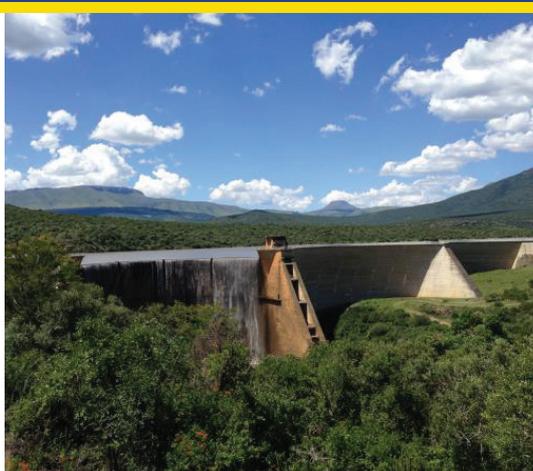
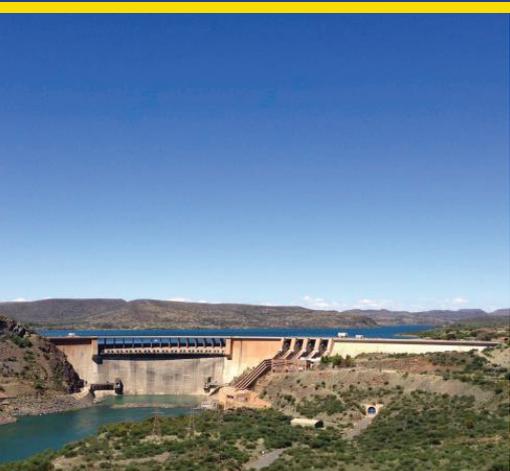




84th ICOLD ANNUAL MEETING



Proceedings of the
International Symposium on
***“Appropriate technology to ensure
proper Development, Operation
and Maintenance of Dams
in Developing Countries”***



18 May 2016
Johannesburg, South Africa



Proceedings of the
International Symposium on
***“Appropriate technology to ensure
proper Development, Operation and
Maintenance of Dams in Developing
Countries”***

Johannesburg, South Africa, 18 May 2016

Organised as part of the 84th ICOLD Annual Meeting,
Johannesburg, South Africa, 15 to 20 May 2016.

The information contained in this publication regarding commercial projects or firms may not be used for advertising or promotional purposes and may not be construed as an endorsement of any product or firm by the South African National Committee on Large Dams (SANCOLD). SANCOLD accepts no responsibility for the statements made or the opinions expressed in this publication.

Copyright © 2016 South African National Committee on Large Dams (SANCOLD)

ISBN 978-0-620-71042-8

South African National Committee on Large Dams (SANCOLD)
PostNet Suite, #498
Private Bag X025
Lynnwood Ridge
Pretoria, 0040, South Africa
secretary@sancold.org.za
www.sancold.org.za

