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Proceedings of the

International Symposium on

“Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries”



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Foreword

From the Chairperson of the Local Organising Committee of ICOLD 2016 and Chairperson of the South African National Committee on Large Dams (SANCOLD)

We are extremely happy that this ICOLD Symposium was staged in South Africa as part of the 84th ICOLD Annual Meeting held in Johannesburg in May 2016.

Sunny South Africa is known:

- for its friendly “rainbow” nation as demonstrated during the highly successful 2010 Soccer World Cup event;
- for its beautiful scenery with the Big Five animals in our National and Private Game Parks, the Drakensberg Mountains with its Lesotho Highlands dams and Cape Town with its world heritage site Table Mountain;
- to have 5 030 registered dams of which more than 1 114 are large dams;
- for contributing significantly since 1965 to ICOLD and Africa regarding development of the art and science of dam engineering.

Our SANCOLD Local Organising Committee worked very hard to ensure that this event was well organised, had a high technical content and could provide a forum to experience Africa.

This Symposium reflects much of local, regional and international experience with dams with an emphasis on the developing Africa. The keen interest we received from authors reflects that the subject matter is apt and we hope that these Proceedings together with the delivered Symposium Presentations will form a valuable resource for the future of dams throughout the world.

DBBadenhorst.

Danie Badenhorst
Chairperson of the Local Organising Committee of ICOLD 2016
Chairperson of SANCOLD

Preface

Not only do many countries in Africa and other developing countries still require major water resources and dam engineering development for both water and energy supply but these countries also experience problems with proper long term operation and maintenance of their existing infrastructure. These problems in many cases lead to unsafe and unsustainable conditions that negatively impacts on the surrounding communities as well as the environment.

To try and mitigate this and share the some of the collective wisdom and knowledge available in the larger ICOLD family it was decided have organise an International Symposium titled “Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries” to address some of these issues, in conjunction with the 84st Annual Meeting of the International Commission on Large Dams (ICOLD). The ICOLD Meeting host, the South African National Committee on Large Dams (SANCOLD), organized the Symposium.

These Proceedings contain papers on 9 different themes. Before the Symposium call for papers, 8 different themes were identified as appropriate. A number of relevant abstracts that satisfied the main theme but that did not necessarily satisfied any of the 8 chosen themes were received and subsequently categorised under a theme called “Other”. The 9 themes for the Symposium therefore are:

1) Social and environmental impacts and mitigation measures;
2) Advances in the rehabilitation of dams and appurtenant works to extend their service life including the following:
    a) Improving spillway capacity and flood hydrology determination;
    b) Structural improvements to mitigate the effects of Alkali aggregate reaction, internal erosion potential, foundation failure;
3) Innovative river basin management including the optimisation of the operation of dams;
4) Reservoir sedimentation and management;
5) The state of the art of the tailings dams for their complete lifespan;
6) Strategies for proper surveillance of dams;
7) Sustainable hydropower development in developing countries; and
8) Other

We have received a total number of 333 papers for the Symposium. After the review process 245 papers from 42 different countries were chosen for publication in the proceedings. Of these 245 papers, 96 papers from 34 different countries were chosen for oral presentation in 4 parallel sessions and another 68 papers from 26 different countries were chosen for poster presentation.

All papers submitted for the Symposium were subjected to a full process of peer review and the proceedings contain only those papers that were accepted following this process. The review of the papers was undertaken by the members of the review panel acting independently on one or more assigned papers. This invaluable assistance, which has greatly enhanced the quality of the Proceedings, is gratefully acknowledged.

Finally, the editor wishes to thank the authors for their efforts at producing and delivering quality papers of appropriate quality and relevance. We trust that the Proceedings will be a valued reference for those working in the various fields covered and that it will form a suitable basis for discussion and future development and research.

Louis C. Hattingh
Editor

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Theme 4. Reservoir sedimentation and management

Theme 5. The state of the art of the tailings dams for their complete lifespan

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Theme 7. Sustainable hydropower development in developing countries

Theme 8. Other

Theme 5. The state of the art of the tailings dams for their complete lifespan

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RUN OF RIVER HYDRO – LATEST INNOVATIONS IN DIVERSION DAMS AND SEDIMENT EXCLUSION

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ABSTRACT

The exclusion of sediment for hydropower intakes and the flushing of sediment from reservoirs in order to maintain live storage are critical to the long- term viability and sustainability of hydroelectric projects around the World. This paper presents several design innovations and case studies of run- of-river diversion dams and intakes incorporating inflatable rubber dams, vortex de-sanders and Coanda screen intakes for sediment exclusion and flood passage. It presents the findings of physical and CFD model tests, case studies of operating facilities and lessons learned. The projects showcased include:

- The 147 MW East Toba Hydroelectric Project with inflatable rubber dam for sediment scouring and flood passage.
- The largest capacity Coanda Screen intake in the World on the 45 MW Kokish River Hydroelectric Project, designed for sediment exclusion and fish passage.
- Case studies and lessons learned from 8 other run- of- river hydroelectric projects recently constructed that use crest gates (i.e. rubber dams, Obermeyer crest gates or similar) and/or Coanda Screen intakes for sediment flushing and exclusion.

