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Bearings & Seals: Examples of Innovations and Good Ideas

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By

Innovative approaches to designing, installing, retrofitting, and operating two major components of a hydroelectric plant are saving facility owners time and money.

Compiled by Elizabeth A. Ingram and Russell W. Ray

Bearings and seals are two primary components of hydro turbine systems. While project owners and operators often take these components for granted, if a problem occurs, this can create significant costs and unit downtime.

Hydro Review recently went on a quest to find solutions to some common challenges plant owners and operators experience with bearings and seals. From our search, we found a number of alternative materials, design tools, and new types of components that are being used in hydroelectric plants.

The following examples are meant to be just that … examples. The intent is not to be comprehensive. In fact, we hope these examples prompt readers to share other innovations and good ideas with us!

Bearings

Here are few examples of some of the bearing problems hydropower producers can face and the remedies that were used used to fix them:

Bearing lubrication: water over oil

Using water instead of oil as a lubrication for guide bearings provides obvious environmental benefits, including eliminating the risk of river pollution as a result of oil leakage. Throughout the world, more than 20 hydro units are equipped with hydrostatic water guide bearings, representing more than 124 years of cumulative operating time. These bearings use filtered, pressurized water from the penstock — instead of oil — to lubricate and cool the bearing.

Hydrostatic water guide bearings contribute to overall plant efficiency by reducing friction losses by about 50 percent compared with oil bearings, according to Alstom Hydro engineers Philippe Gilson, Stephane Roy, Jean Doyon, and Emmanuel Godoc, who authored a technical paper written for the Waterpower XVI conference in Spokane, Washington, in July 2009.[1]

With regard to reducing operation and maintenance costs, the authors say hydrostatic bearings have a higher bearing stiffness and proximity to the runner, both of which reduce vibrations. This reduces labyrinth wear because the shaft movements are attenuated. Thus, maintenance is limited to the water supply system, the authors say.

The Waterpower paper provides examples of installations of this type of bearing, including two units at the 48-MW Lake Chelan hydro plant in Washington State (first application of this technology in the U.S.).[2]

PTFE: alternative to babbitt for thrust bearing facings

The use of polytetrafluoroethylene (PTFE) composite for the facing of a turbine thrust bearing, as an alternative to white metal (babbitt), continues to receive attention. This material is especially attractive for use in equipment subjected to severe operating conditions. Units with PTFE-faced thrust bearings have been in operation for more than 30 years at hydro plants in Europe and Asia. There are more than 1,000 PTFE thrust bearings installed throughout the world.

Users of the PTFE composite point to a number of advantages over babbitt: low coefficient of friction, broad temperature range, excellent anti-seizure properties, superior resistance to chemical attack and moisture, a thermal conductivity about 170 times lower than that of babbitt, increased thrust bearing load carrying capacity compared with babbitt, and improved tolerance to misalignment and distortion.[3]

A recent installation of PTFE-faced thrust bearings in Syria is described in a technical paper written by Sergei B. Glavatskih of Lulea University of Technology in Sweden for the Waterpower XVI conference.

The plant, an eight-unit, 800-MW facility, operates with frequent start ups and shutdowns. This type of operation led to elevated oil bath and bearing temperatures and frequent thrust bearing failures. To solve the problem, the plant owner replaced the thrust bearing facings with a PTFE composite. Thermocouples were placed in the PTFE layer at the PTFE-oil film interface to measure oil film temperature. Tests carried out to commission the bearings indicated that the temperature of the PTFE pad was 42 degrees Celsius (C), compared with 71 C for another unit with a babbitt-faced bearing.

Installing composite bearings: tool for determining required clearance

Replacing traditional bearings that rely on grease for lubrication with "greaseless" composite bearings is an attractive alternative for many hydro project owners. Use of these bearings avoids environmental concerns related to leakage of oil-based lubricating fluids. However, one potential concern is the larger running clearance required for a composite bearing than for traditional bronze bearings.

Hydro Review's editorial staff found a software program that can be used to determine the required clearance for bearings made using Orkot composite materials.[4] The software is offered by Trelleborg Sealing Solutions in Trelleborg, Sweden.