Symposium organisation

Editor

Louis Hattingh

Secretariat

Louis Hattingh

Paul Roberts

Paul Vinagre

Review panel

Mr Michael Abebe (Ethiopia)
Prof Mark Alexander (South Africa)
Ms Henriette Anderson (South Africa)
Dr George Annandale (USA)
Ms Ilse Aucamp (South Africa)
Mr Christian Auel (Japan)
Dr Markus Aufleger (Germany)
Mr Danie Badenhorst (South Africa)
Dr Gerrit Basson (South Africa)
Mr Andrea Baumer (Switzerland)
Mr Johan Beukes (South Africa)
Ms Michelle Blaeser (South Africa)
Ms Terry Calmeyer (South Africa)
Mr David Cameron-Ellis (South Africa)
Dr Robin Charlwood (USA)
Dr Pierre Choquet (Canada)
Dr Ahmed Chraibi (Morocco)
Mr Bertrand Collet (South Africa)
Mr Ross Cooper (South Africa)
Mr Andrew Copeland (South Africa)
Mr Gerald de Jager (South Africa)
Dr Manuel Gomez de Membrillera Ortuño (Spain)
Dr Michael Detering (Germany)
Prof Ignacio Escuder Bueno (Spain)
Mr Jurgen Fleitz (Spain)
Mr Leon Furstenburg (South Africa)
Prof André Gorgens (South Africa)
Mr Duncan Grant-Stuart (South Africa)
Mr Thierry Guilloteau (France)
Mr DJ Hagen (South Africa)
Mr Louis Hattingh (South Africa)
Mr Dieter Heinsohn (South Africa)
Dr Andy Hughes (UK)
Dr Sam Johansson (Sweden)
Dr Andrzej Kijko (South Africa)
Mr Helmut Knoblauch (Austria)
Mr Johan Koekemoer (South Africa)
Mr Ian Landon-Jones (Australia)
Dr Aldu le Grange (South Africa)
Mr Stephen Mallory (South Africa)
Dr Peter Mason (UK)
Dr Ronnie McKenzie (South Africa)
Mr Andre Mostert (Namibia)
Mr Dawid Mouton (South Africa)
Dr Laurent Mouvet (Switzerland)
Prof Pilate Moyo (South Africa)
Mr Chris Muir (Namibia)
Ms Kogi Naidoo (South Africa)
Mr Jan Nortje (South Africa)
Dr Chris Oosthuizen (South Africa)
Dr George Papageorgiou (South Africa)
Dr Alan Parrock (South Africa)
Dr Alejandro Pujol (Argentina)
Mr Peter Pyke (South Africa)
Dr Paul Roberts (South Africa)
Dr Tendai Sawunyana (South Africa)
Mr Ivor Segers (South Africa)
Dr Mike Shand (South Africa)
Dr Quentin Shaw (South Africa)
Mr Frezer Shiferaw (Ethiopia)
Mr Jay Stateler (USA)
Mr Gawie Steyn (South Africa)
Mr T Sumi (Japan)
Mr Martin Teal (USA)
Mr Tente Tente (Lesotho)
Dr Michel Tremblay (Canada)
Ms Mari Trumpelmann (South Africa)
Mr Leo van den Berg (South Africa)
Mr Danie van der Spuy (South Africa)
Mr Walther van der Westhuizen (South Africa)
Mr Marco van Dijk (South Africa)
Mr Pieter van Rooyen (South Africa)
Dr Martin van Veelen (South Africa)
Mr Dawid van Wyk (South Africa)
Mr John Wates (South Africa)
Dr Pieter Wessels (South Africa)
Mr Henry-John Wright (South Africa)

