduce or eliminate occupational hazards, and farmers have innovated to prevent or mitigate these risks.

Fishing and gathering deplete the resources of the wild aquatic environments because of a growing world population and ever-more-efficient fish capturing technology. This depletion of wild fish has led to farming the waters to maximize the output of aquatic environments—a modern day Neolithic Revolution similar to the shift from hunting and gathering to terrestrial farming.

Worldwide, nearly 11.3 million people worked in aquaculture in 2004—up almost three-fold from 3,832,000 workers in 1990 (Watterson, Little, Young, et al., 2008). Aquaculture is a potentially fast-growing sector of U.S. agriculture but it presents unaddressed safety and health issues to workers. This growth is at the heart of this investigation; intervening early in an emerging industry ensures that best safety practices are established as part of the business from the start by displacing potentially unsafe habits which otherwise may become engrained within the industry's culture (Myers, 2005).

Many fish farming tasks are dangerous. Working around water poses a particular danger, and working at night (and alone) compounds the danger. According to U.S. Bureau of Labor Statistics (BLS), the nonfatal occupational injury rate per year for aquaculture was 7.2 per 100 full-time employees in 2006, dropping to 4.2 injuries per 100 full-time employees in 2009 (Figure 1, p. 46). But this reported rate peaked at a staggering 16.5 recordable injuries (for establishments with 11 to 49 full-time workers) and 21.0 injuries (for establishments with 50 to 249 employees) per 100 full-time workers in 2008. In comparison to other sectors, rates were 8.1, 5.8 and 4.4 nonfatal injuries per 100 full-time employees in 2006 for livestock production, crop production and all occupational sectors, respectively, which,

©ISTOCKPHOTO.COM/DEFUN

by 2009, declined to 6.9, 4.9 and 3.6 injuries per 100 full-time employees, respectively. Aquaculture-related injury rates typically fall between livestock and crop injury rates, but the extreme rates for 2008 remain unexplained. Something unusual or a data abberration happened. Nonetheless, the high occupational injury rates in aquaculture exceed the overall occupational injury rates, which demands improved protection for fish farmers.

The 2005 Census of Aquaculture provides information on the aquaculture sector at the state level (USDA, 2006). Catfish is the major fish species grown in the U.S., with most of the production occurring in Mississippi and Alabama. Trout is another major species, with Idaho and North Carolina raising the most fish. Other farm-raised organisms in the U.S. include mollusks, tilapia, bass, sturgeon, walleye, ornamental fish and aquatic plants, including hydroponic crops. Aquaculture also engages in raising fish primarily for sport and game, and for the live food fish market. Aquaculture has even extended into raising phytoplankton (microalgae) for fuel. Cyanobacteria (also called blue-green algae) are among a larger group of phytoplankton produced for their oil secretions for use in biofuels (Totty, 2011). The generalized fish raising flowchart shown in Figure 2 (p. 46) will vary and be more complex from one species to another.

The two principle technologies used to raise fish in the Southeast are ponds and raceways. Pond technology is used for catfish culture, a warm water fish. Levee ponds with three to four levees built to hold water are typical, although ponds can be built with dams along stream beds as well. Trout, a cold water fish, are typically reared in concrete raceways. Raceways are flow-through systems that use gravity to move water from a stream or spring at an intake, called a head box, through a series of rectangular concrete basins, where one basin cascades water into the next lower basin. The water is oxygenated by turbulence and splashing of the water as it falls into the next raceway and/or by passing the water through a metal box supersaturated with oxygen (i.e., a low-head oxygenator or LHO).

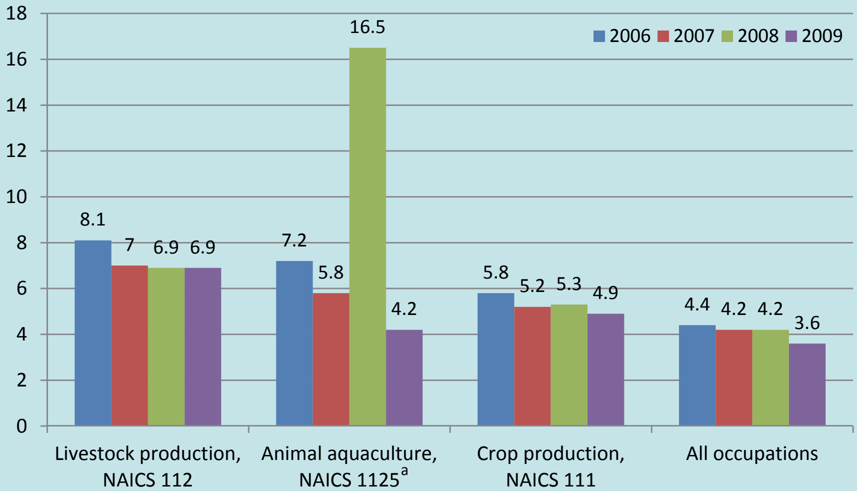
Other technologies include tanks, cages, net bags, aquariums and pens. Mussels are grown on rope-like tubes made of netting suspended into estuarine areas; clams are grown inside net bags; oysters are grown in floating raceways; and tilapia are raised in tanks. All hatcheries are smaller scale, and typically the animals are hatched and reared indoors in troughs before being moved for grow-out.