Here's how the software works: to determine the smallest running clearance for a given radial load, personnel enter dimensions of various unit components (shaft diameter, housing diameter, bearing length, radial load, and projected bearing pressure), as well as machining tolerances and design load. The software then produces two calculations: the minimum required clearance and an "optimized" clearance.

By providing accurate running clearances, this software program allows hydro project owners to optimize the clearance on an Orkot composite bearing for a specific application, says Peter Bakker with Trelleborg. This can include retrofitting an existing unit or equipping a newly designed turbine, Bakker says.

CIP Composites used to improve fish passage at John Day Dam

The Northwest Power and Conservation Council called on the U.S. Army Corps of Engineers to develop juvenile fish passage plans on the lower Snake and Columbia rivers. The council amended the program to call for dam-by-dam case studies to "determine the most efficient level of bypass spill to maximize passage efficiency and fish survival," according to the council.

At John Day Dam, CIP Composites, manufactured by Columbia Industrial Products, were used to improve fish passage. CIP Composites are laminate composite materials made of polyester resins and polyester textiles incorporated with solid lubricants.

John Day Dam was included in the case studies. Officials determined a new fish ladder design would be necessary after discovering the fish at John Day were not moving through the ladder as fast as expected. In many instances, the fish would "fall back," or turn back to the beginning and start again. The problem was isolated to the upper third of the ladder, which was redesigned.

The original design was a pool and weir system (a series of fixed concrete weirs). The fish had to jump over a series of small dams and pools to move upstream.

The new design, which was completed in February 2010, incorporated a new fish-friendly shape and vertical-slot fish passage. The new design included a narrow slot near the channel wall, allowing the fish to swim upstream without leaping over the fixed weirs. The weirs now have the capability to open and close by the control of actuators and regulate the water levels more efficiently throughout each season.

The weirs rotate by actuators connected to a shaft held in place by two or three bearings, depending on the length of the shaft in its section. The project specifications called for self lubricated, greaseless composite bearings, inferring the avoidance of grease near waterways. In addition, the project included a section of wear plates. The wear plates were required to have higher creep resistance and load capabilities than the previous design. Transco Inc., the subcontractor of the project, chose CIP Composites™ as the material to supply for the bearings and wear plates for the fish ladder.

While project owners and operators often take proper operation of bearings and seals for granted, if a problem occurs, this can create significant costs and unit downtime.

Transco chose CIP Composites over other greaseless bearing materials because they had "good luck and past experience with CIP," and they met all the required specifications for the project. CIP provided Transco with the finished, machined bearings and wear plates.

CIP Composites, manufactured in Eugene, Ore., by Columbia Industrial Products (CIP), are custom laminate composite materials made of polyester resins and polyester textiles incorporated with solid lubricants. For the fish ladder project, CIP provided Transco with their CIP 151A material which includes solid lubricants (moly and PTFE) in addition to their proprietary additive, Enhancement A™.

Operating dry or submerged in water, the self lubricating bearing material does not require external lubrication, making it environmentally friendly and ideal for fish ladders. Along with its low coefficients of friction, it has exceptionally high load capacities with capabilities to withstand high shock loading and edge loading.

This allows the material to be stable where any misalignment may become present and because it is a 100 percent bearing material with no fiberglass or metallic shell. The material will not corrode, is light weight, and will not absorb water. The excellent resistance to wear and long life expectancy of the material allowed the subcontractor, Transco, to be certain it will meet and exceed the project specifications and requirements.

Using water-lubricated bearings

The use of biologically degradable lubrication in turbine main bearings is better for the environment. However, it can lead to operational breakdowns and reduced availability because these types of lubricants react hydrolytically in the presence of water.

Water lubrication is the best way to solve the ecological problem and the lubrication problem, according to Federal-Mogul Deva GmbH.

Deva.metal main bearings, a product of Federal-Mogul Deva, evoke a protective graphite film on the shaft through their self-lubricating characteristics. The graphite film avoids excessive wear during solid component friction.

Federal-Mogul Deva conducted calculations and test rig examination, which showed that reliable operation with water lubrication is possible. The application has been used in more than 100 power stations for more than 20 years, according to Federal-Mogul Deva.

The disadvantage of using water lubrication arises mainly from its low viscosity in comparison with other lubricants such as mineral oil. Only a relatively thin lubricating film exists, which is stripped away at high surface pressures and low speeds.

