“Best Practice” Guidelines for Hydro Performance Processes

by

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Abstract

This paper discusses hydro performance processes and presents draft “Best Practice” guidelines for the processes. Elements of the guidelines include: (1) the basic foundation, which is valid unit and plant performance data; (2) effective utilization of that data-based information throughout the organization; (3) knowledge-based optimization of the water resources; and (4) wise integration of the performance data, information, and knowledge into the organization’s business processes and policies. Each element (i.e., foundation, utilization, optimization, integration) is assessed with respect to three key dimensions, including economic (technologies and business processes); social (people and people-related processes); and environmental (environmental technologies and processes).

Introduction

Hydroelectric generating facilities are sustainable and relatively simple systems for converting the potential energy of stored water and the kinetic energy of flowing water into a useful form, electricity. This fundamental process for a hydroelectric generating unit is described by the efficiency equation, defined as the ratio of the power delivered by the unit to the power of the water passing through the unit. The general expression for this efficiency (η) is

$$\eta = \frac{P}{\rho g Q H}$$

where P is the output power, ρ is the density of water, g is the acceleration of gravity, Q is the water flow rate to the turbine, and H is the head across the unit.

As an example, Figure 1 shows the unit performance characteristics at multiple heads for a single, conventional Francis unit at an intermediate-head, two-unit, 120 MW tributary plant with aerating turbines. Performance curves such as these provide guidance for effective use of a hydro unit. In this case, the points of most efficient operation can be identified and the efficiency penalty for straying from the optimum can be quantified and evaluated. When maximum power output is required, these curves show that there is a point at which very small gains in power result in drastic reductions in efficiency. Operation in this high-load, lower-efficiency region is also associated with increased cavitation damage to the turbine and accelerated bearing wear.

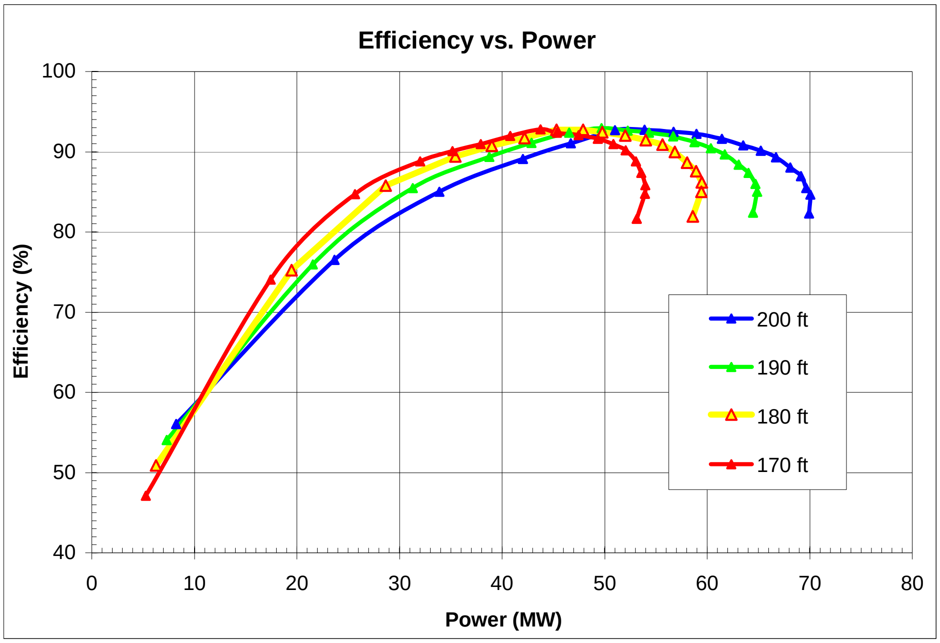

Figure 1: Example of Single Unit Performance Characteristics versus Head

However, information from the single-unit performance characteristics alone is not sufficient for achieving effective operations in a multi-unit plant. This is illustrated in Figure 2, which shows overall plant performance characteristics (assuming all units are available) at multiple heads for generating mode operation of reversible Francis units at a high-head, six-unit, 3,000 MW pumped storage plant with one new unit and five original units. The overall plant efficiency is dramatically affected by the plant load and head. For example, when operating at 1140 feet of head, a 500 MW load is quite inefficient for this plant, with an efficiency penalty of about 5%.

