Best Practice Catalog

Leakage and Releases

Revision 1.0, 12/01/2011

Prepared by

MESA ASSOCIATES, INC.
Chattanooga, TN 37402

and

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

Contents

1.0 Scope and Purpose 4
1.1 Hydropower Taxonomy Position 4
1.1.1 Causes of Leakage & Releases 4
1.2 Summary of Best Practices 5
1.2.1 Performance/Efficiency & Capability - Oriented Best Practices 5
1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices 6
1.3 Best Practice Cross-references 6
2.0 Technology Design Summary 6
2.1 Material and Design Technology Evolution 6
2.2 State of the Art Technology 7
3.0 Operation and Maintenance Practices 7
3.1 Condition Assessment 7
3.2 Operations 8
3.3 Maintenance 9
4.0 Metrics, Monitoring and Analysis 10
4.1 Measures of Performance, Condition, and Reliability 10
4.2 Data Analysis 10
4.3 Integrated Improvements 11
5.0 Information Sources 11

1.0 Scope and Purpose

This best practice for leakage and releases addresses technology, condition assessment, operations, and maintenance best practices with the objective to maximize performance and reliability. Leakage is an unintentional release of water and occurs to some extent at all hydroelectric facilities. In most cases the loss from leakage is less than 1% of the average flow [1]. There are certain cases where seepage can create a substantial loss of flow, but the cost associated with preventing this loss is typically very high and almost always outweighs the cost of lost generation. For these reasons, leakage is considered to have a minor impact on efficiency, performance, and reliability of a hydro unit.

The release of excess water from spillways and sluiceways when flow exceeds storage and generation capacity can become substantial over a long period of time. In some areas, meeting minimum downstream flow requirements can also result in the release of substantial amounts of water. Inadequate flow measurements can also lead to excess water losses through releases. A variety of equipment is available on the market to generate electricity from releases without a powerhouse structure [7]. This equipment has the potential to provide a sizeable amount of power generation by harnessing the power from flow releases that previously generated no revenue, contributing to unit efficiency, performance, and reliability.

1.1 Hydropower Taxonomy Position

This best practice encompasses the leakage and releases issues associated with spillways, weirs, and sluiceways; also addresses the seepages through the abutments and foundation of dams. The above chart indicates the position of this topic implied in the Taxonomy.

1.1.1Causes of Leakage & Releases

Leakage is usually a minor problem in plant operations. In a survey on plant leakage, the average loss from leakage reported by plant owners was less than 0.5% of the average river flow. Very few plants reported leakage in excess of 1% [1].

The most common and controllable source of leakage occurs at spillway gates due to inadequate sealing. “Many old plants were built without gate seals for economic or other reasons [1].” Even where gate seals are used, they deteriorate over time.

Another form of leakage comes from seepage. Seepage occurs under the foundation or around the abutments of a dam. Small amounts of seepage are inevitable. Severe cases of seepage under the foundation, however, can cause major damage due to increased uplift pressure and piping of soils in embankment dams [12]. These cases are safety concerns, and repairs can be very costly. An example of this is Wolf Creek Dam in Kentucky where seepage under the dam required hundreds of millions of dollars in repairs [2].

Seepage around abutments can divert a portion of the reservoir’s flow around the dam. “These leaks usually cannot be prevented except by redoing the upstream cut-off or grout curtain of the dam and even then may not be possible to stop [1].” These techniques are costly, but in certain cases where it is found that seepage can be prevented, the reduction in losses can be substantial.

The primary purposes of releases are to maintain a minimum required flow downstream of the dam and to regulate the water level of the reservoir. Minimum flow requirements ensure that various needs of the downstream community are met, such as:

- Protecting water quality and aquatic resources.
- Ensuring year-round navigation.
- Providing water for power production and municipal and industrial use downstream [3].

Several examples of plants with flow release requirements are found in Flow Measurement at Hydro Facilities: Achieving Efficiency, Compliance, and Optimal Operation [4].