It is possible to compensate for this lubricating disadvantage by improving the self-lubricating characteristics of the materials used to make sliding bearings.

The Lignum Vitae Supply Project

Lignum vitae is a dense tropical wood with a unique combination of mechanical and physical properties that make it ideal for underwater bearing applications.

The history of its use and exploitation spans hundreds of years and includes ancient pumping devices, water wheels, the first Francis turbines, and the water lubricated bearings for Thomas Edison's first hydroelectric plant in 1882.

Lignum vitae is used in hundreds of older hydroelectric plants. However, demand for a slow growing, overexploited tropical wood will one day exceed supply. Until then, there is the Lignum Vitae Supply Project, established by Bob Shortridge, a wood craftsman and founder of Dreaming Creek Timber Homes.

Lignum vitae was only available in small quantities from widely scattered sources. Shortridge has stockpiled the world's largest quantity of military industrial grade lignum vitae, doing business as Lignum-Vitae.com.

"Lignum vitae is not just another commodity," Shortridge said. "We all benefit when this wood is set aside for its highest and best use in hydroelectric and other core industries."

About 30 hydroelectric plants are using blocks from Lignum-Vitae.com. The operators and engineers of these plants typically speak of 20 to 30 years of service from their lignum vitae bearings, depending on conditions.

On these gate arms, the hydro project owner is using self-lubricated spherical bearings embedded with a polytetrafluoroethylene lubricant. These bearings are resistant to corrosion and do not present concerns regarding oil leakage into the water.

Lignum-Vitae.com said it is committed to the responsible harvest of mature trees. It has a replanting program in the Bahamas, where lignum vitae is the national tree.

Using self-lubricated bearings on radial gates

Choosing the proper bearing material and design for gates at hydro facilities can be challenging for several reasons.

First, these gates are subjected to high specific loads so the bearings must be of sufficient strength to withstand this load. Second, gates may have long periods with no operation, which makes them susceptible to corrosion. Third, use of an oil-based product to lubricate the gate's bearings poses risks of leakage.

To address these challenges, Empresas Publicas de Medellin (EPM) decided to install DB spherical bearings manufactured by GGB of Thorofare, N.J., at its 660-MW Porce 3 plant in Colombia.

DB bearings are self-aligning spherical bearings that feature a stainless steel inner ring and an axially-split aluminum-bronze alloy outer ring embedded with a polytetrafluoroethylene (PTFE) lubricant.

The bearings have a low coefficient of friction, good wear resistance, long service life, and corrosion resistance, GGB says.

The dam at this project, which will be commissioned in 2010, features an open-channel spillway controlled by four radial gates.

These gates are 11 meters high by 14 meters wide.

For this application, the bearings will be subjected to radial loads as high as 12,000 kilo-Newtons.

When the gates open and close, the bearings will rotate 70 degrees in 90 minutes at operating temperatures of 0 C to 40 C.

HydroVision workshop to focus on bearing problems

Pioneer Motor Bearing Co. is surveying registered and prospective attendees of HydroVision International 2010 to identify the most challenging bearing problems for hydropower producers.

Those problems, the root causes, and potential solutions will then be discussed and debated by a panel of experts during Pioneer's pre-conference Hydroelectric Thrust and Guide Bearing Workshop on July 26, 2010, at HydroVision in Charlotte, N.C.

"Our objective is to provide non-commercial, moderated advice, analysis and recommendations, both from the panel and fellow attendees, in an open discussion," Pioneer said.

To participate in the survey, go to http://pioneer.questionpro.com. Pioneer will reimburse workshop attendees the $250 registration fee if their problem or case study is selected for discussion.

Pioneer supplies original equipment manufacturers and end users in the power generation and marine markets with engineering, manufacturing, and repair services related to bearings and seals for large rotating equipment.

The company has extensive experience with the manufacture, repair, and modification of thrust bearings for large vertical hydroelectric turbine-generators.

Seals

The following are examples of some of the challenges involved in fixing a bad seal and the techniques that were used to prevent the problem from recurring:

Solving leakage problems on main shaft seals

A common challenge at many hydro plants — no matter the size or location — is water leaking from the seal around the turbine's shaft. On a turbine with a shaft diameter greater than 1 meter, industry experts say it is nearly impossible for the main shaft seal to completely eliminate leakage. Instead, the seal functions more to control leakage to an acceptable amount.