The occupational hazards of farming the waters include the same hazards as farming the land, but with some important additional hazards: drowning, wet conditions and offshore operations (Myers & Cole, 2009; Myers, 2010). The type of hazard varies by the type of rearing technology used. Many occupational hazards for these fish species are recognized but may vary according to circumstances as well as the rearing technologies:

- drownings;
- electrocutions;
- falls from elevation;
- slips and trips;
- falling objects;
- needlesticks;
- roadway collisions;
- strains/sprains;
- spine wounds;
- impalements;
- overturns;
- dust inhalations from feed;
- decomposition gases (Nikkanen & Burns, 2004);
- net entanglements;
- boat or vehicle battery explosions;

Figure 1

Injuries in the U.S., 2006-2009

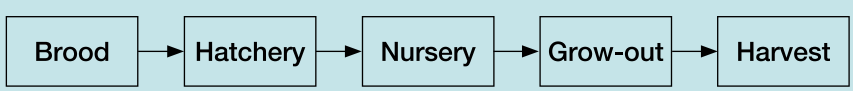


***Note.** Injuries/100 full-time employees in the U.S., 2006-2009. Self-employed farmers and employees on farms or hatcheries with less than 11 employees and government employees are not counted. Bureau of Labor Statistics.*

[a]Summary measure not provided; 16.5 aquacultural injuries/100 workers reported for establishments with 11 to 49 employees; 21.0 injuries/100 workers were reported for establishments with 40 to 249 employees.

Figure 2

Fish Production Process Flowchart



•O_2 fire (e.g., oxygen-impregnated clothing ignition).

Farmers have a tradition of developing innovations to solve problems on their farms. This study reports on farmer innovations designed to reduce or eliminate occupational risk of injury or illness on fish farms. Farmer-generated innovations are typically simple, low-cost solutions. By definition, these solutions have a "proof-of-concept" because they have been implemented.

Descriptions of these hazard-controlling innovations are based on more than 50 individual farmer interviews and farm visits. The surveys were conducted in 10 states (Alabama, Arkansas, Idaho, Kentucky, Mississippi, Missouri, North Carolina, Pennsylvania, South Carolina and West Virginia) and the Canadian province of British Columbia. As a step toward sharing these innovations with the fish farming community, the innovations have been classified—aligned with the hazards that they control—against a hierarchy of controls commonly used by industrial hygienists, safety professionals and design engineers.

Method

Prevention through design (PTD) focuses on ways to prevent and control occupational injuries and illnesses by designing out or minimizing hazards and risks early in the design process (Walter, 2011). PTD emerged from two conceptual streams. One stream is traced back to National Safety Council's (NSC) 1955 edition of the *Accident Prevention Manual*, which states, "Company policies should be such that safety can be designed and built into the job." (Scannell 1999). In the early 1990s, safety professionals recognized inadequate attention to design as a factor in safety, and as a result, NSC established the Institute for Safety Through Design in 1995. The aim was to reduce the risk of injury, illness and damage to the environment through all stages of design with a focus on engineers and educators. Following many conferences, workshops and publications, the institute was disbanded in 2005 consistent with its sunset provision. Nevertheless, the published material has had lasting impact internationally and is the hallmark of the program's success (Manuele, 2008).

The other conceptual stream emerged from the field of industrial hygiene engineering. Most industrial hygienists during the early years of the profession were engineers, thus they applied their knowledge to engineer systems of ventilation and later approaches to eliminate human exposures to hazards. In 1979, NIOSH convened a workshop entitled, "NIOSH/University Occupational Health Engineering Control Technology" that addressed the design of occupational health hazard control systems (Talty & Konzen, 1981).