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. Hartingh
Editor

Table of contents

<i>Symposium organisation</i>	<i>ii</i>
<i>Foreword</i>	<i>iii</i>
<i>Preface</i>	<i>iv</i>
 <i>Theme 1. Social and environmental impacts and mitigation measures</i>	
Public Safety and Security of Dams are not Mutually Exclusive <i>WF Foos, F Calcagno, & PG Schweiger (USA)</i>	1-1
Health and Development in Large Projects <i>SA Kaul, M Kumalo & E Barendse (Lesotho)</i>	1-9
Assessment of the Relationship between Dams Owners and the Host Territory: The Italian Experience <i>G Mazzà, & A Frigerio (Italy)</i>	1-17
Conflict Management for Existing Water Resource Projects and Dams <i>P Mulvihill (New Zealand)</i>	1-27
Improvement of the Procedure for Conflict Resolution of Dam Projects in Korea <i>Hye Jin Kim, Seong Won Jin & Bong Soo Kim (South Korea)</i>	1-33
Veľká Domaša Dam – Current State in Water Management as a Result of Socio-Economic Changes in the Catchment Area <i>D Mydla & R Ivančo (Slovakia)</i>	1-39
Social Issues and Land Acquisition Mitigation in Construction of Nipah Dam and Gongseng Dam – East Java Indonesia <i>NA Fady, A Rahmat & S Inasih (Indonesia)</i>	1-45
Resettlement and Livelihood Restoration in the Context of Large Dams: Phase II of the Lesotho Highlands Water Project <i>TA Sekhesa & EG Barendse (Lesotho)</i>	1-55
Implementation of the LHWP Phase II - Approach towards Social Matters <i>T Tente, M Thokoa, G Mokone & M Phakoe (Lesotho)</i>	1-65
Effectiveness and the Role of Social Studies in the Localization and Selectivity Normal Level of Dams (Case Study: Layleh Dam and Hydro Power Plant) <i>A Nourisani, RG Rad (Iran)</i>	1-75
Rehabilitation of Bell Springs as a Symbol of Corporate Social Responsibility- A Case Study of Daryan Dam and Power Plant <i>A Nourisani (Iran)</i>	1-83
Construction of Chitgar Dam's Artificial Lake - Social and Environmental Impact Assessment <i>A Emam, M Zolfagharian, Kh Binazadeh, H Alavi Deilami, A Eslaminia & J Bayat (Iran)</i>	1-91
Environmental and Social Aspects of the Lom Pangar Reservoir Filling Program <i>JP Grandjean, G Gwét & M Lino (France)</i>	1-101
Environment Management of Jinping-I Hydropower Project during Construction <i>W Shiyong, C Wei, W Hongmei (China)</i>	1-109
The Challenges of Implementing Mega Projects in Urban Areas – A Case Study of BWP And MMTS-2 <i>K Naidoo, J Nyakale & T Tente (South Africa/Lesotho)</i>	1-119
Hydropower Reservoirs as Ramsar Sites: Dams to Support the Protection of Wetland Conservation Areas <i>E Branche (France)</i>	1-127
Practical Solutions for Accommodating Ecological Water Requirements in the Design and Operation of Dams in South Africa <i>H Pieterse, P Scherman, M Shand, G de Jager & J Lombaard (South Africa)</i>	1-137
Managing Ecological Flow Releases from the Berg River Dam in South Africa <i>M Shand, B Abban, D Van Wyk & N Rossouw (South Africa)</i>	1-147

Adapting to Environmental Demands: High Capacity Coanda Intake <i>S Løvfall, HT Ose & T Bakken (Norway)</i>	1-157
Promoting Eco-Friendly River Basin Development Solutions <i>A Abdulmit & S Ionescu (Romania)</i>	1-165
De-Commissioning of Hammarsdale Dam by Transforming it from a Contaminated Problem Child into a Sustainable Wetland <i>S Reynolds & W van der Westhuizen (South Africa)</i>	1-175
Environmental Vulnerability Assessment of Basin Climate Change and its Effects on Adaptive Conservation Countermeasures for Key Fishes involved with Huge Hydropower Station Operation in Yangtze River <i>G Yong, Z Xu , C Yongbo & S Zhiyu (China)</i>	1-185
Change of Redoks Potential in Aquatic Ecosystem at Djuanda Dam <i>M Amron, H Idrus, R Mayasari & E Dwi P (Indonesia)</i>	1-191

Theme 2a. Advances in the rehabilitation of dams and appurtenant works to extend their service life including improving spillway capacity and flood hydrology determination