Hydro Review took a look at what was being done at hydro plants to control leakage from turbine shaft seals and uncovered some innovative approaches.

One such approach is the use of a seal with a sealing face made of elastic polymer instead of carbon. Thordon Bearings Inc., headquartered in Burlington, Ontario, Canada, manufactures the seal, called a Thordon SXL seal. A technical paper written by Thordon and presented at the Waterpower XVI conference in Spokane, Washington, in July 2009, outlines the advantages of the elastic polymer material.[5]

According to the paper, the material can be machined to the required size, up to 4 meters in diameter. The elastic polymer exhibits good abrasive resistance. Solid particles trapped between wear surfaces do not imbed into the material. Instead, they deform the polymer surface locally and roll between sealing faces until they escape the seal.

In the paper, authors Dr. Guojun Ren and Ken Ogle share an example in which installation of an elastic polymer seal on the shaft of a large vertical Francis turbine significantly reduced leakage and wear.

Before the installation, the shaft featured a segmented carbon axial seal with an average diameter of 4 meters. Seal leakage was about 140 liters per minute, and the segments were suffering from severe abrasive wear. Thordon installed the new seal, and the turbine was restarted. Over the next year, plant personnel monitored cooling water pressure, water supply flow, leakage rate, and temperature increase.

All results were satisfactory. Leakage past this new seal ranged from 10 to 90 liters per minute — reducing leakage by more than a third. At the end of the monitoring period, personnel dismantled the turbine for inspection. The sealing face was clean, and measurements indicated only one small section of the seal had worn by 0.1 millimeter.

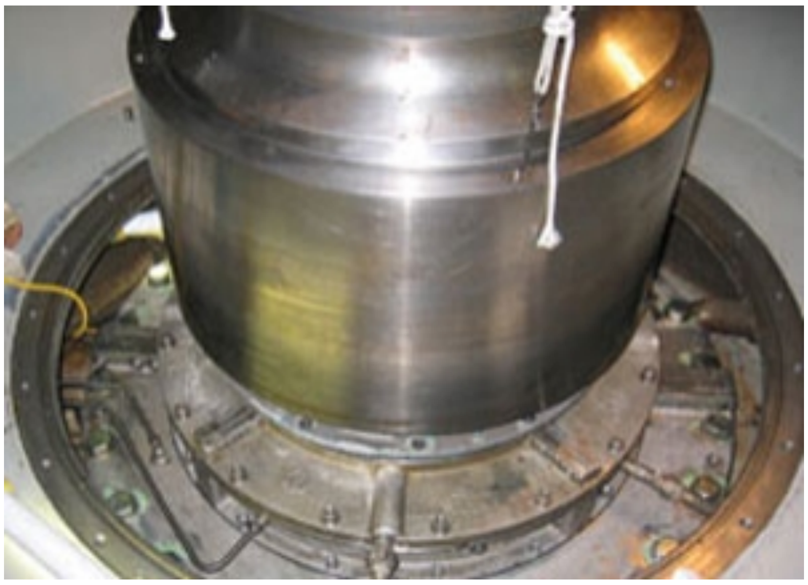
Fugesco provides solution to mechanical seal problem

A pumping storage plant in southern California had a problem. The plant's waterways are exposed to the desert sand blowing into the canals.

This sand and silt end up in the pumps. As a result, the pumps' spring-energized, conical wedged mechanical seals were being destroyed within three months of start up. As a result, the pit would flood out.

The existing seal was not the right solution for this particular application. Canadian seal manufacturer Fugesco, known as a leader in mechanical seal technology, was asked to go on site and find a solution for this ongoing situation.

The Fugesco crew analyzed the water conditions below the seal, the water supply to the seal, the pressures below the seal as well as the access to the seal area for assembly and disassembly of the seal unit without having to dismantle the entire pump turbine. A Fugesco axial type F5000 was installed.



The new axial seal installed on this pump, at a facility in California, contains an innovative combination of face materials that can withstand severe applications. The old seal had to be replaced every three months; the new one has been in operation for three years.

But the design alone was not the cure. The material selection was key. This model has an innovative combination of face materials that can withstand severe applications. By blending a mix of conventional metals and composite materials, Fugesco was able to resolve the customer's problem. The seal has been running for three years with no problems.