In the early 1990s, NIOSH launched a project entitled "Safety and Health Awareness for Preventive Engineering" (SHAPE) to develop curricula for teaching in engineering schools solutions to occupational safety and health problems (Talty, 1985; Manuele, 2008). SHAPE led to the publication of several curricula in collaboration with engineering societies and schools in the early 1990s.

As part of the National Occupational Research Agenda launched in 1995, NIOSH set several research priorities including "Control Technology and Personal Protective Equipment" and another area with a hazard anticipation and design focus, "Emerging Technologies" (Myers, 2006). With a demand for safer designs to protect workers, NIOSH merged the two conceptual streams in 2007 into PTD aimed at anticipating and designing out potential safety and health hazards (Schulte, Rinehart, Okun, et al., 2008).

PTD includes the application of a hierarchy of controls schema to improve safety on fish farms (NIOSH, 2009). This schema follows hierarchies used both in professional safety and industrial hygiene, and moves from less safe strategies that rely on active controls (which require human action) to inherently safer strategies based on passive controls (which are built into the design and do not rely on human action).

A hierarchy of controls approach was used to evaluate the effectiveness of farmer-created controls to prevent occupational injuries and illnesses in

Table 1

Two Hierarchies of Controls

Priority	Safety[a]	Industrial hygiene[b]
1	Eliminate the hazard and/or risk	Elimination of the hazard
2	Apply safeguarding	Substitution of material
3	Use warning signs	Engineering control (e.g., isolation, ventilation)
4	Train and instruct	Administrative controls (e.g., worker rotation, education/training, work practices)
5	Prescribe personal protection	PPE (last line of defense)

Note. *[a]From "Principles of Human Safety," by R.L. Barnett and W.G. Switalski, 1988,* Safety Brief, *5(1), pp. 1-15; "Review of Safety Strategies According to the Safety Hierarchy," by D.D. Mann, 2007,* Proceedings of the 2007 ASABE Annual Meeting, USA, *Paper no. 075108. [b]From "Application of the Industrial Hygiene Hierarchy of Controls to Prioritize and Promote Safer Methods of Pest Control: A Case Study, by J.L. Weinberg, L.J. Bunin and R. Das, 2009,* Public Health Reports 124*(Suppl 1), pp. 53-62.*

Table 2

Hierarchy of Controls for Design

	ANSI Z10	Manuele, 1999	Wogalter, 2006	Haddon, 1974
1	Elimination	Elimination	Elimination	
2	Substitution			Passive controls
3	Engineering controls	Safety devices	Guarding[a]	
4	Warnings	Warning devices	Warning	
5	Administrative control	Procedures and training		Active controls
6	PPE			

Note. *[a]Wogalter includes PPE (e.g., gloves) as a guard against exposure.*

aquaculture. This approach had its genesis in 1913, when Lucian Chaney at U.S. Department of Labor completed a safety study concluding in 1917 with the term *engineering-revision*, claiming it could result in the "entire elimination of fatalities." This revision expressed a cultural shift from blaming the worker for carelessness to an emphasis on the cause of the injury and its prevention; the emerging safety engineering profession ardently accepted the engineering revision (Aldrich, 1997). Following World War II, several hierarchies of control emerged (Barnett & Brickman, 1986). Two sets of priorities coalesced around a precedence order (Table 1). Over this time, the use of the hierarchy of controls has received widespread acceptance (Grant & Hay, 2008).

A simple two-step hierarchy was used in highway safety with the highest precedence based on 1) passive control that requires no human intervention at the work interface, whereas the less safe approach was 2) the active control that relies on human behavior at the work interface (Haddon, 1974; Williams, 1982). The passive control emphasized roadway and vehicle design features, while active controls focused on the driver. An example of a passive control is the presence of a roll-over protective structure (ROPS) on a tractor (Myers, Westneat, Myers, et al., 2009), whereas this technology becomes an active control as a foldable ROPS that can be folded down but then requires human action to fold it upright again. Seatbelt use (in conjunction with a ROPS) also is an active control.

A three-step hazard control hierarchy has evolved for safety engineering that follows the precedence of 1) eliminate the hazard through design; 2) guard against the hazard; and, last, 3) warn against the hazard. Warnings are not always reliable in preventing contact with hazards (Wogalter, 2006).

In a safety through design concept, a four-level order of precedence is used that applies to all design and redesign processes: 1) design for minimum risk by eliminating the hazard; 2) incorporate safety devices; 3) provide warning devices; and 4) develop and institute operating procedures and training. The first two levels are passive controls and are more effective, whereas the latter two levels are active controls that rely on human intervention. In many applications, all four principles apply, but a lower level of priority is not chosen until practical applications of the preceding level or levels have been exhausted (Manuele, 1999).

