Jun 29th, 4:00 PM - 6:00 PM

Technical Developments in Fish Exclusion, Guidance, and Collection Materials

A. L. Peters
Pacific Netting Products, andy@pacificnettingproducts.com

Follow this and additional works at: https://digitalcommons.usu.edu/ishs

Part of the Hydraulic Engineering Commons, and the Polymer and Organic Materials Commons

Recommended Citation
Technical Developments in Fish Exclusion, Guidance, and Collection Materials

A. L. Peters
Pacific Netting Products
2553 United Road Northeast
Kingston, WA 98346
USA
E-mail: andy@pacificnettingproducts.com

ABSTRACT

Construction of mills, dams and other structures in rivers and streams and the withdrawal of water for irrigation or cooling industrial facilities vital to social and economic progress have impacted the survival of marine life. Barriers and guidance or collection nets can protect fish and aquatic species while allowing water to flow unimpeded for commercial and industrial use. However, nets can attract aquatic growth, fill with debris, degrade with environmental stress, and be expensive to operate and maintain. A closer look at the technical developments of materials and net designs in diverse settings can offer guidance that will be of use to engineers and community stakeholders in varied environments who are striving to meet similar challenges. With careful consideration of bathymetry, topography, pool fluctuation, water flow, debris, weather, and deployment, the principles and materials outlined can be adapted to environments around the world. Successful implementation will allow humans to continue to harness our most valuable resource with respect for the wider social and economic health of the planet.

Keywords: Pacific Netting, UHMWPE, fish exclusion, downstream fish passage, barrier net, guidance net, collection net, Dyneema®

1. INTRODUCTION

For almost as long as humans have been harnessing water to perform work, industrial and agricultural applications have been in conflict with those who depend on continued healthy populations of fish and aquatic life. Construction of mills, dams, and other structures in rivers and streams and the withdrawal of water for irrigation or cooling industrial facilities have impacted the survival rate of marine life that is vital to related social and economic progress. In 1872, the U.S. Supreme Court required persons who own or build dams to construct fish ways to enable fish migration and required compensation from upstream riparian land owners for loss of fishery and related property value (Holyoke Co. v. Lyman, 1872).

Ideally, a barrier, guidance, or collection net could allow water to flow unimpeded while protecting fish and aquatic species from harm. However, nets tend to attract aquatic growth, get filled with debris, be destroyed by ice, and require costly maintenance and operation time. The challenge is to design a fish exclusion system that not only maintains sufficient population but successfully repels debris and other stressors and can be installed and maintained economically and efficiently.

In this paper, the author will take a closer look at the technical developments of material used in fish exclusion, guidance, and collection netting systems and review three installation designs that successfully deploy these nets in diverse settings, offering guidance that will be of use to engineers and community stakeholders around the world who are striving to meet similar challenges.

2. ADVANCES IN NETTING MATERIALS

Until the early 1880s, nets were woven from natural plant fiber including manila, hemp, linen, cotton, coir, jute, straw, and sisal. The fiber was twisted or braided to a line and sewn into the form of a net. Joseph Swan, while...
searching for a better carbon filament for his light bulb, discovered a method for creating an artificial fiber that was ultimately used by the textile industry for clothing and domestic products.

Beginning in the 1940s, DuPont’s nylon was introduced and quickly became the preferred material for rope manufacture. Nylon is a polyamide, a macromolecule with repeating units linked by amide bonds. It offers several advantages over natural fiber rope. It is stronger for a given diameter, more elastic, more consistent in quality, and immune to dry rot. Although nylon tends to lose some of its strength when it is wet, it remains shock absorbent. However, it is weakened by exposure to acid and extreme sunlight. DuPont next introduced Dacron®, a polyethylene terephthalate fiber, in 1953. Dacron® ropes stretch much less, remain strong when wet, are more abrasion-resistant than nylon, and are also immune to most acids and alkalis. However, they do not absorb energy very well, nor can this rope be manipulated as easily as rope made from nylon (Wolfe 2008).