1. INTRODUCTION

Run-of-river hydroelectric projects typically do not have large storage reservoirs upstream of their intakes, reservoirs that would have sufficient volume and depth to accommodate the exclusion of sediment through settling. Figure 1 below shows the schematic layouts of a typical large hydro storage dam versus a run- of- river hydroelectric facility. A typical run-of-river intake is designed to efficiently divert the hydroelectric project's generation flow into the water conveyance system and as much as practical eliminate sediment from entering the power facilities. Sediment exclusion for run-of-river intakes has historically been managed using desanding basins, large complex structures that are costly to operate and add significantly to the overall project capital cost.

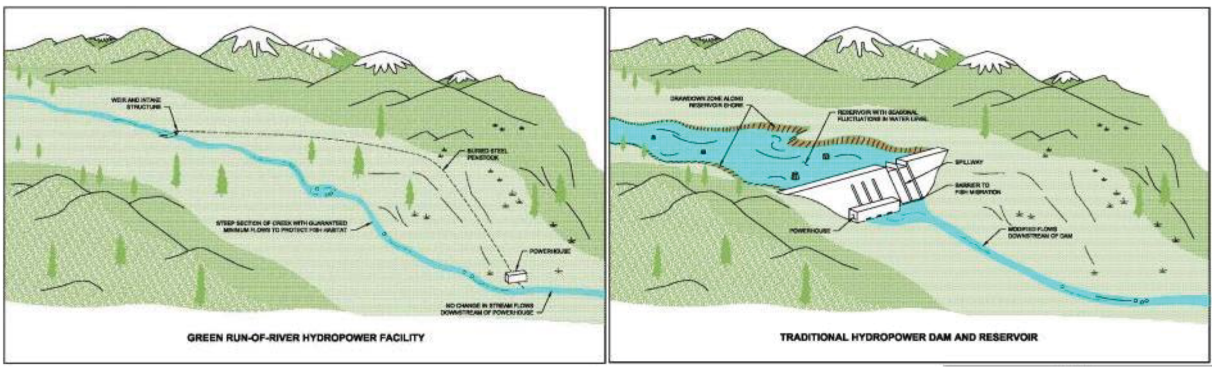

Figure 1. Schematic Layout of Large Dam and Run- of-River Hydroelectric Facilities

This paper will illustrate various alternatives to using large desanding basins. These alternatives have proven to be effective at sediment flushing and exclusion, while also being very cost effective and thereby increasing the likelihood of the run-of-river projects being economically viable. Technologies that Knight Piésold have implemented in the design of run-of-river intakes include:

- **Reservoir De-sander Type Intake** – using the upstream head pond as the primary sediment settling basin.
- **Coanda Screen Type Intake** – where a fine screen is used to physically separate sand particles from the diversion flow using the Coanda shear effect.
- **Combination of Coanda Screens and Reservoir De-sanding**

Several case studies are provided illustrating the application of each technology and the findings of physical and computer based model testing completed to support each design, as well as the lessons learned from commissioning and operating the facilities.

2. RUN- OF- RIVER SEDIMENT EXCLUSION AND FLUSHING TECHNOLOGIES

2.1 Reservoir De-sander

Given the right site conditions with large flat upstream reaches, some run-of-river intake facilities can be designed and constructed such that the upstream reservoir can be used as a settling basin for a larger fraction of mobilized sediment that arrives at the facilities intake. The relative size, depth and surface area, of run- of- river reservoirs is small compared to those of large hydroelectric facilities, limiting the reservoirs ability to settle smaller sediment particles. In addition run- of- river reservoirs will infill with settled sediments over time taking away some of the active storage and reducing the reservoirs ability to exclude sediment.

Reservoir flushing is required to maintain active storage and the ability of the reservoir to instigate settling of sediment. Intake designs that utilize reservoir de-sanding technology incorporate one or more modes for flushing the reservoir to regain active storage and settling capacity. Reservoir flushing is typically accommodated by incorporating crest gates (typically Obermeyer or inflatable rubber dams) or sluicing facilities to increase flow velocities past the intake to mobilize deposited sediments. In addition these facilities are also designed to aid in the passage of flood flows through the intake. Figure 2 below shows the 49 MW Rutherford Creek Project intake that creates a small upstream reservoir and incorporates an inflatable rubber weir and low level sediment sluice to facilitate reservoir flushing and flood passage.

Figure 2. Rutherfod Creek 49 MW Hydro Project - Inflatable Rubber Dam

Knight Piésold has completed the design of several intake structures that utilize reservoir de-sanding to aid in the reduction of sediments from entering the hydroelectric facilities. Throughout the detailed design key considerations are taken into account with respect to the size and location of such facilities, together with the sediment characteristics, in order to optimize their effectiveness. Physical and computer fluid dynamic (CFD) models are developed in most cases to help in this regard. A typical cross- section of an intake that uses an inflatable rubber weir is shown below in Figure 3.

