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NORTHWEST HYDRAULIC CONSULTANTS – USING EXPERIMENTAL METHODS TO ADVANCE SEDIMENT MANAGEMENT SOLUTIONS AT HYDROELECTRIC FACILITIES

BY BRIAN R. HUGHES

As existing hydroelectric facilities age, and as new facilities are developed, the management of sediment both upstream and downstream of these developments is repeatedly identified as a critical parameter in the project life cycle. For over 50 years specialists at Northwest Hydraulic Consultants (NHC) and Lasalle|NHC have been utilizing in-house hydraulic laboratories, together with advanced numerical methods, analyses and field investigations, to assist clients throughout North and South America and elsewhere in developing techniques to effectively manage sediment at their projects.

The Problems

The management of sediment accumulation and passage at hydroelectric projects is an ongoing and increasing problem around the world. The most prominent problems associated with sediment accumulation, passage and scour at hydroelectric facilities include loss of storage, restricted flow to the intake, damage to equipment, and degradation downstream of the project often leading to loss of habitat.

Figure 1 - Sediment accumulation within a hydroelectric reservoir in the Western United States

Many of today's large hydroelectric projects were built with a dead storage capacity designed to trap sediment for a period of approximately 50 years. Since many of these facilities are now approaching their design life, it is expected that the problems associated with upstream sediment accumulation will become more pronounced in the coming years. Smaller, run-of-river facilities which were designed with minimal storage but are often located on steep, sediment-laden rivers are potentially subject to annual sediment volumes that must be diverted away from the intake by some means.
As a reservoir fills with sediment, water depths are reduced and sediment transport capacity within the reservoir increases. This results in more sediment reaching the intake, which can restrict the volume of water entering the intake during periods of lower flows and can increase abrasion damage to the turbines and other mechanical equipment. The resulting impacts on performance, operation and maintenance can have a huge impact on the economic and technical viability of the project. In 2009 it was estimated that the total yearly loss resulting from sediment accumulation in reservoirs was reaching almost US$20 billion (ICOLD 2009), and this number is expected to continue to increase as the world's reservoirs continue to fill with sediment.

The Tools

Numerous examples are cited in the literature where reservoirs have filled with sediment well in advance of time predictions made during the project design, requiring development of remedial sediment management measures at existing facilities. Similarly, new projects are being developed each year that must consider sediment management measures in their designs. Tools available to analyze and develop sediment management measures include drawing on the experience of sedimentation specialists, implementing field investigations and monitoring systems, applying advanced numerical analyses, and conducting reduced-scale experiments in a hydraulic laboratory. In many cases, two or more of these tools are required to arrive at a technically feasible solution.

Brian Hughes **holds a Bachelor's degree in Civil Engineering and a Master's degree in Water Resources, both from the University of British Columbia. He has over 25 years of experience in modelling and hydraulic design having worked on a variety of hydroelectric developments, spillway projects and sediment transport investigations. Since joining Northwest Hydraulic Consultants in 1988, Brian has participated in over 200 physical and numerical model studies. He is a Principal of NHC and the Director of the firm's physical modelling operations.**

NHC and Lasalle|NHC have operated hydraulic laboratories in Canada and the United States for over 50 years. While the laboratories have formed the foundation for many studies related to sediment management at hydroelectric facilities, the capabilities and expertise of the firms' senior specialists, together with advancements in numerical analyses and field investigations, have all played important roles in the development of practical and effective solutions for managing sediment at these facilities.
Reservoir sedimentation and scouring processes, where 3D effects are important,

usually require the use of a physical (scale) model. The biggest challenge in conducting reduced-scale experiments to address sediment management issues is the scale effect associated with simulating the scour and deposition processes occurring in the field. Nonetheless, NHC and LaSalle|NHC have adopted experimental methods using fine sands, low-density model sediments and distorted scale models to study a range of sediment-related problems commonly found at hydroelectric projects.

The experiments conducted at NHC often include both a "comprehensive model" and a larger-scale "section model". The comprehensive model represents a relatively large area of the reservoir and downstream channel, and is used to assess the general sedimentation patterns and behavior of both suspended and bedload sediments approaching the project. Typical scales for comprehensive models of this type generally fall between 1:40 and 1:100. The section model of the intake structure or desanding facility is then used to provide a detailed evaluation of their performance and refine their designs to make them more efficient at preventing sediment from entering the penstock. Examples of comprehensive and section models are illustrated in Figures 2 and 3.

In addition to laboratory experiments, NHC often apply advanced numerical methods and field investigations to gain a better understanding of the processes that are occurring in the field. These methods are applied both during the design stage for assessing the performance of new facilities and during the operation stage if sediment management problems have developed since the facility was constructed. The results of the numerical analyses and field investigations are often used as input parameters for a physical model used to confirm their findings.

Numerical methods utilized by NHC include 1-, 2- and 3-dimensional models, with both hydrodynamic and morphologic capabilities. Recent studies conducted by NHC include assessing the morphologic impacts downstream of a proposed hydroelectric development in western Canada using Telemac 2D (Figure 4), and assessing the efficiency of a proposed sediment bypass tunnel at an existing hydroelectric development in the United States (Figure 5). Field monitoring studies have included the installation of turbidity meters and bed level sensors upstream of the intake for a run-of-river project, to provide real-time information critical to powerhouse operation.

Finally, in-house specialists in sedimentation and geomorphology use the information generated from these tools to develop solutions designed to mitigate the problems associated with sediment accumulation.