Generation and releases make up the flow that a plant produces downstream. Inaccurate flow measurements from these sources can lead to an excess or insufficient flow being released from the reservoir. In order to provide a flow that meets regional requirements, many plants release more water than the required amount. Over time, this excess release can become a substantial loss of generation revenue. To obtain the highest efficiency, care should be taken to release the minimum amount of water above the generation capacity to meet flow requirements. When releases are unavoidable, accurate flow measurements and gate calibration can assist in providing increased efficiency.

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability - Oriented Best Practices

- Routine monitoring and recording of gate leakage and downstream seepage.

- Trend gate leakage to trigger feasibility studies of seal replacement/addition or gate replacement.
- Trend downstream seepage to trigger feasibility studies of prevention techniques.
- Obtain information of releases at Current Performance Level (CPL) by measurements or models if none is currently available.
- Limit releases to minimum required flow, and only release when required.
- Use information of releases at CPL to regulate releases.
- Periodic comparison of the CPL of releases to the Potential Performance Level (PPL) to trigger feasibility studies of major upgrades.
- Maintain documentation of Installed Performance Level (IPL) and update when modifications are made (e.g. replacement/addition of seals, prevention of seepage, addition of generating equipment, changes in release control).
- Include industry acknowledged "up to date" choices, for leakage prevention and release control practices to plant engineering standards.

1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices

- Monitor conveyance components and gates for signs of excessive leakage, and repair or replace damaged or defective components causing the leakage.

1.3 Best Practice Cross-references

- Civil – Penstocks, Tunnels, & Surge Tanks
- Civil – Trash Racks & Intakes

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

Gate seals are used to close the gap between the edge of a movable gate and a fixed sealing surface. Most gates of modern hydroelectric plants have seals that are made of rubber. However, wood, plastic, and even leather have been utilized for gates, typically under low head applications. Dissimilar metal was also a common pre-1950's seal material and was seen as a more durable, longer-lasting option [14].

Performance levels for leakage and releases can be stated at three levels as follows:

- The Installed Performance Level (IPL) is described as the loss characteristics at the time of the plant's commissioning or at the point when an upgrade, addition, or modification is made.

- The Current Performance Level (CPL) is described by an accurate set of loss characteristics encompassing all sources of leakage and releases. It is important to locate and accurately quantify all sources of leakage and releases for this performance level.
- The Potential Performance Level (PPL) is ideally considered as the condition where no power generation loss occurs from leakage or releases. However, this ideal condition is never completely obtainable. Therefore, the PPL can be considered as the condition where the minimum amount of losses can be obtained through upgrade to the best designs and technologies.

2.2 State of the Art Technology

Performance data on leakage and releases is only as reliable as the methods used to collect the data. Emerging and state of the art technology continues to provide increasingly accurate instrumentation and analysis software used to calculate hydraulic flow properties. These tools can then be used to determine the difference between the CPL and the PPL of hydro plant leakage and releases.

State of the art design of gate seals typically incorporates rubber as the primary seal material. Although the designed service life of rubber seals does not greatly exceed that of other materials, the biggest advantage comes from the reduction in leakage around the seals. Leakage around rubber seals is approximately 10 times less than that of metal on metal seals [14].

3.0 Operation and Maintenance Practices

3.1 Condition Assessment

To inspect for leakage from gates, visual inspection can be performed by observing if any water flows from the gates when they are closed. If the gates are not visible, it may be possible to observe the flow from their outlets.

To inspect for leakage caused by abutment seepage, a variety of methods may be implemented. In some cases simple visual inspection can be used. Muddy tailwater flows, sinkholes, and downstream appearances of leakage are all possible signs of seepage. Figure 1 on the following page shows an example of the appearance of leakage from Center Hill Dam in Tennessee [5]. Other cases may require the use of electronic, audio, or magnetic field measuring devices to find the cause of seepage [8] [9]. *Seepage Analysis and Control for Dams* provides guidance in seepage analysis [12].