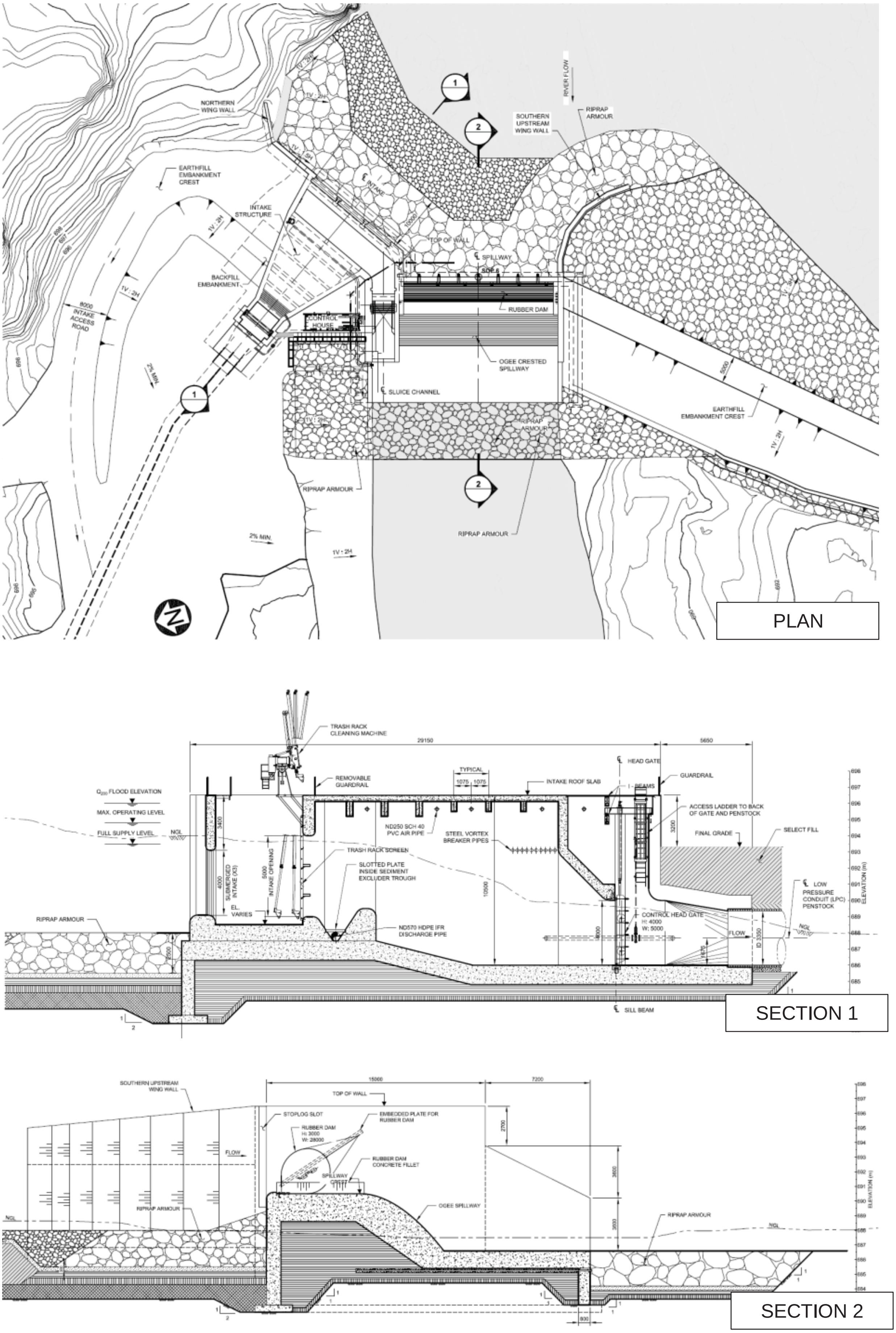

Figure 3. Reservoir De-sander Type Intake – Plan and Sections

Physical models have proven to be a cost effective solution in optimizing intake designs that utilize reservoir de-sanding technologies. Knight Piésold has worked with Northwest Hydraulics Inc., hydraulic modelling specialists, to develop and test physical intake models. A joint paper authored by Knight Piésold and Northwest Hydraulics entitled "Run-of-River Hydroelectric Projects – Intake Design Considerations Based on Physical Hydraulic Model Study Results" (Mottram et al. 2009) describes in detail the physical model testing conducted for run- of- river intakes. Figure 4 below illustrates the physical model that was constructed and tested for the 33 MW Upper Stave River Hydroelectric Facility (HEF).