In 2005, ANSI approved a consensus standard that merged safety and industrial hierarchy of controls in ANSI/AIHA Z10, Occupational Health and Safety Management Systems (Manuele, 2006). The standard specifies that an organization shall apply the methods of risk reduction in the order prescribed by the hierarchy of controls.

Design-related hierarchies of control were used as criteria for this evaluation (Wogalter, 2006). Based on an identified hazard, controls that are used on different farms are compared for their effectiveness in preventing injury and are classified using the order of precedence shown in Table 2.

In this study, individuals on fish farms developed their hazard assessments by recognizing the need for an intervention either because of 1) a close call; 2) an injury event; or 3) knowledge of an impending hazard. As an example of a close call, one farm operator fell into a vinyl-lined pond with slick banks. He was unable to climb out because he slid back into the water whenever he attempted to pull himself out of the water. Finally, he found a crease in the liner that provided enough of a handhold to crawl out of the pond. This close call prompted him to place safety buoys with ropes in his ponds.

As for an actual injury event, a feed delivery worker fell from an elevated feed bin as he climbed a ladder to the top to open a hatch to bin. He died. This led to a widespread practice of providing ground level handles for opening and closing the hatch lids on the bins, which is described later in this article. Also discussed is an example of acting to eliminate an impending hazard by burying electrical lines to prevent a crane boom from contacting overhead power lines.

While typically simple, the farmers' processes were similar to the engineering design process.

Table 3

Prevention Effectiveness Related to the Hierarchy of Controls

	Hazard	Warning	Guarding	Elimination
1	Falling lid on live tanks	Place wooden wedge under open lid	Use lightweight plastic lids	Install locking or pneumatic hinges
2	Impalement on fence rods	Be careful and don't fall	Use top insulators as impalement caps	Place rods horizontally on raceway walls
3	Fall from feed bin roof	Hang on tight to ladder	Install a ladder guard or use a harness	Install hatch handles at ground level
4	Needlestick while vaccinating fish	Keep fingers away from injection site	Use corrugated table top to hold fish in perpendicular position	Install automatic fish vaccination machine
5	Overhead power line contact	Flag areas under power lines	Raise power lines (e.g., from 30 ft to 45 ft height)	Bury power lines
6	Lifting fish with a dip net from raceway	Keep good posture while lifting		Use pulley and rail or crane to raise fish nets from raceway
7	Tractor overturn	Stay off of slopes	Install ROPS and seatbelt	
8	Net pen entanglement and drowning	Don't panic	Place regulator shrouds on O_2 scuba tanks	
9	Traffic collision hazard	Don't drive sleepy; use proximity warning devices	Maintain distance from other drivers	
10	Aerator PTO entanglement	Keep away from rotating PTO shafts	Place guards on long shafts to aerators	Use electric powered aerators
11	Paddle entanglement	Use panic wire to stop shaft when hair or clothing entangles	Substitute a nonsecured drive motor to disengage if disturbed	Replace bolted paddles with plastic slip paddles
12	Solar radiation	Don't expose bare skin	Wear sunblock	Work in covered areas
13	Wasp stings	Spray ladder rungs with insecticide	Wear protective clothing	Fill ladder rungs with foam insulation to eliminate wasp habitat
14	Confined space	Post "confined space" warnings	Place railings as barrier to confined space	Redesign pit for pump for no human entry
15	Net entanglement	Don't fall into bird netting strewn over raceway	Frame bird netting on top of raceway	Build net structure high atop work area
16	Harvest lifting	Avoid twisting body when handling netting	Get help when scooping fish with dip net	Use fish pump to harvest fish
17	Fall from truck bed	Be careful when climbing from cab steps to the bed	Place retractable railing alongside truck bed	Block access from cab steps and place ladder at the rear of truck

The assessment described was 1) the problem recognition and formulation stage of design, which was followed by 2) an analysis of the problem that was a search for solutions. Since the original solutions were active interventions, they 3) sought alternative solutions focusing on passive interventions. The next stage in the process was 4) making the decision, which considered simplicity over complexity and cost-effectiveness. The last stage was 5) specification of the solution with focus on implementation of the solution (Krick, 1969). For the farmer, specification involves procuring and constructing the solution or hiring a contractor to complete the job.