Design Flood Estimation in South Africa: Challenges and Developments <i>JC Smithers (South Africa)</i>	2a-1
New Methodology for a Robust Estimation of Large Return Period Floods for Design of Large Dam Spillways <i>E Cifres (Spain)</i>	2a-11
Risk Governance Implementation for a Cascade System on Drini River, Albania <i>I Escuder-Bueno, A Jovani, J Moralo-García & JM Alonso Muñoz (Spain/Albania)</i>	2a-21
The Advantages of Performing a Probabilistic Spillway Assessment in an Arid Environment – The Namibia Example <i>A Mostert & LC Hattingh (Namibia/South Africa)</i>	2a-29
Generation of Extreme Events for Flood Risk Assessment - Single Events and Continuous Discharge Time Series <i>H Lohr (Germany)</i>	2a-39
Devils Lake Flood Risk Management <i>SL McCaskie, PD Madison & BK Greenleaf (USA)</i>	2a-49
A Study of the Effective Hydrological Safety of Concrete Dam <i>S Cho, S Jang & D Cha (South Korea)</i>	2a-59
Flood Control Ability Improvement Project for the Peace Dam in Korea <i>HS Park, DH Kwon & HI Kim (South Korea)</i>	2a-69
A Comparative Study of Telemetric Rainfall Data in Three Gorges Project <i>Y Xu & L Zhiwu (China)</i>	2a-77
Hydraulic Scaled Model Tests for the Optimization of Approach Channel Excavation and Approach Flow Conditions of Haraz Morning Glory Spillway <i>S Emami & AJ Schleiss (Iran/Switzerland)</i>	2a-87
Existing Shaft Spillway Enhancement Based on Physical Modelling <i>M Broucek , L Satrapa, M Zikal & M Kralik (Czech Republic)</i>	2a-97
Investigation into the Fluid and Structural Behaviour of Piano Key Weirs <i>FJM Denys, GR Basson & JAvB Strasheim (South Africa)</i>	2a-107
Breach Formation in a Fuse Plug – Evaluation of Field and Laboratory Tests <i>J Lagerlund, A Vazquez, M Svensson, M Billstein & P Viklander (Sweden)</i>	2a-117
Dam Kjøljua, Efficient Spillway Design Reassessment using CFD <i>C Thomas-Lepine, (Norway)</i>	2a-127
The Development of the Vc-Ogee Relationship which Incorporates Upstream 3-Dimensional Flow Conditions <i>SJ van Vuuren & GL Coetzee (South Africa)</i>	2a-137
Rehabilitation of Dams owned by the Department of Water and Sanitation in South Africa <i>W Ramokopa & W van der Westhuizen (South Africa)</i>	2a-147

“Smaller” Dam Spillway Rehabilitation <i>H Anderson (South Africa)</i>	2a-157
Planning and Design of Additional Discharge Facilities in Japan <i>N Hakoishi, T Sakurai & T Ikeda (Japan)</i>	2a-161
Kariba Dam Rehabilitation Project – Improving Spillway Capacity through Reshaping of the Plunge Pool <i>MC Munodawafa, DZ Mazvidza & SZ Mhlanga (Zambia)</i>	2a-171
Hazelmere Dam Raising <i>AJ Botha, D Booyse & IP Fitz (South Africa)</i>	2a-181
Reconstruction of Emergency Spillway on the Vihorlat Dam <i>M Miščík & O Hrabovský (Slovakia)</i>	2a-191
Safety Improvement of Massingir Dam <i>LP Mandlate, P Anthinac & F Del Rey (Mozambique/France)</i>	2a-195
Decreasing of Nipah Spillway Crest Elevation due Social Issue, Sampang - Indonesia <i>CD Yuliningtyas, B Prasetyo, N Hidayat & AI Ambara (Indonesia)</i>	2a-205
Practical Lessons Learnt from the Rehabilitation of Spillway Gates at Cahora Bassa Dam <i>AJ Botha, A Campos De Carvalho, J Chipuazo, E Carvalho L Boulat, D Hensi & C Chatron (South Africa/Mozambique)</i>	2a-209
Re-Commissioning Storfinnforsen’s Bottom Outlet after over 60 years’ idling <i>J Yang, J Larsson & C-O Nilsson (Sweden)</i>	2a-219
Refurbishment of the Phalaborwa Barrage <i>A Chaminuka, AJ Botha, F Shabalala & M Motaung (South Africa)</i>	2a-229
Hydro-Mechanical Equipment Design for the Rehabilitation of the Corumana Dam <i>RSJ van Wyk, AM Hay, RJ Minnaar, M Perduh & H Barnard (South Africa)</i>	2a-239
Strategies for Improving the Safety of Spillway Gates <i>BW Leyland (New Zealand)</i>	2a-249
Automatic Self Actuating Spillway Gates to Improve Dam Safety and Storage in Dams <i>PD Townshend (South Africa)</i>	2a-259
Assessment and Surveillance of Erosion Risk in Unlined Spillways <i>SE Pells (Australia)</i>	2a-269
A Tale of Two Spillways <i>PJN Pells, S Pells & M van Schalkwyk (Australia)</i>	2a-279
Mechraa Homadi Dam Bottom Outlet Rehabilitation <i>A Kwayep, F Bouajaj & M El Alaoui (Morocco)</i>	2a-289
Computational Fluid Dynamic (CFD) Modelling of the Outlet Control Valve of Ncora Dam <i>O Sawadogo, P Townshend & GR Basson (South Africa)</i>	2a-297
Power Intake Structure Model Testing of Mica Project <i>W Yihong, Z Jinxiong, Y Fan, Z Wenyuan & Z Dong (China)</i>	2a-307