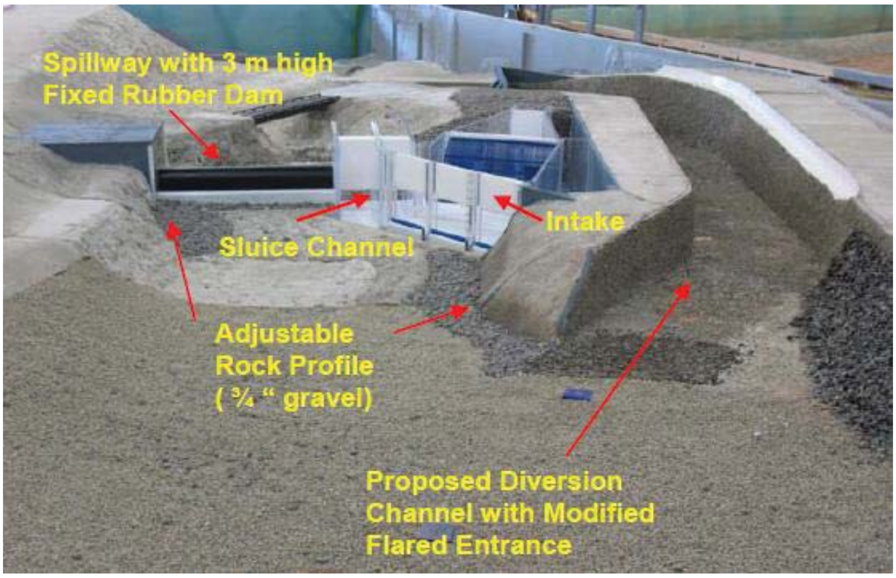

Figure 4. Physical Model Constructed and Tested for the 33 MW Upper Stave River HEF

Knight Piésold's involvement in run-of- river hydroelectric facility intakes that incorporate inflatable rubber dams to create an upstream reservoir and aid in sediment flushing include:

- Lower Mamquam 55 MW Hydroelectric Project – Canada
- Rutherford 49 MW Hydroelectric Project – Canada
- Upper Stave 33 MW Hydroelectric Project – Canada
- East Toba 147 MW Hydroelectric Project – Canada
- Sabanilla 30 MW Hydroelectric Project – Ecuador

Case studies illustrating the effectiveness of reservoir de-sanding technologies for sediment exclusion are provided below.

2.1.1 147 MW East Toba River Hydroelectric Facility

The East Toba River Hydroelectric Project is a 147 MW run-of-river hydro development located approximately 100 km north of Powell River B.C., Canada. The Project was identified and permitted by Knight Piésold for Toba Montrose General Partnership (Alterra Power and GE). Knight Piésold was subsequently hired by Peter Kiewit Infrastructure Co. to perform the detailed design of the Project under an EPC contract that guaranteed performance, schedule and price.

Salient details for the major project components are as follows:

- Rated Capacity of Plant: 147 MW
- Design Flow: 30.7 m^3/s
- Penstock Length: 5.3 km (Diameter: 2.54 m to 3.35 m)
- Gross Head: 581.1 m
- Turbine(s): 2 x Pelton Units, 6-Jet Vertical Axis

The East Toba River facility utilizes an upstream de-sanding reservoir to eliminate a significant fraction of sediment from entering the generating facilities. The reservoir has an approximate surface area of 6.5 ha (~600 m in length) with a maximum depth of 5 metres at the intake. The reservoir volume is maintained using an inflatable rubber dam located across the intakes diversion weir spillway crest. The rubber dam spans a 28 metre section of the diversion weir and when lowered allows deposited sediment to be flushed out of the reservoir thereby maintaining the active storage.

In addition to the upstream deposition zone created by the reservoir the intake was designed with a sluice way located immediately upstream of the main intake trash rack. Sediment deposits within the sluiceway are flushed periodically through a radial sluice gate. The design also included a vortex de-sander located immediately downstream of the main intake trashrack. The vortex de-sander is designed to create a vortex across the intake flow profile that allows sediment to be captured through a grated opening in the intake floor that is continuously drawing a low flow out of the intake box, and serves the dual purpose of also providing the continuous ecological flow release (instream flow requirement – IFR).

2.1.2 Upper Stave River Hydroelectric Facility

The Upper Stave River Hydroelectric Project is a 33 MW run-of-river hydro development located approximately 50 km northeast of Vancouver B.C., Canada. The Project was identified and permitted by Knight Piésold for Cloudworks Energy (now Innergex Renewable Energy). Knight Piésold was subsequently hired by Kiewit to perform detailed design of the Project under an EPC contract that guaranteed performance, schedule and price.

Salient details for the major project components are as follows:

- Rated Capacity of Plant: 33 MW
- Design Flow: 43.8 m^3/s
- Penstock Length: 1.8 km with maximum diameter of 3.8 m
- Gross Head: 101 m
- Turbine(s): 4 x Francis Units, Horizontal Axis

The Upper Stave River Hydroelectric Project also utilizes an upstream reservoir as the first measure to exclude sediment from the generating facilities. The Upper Stave reservoir has an approximate surface area of 5 ha (~600 m in length) with a maximum depth of approximately 5 metres at the intake. The reservoir volume is maintained using an inflatable rubber dam located across the intake crest. The rubber dam spans a 24 metre section of the intake and when lowered allows deposited sediment to scour out of the reservoir.

The Upper Stave River facility has two sluiceways incorporated into its design; one situated between the rubber dam and the main intake portals with direct connectivity to the upstream reservoir and one downstream of the main intake portals. The addition of a sluiceway between the rubber dam and main intake portals allows for regular removal of sediment that accumulates upstream of the intake portals. This feature allows for the scouring of sediment without the need to lower the rubber dam resulting in no disruption of plant operation. A vortex de-sander is also incorporated into the Upper Stave intake.