Results

With more than 50 fish-farm visits, investigators were able to identify hazards on these farms as well as different levels of hazard control. Farmers are generally aware of existing hazards but are less aware of controls that other farmers use to prevent injury from the hazards. Seventeen hazards and a range of controls for each hazard are described and summarized in Table 3, which classifies the interventions according to the order of precedence of the hierarchy of controls.

1) Falling Lid Hazard

Live tanks on hauling trucks have lids used for filling with water and dumping fish into the tanks. The raised lids traditionally would stand upright off-center to the rear. If the truck moves or wind strikes the lid, it could fall (Photo 1). Several farmers reported incidents in which a lid had fallen on their heads, and one reported that an employee's finger was amputated in such an event. One farmer used a wooden wedge placed under the raised lid to hold it in place, while another farmer used a locking hinge. Still another used pneumatic hinges as a control against falling lids, thus eliminating the hazard (Photo 2). Some manufacturers have replaced the metal lids with lightweight plastic lids.

2) Impalement Hazard

An impalement hazard exists when trout farmers install electric fences to deter otters by using short rebar rods as posts inserted vertically into the concrete wall of a raceway. A farmer placed insulator caps for the electric wire on top of the rod as an impalement guard and further eliminated the hazard by placing the rods horizontally on the walls.

3) Fall From Elevation Hazard

A fall hazard exists when climbing the ladder on elevated feed bins in order to open and close hatches for feed delivery by an auger (Photo 3). A delivery man fell to his death at a catfish farm in Mississippi more than 5 years ago. Warning signs provide insufficient protection.

One farmer guards against falls by placing a ladder guard on the bin surrounding the ladder so as to counter a fall. At an Idaho trout farm, workers can attach a harness to a cable running up the ladder; the attached self-locking device allows the worker to ascend but grabs the cable in the event of a potential rapid descent. Many farmers eliminate the hazard by designing and installing a ground-level pull handle to open and close the hatches (Photo 4). Nonetheless, if the ladder remains, it should have fall protection installed.

4) Needlestick Hazard

Trout and salmon are vaccinated against disease, which involves using a pneumatic injection gun. Needlestick injections have been known to result in anaphylactic shock. The gun has a finger guard that protects against an inadvertent injection, but


Photos 1 (left) and 2: The lids of live tanks on hauling trucks can fall if the truck moves. One farmer used pneumatic hinges to eliminate the hazard.


Photos 3 (left) and 4: A fall hazard exists when climbing the ladder on elevated feed bins in order to access hatches. Many farmers eliminate the hazard by installing a ground-level pull handle.


Photos 5 (left) and 6: Vaccinating fish on a flat tabletop can pose inadvertent needlesticks. Farmers have used a corrugated tabletop to better secure fish, thus reducing the likelihood of inadvertent needlesticks.

the guard is not designed to protect the worker when the injection is done perpendicular to the hand holding the fish.

To solve this problem, farmers have used a corrugated tabletop rather than the traditional flat table top for the procedure (Photos 5 & 6), thus reducing the likelihood of an inadvertent needlestick, since the fish could be better secured in a longitudinal direction. This innovation also improved the speed of the operation by better directing the vaccinated fish off the edge of the table and back into the water. Salmon vaccinators in Scotland and Norway have experienced needlestick injuries (Douglas, 1995) and, as a result, a machine has been invented in Norway to automate the vaccination process, thus eliminating the needlestick hazard (Sommerset, Krossøy, Biering, et al., 2005).

5) Overhead Power Line Hazard

Another hazard is overhead power line contact by fish harvesting cranes. Warning labels frequently appear on cranes regarding the electrocution hazard of overhead power lines. In an effort to move beyond this kind of active safety control, one farmer replaced 30-ft high poles with 45-ft high poles to provide an additional margin of error against inadvertent electrical contact, whereas other farmers bury power lines, thus eliminating the hazard of overhead contact.

6) Lifting Hazard

Workers in a catfish hatchery would crowd the fish at one end of a raceway, then use a dip net to capture and lift the fish into live tanks for transport. To eliminate the hazard of awkward lifting (often resulting in lower back strain), a farmer constructed a net-and-pulley system for capturing and lifting the fish. The filled net could slip along a rail track for dumping the load into a hauling tank, thus eliminating the lifting hazard.

7) Tractor Overturn Hazard

Tractors that lack ROPS are a well-known hazard that can result in crushing or drowning. When tractors with cabs are used, a second exit is necessary to prevent drowning in the event that the door is blocked by an overturn.

