Best Practice Catalog

Trash Racks and Intakes

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1.0 Scope and Purpose

This best practice for trash racks and intakes addresses the technology, condition assessment, operations, and maintenance best practices with the objective to maximize performance and reliability.

The primary purpose of the trash rack is to protect the equipment by keeping floating debris, leaves, and trash from entering the turbines. The primary purpose of the intake is to divert water at the river/reservoir source and deliver the required flow into the penstocks which in turn feed the hydropower plant.

1.1 Hydropower Taxonomy Position

Hydropower Facility → Water Conveyances → Trash Racks and Intakes

1.1.1 Components

The components of the trash rack and intake systems are those features that directly or indirectly contribute to the efficiency of water conveyance operations. The trash rack system is made up of the trash rack itself along with its cleaning and monitoring components. The intake system is comprised primarily of the intake structure, intake gates, and hoisting machinery.

Trash Rack: The primary function of trash racks is to protect equipment, such as wicket gates and turbines, from debris that is too large to pass through without causing harm. The trash rack is probably the single most important debris control device [1]. Typically, a trash rack consists of stationary rows of parallel carbon steel bars located at the dam intake.

Trash Rake: The function of the trash rake is to remove any debris that accumulates on the trash rack. By cleaning clogged racks, trash rakes reduce head differential. Rakes vary in size to accommodate a variety of debris sizes. Rakes also vary in level of automation with some plants using manual trash rakes and others using mechanical systems.

Trash Conveyor: The function of the trash conveyor is to remove trash cleaned from trash racks. Trash conveyors reduce cost by eliminating the need for manual trash removal.

Monitoring System: The function of a monitoring system is to measure head differential across a trash rack. The measurements can then be used to schedule trash cleaning or justify improvements.

Intake: The function of an intake is to divert water from a source such as a river, reservoir, or forebay under controlled conditions into the penstocks leading to the power plant. Intakes are designed to deliver the required flow over the desired range of headwater elevations with maximum hydraulic efficiency.

Intake Structures: Intake structures are commonly built into the forebay side of the dam immediately adjacent to the turbine. Another common intake design is a tower structure connected to a penstock. Tower intakes are often separate structures in the reservoir, typically constructed of reinforced concrete. Intake structures commonly house (1) trash racks that prevent large debris and ice from entering the water passages and (2) gates or valves for controlling the flow of water and for dewatering of the intake for maintenance purposes.

Intake Gates: An intake gate is arranged to shut off the water delivery when the conduit system has to be emptied. Types of gates include hydraulically operated slide gates, roller and wheel-mounted gates, and radial gates.

Stoplogs/Bulkhead Gates: Stop logs and bulkhead gates are used to block water so that construction, maintenance, or repair work can be accomplished in a dry environment. Stop logs are stored in a secure storage yard, positioned by a crane and dropped into slots on the pier of a dam to form a wall against the water.

Air Vents: Air vents are typically incorporated in the intake structure and configured to prevent collapse of the penstock due to excessive vacuum when closing the intake gates.

Hoisting Machinery: Hoists are mechanical (electrically or manually driven), hydraulic (oil or water), or pneumatically operated machines used to raise and lower in place heavy water control features such as gates and stop logs.