Another fiber, discovered in 1951, was found ideal for many marine applications. “In 1951, while attempting to convert propylene into gasoline, J. Paul Hogan and Robert L. Banks of Phillips Petroleum Company discovered polypropylene, a high-melting crystalline aliphatic hydrocarbon” (American Chemical Society, 1999, 2). When used for ropes and lines, polypropylene stretches a considerable distance under load. Though its breaking strength is considerably less than nylon or polyester, this relatively cheap fiber is lightweight and buoyant, making it suitable for numerous uses.

Each of these materials have played important roles in the development of modern nets for fishing, safety, security, and now fish protection. Engineers and designers try to match the properties of a particular fiber to a specific application. For instance, it may be that nylon is the best fiber for a safety net if elasticity and elongation are a critical part of a design. In an environment with acids or alkalis, a polyester fiber might prove a better choice.

The most modern development in construction of large barrier nets is due in large part to the development of a gel-spun, multi-filament fiber produced from ultra-high molecular weight polyethylene (UHMWPE). First commercialized as Dyneema® in the late 1970s by the Dutch science-based company DSM, UHMWPE provides the characteristics of high strength, low weight, low elongation at break, and resistance to most chemicals. Today, other manufacturers of UHMWPE include Honeywell (Spectra®), Quadrant EPP, Inc. (TIVAAR®), and Röchling Engineering Plastics (Polystone-M®).

DSM testing indicates that UHMWPE rope is seven times stronger than steel wire rope, based on comparative weight. Two of the reasons for its strength are its molecular weight and orientation. “Normal” polyethylene has a low molecular orientation and low molecular weight. By untangling these molecules through a gel spinning process and aligning them all in one direction through a drawing process, UHMWPE fiber has very long molecular chains with very high molecular weight (between 2 and 6 million) and very high molecular orientation. UHMWPE is lighter than water and extremely durable. It is four times stronger than polyester fibers, and yet its mechanical elongation at load is substantially less.
In addition, the fiber offers excellent abrasion, cut, and tear resistance even if the loading is partly in compression, as in repeated bending of rope applications. The fibers are flexible and have a long flexural fatigue life. Because of the low friction coefficient and good abrasion resistance, internal abrasion of ropes is usually negligible. The fiber has high resistance to chemicals and excellent UV resistance, described as the ratio of the retention of strength to exposure time. When comparing Dyneema® to a polyester fiber, its UV resistance is nearly three times higher. Of tremendous value for fish passage applications, UHMWPE has excellent biological resistance. The fiber neither stimulates undesired growth nor is it sensitive to attack by microorganisms. It is regarded as biologically inert and is IARC classified 3 (not classifiable carcinogenic to humans) based upon its length-weighted geometric mean diameter.

According to Dave Erickson, a partner at Pacific Netting Products, “It is the combination of these fiber properties: strength, longevity, surface area, biological resistance, fatigue, and low friction coefficient, which have allowed engineers and designers to build modern fish guidance, barrier, and collection structures that are larger, stronger, last longer, and cost less to operate than anything built before.”

3. ADVANCES IN DEBRIS CONTROL MATERIALS

Log booms have been used for years to protect facilities from debris, ice, and water borne traffic. Trees, often plentiful, were inexpensive and easily replaced. Constructed in a daisy chain method, the strength of log boom
systems was limited by the chain, wire rope and fittings and attachment methods used. Over time, log booms become waterlogged, and during their life, they will attract a variety of biological growth.

More recently, barriers for fish guidance and collection systems, as well as facility protection, visibility and demarcation, have been built using colorful, foam-filled plastic floats strung on a wire like a necklace. The floats are fabricated with rotational molding, or rotomolding, a casting process that is ideal for making hollow articles. When designed to be used as debris booms, the finished product can be filled with foam for floatation. Inexpensive, lightweight and easy to ship, these type of floats are similar to those that protect swimmers from boat traffic.