2.2 Coanda Screen

Sediment exclusion from hydroelectric facilities has also been achieved effectively using screening technologies. Screening technologies are typically implemented at sites where an upstream reservoir may not be effective at settling the target fraction of mobilized sediment. Reasons for the ineffectiveness of upstream reservoirs are usually attributed to reservoir size, limiting settling capacity, and sediment volume. Knight Piésold has incorporated the Coanda Shear Effect Screen into several intake designs to overcome this condition.

Coanda Screens are located within the diversion structure at the intake where all design flow diverted into the hydroelectric facility must pass the screen. Coanda Screens use the Shear Effect to separate diversion flows from the stream flow and have been effectively used to eliminate sediment particles greater than 1 mm resulting in only finer sediment entering the hydroelectric facility intake box. Vortex de-sanders have also been incorporated into the intake boxes to provide ecological flow releases and remove additional sediment. The impact that the finer sediment has on the generating facilities, pipelines and turbines, is mitigated in the design where coatings and materials are specified to accommodate the types and fraction of sediment for each facility.

In addition, even though the Coanda type intakes upstream reservoirs are typically smaller than those created using reservoir de-sanding for sediment exclusion, they do provide the first line of defence against sediment. These smaller reservoirs are expected to infill with larger sediment at a quicker rate and consideration in the design must be made for the regular removal of these sediments. Removal of deposited sediment is most effectively dealt with by incorporating low level sluicing facilities that will aid in flushing deposited sediments. The size and location of these facilities is a key consideration in the overall layout of a Coanda Screen intake. A typical layout and cross section of an intake that uses a Coanda Screen is illustrated in Figure 5 below.