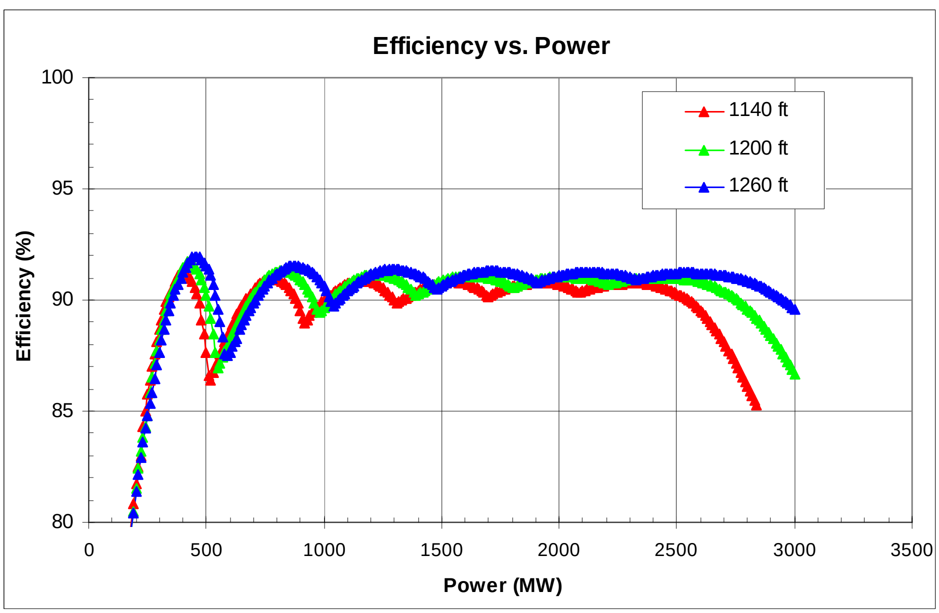

Figure 2: Example of Overall Plant Performance Characteristics versus Head

Effective, “best practice” operations ensure that data-driven performance information, such as the unit and plant characteristics summarized in Figures 1 and 2, is incorporated into the load planning, dispatching, and other processes to optimize generation for the plant or power system.

Figure 3 is presented below as a useful way to consider performance-related processes in the context of the “Best Practice” Guidelines which are introduced in the following section:

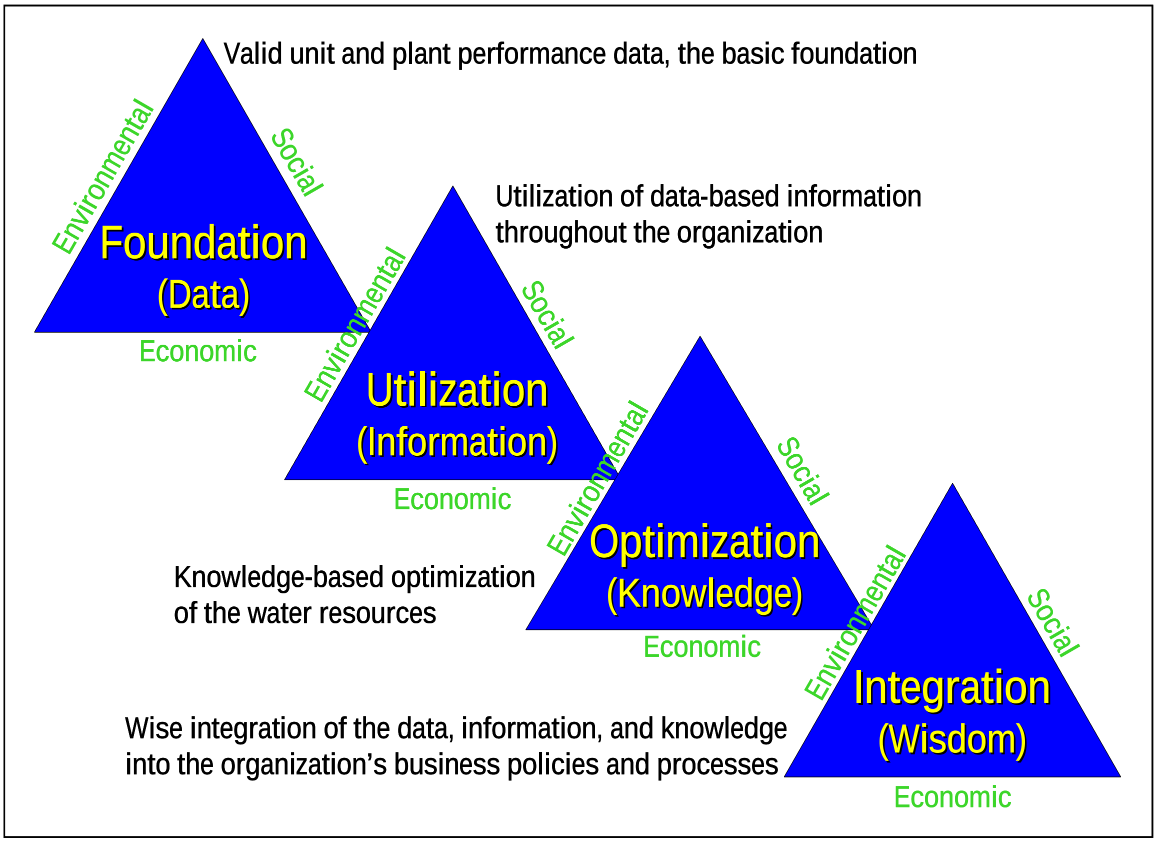

Figure 3: Diagram of Hydro Performance Processes

Figure 3 shows that valid unit and plant performance data form the basic foundation for effective performance processes, but the performance data must be widely available in useful form, such as unit and plant performance characteristics. The performance data must be incorporated into operator-based or automation-based optimization systems at the unit, plant, and system levels and at a variety of time scales ranging from real-time to a year or longer. And, for effective processes, all of the relevant performance-related data, information, and analyses must be fully integrated into the organization’s business policies, processes, and systems.

Draft "Best Practice" Guidelines for Hydro Performance Processes

As a tool for process understanding and improvement, the draft rating assessment for hydro performance processes addresses twelve economic, social, and environmental aspects related to operational performance for hydropower units, plants, and systems. The draft assessment and aspects are inspired by, and, in large part, derived from, the International Hydropower Association's *Sustainability Guidelines (Compliance Protocol)* (IHA, 2004). The rating scores are useful for assessing the overall operational performance of hydropower units, plants, and systems; comparing the relative performance of units and plants within a system; and providing guidance for allocating capital and maintenance resources and prioritizing upgrades and improvements.

The twelve performance aspects for existing hydropower schemes are shown in Figure 4. Aspects P1 to P4 relate to the economic aspects of performance processes; P5 to P7 relate to the social aspects of performance processes; and P8 to P12 relate to the environmental aspects of performance processes (March and Almquist, 1995; Fisher and March, 1999; March and Wolff, 2003; March and Wolff, 2004; March, 2004).

In the assessment document, scoring is based on the following system:

5 for each aspect where the hydro scheme meets all of the relevant criteria.

3 where most of the criteria are met.

1 where only some of the criteria are met.

0 where none of the criteria is met.

Guidance on scoring is provided for each aspect. Scores can be totaled and divided by the number of aspects to obtain an average or converted to a percentage score. The range of scores can be displayed in a variety of ways, depending on individual preferences. As an example, the draft scoring sheet for Aspect P1, Unit performance data for economic operations, is shown in Figure 5. In addition, the draft scoring sheets for Aspects P2, P3, and P4 are provided as Figures 6, 7, and 8, respectively.

DRAFT “BEST PRACTICE” PROTOCOL –
APPRAISAL OF HYDRO PERFORMANCE PROCESSES

SCHEME NAME	
LOCATION DETAILS	
DATE OF ASSESSMENT	
NAME AND POSITION OF PERSON CARRYING OUT ASSESSMENT	
DETAILS OF OTHERS CONSULTED DURING ASSESSMENT	
SIGNATURE OF AUTHORIZING OFFICER	