Choosing the right seal

Some faults in hydropower stations are obvious. Others remain hidden until the very last moment. But whatever the problem, there is often a direct or indirect link to some kind of seal.

The cause of these problems and a whole variety of others is the type of seal design that has normally been used, said Frank Knoefel, technical director at IDG-Dichtungstechnik GMBH. Many of the problems often lead to repair work or even a permanent overhaul, Knoefel said.

A common challenge at many hydro plants – no matter the size or location – is water leaking from the seal around the turbine's shaft. One solution to this challenge is using a seal with a face made of elastic polymer instead of carbon.

Plaited cords, elastomeric profile rings, molded seals, and simple O-Rings are commonplace. Such seals can withstand neither extreme contamination of the water nor the vibration. The seals and their mating surface wear each other away. Sometimes abrasion of the material leads to the total disappearance of the seal. Simply fitting a new seal will seldom be sufficient.

"At the very least, the surfaces will have to be refashioned or redressed or, at worst, whole components replaced," Knoefel said. "Problems of this nature can be avoided by using seals that differ from conventional types in respect of their geometry and the materials employed."

Knowing the problem is the first step. Informing the manufacture is the second step, Knoefel said. A technical designer of components should also be informed about the limit advantages and disadvantages of a seal. The designer could make a minor change to material or profile to get the seal functioning properly.

Sealing system reduces leakage around turbine shaft

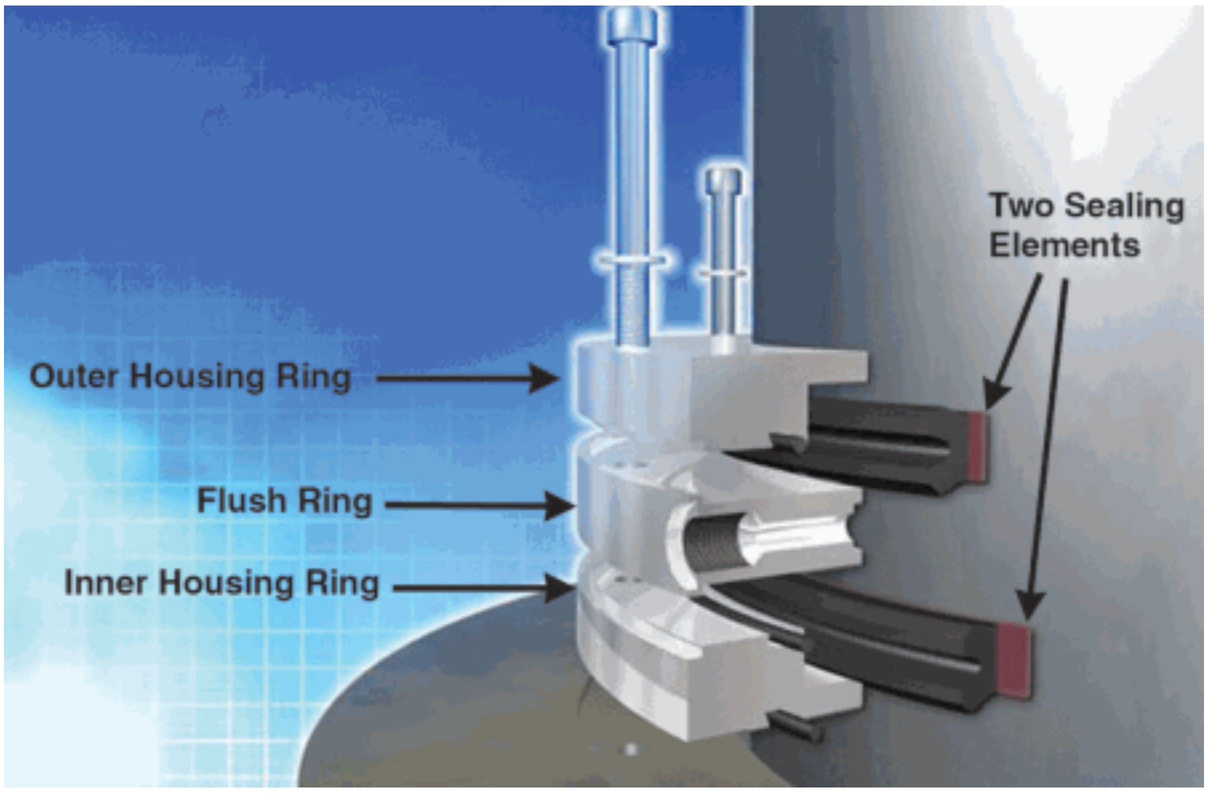
To reduce water leakage within the turbine-generating unit of its 5-MW Foyers Falls hydro plant In Scotland, Scottish & Southern Energy PLC in Scotland retrofitted the 12-inch-diameter main shaft with a split-type HydroSele cartridge seal from James Walker & Co.