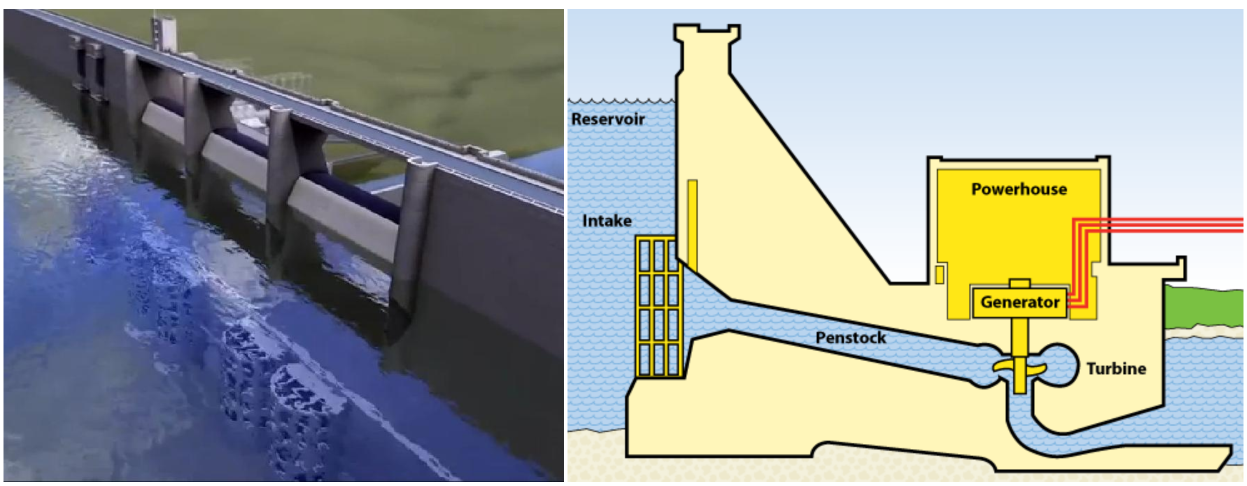

Figure 1: Illustrations of submerged intakes built into the face of the dam

Figure 2: Tower intake structures (Left: Blue Ridge Dam, Fannin County, Georgia; Right: Hoover Dam, Clark County, Nevada/Mohave County, Arizona)

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability - Oriented Best Practices

- Routinely monitor and record unit performance at CPL.
- Periodically compare the CPL to the PPL to trigger feasibility studies of major upgrades.

1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices

- Routinely inspect trash racks for degradation.
- Trend trash rack degradation and adjust life expectancy accordingly.
- Routinely clean trash racks, regulated by visual inspection, timed intervals, or head differential monitoring.
- Routinely inspect and maintain trash rack cleaning systems (e.g. trash rakes, conveyors).
- Maintain documentation of IPL and update when modification to equipment is made (e.g. trash rack replacement/repair, trash rake addition/upgrade).
- Include industry knowledge for modern trash rack system components and maintenance practices to plant engineering standards.

1.3 Best Practice Cross-References

- Civil – Penstocks, Tunnels, and Surge Tanks
- Civil – Flumes/Open Channels
- Civil – Draft Tube Gates
- Civil – Leakage and Releases

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

Traditionally, trash racks were cleaned by hand with equipment developed by the personnel who used it (i.e., management and staff). Thus, these hand rakes became easier and easier to handle and some even had wheels. Even today, some hydropower plants clean their trash racks by hand. This requires intense manpower at times, particularly in the autumn when rivers are full of fallen leaves. The size and position of trash racks were influenced by the necessities of manual trash rack cleaning. Issues with manual cleaning of trash racks, including limitations on the flow rate and economic inefficiencies, led to mechanization of trash rack cleaners several decades ago. Initial mechanization involved trash racks that were crossed upwards by a chain driven scraper with the collected trash dumped into a cross belt. Chain-driven trash rack cleaning machines are still in use today at small hydropower plants and quickly evolved into the classical wire rope trash rack cleaning machines that are in use today at medium and large plants.

2.2 State of the Art Technology

Currently used trash rack apparatus can be categorized by hydropower plant size. For medium-sized hydropower plants with cleaning lengths up to 65 feet, two types of trash rack cleaning machines are typically used: the classic wire rope trash rack cleaner, and more recently the hydraulic jib trash rack cleaner. For large-scaled hydropower plants, the wire rope trash rack cleaner is used.

While the wire rope type trash rack cleaner has been in use for about 100 years, many advances have been made by the way it is transported. Many solutions to the debris storage problem have been created with examples being integrated containers used as buffer storage containers towed by the cleaner and trucks that follow the trash rack cleaning machine under their own power or by being positioned on a platform connected to the cleaner. Wire rope type trash rack cleaners can be used for nearly unlimited cleaning lengths such as 200 feet. The inclination of the trash rack should be at least 10 degrees to the vertical.

The hydraulic jib trash rack cleaners, which have been manufactured for only a few years now, have a base frame with a travelling device along with a pivoted machine house with booms and a grab rake [10]. The revolving superstructure of the machine enables dropping of the trash beside or behind the railway of the trash rack cleaner. The grab rake is designed to pick up oversized trees as well as to push floating debris to the weir. It has a scraper sliding along the trash rack bars. The grab rake can be rotated to conform to the position of a tree or other debris. Therefore, floating debris can be pushed to the weir to be drifted and large debris, such as trees, can be picked up by the grab rake and disposed of. The cleaning length is limited to about 50 to 60 feet, with greater cleaning lengths requiring the use of telescopic beams. This device also makes possible the use of cleaning vertical trash racks.