However, the end product can be adversely affected by such variables as ambient temperature, humidity, types of mold, material specification, and powder quality (Engineers India Research In, 2009). In addition, for heavy debris applications, the excessive amount of moving hardware and lack of continuity in the boom surface (gaps between floats), when combined with a lack of UV protection and minimal impact resistance, has resulted in limited life span and costly deployments.

Multi-Function Booms™, built by Pacific Netting Products (PNP), are built with custom extruded, high-density polyethylene. They are corrosion-free, rot-resistant, able to withstand temperatures to 140 degrees below zero, and feature excellent UV resistance, flexibility in design, and tremendous strength. A September 2015 pull test on a 24” diameter Multi-Function Boom, designed for medium debris applications, showed a safe working load of 34,000 Kg with an ultimate break of nearly 135,900 Kg on the HDPE floats.

The booms come standard with a keel for attachment of a debris curtain, temperature curtains, Dyneema Fish Barrier curtain, or a combination of these options. To enhance efficiency of operations and maintenance, especially in installations where fine mesh or wedge wire screens are installed, the booms are fitted with a debris splash guard. Access within a closed area is provided by means of a manually operated boat gate. To allow ease of shipping, configuration, and installation, booms are provided in 15 M sections with flanged ends for connection to other sections. They are anchored to the shore by embedment anchors, with the ability to attach mid-barrier bottom anchors as necessary.

Figure 4. Typical rotomolded float boom with excessive moving hardware, as described above. Illustration: Pacific Netting Products

Figure 5: Degraded rotational molded boom. Photo: Andrew Peters, Pacific Netting Products
In a December 2015 installation at Portland General Electric’s North Clackamas facility, a Multi-Function boom was installed to replace an existing log boom. The PNP boom was chosen to better protect the downstream fish passage collection system, which includes a floating surface collector and guide nets built of Dyneema®. To reduce operations and maintenance cost, the boom was aligned to guide debris to one side of the river for efficient removal of collected debris. With fewer moving parts, anchored securely to shore by embedment anchors, bolted together to form a long continuous surface, and built of a thick walled high density polyethylene, the expected operating life of the boom is 50 years with periodic maintenance.
4. IMPROVED DESIGN AND CONSTRUCTION TECHNIQUES

Advances in materials for netting, flotation, and debris control have allowed designers the flexibility to install exclusion, guidance, and collection systems that demonstrate dramatic improvements in operations and maintenance. The lightness of the UHMWPE netting aids not only in shipping and installation logistics, but in deployment as well. Lighter weight means installations can be accomplished with fewer people and smaller, less costly equipment. A UHMWPE barrier net, with its specific gravity of less than 1.0 (DSM), can easily be anchored to the bottom of a waterbody with the net floating to the head rope. As a result, pool fluctuations can be accommodated so that the barrier net maintains a smooth shape and holds its position when the elevation of a reservoir changes. The result is a full exclusion net that provides complete fish passage protection.

The smaller surface area of UHMWPE fiber means a smaller size twine can be used to get a similar strength when compared to other fibers. The reduction provides less area for attachment of aquatic growth, and therefore, less material to clean. In addition, once attached, the UHMWPE smooth surface and natural abrasion resistant properties makes marine growth easier to remove.

Aquatic growth factors vary from site to site, influenced by water depth, bottom type, water clarity, and variables in the watershed (rainfall, snowmelt, or groundwater, topsoil, fertilizer). Generally, in cold, deep water, there will be little growth compared to warmer, shallow water. Net cleaning techniques and equipment will therefore depend on site considerations. In some applications where the net panel is flat and strung tight, machines can be used to maintain the netting. In other areas, sonic devices or manual brushing are more practical.