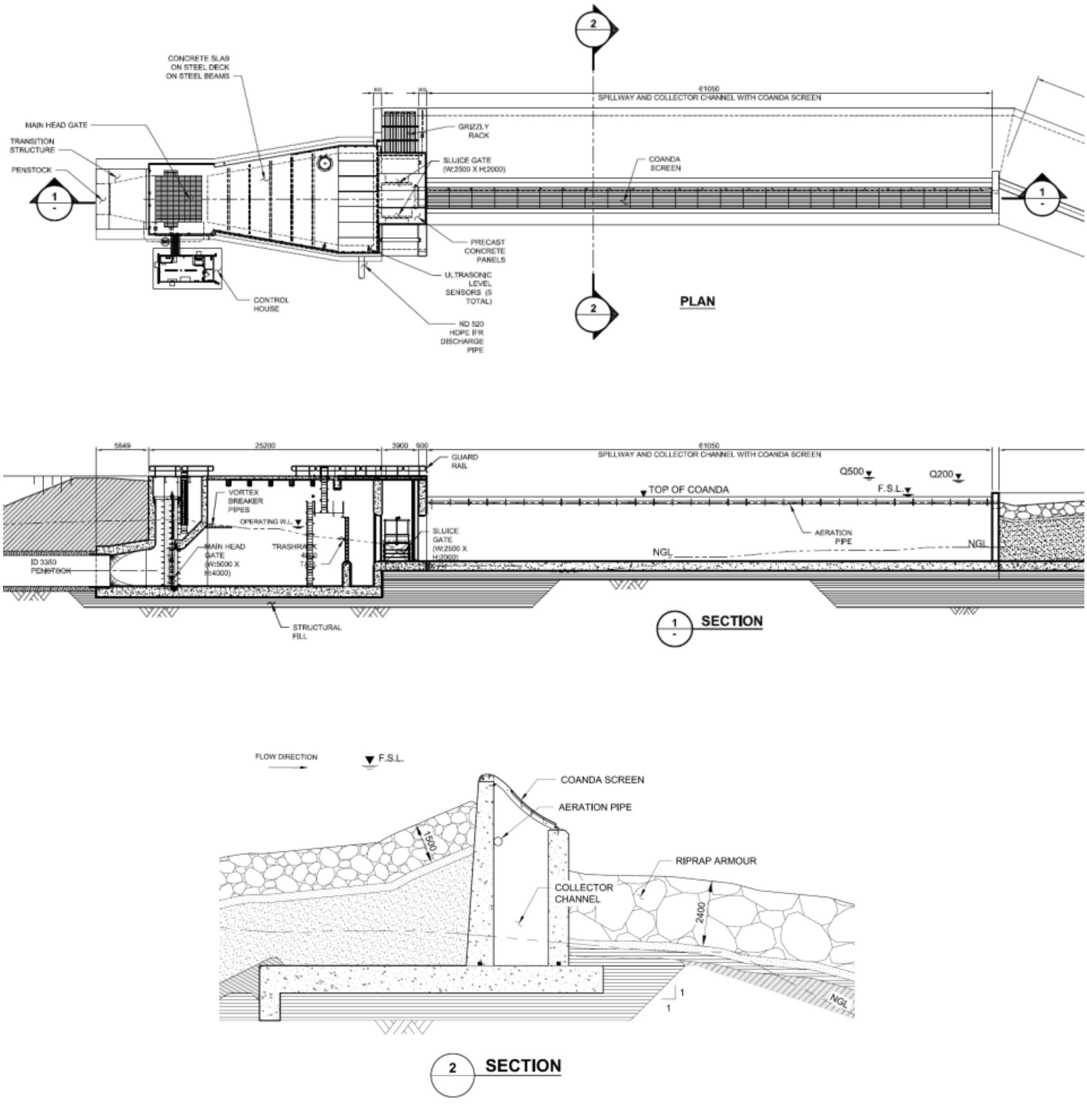

Figure 5. Typical Layout and Cross Section of a Conada Screen Intake

In order to determine the effectiveness of a Coanda Screen for sediment exclusion Knight Piésold conducted extensive research into their use. Interviews were held with operators of existing hydroelectric facilities and inspections were conducted. This research was considered invaluable when optimizing the layout and sizing of the intake facilities.

The first Coanda screen intake designed by Knight Piésold was in 2004 and since that time an additional eight (8) Coanda intakes have been designed, all of which were designed under Engineer, Procurement and Construction (EPC) contracts with Peter Kiewit Infrastructure Co. (Kiewit). During the EPC design of six (6) of these facilities Norrish Screen, the Coanda Screen manufacturer, in partnership with Knight Piésold and Kiewit, conducted physical model testing at the University of Colorado. Model testing required the construction of a 1 metre wide full scale section of Coanda Screen. Testing was conducted to confirm the diversion flow capacity of the screens and the sediment exclusion characteristics. Figure 6 below shows the full scale model that was constructed for this testing.

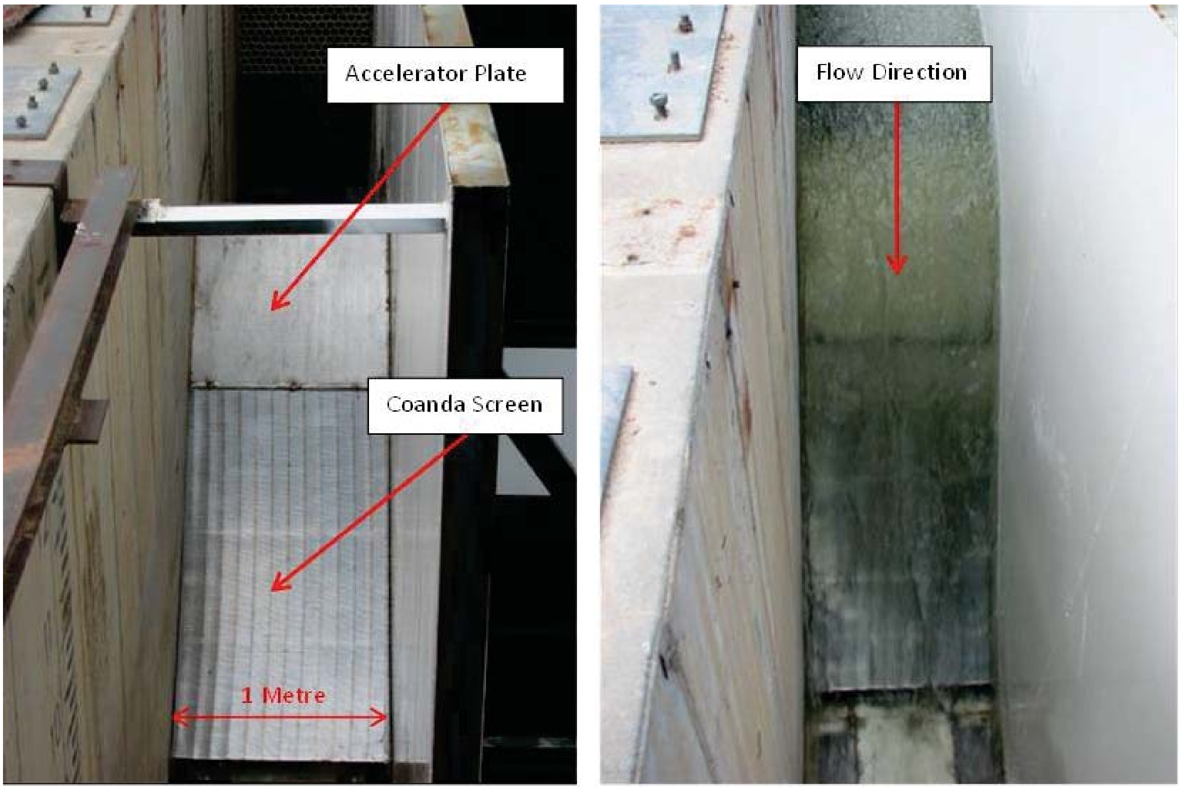

Figure 6. Full Scale Coanda Screen Model

Run- of- River hydroelectric facilities designed by Knight Piésold that incorporate Coanda Screens into the intake for sediment exclusion include:

- 9 MW Mc Nair Creek Hydroelectric Project
- 23 MW Fire Creek Hydroelectric Project
- 22 MW Stokke Creek Hydroelectric Project
- 18 MW Tipella Creek Hydroelectric Project
- 27 MW Douglas Creek Hydroelectric Project
- 88 MW Montrose Creek Hydroelectric Project
- 27 MW Lamont Creek Hydroelectric Project
- 15 MW Box Canyon Hydroelectric Project (3 Coanda Intakes)
- 45 Kokish River Hydroelectric Project

Case studies illustrating the effectiveness of the Coanda Shear Effect screen technology for sediment exclusion are provided below for a selection of these facilities.