8) Drowning Hazard

In offshore salmon farming, the most serious hazard is drowning, especially among divers. Working around nets exacerbates the hazard because of the potential for entanglement. Net pens may involve an interior net to restrain the fish and an exterior net to protect against predators. A diver died when the regulators on his oxygen tanks were entangled in a net. A control for the hazard is to mount a shroud over the regulators.

9) Traffic Collision Hazard

Traffic collisions are a serious hazard since many deliveries of fish require long hauls with a live load. The loads are in water that can slosh back and forth, leading to instability. In addition, driver fatigue is a problem. This is a difficult problem to solve, but one farmer made the point that maintaining distance from other vehicles is an important intervention. More sophisticated interventions are possible, including electronic distance warning devices.

10) Aerator Entanglement Hazard

Power-take-off (PTO) entanglements are a recognized problem on farms, but in powering aerators, this problem is exacerbated by the use of PTOs with extended drivelines to reach the aerators in ponds. Guarding is typically absent from these drive lines, but a substitute power source is electric motors mounted on the aerator itself that can eliminate the PTO entanglement hazard.

11) Paddle Entanglement Hazard

Catfish hatcheries require simulation of the male fanning water flow over the eggs before they hatch, and mechanical paddles in troughs are the technology that is typically used to artificially provide this flow. Metal paddles are bolted to a shaft that continuously turns, but skin abrasion and hair/

PS EXTRA

For more before and after photos showing examples of farmer-devised hazard controls, visit www.asse.org/psextra.

clothing entanglement are hazards for workers exposed to the rotating paddles.

A control used to stop the rotation of the shaft in the event of an entanglement is a panic wire running overhead above the trough. Alternatively, a facility simply set the motor that powered the paddles (by way of drive belts) on top of an unsecured sawhorse; when unusual tension was placed on the trough paddles, the motor was disturbed, became disengaged from the drive belts and no longer powered the paddles. Another farmer eliminated the risk by replacing the metal with plastic paddles (created from 5-gallon containers) that were wrapped and bolted around the shaft loosely enough to allow them to slip when entanglements occur (Coblentz, 2005). The plastic paddles also prevent abrasions.

Farmer-developed technologies are typically simple and low cost, have generated a proof-of-concept, and have a high likelihood of early acceptance.

12) Solar Radiation Hazard

While most tasks around raceways require a lot of mobility, some do not. One of the stationary tasks is vaccinating fish. To protect the worker against solar radiation (as well as rain), a farmer constructed a simple canopy for shade.

13) Wasp Sting Hazard

Ladder rungs used when climbing up the side of feed bins are curled, hollow bars with open fluting across the backside of the step, which often harbor nesting wasps. Workers would be stung when climbing the ladders. The problem was eliminated by filling the hollow space with foam insulation.

14) Confined Space Hazard

On some farms and hatcheries, pumps are placed in pits to run water efficiently. These pits are confined spaces, especially when covered with a manhole cover or lid. To eliminate this hazard, one farm operation removed the pit cover, placed rails as barriers around the pit, raised pump controls up to ground level, and arranged ground piping disconnects and cables for raising the pump from the pit for repair or maintenance. This employer adapted its occupational safety and health procedures from its fish processing division to its farming operation. This employer also requests an annual inspection by the state OSHA consultation program to continuously improve worker safety.

15) Net Entanglement Hazard

Farmers use bird netting to protect the fish from bird predators in raceways. One farmer tossed netting across the raceway where it draped down into the water. This posed a hazard for potential drowning if a worker were to fall into the raceway and become entangled in the net. Other farmers built a wood frame for the net that would rest on the raceway walls to keep birds away, but nonetheless, some birds such as ducks were able to lift the frame and enter the raceway. The best solution was to build net structures over the raceways high enough to allow workers and equipment to maneuver, eliminating the entanglement hazards.

16) Fish Harvesting Hazard

Harvesting fish is a labor-intensive activity. Workers must crowd fish with a seining net in ponds or screens in raceways, then use dip nets to scoop up the fish, and lift the dip nets either manually or by a crane into a live haul tank for transport to the processing facility. Trout and shrimp farmers have found that this drudgery can be eliminated by using a fish pump. Pumps can be part of a fixed structure or can be portable and are used to pump fish from raceways into live haul tanks or to remove shrimp from pond bottoms. Pumps do not work yet for catfish because their spines jam in the pump.