Intakes are designed to deliver the required flow over the desired range of headwater elevations with maximum hydraulic efficiency. Modern design basis requirements include geologic, structural, hydraulic and environmental attributes. The intake design should shape the water passages such that transformation of static head to conduit velocity is gradual, eddy and head losses are minimized, and the formation of vortices at the intake are limited. Advancement in computer modeling technology has yielded a more accurate design of intake structures for hydrodynamic loads, and particularly for updated seismic criteria as specified by modern building codes.

Hydraulic head losses can be mitigated during the intake design by limiting the velocity of the water through the trash rack and minimizing the acceleration of the water to achieve a smooth rate of acceleration. Trash racks should not be exposed and the intake gate lintel should be submerged below the minimum forebay level to lessen potential problems caused by air entrainment.

3.0 Operation and Maintenance Practices

3.1 Condition Assessment

If trash racks are located at or near the water surface, visual inspection from the surface may be possible. If trash racks are located far enough below the water surface that they cannot be seen from the surface, divers, underwater cameras, and/or ROVs (Remotely Operated Vehicles) may be used to perform inspections.

"ROV's may provide a more cost effective method for performing inspections – inspections that previously would have required risky diving operations or costly facilities dewatering [8]." The use of a new ROV system saved the U.S. Bureau of Reclamation more money in fixing one "serious problem" than the cost of the ROV [9]. "ROVs can often work in hazardous areas without requiring the dam to stop and tag out intakes and are not subject to diving limits of depth or duration [9]." Using sonar, ROV's can also work in low and zero-visibility environments. Both still and sonar images taken with a ROV can be seen in Figures 3 and 4 on the following page.

Plants should use manual or automated measurement tools whenever possible to monitor and record head differentials across trash racks to determine energy losses. Data from these measurements can be used to schedule trash rack cleanings and can be incorporated into systems for unit, plant, and system optimization [7]. When head differential data is used to quantify lost production, the calculated economic losses can be used to justify funding for improvements in trash rack cleaning methods and/or trash rack design [7].

The unique orientation of the intake structure in relation to the incoming water may have a significant impact on the overall effectiveness of the intake. Civil aspects of intakes include not only the structure, but also the gates that control the flow. Intake gate life expectancy should be at least 50 years, however corrosive water chemistry, poor coating performance and lack of maintenance can greatly shorten service life [11].

Hydro plant structures have design features to accommodate gates. These features include slots in piers and walls, and steel embedments that provide bearing/sealing surfaces for the gates. The installation of the gates also typically requires hoist lifting machinery. As the hydro plant ages, the intake gates are subject to wear, corrosion and physical damage. Seals other than metallic are subject to environmental deterioration. Metallic seals are subject to wear. Coating systems can wear or fail exposing steel to corrosion. The hoist lifting systems are subject to mechanical wear.

Concrete structures should be inspected for cracking and spalling, and observed cracks should be monitored to determine if the cracks are progressing or dormant. It is essential to note if the concrete defects are structural or non-structural. Although non-structural distress such as local spalling due to insufficient concrete cover may be unsightly, it is less likely to need to be addressed through remediation than structural cracking. Guides available to assist with concrete condition assessment include U.S. Army Corps of Engineers Manual EM-1110-2-2002, the U.S. Bureau of Reclamation Guide to Concrete Repair, and the American Concrete Institute Standards 201.1 and 364.1R.