The seal – which features two elastomer-based rotary sealing elements working back-to-back with flush water introduced between them instead of a face sealing arrangement typically used by mechanical seals – solved the leakage problem.

When the Foyers Falls unit was constructed in 1968, the shaft was outfitted with a pair of internally mounted mechanical seals of the spring-retained segmented carbon ring type, plus an outboard labyrinth system. Over time, sand and peat in the water caused excessive wear to these seals. In addition, the turbine shaft was becoming eroded and scored around the labyrinth system. Water was spraying out of the seal housing toward the generator. The utility was replacing the carbon seals every 12 months.

By 1996, the utility decided to replace the mechanical seals with the HydroSele system. The feature of the system is the way its two sealing elements operate within their housings. The two elements work back-to-back, with filtered water flushed between them at 30 pounds per square inch above the water pressure at the sealing gland.

The cartridge is a bolt-on unit that incorporates the housings for the two sealing elements and the flush area between them. Because the system is modular, each component can be designed and precision manufactured to fit together around a specific turbine shaft.



This split-type HydroSele cartridge seal was installed on the turbine shaft at the 5-MW Foyers Falls plant to reduce water leakage. The seal features two elastomer-based rotary sealing elements working back-to-back with flush water introduced between them instead of a typical mechanical face sealing arrangement.

Scottish & Southern chose the HydroSele system, in part, because its modular concept and custom design minimizes installation time. What's more, by installing the seal system, the utility could reduce seal maintenance requirements to intervals greater than five years.

Two engineers with James Walker installed the sealing system at the Foyers Falls plant in less than two days without mechanical lifting gear. The new sealing system reduced leakage to three-quarters of a gallon per hour, thus eliminating the problem of water spraying toward the generator.

Retrofitting a seal without tearing down the unit

When retrofitting mechanical seals on turbine shafts, the time required to disassemble and/or modify the machine can be costly in terms of lost production and labor. Depending on the size of the unit and the amount of time it typically runs, disassembling the unit to replace a seal can involve hundreds of man-hours and several hundred thousand dollars in outage losses.

In looking for ways to reduce the time required to retrofit seals, Hydro Review's editorial staff discovered a solution. The E.A.S.-S.E.E. Seal, offered by Sealogic Innovations Corporation, can be installed without disassembling or modifying the unit. This seal is a fully split mechanical face seal; it can be used as an external main shaft seal on horizontal or vertical units or as the internal submerged bearing seal upstream of the runner on S-type and bulb turbines.

The design of this seal incorporates two "floating" faces (not subjected to any mechanical stresses) that self-align into the plane that is precisely perpendicular to the shaft's axis of rotation, says Kevin Drumm with Sealogic. This means the seal does not "flex," or oscillate during revolutions, minimizing wear and spring fatigue, he says.

The seal can be designed to accommodate axial movements in both directions, as well as radial movements, of 0.25 inch. It also has minimal requirements for micro-filtered flushing water and can run dry.

Notes

1. Gilson, Philippe, Stephane Roy, Jean Doyon, and Emmanuel Godec, "Hydrostatic Water Guide Bearings: Making Environmental Technology Profitable!" Waterpower XVI Conference Proceedings CD-Rom, Pennwell Corporation, Tulsa, Okla., 2009.
2. Roy, Stephane, Jean Doyon, Vincent De Henau, and Steve Sembritzky, "A Rehabilitation Scheme for the Lake Chelan Hydroelectric Project Based on Schedule Reduction," Waterpower XVI Conference Proceedings CD-Rom, Pennwell Corporation, Tulsa, Okla., 2009.
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Elizabeth Ingram and Russell Ray are associate editors of Hydro Review.

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