17) Truck Bed Fall Hazard

The principle fall hazard associated with working around live tanks on truck beds is climbing onto the bed from the steps to the cab. In addition, falls occur from the truck bed ledge around the live tanks. Some farmers have redesigned truck beds with safety features. One such feature is a fold-down walkway alongside the truck bed; another is a retractable safety rail along the length of the truck that protects workers on the walkway from falls. This railing also blocks access from the cab steps, thus eliminating awkward access from the cab steps, but with another feature to be added: a ladder at the rear of the truck bed with hand rails. Two other features need to be added; a midrail and a toe board.

Conclusions

Inherently safer technologies for the protection of workers on fish farms can be evaluated using the hierarchical order of precedence. Individual farmers have innovated in producing inherently safer technologies using this technique. These technologies are typically simple and low cost, and have generated a proof-of-concept. Moreover, since farmers created these technologies, they have a high likelihood of early acceptance.

The mantra for not only the farmer but also the design engineer is to follow the hierarchy of controls, giving precedence to elimination of the hazard; failing that, guarding against the hazard; and failing that, warning against the hazard including warning devices (e.g., audible and/or visual alarms).

This study was limited to innovations used by farmers to eliminate or reduce exposures to hazards on fish farms. However, some major and complex problems require engineering research beyond the farm. Examples include 1) catfish harvesting from ponds; and 2) reducing slips and trips where algae-laden, icy or spalled concrete surfaces are typical hazards. This research can improve productivity along with improving safety. **PS**

References

Aldrich, M. (1997). *Safety first: Technology, labor and business in the building of American work safety, 1870-1939.* Baltimore, MD: The John Hopkins University Press.

Barnett, R.L. & Brickman, D.B. (1986). Safety hierarchy. *Journal of Safety Research*, *17*(2), 49-55. doi:10.1016/0022-4375(86)90093-9

Barnett, R.L. & Switalski, W.G. (1988). Principles of human safety. *Safety Brief*, *5*(1), 1-15. Retrieved from **www.triodyne.com/SAFETY~1/SB_V5N1.PDF**.

Coblentz, B. (2005). Plastic paddles improve catfish hatchery safety [Press release]. Mississippi State, MS: Mississippi State University, Office of Agricultural Communications. Retrieved from **http://msucares.com/news/print/fwnews/fw05/050317.html**.

Douglas, J.D.M. (1995). Salmon farming: Occupational health in a new rural industry. *Occupational Medicine*, *45*(2), 89-92. doi:10.1093/occmed/45.2.89

Grant, F.L. & Hay, R.K. (2008). Case study: Using saturation campaigns to effectively communicate with employees. *Proceedings of the 2008 SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, France*, SPE 111987. doi:10.2118/111987-MS

Green County man dies after farming accident. (2011, Jan. 27). *LaRue County Herald News*. Retrieved from **www.laruecountyherald.com/content/green-county-man-dies-after-farming-accident**.

Haddon, W. (1974). Strategies in preventive medicine: Passive vs. active approaches to reducing human wastage [Editorial]. *Journal of Trauma-Injury Infection & Critical Care*, *14*(4), 353-354. doi:10.1097/00005373-197404000-00022

Krick, E.V. (1969). *An introduction to engineering and engineering design*. New York, NY: John Wiley & Sons.

Mann, D.D. (2007). Review of safety strategies according to the safety hierarchy. *Proceedings of the 2007 ASABE Annual Meeting, USA*, Paper no. 075108.

Manuele, F.A. (1999). Concepts, principles and methods for safety through design. In W.C. Christensen & F.A. Manuele (Eds.), *Safety through design* (pp. 9-21). Itasca, IL: National Safety Council Press.

Manuele, F.A. (2005, May). Risk assessment and hierarchies of controls. *Professional Safety*, *50*(5), 33-39.

Manuele, F.A. (2006, Feb.). ANSI/AIHA Z10-2005: The new benchmark for safety management systems. *Professional Safety*, *51*(2) 25-33.

Manuele, F.A. (2008). Prevention through design (PTD): History and future. *Journal of Safety Research*, *39*, 127-130.

Morgan, J.J. (2011, November/December). Freshwater farming. *Hobby Farms*, *11*(6), 40-47, 49.

Myers, M.L. (2005, April). Addressing risks and benefits: Emerging technologies assessed for safety and health of farming people. *Resource: Engineering & Technology for a Sustainable World*, *12*(3), 13-14.

Myers, M.L. (2006, Oct.). Emerging technologies: Inherently safer designs. *Professional Safety*, *51*(10), 20-26.