Summary of Aspects and Scores

No.	Aspect	Score	No.	Aspect	Score
P1	Unit performance data for economic operations		**P7**	Integration of multipurpose operations with business policies, processes, and systems	
P2	Organizational utilization of performance data for economic operations		**P8**	Effects of minimum flow and water quality operations on performance	
P3	Optimization for economic operations		**P9**	Effects of fish passage operations on performance	
P4	Integration with economic business policies, processes, and systems		**P10**	Environmental optimization of minimum flow and water quality operations	
P5	Effects of multipurpose operations on performance		**P11**	Environmental optimization of fish passage operations	
P6	Optimization of multipurpose operations		**P12**	Integration of environmental operations with business policies, processes, and systems	

	Total	Average	Percentage	Range
Score				
Comments				

Figure 4: Summary of Aspects and Scoring Form for Draft Guidelines

P1 - Unit performance data for economic operations	
Valid unit performance data provides the basic foundation for effective hydro performance processes.	
Performance Processes Scoring	
5 = Highest	• Turbine and generator (i.e., unit) performance characteristics consistent with relevant international and/or national standards (e.g., IEC 60041-1991-11, ASME PTC18-2002) are available for each generating unit over the entire range of operating heads. • Performance-related data consistent with relevant international and/or national standards, including power, headwater elevation, tailwater elevation, flow rate, water temperature, gate opening, and blade angle (where appropriate) are continually measured and readily available for each generating unit. • Adequate personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain performance-related instrumentation, including obsolescence management for hardware and software and succession planning for personnel; to periodically compare expected performance characteristics for each unit with measured performance characteristics; to periodically evaluate and train relevant personnel; and to take timely and appropriate action when necessary.
3 = Medium	• Unit performance characteristics consistent with relevant international and/or national standards are available for most units over most of the range of operating heads, and relative unit performance characteristics based on index testing are available for the remaining units. • Performance-related data consistent with relevant international and/or national standards, including power, headwater elevation, tailwater elevation, flow rate, water temperature, gate opening, and blade angle (where appropriate) are continually measured and readily available for most units, but some flow rates are relative rather than absolute. • Significant personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain performance-related instrumentation. However, some improvements could be readily achieved.
1 = Low	• Unit performance characteristics consistent with relevant international and/or national standards are available for some units over some of the range of operating heads, and relative unit performance characteristics based on index testing are available for some of the remaining units. • Some performance-related data, including power, headwater elevation, tailwater elevation, flow rate, water temperature, gate opening, and blade angle (where appropriate) is available for some units, but most flow rates are relative rather than absolute. • Some personnel, budgets, systems, processes, and procedures are in place, but these are generally ineffective and/or inadequate.
0 = Zero	• No unit performance characteristics are available, and no attention is paid to performance-related instrumentation, data, or personnel.
Comments	

Score	

Figure 5: Summary of Aspect P1 (Unit performance data for economic operations)

P2 – Organizational utilization of performance results for economic operations	
Proper utilization of valid performance results throughout the organization is required for effective economic operations.	
Performance Processes Scoring	
5 = Highest	• Unit performance characteristics and past performance test results consistent with Aspect P1 are readily available to appropriate personnel (e.g., operations, maintenance, engineering, power management, water management, environmental management) and systems (e.g., monitoring system, automation system, maintenance management system, environmental management system) within the organization. • Real-time and archival performance-related data consistent with Aspect P1, as well as supplementary performance-related information (e.g., unit operational data; electrical, mechanical, and hydraulic operational limits; power/energy rates versus time; operational scheduling information such as unit status and schedule request) are securely stored, appropriately backed-up, and readily available to appropriate personnel and systems within the organization. • Adequate personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain performance-related communications infrastructure and archival software, including obsolescence management for hardware and software and succession planning for personnel; to periodically review performance-related data and information; to periodically evaluate and train relevant personnel; and to take timely and appropriate action when necessary.
3 = Medium	• Unit performance characteristics and past performance test results consistent with Aspect P1 are readily available to appropriate personnel and systems within the organization for most units. • Real-time and archival performance-related data consistent with Aspect P1, as well as supplementary performance-related information, are securely stored, appropriately backed-up, and readily available to appropriate personnel and systems within the organization for most units. • Significant personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain performance-related communications infrastructure and archival software. However, some improvements could be readily achieved.
1 = Low	• Unit performance characteristics and past performance test results are available to appropriate personnel and systems within the organization for some units over some of the range of operating heads. • Real-time and archival performance-related data, as well as supplementary performance-related information, are stored and available to appropriate personnel and systems within the organization for some units. • Some personnel, budgets, systems, processes, and procedures are in place, but these are generally ineffective and/or inadequate.
0 = Zero	• No unit performance characteristics are available, and no attention is paid to performance-related instrumentation, data, or personnel.
Comments	