Figure 1: Appearance of Leakage (Center Hill Dam) [7]

It has historically been difficult to accurately measure the flows released from gates and spillways. Antiquated plants have often relied only on charts that estimate flows for given gate opening heights. In plants where accurate measurements of flow release are unavailable, tests may be run to obtain flow data and/or a physical or computer model can be produced. Using data collected through these methods, accurate flow measurements can be obtained. A list of flow tests along with their applicability and advantages can be found in *Flow Measurements at Hydro Facilities: Achieving Efficiency, Compliance, and Optimal Operation* [4].

3.2 Operations

Gate seals deteriorate over time and they should be inspected periodically. Any leaks discovered should be recorded and their severity monitored. While a small leak may cause a negligible loss, if left unchecked, it can become a much larger loss over time.

Seepage in one form or another occurs at all dams. Therefore, the appearance of any of the signs of seepage previously mentioned may not indicate a need for repair. These signs should be monitored. If they worsen or are accompanied by other signs, the operators should investigate the source of seepage before permanent damage occurs. Downstream appearances of water should be monitored. These may be from a separate source or may be water escaping the reservoir through seepage. The volume of flow from these sources should be recorded regularly, and any increases may indicate a need for further investigation [12].

Once accurate flow measurements are obtained, they can be used to regulate releases more efficiently. In plants where previous data of flow through gates and spillways are available, the flow measurements can be used for gate calibration. In plants where no previous data of flow through gates and spillways is available, the flow measurements can be used to implement a procedure for flow control.

Operators should consider altering generating schedules if excess amounts of water are being released through spillways and gates. Any water released from the reservoir that is not used to generate electricity is ultimately a loss of revenue.

3.3 Maintenance

Over time, gate seals will deteriorate and will need to be replaced. If possible, seals should be replaced when the gates are out of use, either from dewatering or seasonal reservoir level drops. To reduce maintenance, the use of improved seals may be a cost effective solution. In cases where no seals are present, it may be cost effective to install seals on the gates. In extreme cases of leakage, particularly where gates are severely deteriorated or have an outdated design, it may be cost effective to replace the gate entirely if the addition or replacement of seals is not sufficient.

Seepage prevention is typically a costly improvement and doesn’t always fix the problem. Grout curtains are the most common form of seepage prevention [13]. Even after they are installed, seepage water may still find a path around the grouting or may find an outlet further downstream. In the case of Great Falls Dam in Tennessee, an extensive grouting program was successful in stopping 98% of reservoir leakage [6], but the largest of the uncorrected leakage, located a few hundred feet downstream from the powerhouse, has increased since the grout curtain was installed. This leakage can be seen in Figure 2. Operators must take care to ensure that seepage prevention is a cost effective endeavor. In many cases the small amount of water lost cannot justify the cost of correcting the problem. A variety of seepage control methods and their appropriate applications can be found in *Seepage Analysis and Control for Dams*, EM 1110-2-1901 [12].

At some point every plant must release water due to the generator or reservoir capacity limit. Some plants, however, require a large volume of releases for environmental purposes. There is a variety of equipment that can be installed to generate power from these types of releases without the need for a powerhouse. Some of the most recent hydro generation equipment can be found in “Top 5 Developments in Hydro” [7]. Among these are a fully-sealed combined axial turbine and generator [10] and hydrokinetic technologies [11]. These options can utilize previously unused generation potential from environmental releases.

Figure 2: Great Falls Leakage (powerhouse shown at left)

Additionally, some plants use releases to provide required dissolved oxygen concentrations downstream of the dam. For these plants, the releases may not coincide with minimum flow requirements and therefore contribute to decreased plant efficiency. Other means of providing minimum dissolved oxygen, such as aeration weirs or aerating turbines, are recommended in this case.