2.2.1 McNair Creek Hydroelectric Facility

The 9 MW McNair Creek Hydroelectric Facility was the first project designed by Knight Piésold that utilized a Coanda Screen for diverting generation flows into the intake structure. Prior to detailed design Knight Piésold conducted extensive research into the use of the Coanda Screen. Research included review of designs completed by other firms, inspection of operating facilities and interviews with operators to fully understand the screens functionality, lessons learned and recommended optimization.

The McNair Creek project is a 9 MW run-of-river hydro development located approximately 35 km northwest of Vancouver B.C., Canada. The Project was optimized by Knight Piésold for Renewable Power Corp. Knight Piésold was subsequently hired by Kiewit to perform detailed design of the Project under an EPC contract that guaranteed performance, schedule and price.

Salient details for the major project components are as follows:

- Rated Capacity of Plant: 9 MW
- Design Flow: 3.3 m^3/s
- Penstock Length: 3.3 km
- Gross Head: 338 m
- Turbine(s): 1 x Pelton Unit, 5-Jet Vertical Axis

The McNair Creek intake incorporated a 19.8 m long Coanda Screen with a concrete overflow weir on the right bank and the intake structure on the left with earth embankments tying the structure into the existing terrain. The resulting upstream head pond (reservoir) has an area of approximately 0.4 ha with a maximum depth of approximately 2 metres from the natural bed to the crest of the Coanda spillway. The resulting small reservoir has some capacity to settle settlement, with the primary exclusion mechanism for sediment being the Coanda Screen.

The Coanda Screen currently installed in the facility has a 2 mm screen spacing which excludes sediment particles larger than 1 mm in size. The overall length of the screens is larger than required to pass specified design flow. The additional length allows for blockage of screens with floating debris and wear of the leading edge of the wedge wires, which reduces their efficiency over time. As the sediment yield of this catchment area is fairly low, the small reservoir has taken some time to infill with sediment. A low level sluice gate was incorporated into the overflow weir to accommodate removal of some of this accumulated sediment, as well as provide a bypass facility for screen maintenance.

2.2.2 Box Canyon Hydroelectric Facility

The 15 MW Box Canyon Hydroelectric Facility is a run- of- river hydro project that is currently under construction. The project is located within the McNab Creek Valley approximately 40 km northwest of Vancouver, BC Canada. The Box Canyon project includes three main intake structures with 5 tributary diversions that divert generation flows into two separate low pressure pipelines. The low pressure pipelines are connected to a common high pressure penstock that conveys generation flows to the powerhouse. All three main intakes utilize Coanda Screens for sediment exclusion. Tributary intakes utilize coarse chute screens to remove only the large fraction of sediment, and deposit water into the main intake headponds.

Salient details for the major project components are as follows:

- Rated Capacity of Plant: 15 MW
- Design Flow: 3.96 m^3/s
- Low Pressure Penstock Length:
  - Marty Creek 1.5 km
  - Cascara Creek 2.9 km
  - Box Canyon Creek 1.1 km
- High Pressure Penstock Length: 3.2 km
- Gross Head: 517 m
- Turbine(s): 1 x Pelton Unit, 6-Jet Vertical Axis

All three main intakes are located within steep reaches of their respective catchments, resulting in small head ponds upstream. Coanda Screen and Headpond characteristics for the three intakes are listed below:

Box Canyon Creek:	Head Pond Area = 0.15 ha, Maximum Depth = 2.5 m Screen Length = 5 m
Marty Creek:	Head Pond Area = 0.06 ha, Maximum Depth = 2.0 m Screen Length = 5 m
Cascara Creek:	Head Pond Area = 0.03 ha, Maximum Depth = 2.5 m Screen Length = 5 m

Each Coanda Screen has been sized to pass twice the required design flow in order to allow for some clogging of screens with debris and screen wedge wire wear over time. The Coanda Screens specified have a 2 mm screen spacing which is anticipated to exclude sediment particles larger than 1 mm. Low level sluice gates are incorporated into the overflow weir at each intake site to accommodate removal of accumulated sediment in addition providing flood flow capacity.

2.3 Combination of Coanda Screen and Reservoir De-sander

Where the right conditions exist, the use of Coanda Screen and Reservoir De-sanding technologies may be combined in order to realize the benefit of both systems. The Coanda Screens also act as effective fish screens, and this provides a cost effective screening solution for fish bearing systems. The resulting general intake layout consists of a sufficiently large flat area upstream of the intake structure to develop a reservoir that can accommodate settlement of the larger fraction of mobilised sediments. The intake diversion structure incorporates the use of the Coanda Screen to divert generation flows while allowing the exclusion of finer sediments and fish from entering the intake.