Figure 3: ROV Still Image of Trash Rack*

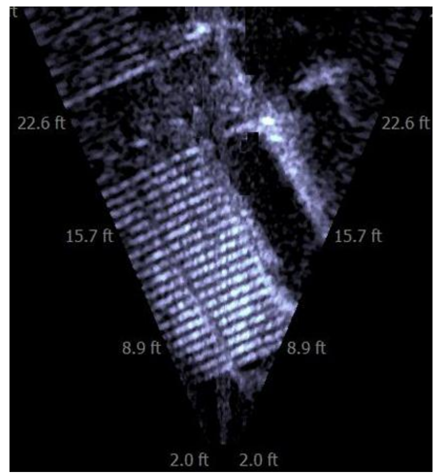

Figure 4: ROV Sonar Image of Trash Rack*

**Photos were taken using a VideoRay Pro 4 ROV and are courtesy of VideoRay LLC.*

3.2 Operations

Efficient and timely cleaning of trash racks can have a significant impact on the plant's efficiency and generation. Trash racks capture debris on their upstream surface which creates an energy (head) loss as water passes through them [6]. This energy loss can be excessive when the rack is clogged, reducing the net head for generation and potentially causing a significant reduction in plant efficiency. Although hydraulic losses due to debris accumulation can be costly, they are one of the most common avoidable losses occurring in hydropower plants [2]. Experience has shown that custom-engineered cleaning of trash racks can provide annual power production increases of up to 25% [7]. While there is a cost for cleaning equipment and cleaning operations, the benefits can be significant. Improved trash rack design can also improve efficiency and generation for clean, unclogged racks.

"If there is a need to intercept trash with a trash rack, then there is a need to remove the intercepted trash so that the flow of the water will not be hindered [6]." Some hydro plants have such a relatively small and/or infrequent debris load that cleaning can be carried out manually. Other plants have large debris loads (Figure 5), which require mechanical cleaning. Selection of trash rack cleaning equipment is site-specific.

Figure 5: Debris removed from trash racks can range in size from aquatic milfoil to tree trunks, shown here [2]

Plants located in colder regions may have the additional problem of frazil ice accumulation on trash racks. This ice affects trash rack efficiency in the same manner as debris, clogging the trash rack and reducing the net generation head. In some cases frazil ice may be removed by trash rakes, but in others, additional systems are needed to prevent the accumulation of frazil ice [3]. See the discussion on frazil ice prevention in the following section for more information.

The frequency of trash rack cleaning is site-specific and will vary from season to season at each plant. Cleaning systems should be operated as frequently as needed to maintain plant efficiency and capacity. Using head differential data as discussed in the above section, an automated cleaning system can be installed. See the discussion on automated trash rakes in the following section for more information.

3.3 Maintenance

As described in the system components, trash racks traditionally have been made of parallel bars, and such installations have often served well for many decades. Carbon steel trash racks typically need a protective coating, such as epoxy paint, to increase their life expectancy, particularly if portions of the trash rack are periodically exposed to the atmosphere. In some cases, it is cheaper to replace structurally weakened racks than it is to repaint them periodically [6].

When trash racks are replaced, consideration should be given to improve trash rack design, including modifications to bar shape and increased corrosion protection. Hydrodynamically shaped bars have lower head losses, are less affected by flow-induced vibration, and are more easily cleaned [4]. To protect against corrosion, stainless steel, high density polyethylene (HDPE), and fiber reinforced polymer (FRP) trash racks are available. The life expectancy of steel trash racks is typically 15 to 35 years and 25 to 50 years for plastic or fiberglass trash racks [3]. Some installations also use cathodic protection systems to combat corrosion. These systems create a galvanic cell between the trash rack and an attached metal. The attached metal suffers corrosion, thereby protecting the trash rack [6]. Additional guidance in the replacement and detailed design of trash racks can be found in *The Guide to Hydropower Mechanical Design* [6].

In colder regions where frazil ice accumulation is a problem, it may be cost effective to take steps in preventing ice buildup. One approach is to install air bubblers or water circulating pumps at the bottom of the racks providing a thermal change of water temperature. Another approach is to alter the conductivity of the trash racks through replacement or modification. Installing non-conductive racks (HDPE or FRP) can usually solve the problem. If metal racks are used and they project above the surface of the water, a physical non-thermal conducting break can be installed just below the water surface. This will prevent below freezing temperatures from being transferred into the water through the trash rack. Electrically heating the bars has also been used to prevent ice buildup, but the cost of doing so has not been proven effective or economical [3].