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

The fundamental process of a hydro plant can be described by the power equation. In the case of leakage and releases, the power loss can be determined based of the following calculation:

Where:
- **P** is the power loss of the hydroelectric plant (MW)
- **Q** is the flow rate lost through leakage or releases (ft^3/s)
- **γ** is the specific weight of water (62.4 lb/ft^3)
- **H** is the effective pressure head across the system (ft)

The general expression for power loss (P): $$P = \frac{Q\gamma H}{737{,}562}$$

4.2 Data Analysis

Analysis of performance data shall determine plant efficiency relative to power generation. The results from the analysis (CPL) shall be compared to previous or original performance data (IPL) as well as the efficiency gained from potential improvements to leakage and releases (PPL). The cost of rehabilitation and internal rate of return must be calculated to determine if improvements are justified.

4.3 Integrated Improvements

The periodic field test results should be used to update the unit operating characteristics and limits. Optimally, these would be integrated into an automatic system (e.g., Automatic Generation Control), but if not, hard copies of the data should be made available to all involved personnel – particularly unit operators, their importance to be emphasized, and their ability to be understood and confirmed. Justified projects a method to constantly monitor unit performance should be implemented.

5.0 Information Sources

Baseline Knowledge:

Electric Power Research Institute (EPRI), *Increased Efficiency of Hydroelectric Power*, EM-2407, June 1982

United States Army Corps of Engineers (USACE), *Wolf Creek Dam Seepage Rehabilitation Project*, Retrieved from http://www.lrn. usace.army.mil/wolfcreek/, Page last updated on April 19, 2011

Tennessee Valley Authority (TVA), *Managing River System Flows*, Retrieved from http://www.tva.gov/river/lakeinfo/systemwide.htm

EPRI, *Hydropower Technology Roundup Report: Flow Measurement at Hydro Facilities: Achieving Efficiency, Compliance, and Optimal Operation*, TR-113584-V5, January 2002

USACE, *Seepage*, Retrieved from http://www.lrn.usace.army.mil/centerhill/pdf/ seepage.pdf

TVA, *Great Falls Hydro Plant - Dam Safety Instrumentation Project Performance Report*, EDMS J22060427001, 2005

Hydro Life Extension Modernization Guides: Volume 1 – Overall Processes, EPRI, Palo Alto, CA: 1999. TR-112350-V1.

State of the Art

Top 5 Developments in Hydro, International Water Power and Dam Construction, January 26, 2011

Diagnosing Dam Seepage, International Water Power and Dam Construction, March 21, 2011

Montgomery, J. R., M. L. Jessop, M. J. Wallace, and V. O. Kofoed, *Using Controlled Source Audio Frequency Domain Magnetics for Seepage Diagnosis of Earthen Embankments*, SAGEEP 22, 785, March 2009

Opsahl, E., and Ø. Krøvel, *Installing the Turbinator*, International Water Power and Dam Construction, December 22, 2010

Hydro Green Energy, LLC, *Full Operations Initiated at Nation's First Commercial Hydrokinetic Power Station*, Retrieved from http://www.hgenergy.com/moellerrelease.pdf

Standards:

USACE, S*eepage Analysis and Control for Dams*, EM 1110-2-1901, April 30, 1993

USACE, *Engineering and Design - Planning and Design of Navigation Dams*, EM 1110-2-2607, July 31, 1995

American Society of Civil Engineers, Civil Works for Hydroelectric Facilities: *Guidelines for Life Extension and Upgrade*, 2007

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.

For overall questions
please contact:

Brennan T. Smith, Ph.D., P.E.
Water Power Program Manager
Oak Ridge National Laboratory
865-241-5160
smithbt@ornl.gov

or

Qin Fen (Katherine) Zhang, Ph. D., P.E.
Hydropower Engineer
Oak Ridge National Laboratory
865-576-2921
zhangq1@ornl.gov