The Solutions

Having developed the necessary tools, NHC has worked with clients on establishing solutions for both existing and proposed hydroelectric facilities, ranging in capacity from less than 1 MW to over 2000 MW. The solutions have been as varied as the problems themselves. For small, run-of-river developments they can include (i) field monitoring to guide operation, (ii) controlling the sediment source, (iii) incorporating sediment guide walls or sediment vanes upstream of the intake, and (iv) periodic dredging or sluicing of the accumulated sediment. For larger developments the solutions can also include incorporating sediment bypass

Figure 2 - Comprehensive mobile-bed model using low-density model sediments

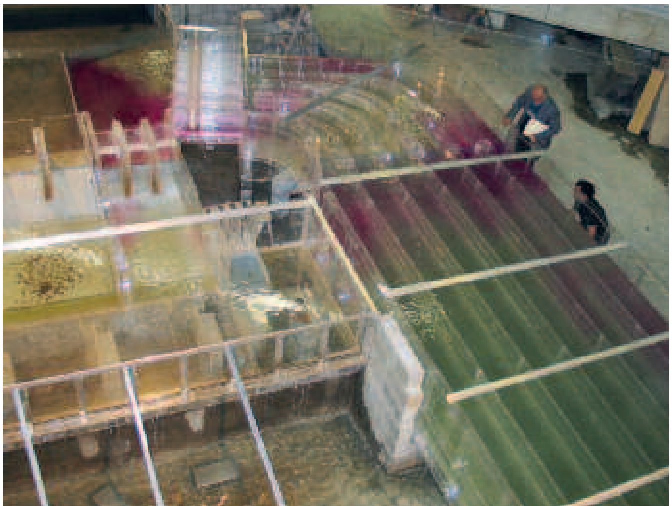

Figure 3 - Detailed section model of a desanding facility for a project in India

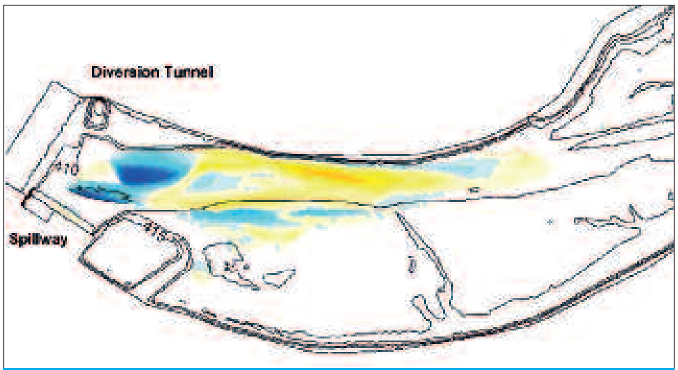

Figure 4 - Prediction of morphologic changes downstream of a proposed hydroelectric project in Canada using Telemac2D

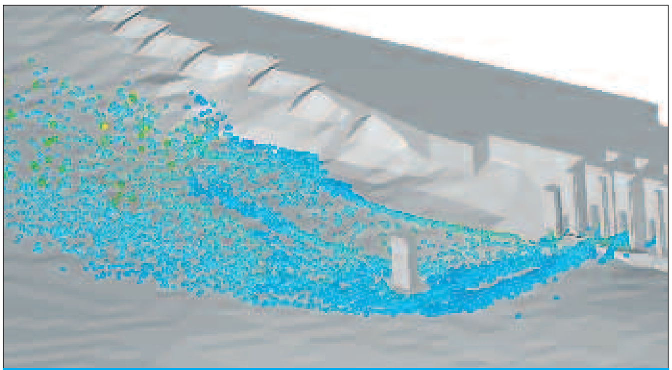

Figure 5 - CFD particle tracking used to assess the efficiency of a proposed sediment bypass tunnel at an existing hydroelectric project

and/or desanding facilities. In many cases the preferred solution may include two or more of these components.

Examples of these solutions include a small run-of-river development in Western Canada where turbidity meters and bed level sensors were installed upstream of the power tunnel intake. Information from these sensors is used by the operators to assess when the power intake should be shut down to protect the turbines and when the sluicing facilities should be operated to remove accumulated sediment from the headpond. For a much larger project, field monitoring sensors, sediment sluicing facilities and a desanding facility were all incorporated into the design to manage very high sediment loads at the intake. In this case, NHC conducted extensive field investigations, numerical model analyses and mobile-bed physical model studies to arrive at a practical and effective solution.

Figure 6 - Intake facility that includes field monitoring sensors, sediment sluicing facilities and a desander

The Next Steps

As existing hydro projects continue to age and as new projects are developed, the need to effectively manage sediment at these facilities will continue to increase. At the same time, the experience of specialists and the capabilities of investigative tools will continue to improve, and the solutions will continue to evolve. NHC and LaSalle|NHC will continue to advance their capabilities and expand their "toolbox" to assist clients with developing solutions related to sediment management – whether a 0.5 MW development on a small stream or a 2000 MW development on one of the world's largest rivers. Advances in numerical analyses and in the capabilities of real-time field sensors may reduce reliance on large-scale physical models; however, specialised skills and experimental capabilities for site-specific investigations and the development of innovative solutions will continue to be in demand for several decades to come. ■

References

International Committee on Large Dams, Sedimentation Committee. March 2009. Sedimentation and Sustainable Use of Reservoirs and River Systems, Draft ICOLD Bulletin