Score	

Figure 6: Summary of Aspect P2 (Organizational utilization of valid performance results)

P3 – Optimization for economic operations	
Knowledge-based optimization of the water resource at the unit, plant, and system levels, for time periods ranging from real-time to an annual operating cycle is required for effective economic operations.	
Performance Processes Scoring	
5 = Highest	• Unit performance characteristics, consistent with Aspects P1 and P2, are used in the long-term, medium-term, short-term, and real-time optimization of unit/plant and system operations for a wide variety of operational modes (e.g., specific load, specific flow, most efficient load, most efficient load within a specified range of a specified load, conventional AGC, optimization-based AGC). • Systems, processes, and procedures are in place to periodically compare expected performance data for each unit with real-time and archival performance-related data and supplementary performance-related information, consistent with Aspects P1 and P2, to ensure that improvements and corrections to performance characteristics are incorporated in a timely fashion into all appropriate optimization systems and processes. • Adequate personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain operator-based and/or automation-based optimization infrastructure and software, including obsolescence management for hardware and software and succession planning for personnel; to periodically evaluate and train relevant personnel; and to take timely and appropriate action when necessary.
3 = Medium	• Unit performance characteristics, consistent with Aspects P1 and P2, are used for most units in the long-term, medium-term, short-term, and real-time optimization of unit/plant and system operations for a wide variety of operational modes. • Systems, processes, and procedures are in place for most units to periodically compare expected performance data for each unit with real-time and archival performance-related data and supplementary performance-related information, consistent with Aspects P1 and P2. • Significant personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain operator-based and/or automation-based optimization infrastructure and software. However, some improvements could be readily achieved.
1 = Low	• Unit performance characteristics are used in the long-term, medium-term, short-term, and real-time optimization of unit/plant and system operations for a variety of operational modes for some units. • Systems, processes, and procedures are in place for some units to periodically compare expected performance data with real-time and archival performance-related data and supplementary performance-related information. • Some personnel, budgets, systems, processes, and procedures are in place, but these are generally ineffective and/or inadequate.
0 = Zero	• No unit performance characteristics are available, and no attention is paid to performance-related instrumentation, data, or personnel.
Comments	

Score	

Figure 7: Summary of Aspect P3 (Optimization for economic operations)

<table>
<tr><th colspan="2">P4 - Integration with economic business policies, processes, and systems</th></tr>
<tr><td colspan="2">Wise integration of the economic performance data, information, and knowledge into the organization's economic business policies, processes, and systems is required.</td></tr>
<tr><th colspan="2">Performance Processes Scoring</th></tr>
<tr><td>5 = Highest</td><td>• Unit performance characteristics, consistent with Aspects P1, P2, and P3, are used in the evaluation and quantification of economic losses associated with optimization, instrumentation, avoidable losses, unit/plant scheduling, environmental operations, and operational impacts on maintenance (e.g., AGC operation).
• Systems, processes, and procedures, consistent with Aspects P1, P2, and P3, are in place to compute quantitative performance metrics which ensure that relevant economic results are available for establishing maintenance priorities, developing capital equipment priorities, and evaluating operational policies: (1) a timely comparison of actual operations to optimized operations under the same conditions; (2) a timely comparison of expected (i.e., historical) performance data for each unit with real-time and/or archival performance-related data to ensure that improvements and corrections to performance characteristics and instrumentation are incorporated in a timely fashion; (3) a timely evaluation of avoidable energy losses (e.g., trash rack fouling, penstock/tunnel fouling, penstock/tunnel degradation); (4) a timely evaluation of unit/plant scheduling.
• Adequate personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain the infrastructure and software for integrating performance-related data, information, and knowledge into the organization's economic business policies, processes, and systems, including obsolescence management for hardware and software and succession planning for personnel; to periodically evaluate and train relevant personnel; and to take timely and appropriate action when necessary.</td></tr>
<tr><td>3 = Medium</td><td>• Unit performance characteristics, consistent with Aspects P1, P2, and P3, are used in the evaluation and quantification of economic losses associated with optimization, instrumentation, avoidable losses, and unit/plant scheduling for most units.
• Systems, processes, and procedures, consistent with Aspects P1, P2, and P3, are in place for most units to compute quantitative performance metrics.
• Significant personnel, budgets, systems, processes, and procedures are in place to properly manage and maintain the infrastructure and software for integrating performance-related data, information, and knowledge into the organization's economic business policies, processes, and systems. However, some improvements could be readily achieved.</td></tr>
<tr><td>1 = Low</td><td>• Unit performance characteristics are used in the evaluation and quantification of economic losses associated with optimization, instrumentation, avoidable losses, and unit/plant scheduling for some units.
• Systems, processes, and procedures are in place for some units to compute quantitative performance metrics.
• Some personnel, budgets, systems, processes, and procedures are in place, but these are generally ineffective and/or inadequate.</td></tr>
<tr><td>0 = Zero</td><td>• No unit performance characteristics are available, and no attention is paid to performance-related instrumentation, data, or personnel.</td></tr>
<tr><td>Comments</td><td></td></tr>
</table>