![Image](image_url)

Figure 8: 731 M wide, 91 M deep guide net built of Dyneema®

5. CASE STUDIES

5.1. Puget Sound Energy, Upper and Lower Baker Lakes, Concrete Washington

The construction of two dams (Upper Baker: 95 M high, Lower Baker: 87 M high) for the Baker River Hydroelectric Project, in the state of Washington created challenges for fish passage in that watershed. Baker river sockeye (O. nerka) are native to Baker Lake and Baker River, the tributary to the Skagit River. Artificial enhancement began in 1896 when the state of Washington built a hatchery on Baker Lake. The natural run at that time was estimated to be approximately 20,000 fish. Lower Baker Dam, which was constructed in 1925, creating Lake Shannon, blocked access to the lake. A ladder and "elevating contrivance" was constructed to provide passage. Adults were released above the dam to spawn naturally. Construction of the Upper Baker Dam was completed in 1959 and inundated the valley that included the natural Baker Lake (Washington Department of Fish and Wildlife).
In the late 1950s, Puget Sound Energy (PSE) built the world's first floating system to simulate swift river current behind a large, deep-water dam in order to attract and capture young salmon and transport them downstream. However, by 1980, just 99 fish returned to spawn. In the late 1980s, PSE modified commercial fishing nets to create partial depth fish guidance net systems. The enhanced system allowed downstream migration to steadily rise, reaching a record 20,225 fish in 2003. While showing promise, the materials and engineering were not suitable for long term, low cost deployment. Fluctuating pool levels made it difficult to keep the net in an effective shape. Debris tore the nets, and once a tear started, it could rip from side to side.

PSE and stakeholders enacted a number of strategies to support the watershed's fish populations. Pacific Netting Products installed full exclusion netting at both the upper and lower Baker Lake Dams in 2012. The 47000 Sq M nets were built of .635 cm- and .3175 cm mesh, 731 M in length, with an average depth of 91 M. One was built with Dyneema®, the other with a nylon fiber. Both were anchored to shore by embedment anchors, weighted down with chain and anchored to the bottom by ship’s anchors. Both were built in a square-mesh design to maintain load and to accommodate pool fluctuations of up to 24 M. Supported with flotation, and protected by debris booms, the “v” shaped net “worked like an extension of the shoreline” to help guide the fish toward the floating surface collector (FSC) according to Ed Meyer, Senior Hydraulic Engineer for the National Oceanographic service (October 10, 2015 phone conversation).

The PSE exclusion barriers are deployed year-round. The effectiveness of the design of the full barrier net was proven dramatically in its first year of operations, as shown in the chart below. By 2014, over 1,000,000 downstream migrating salmon were counted, with returns of 60,000 to 100,000 adult fish expected in 2016. The anticipated lifespan of the Dyneema® exclusion barrier is 10 years. Operators report that aquatic growth is slow in the cold, deep water, and with excellent debris protection, there is minimal maintenance.

5.2. Bagnell Dam, Osage River, Camden County, Missouri

Bagnell Dam impounds the Osage River in south-central Missouri, creating the Lake of the Ozarks. The 45 M tall concrete gravity dam was built by Union Electric Company in 1931 for the purpose of hydroelectric power generation and is now owned and operated by the Ameren Corporation.

The presence of the dam and hydroelectric facility offered a number of challenges to fish and wildlife resource managers, including fish mortality at the dam. Of particular concern was the protection of American paddlefish (Polyodon spathula), which are endemic to the Mississippi River basin. Paddlefish are a basal Chondrostean ray-finned primitive fish that have evolved with few morphological changes since their earliest fossil records seventy to seventy-five million years ago (Oxford University Press).

Figure 10. Gated spillway at Bagnella Dam, Osage River, Camden

“One of the primary reasons for the decline in paddlefish populations is the loss of spawning and rearing habitat due to environmental alteration. Dam construction has eliminated spawning sites, interrupted natural spawning migrations, altered water flow, and eliminated backwaters that were important as nursery and feeding areas. Industrial contaminants, illegal fishing, and overexploitation by commercial and recreational anglers have also contributed to the decline. Unfortunately, population problems are not always immediately recognized because
paddlefish are long-lived and highly mobile, and their presence is sometimes construed as an indication that the species has not been adversely affected” (U.S. Fish and Wildlife Service).