Myers, M.L. (2010). Review of occupational hazards associated with aquaculture. *Journal of Agromedicine*, *15*(4), 412-426.

Myers, M.L & Cole, H.P. (2009). Simple solutions for reduced fish farm hazards. *Journal of Agromedicine*, *14*(2), 150-156.

Myers, M.L., Westneat, S.C., Myers, J.R., et al. (2009). Prevalence of ROPS-equipped tractors in U.S. aquaculture. *Journal of Agricultural Safety and Health*, *15*(2), 185-194.

Nikkanen, H.E. & Burns, M.M. (2004). Severe hydrogen sulfide exposure in a working adolescent. *Pediatrics*, *113*(4), 927-929.

NIOSH. (2009, April). Prevention through design: Plan for the national initiative. Version 16. Washington, DC: U.S. Centers for Disease Control and Prevention, author. Retrieved from **www.cdc.gov/niosh/review/public/160/pdfs/DraftNIOSHPtDplan.pdf**.

O'Neill, A.C., Ismael, T.S., McCann, J., et al. (2005, June). Fish vaccine injection injuries of the hand. *British Journal of Plastic Surgery*, *58*(4), 547-549. doi:10.1016/j.bjps.2004.10.025

Scannell, J. (1999). Foreword. In W.C. Christensen & F.A. Manuele (Eds.), *Safety through design* (pp. xi-x). Itasca, IL: National Safety Council Press.

Schulte, P.A., Rinehart, R., Okun, A., et al. (2008). National prevention through design (PTD) initiative. *Journal of Safety Research*, *39*, 115-121. doi:10.1016/j.jsr.2008.02.021

Shikina, R. (2011, May 24). Honolulu firefighter died in diving accident. *Honolulu Star-Advertiser*. Retrieved from **www.staradvertiser.com/news/breaking/122557309.html**.

Sommerset, I., Krossøy, B., Biering, E., et al. (2005). Vaccines for fish in aquaculture. *Expert Review of Vaccines*, *4*(1), 89-101. doi:10.1586/14760584.4.1.89

Talty, J.T. (1985). Curriculum: Integrating health and safety into engineering curricula. *Engineering Education*, *76*(3), 136, 138-39.

Talty, J.T. & Konzen, R.B. (1981). Occupational health engineering control technology—Report on a workshop. *AIHA Journal*, *42*(2), 157-160. doi:10.1080/15298668191419505

Totty, M. (2011, Oct. 17). A faster path to biofuels. *Wall Street Journal*, p. R3.

U.S. Department of Agriculture (USDA). (2006). 2005 census of aquaculture. Washington, DC: National Agricultural Statistics Service, author. Retrieved from **www.agcensus.usda.gov/Publications/2002/Aquaculture/index.asp**.

Walter, L. (2011, Sept. 19). New ANSI/ASSE standard focuses on prevention through design. *EHS Today*. Retrieved from **http://ehstoday.com/standards/consensus/Prevention-Through-Design-Standard**.

Watterson, A., Little, D., Young, J.A., et al. (2008). Towards integration of environmental and health impact assessments for wild capture fishing and farmed fish with particular reference to public health and occupational health dimensions. *International Journal of Environmental Research and Public Health*, *5*(4), 258-277. doi:10.3390/ijerph5040258

Weinberg, J.L., Bunin, L.J. & Das, R. (2009). Application of the industrial hygiene hierarchy of controls to prioritize and promote safer methods of pest control: A case study. *Public Health Reports*, *124*(Suppl 1), 53-62.

Williams, A.F. (1982). Passive and active measures for controlling disease and injury: The role of health psychologists. *Health Psychology*, *1*(4), 399-409.

Wogalter, M.S. (2006). Purposes and scope of warnings. In M.S. Wogalter (Ed.), *Handbook of Warnings* (pp. 3-10). Mahwah, NJ: Lawrence Erlbaum Associates.

Acknowledgements

The authors acknowledge the many farmers who participated in interviews as well as the extension agents who facilitated the farm visits. Additional field investigators included Tiffany Ogunsanya of Kentucky State University, Walter Stephens of Mississippi State University, and Ken Lacroix, a consultant in British Columbia. The project was supported by CDC/NIOSH Cooperative Agreement no. 2 U50 OH007547-07, and human subjects review was provided by the University of Kentucky Office of Research Integrity under IRB protocol no. 06-0564-P2G. The authors also acknowledge Teresa Donovan of the University of Kentucky College of Public Health for her help in editing this manuscript.