“The main problem with trash removal is that it can be labor intensive. All improvements or upgrades to the trash raking system that can help reduce costs and improve generation output should be considered [3].” An estimated 5% to 25% increase in power production can be seen with the addition of a custom engineered trash cleaning system, and the cost of these upgrades is usually justifiable [7]. The efficiency gained can be quite significant [5]. One utility determined that $500,000 per year could be recovered from trash-related problems at one of their “smaller” plants’, and $250,000 per year at one of their “larger” plants [7]. There is a variety of trash rake systems currently available on the market (Figure 6). These systems range in size as well as level of automation, so they are applicable to almost every plant situation. The systems can be set to clean continuously, at a set interval, and/or whenever differential head reaches a specified level. Conveyor systems can also be installed to reduce the cost of trash removal (Figure 7). Due to the variety of trash rake options on the market, each plant must evaluate the type of rake that will benefit them the most. “Prior to selecting a particular type of rake or manufacturer, the owner needs to consider the physical location of the machine, the type of trash to be handled, and the complexity of the design and system used to run the trash rake [3]."

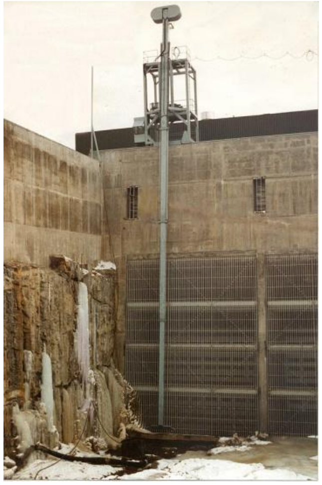

Figure 6: Trash Rake System (courtesy of Alpine Machine Co.)

Figure 7: Trash Rake Conveyer System (courtesy of Atlas Polar Co.)

Surface roughness in the intake can contribute to head loss. Since the intake structure is a relatively short portion of the water flow system, frictional head losses at the intake are usually insignificant, unless the surface profile has been extensively altered or deteriorated. The loss due to friction will increase as the intake walls roughen from cavitation or erosion in high flow areas. Cavitation frequently causes severe damage to concrete or steel surfaces and it may occur at sluice entrances and downstream from gate slots. Surface erosion resulting from debris is sometimes mistaken for cavitation, and cavitation damage may be difficult to determine from examination of the surface within the damaged area. Debris erosion may be identified by grooves in the direction of flow. For both causes, a potential upgrade on an intake having significant surface roughness or pitting would be to apply an epoxy concrete or cementitious repair mortar to the concrete surface. A wide range of these repair mortars are available having high bond strength and excellent workability likely to suit any concrete intake surface. In the case where damage has already occurred, metal-liner plates can be used to protect the concrete from the erosive action of cavitation. For heads above 150 feet, these liner plates should extend five feet downstream from the gate and should not terminate at a monolith joint or transition [10].

Another product that may be effective at reducing head loss at intakes is silicone based coatings used to prevent organic growth. This product also provides a very smooth surface on top of deteriorated areas on the interior intake surfaces. This coating system can be considered in lieu of repair mortar and liner plates in most cases. The potential upgrade to decrease the friction loss of an intake by applying a repair mortar, liner plate, or coating system is highly dependent on accessibility and will vary on a site-specific basis.

Intakes can also introduce head loss to the system through geometric changes in the intake wall structure. Intake walls may have slots to accommodate vertical gates or stoplogs. While the plant is generating power and the stoplogs or gates are removed or raised, these slots present irregular surfaces for flowing water. The void space of these slots will create minor losses due to shape change. If the gates are not used as emergency closures in the conveyance system, slot fillers can be used to significantly reduce these losses. Slot fillers are often steel or aluminum frames that fit snug inside the slots providing a smooth surface for flowing water.

Other water conveyance issues that can negatively impact plant performance include valve issues, restrictions in discharge channels, and sedimentation. Each of these issues affect efficiency in proportion to the amount of head loss introduced to the conveyance system.

Efficiency can be gained by utilizing low-loss valves, such as gate valves, rather than higher-loss butterfly valves. Additionally, a partially open valve will cause more loss than a fully open valve. Therefore, care must be taken to ensure all valves are completely open when the system is in operation.