In December of 2003, Alden Labs conducted studies of behavioral and physical deterrents to prevent paddlefish from impingement. Researchers investigated the effects of behavioral restraints such as low frequency transducers, strobe lights, and air bubble curtains. They also researched physical barriers including bar racks and barrier nets. The study showed paddlefish did not respond to behavioral interference but were effectively restricted by bar racks and exclusion barriers. Following an economic evaluation, the operators of the Ameren facility chose to install barrier nets.

Two exclusion nets built of Dyneema® were installed at the Bagnell Dam. A 366 M exclusion barrier, 36 M deep, built of 2.54 cm and 5.08 cm square mesh sufficient to prevent fish from being caught in it, was installed three meters in front of one of the turbine intakes on the lake side of the dam. 3.5 M upstream, a debris barrier net, 259 M long and 6 M deep, was installed to prevent damage to the fish exclusion nets. The nets were designed for single direction flow and periodic reverse directional currents with water velocities from 0.3 M to 1 MPS. They are anchored by concrete blocks and permanently installed.

Phillip Thompson, Ameren UE plant supervisor, Lake Ozark, MO, noted, “… it is very critical that the right material be chosen to make sure that you don’t have a net failure that ultimately ends up impacting your operation of the turbine.” Today, this installation successfully protects adult paddlefish from passing through the turbines, diverting their passage to safe routes, and allows Ameren to satisfy its regulatory obligations and deliver power to its customers.

5.3. Consumers Energy, Ludington, Michigan

The Ludington Pumped Storage Plant was built between 1969 and 1973. It sits along the Lake Michigan shoreline. The plant, jointly owned by Consumers Energy and Detroit Edison, is operated by Consumers Energy. It is one of the world’s biggest pumped storage facilities. A 27-billion gallon reservoir feeds a set of six turbines that drive electric generators, which double as pumps to fill the reservoir again with water from Lake Michigan. At night, when electric demand is low, Ludington's reversible turbines pump water 110 M uphill from Lake Michigan. The water is pumped through six penstocks, to the 842-acre reservoir. During the day, when electric demand is high, the reservoir releases water to flow downhill through the penstocks (Consumers Energy).

To protect alewives, yellow perch, salmon, and trout from being impinged and entrained during plant operations, Consumers Energy installed a 2.5 mile long barrier net in 1998. The 56,000 Sq. M barrier, which averages about 17 M in depth, was built in 62 sections using 1.27 cm and 1.9 cm Dyneema® netting. Anchored from subsurface steel
embedment anchors, it is designed for bidirectional currents and water velocities of 1.0 – 3.0 fps in ocean-like conditions with rolling surf. As velocities increase, the net floats release pressure while maintaining the net’s position and effectiveness. Late each fall, the net is removed for Michigan’s severe winter season when fewer fish are active. Each spring it is redeployed.

This barrier, which requires continual maintenance, is the longest in the world of its type. The installation design has proved effective in protecting fish while enabling Ludington to continue as an economical generator of electricity (Consumers Energy).

6. CONCLUSION

The ultimate goal of allowing the most efficient and economical use of water power without adversely impacting marine life is within reach thanks to the development of modern materials and advances in engineering. Using ultra high molecular weight polyethylene and modern flotation and debris booms, engineers can now design massive fish exclusion, guidance, and collection structures in locations previously unserved by viable options for fish protection. Current technology allows standard mesh sizes as low as .635 cm, preventing the impingement and entrainment of important or threatened species.

The principles and materials outlined in this paper can be adapted to environments around the world. Of course, each facility’s unique site conditions, which include consideration of bathymetry, shoreline topography, pool fluctuation, water flow, size and type of debris, boat traffic, icing, weather, seasonal or permanent deployment, as well as consideration of impacted aquatic species, must be addressed in the design and installation of each system. With careful consideration and implementation, humans will be able to continue to harness our most valuable resource with respect for the wider social and economic health of the planet.

7. REFERENCES