Score	

Figure 8: Summary of Aspect P4 (Integration with business processes and systems)

Conclusions and Recommendations

Major investments in hardware and software for more efficient turbines and generators, improved automation and control systems, and advanced optimization systems may not provide all of the anticipated benefits in improved performance, due in part to problems with the performance processes. When properly implemented and managed, performance-related processes and the associated performance improvements provide increased generation, increased revenue, additional water supply, and reduced maintenance costs, often at a surprisingly low cost.

This paper introduces "Best Practice" Guidelines for hydro performance processes and provides a framework for expansion and improvement. The guidelines emphasize a foundation of valid and detailed unit and plant performance data; the effective use of that data-based information throughout the organization; the knowledge-based optimization of the water and power resources; and the integration of performance-related data, information and knowledge into the organization's business policies, processes, and systems.

Numerical scoring of key aspects based on identified criteria allows the objective assessment of a hydro organization's performance-related activities. Practical use of the guidelines can help an organization to maximize the value of its water and power resources in a systematic, structured, and quantifiable way. The rating scores are useful for assessing the overall operational performance of hydropower units, plants, and systems; comparing the relative performance of units and plants within a system; and providing guidance for allocating capital and maintenance resources and prioritizing upgrades and improvements. As individual organizations, and the hydro industry as a whole, gain experience with best practice assessments, the efficiency improvements and economic benefits associated with sub-scores on individual aspects can be quantified and correlated along with cost information for specific projects to improve performance.

References

ASME, "Performance Test Code 18: Hydraulic Turbines and Pump-Turbines," *ASME PTC 18-2002*, New York, New York: American Society of Mechanical Engineers (ASME), 2002.

IEC, "Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines," *International Standard IEC 60041-1991-11*, Geneva, Switzerland: International Electrotechnical Commission (IEC), 1991.

IHA, *The Role of Hydropower in Sustainable Development*, London, England: International Hydropower Association (IHA), February 2003.

IHA, *Compliance Protocol (Sustainability Guidelines)*, London, England: International Hydropower Association (IHA), February 2004.

March, P. A., “Best Practice Guidelines for the Hydro Performance Process and Implications for Incremental Hydropower,” 2004 World Renewable Energy Conference, Denver, Colorado, September 2004.

March, P.A., and C.W. Almquist, “Flow Measurement Techniques for the Efficient Operation of Hydroelectric Power Plants,” National Institute of Standards and Technology, Metrology for the Americas Conference, Miami, Florida, November 1995.

March, P. A., and R. K. Fisher, “It’s Not Easy Being Green: Environmental Technologies Enhance Conventional Hydropower’s Role in Sustainable Development,” *Annual Review of Energy and the Environment*, Volume 24, December 1999.

March, P. A., and P. J. Wolff, “Optimization-Based Hydro Performance Indicator,” *Proceedings of WaterPower XIII*, July 2003.

March, P. A., and P. J. Wolff, “Component Indicators for an Optimization-Based Hydro Performance Indicator,” HydroVision 2004, Montréal, Québec, Canada, August 2004.

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