Restrictions in discharge channels, such as weirs and bridge piers, can cause water to back up behind them, increasing back pressure on the generation units and decreasing net available head. The location of these structures plays a critical role in whether plant performance is affected. Therefore, it is important to identify potential effects on generation when considering the installation of such a structure. Additionally, natural obstructions downstream from the dam, such as debris build-up or beaver dams, can cause similar decreases in hydroelectric production. Care should be taken to maintain a clear discharge channel, free of any major obstructions.

Plant efficiency can also be adversely affected by sedimentation in the reservoir behind the dam. Upstream bed sedimentation can partially block an intake, reducing the effective flow area and increasing the intake velocities, causing increased head loss at the intake. This issue could be remediated by occasional dredging of the reservoir immediately upstream of the dam.

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

Determination of the Potential Performance Level (PPL) typically requires reference to new trash rack design information from vendors to establish the achievable unit loss characteristics of replacement racks.

The Current Performance Level (CPL) is described by an accurate set of unit loss characteristics determined by unit testing/monitoring.

The Installed Performance Level (IPL) is described by the unit loss characteristics at the time of commissioning. This condition is used to determine the reference values in the calculations detailed in this best practice. These characteristics may be determined from vendor information and/or model testing conducted prior to or during unit commissioning.

The CPL should be compared with the IPL to determine decreases in trash rack efficiency over time. Additionally, the PPL should be identified when considering plant upgrades. For quantification of the PPL with respect to the CPL, see *Quantification for Avoidable Losses and/or Potential Improvements – Integration: Example Calculation*

4.2 Data Analysis

The key measurements for a generating unit N include:

- ΔH_N – Head differential across the trash rack (ft)
- ΔH_{RN} – Reference head differential across the trash rack (ft)*
- Q_N – Unit flow rate (cfs)
- γ – Specific weight of water (62.4 pcf)
- T – Measurement interval for ΔH_N (hr)
- M_E – Market value of energy ($/MWh)
- E_{AN} – Actual energy generation (MWh)
- E_{RN} – Reference energy generation (MWh)*

**Reference values are found when the trash rack for a given unit is in its original (clean) state*

Measurements can be near real-time or periodic (hourly, daily, weekly, monthly) depending on the site details.

4.3 Integrated Improvements

Utilization: Key Computations

Avoidable power loss P_N (MW) associated with ΔH_N:

$$P_N = Q_N\gamma(\Delta H_N - \Delta H_{RN})/(737{,}562)$$

where 737,562 is the conversion from pound-feet per second to megawatts

Avoidable energy loss E_N (MWh) associated with ΔH_N:

$$E_N = P_N T$$

Avoidable revenue loss R_N ($) associated with ΔH_N:

$$R_N = M_E E_N$$

Avoidable loss efficiency, $L_{eff,N}$ (%)

$$L_{eff,N} = (E_{AN}/E_{RN})100$$

Note that the costs associated with a trash cleaning operation should be established for comparison with the associated revenue losses and used to schedule cleaning, to evaluate and justify new cleaning equipment or trash rack re-design, etc.

Integration: Example Calculation

A theoretical hydroelectric plant has a steel trash rack that has become clogged over time. The hydraulic properties of the trash rack are as follows:

- Head loss across clogged trash rack = 4.0 ft
- Head loss across clean trash rack = 0.5 ft
- Average flow across trash rack = 800 cfs

The avoidable power loss can be calculated as:

$$\Delta P = (800\ \text{cfs})(62.4\ \text{pcf})(4.0\ \text{ft} - 0.5\ \text{ft}) / 737{,}562 = 0.24\ \text{MW}$$

At an estimated market value of energy of $65/MWh, and assuming the plant produces power 75% of the time, the market value of power loss can be calculated as:

$$0.75\ (0.24\ \text{MW})(\$65/\text{MWh})(8{,}760\ \text{hours/year}) = \$102{,}\ 500/\text{year}$$

This analysis indicates a significant avoidable energy and revenue loss over the performance assessment interval.

5.0 Information Sources:

Baseline Knowledge:

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10. Radhuber W., *"Trash Rack Cleaning – The Past-The Present – The Future,"* 15th International Seminar on Hydropower Plants, Vienna 2008.

11. Benson B., J. Blasongame, B. Chu, J. Richter and D. Woodward, *"Aging Plants – Time for a Physical": Conducting a Comprehensive Condition Assessment and the Issues Identified,"* HydroVision 2008.

It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.

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