Combined use of Coanda Screen and Reservoir De-sanding technologies is illustrated below.

2.3.1 Kokish River Hydroelectric Facility

The 45 MW Kokish River Hydroelectric Facility is located on Vancouver Island, approximately 290 km northwest of Vancouver BC, Canada. Knight Piésold was contracted by Kiewit under an EPC contract to complete the detailed design of the Kokish River project, being developed by Kwagis Power Limited Partnership (partnership between Brookfield Energy and Namgis First Nation).

The run- of- river hydroelectric project takes advantage of both reservoir de-sanding and screening technologies to exclude sediment and fish from the generation flow.

- Rated Capacity of Plant: 45 MW
- Design Flow: 25 m^3/s
- Penstock Length: 9.2 km
- Gross Head: 238 m
- Turbine(s): 4 x Pelton Units, 6-Jet Vertical Axis

The Kokish River intake comprises of a 58.6 m long Coanda Screen capable of diverting the project generation flow into the intake box. The intake box is located on the right side of the screen with a concrete overflow weir on the left. The resulting upstream reservoir has a surface area of approximately 1.5 ha and an estimated free storage volume of 23,400 m^3. Figure 7 below illustrates the general arrangement of the Kokish River intake.

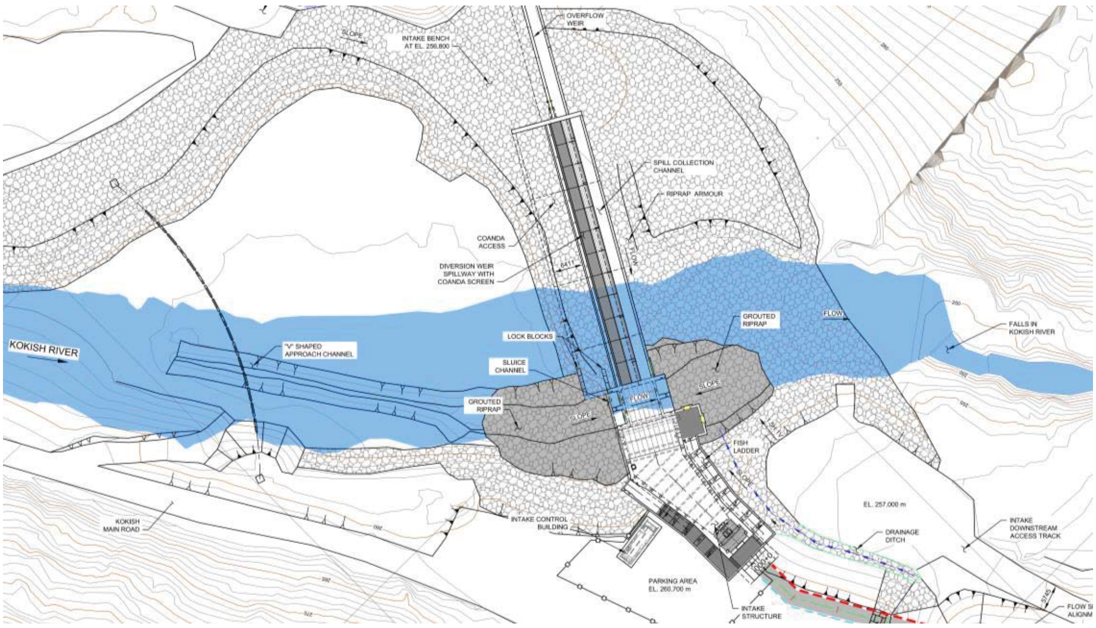

Figure 7. Kokish River Intake General Arrangement

A low level sluiceway, set below the Coanda collector channel invert, allows for scouring of sediment from the headpond when open. Setting the sluiceway below the Coanda collector channel allows for sediment scour while the hydroelectric facility is in operation. A physical model was constructed and tested at NHC laboratory in order to assess the overall functionality of the intake including the ability of the sluiceway to scour deposited sediment from the reservoir. Figure 8 below shows the model created for assessing the Kokish River intake hydraulics and sediment removal characteristics and the as constructed intake.

Figure 8. Kokish River Intake Physical Model

3. CONCLUSION

Developing run- of river- hydroelectric facilities where sediment loads are high requires careful consideration of the various de-sanding alternatives. Traditional de-sanding basins have historically been found to drive up capital costs, are difficult to locate in steep terrain and have long-term maintenance issues that require significant plant downtime. Reservoir de-sanding and screening technologies have been found to be cost effective solutions to these issues. Physical and CFD modelling adds value to designs through increasing the efficiency of the final intake arrangement.

4. ACKNOWLEDGEMENTS

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- Peter Kiewit Infrastructure Co. (www.kiewit.com)
- Elemental Energy (www.elementalenergy.ca)
- Brookfield Renewable Energy Partners (www.brookfieldrenewable.com)

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