Theme 2b. Advances in the rehabilitation of dams and appurtenant works to extend their service life including structural improvements to mitigate the effects of alkali aggregate reaction, internal erosion potential, foundation failure

Natural Pozzolan Effects on Aggregate A.S.R. Delimitation in Sharyar Dam <i>H Khadiv (Iran)</i>	2b-1
Dam Rehabilitation in the presence of AAR – the Matala HEP <i>G Casagran, L Pradolin & J Victor (Canada)</i>	2b-11
Analysis of Inhibiting the Alkali Activity of Concrete Aggregate for Nierji Reservoir Project <i>Z Zhu, P Zheng & Z Wang (China)</i>	2b-21
A Unique Case: New Works at Chambon Dam <i>A Scuero, G Vaschetti, & J Machado do Vale (Switzerland)</i>	2b-27
Kariba Dam Rehabilitation Project – Structural Improvements to the Kariba Dam Spillway Upstream Control Facility to Mitigate the Effects of Alkali Aggregate Reaction <i>MC Munodawafa, DZ Mazvidza & SZ Mhlanga (Zambia)</i>	2b-37

The RCC Moula Dam: Reinforcement Work and Appropriate Instrumentation to Challenge a Weak Foundation <i>NeH Dhiab & M Belaid (Tunisia)</i>	2b-45
Safety Assessment of an Arch-Gravity Dam with a Horizontal Crack <i>A Hadrović, M Partovi & M Selimotić (Bosnia-Herzegovina)</i>	2b-55
Stability Analysis and Repair Measures Assessment of Concrete Dam Cracks in High Water Level Operation <i>S Guo, E Zhai, D Li & H Jin (China)</i>	2b-65
Performance Based Approach for Rehabilitation of Golestan Historical Masonry Gravity Dam <i>M Safi (Iran)</i>	2b-73
Reconstruction and Reinforcement New Techniques for Masonry Gravity Dams Upstream Anti-Seepage Panels <i>P Qi, G Dashui & W Min (China)</i>	2b-83
Application of Reliability Analysis to Slope Stability of an Embankment Dam: A Case Study <i>A Noorzad & H Alimoradi (Iran)</i>	2b-93
Rehabilitation of Downstream Slope of Cacaban Dam due to Wetting <i>D Djarwadi (Indonesia)</i>	2b-103
Improving Slope Protection of Nahand Dam <i>SH Partovi Azar, A Mihandoost, & M Akbarzad (Iran)</i>	2b-111
Engineering Characterization of Aging Cores of Earth-Cored Fill Dams <i>P DongSoon & S Dong-Hoon (South Korea)</i>	2b-119
Impact of Lime Treated Soils Performance on Design of Earthfill Dams and Dikes <i>N Nerinx, S Bonelli, D Puiatti, G Herrier, J-J Fry, R Tourment & S Nicaise (France)</i>	2b-129
Using ICOLD Bulletin 164 to Develop Good Practice Against Internal Erosion in Dams <i>R Bridle (United Kingdom)</i>	2b-139
Probability of Failure of an Embankment by Backward Erosion Using the Formulas of Sellmeijer and Hoffmans <i>T Mallet & J-J Fry (France)</i>	2b-149
A Theoretical Framework to Understand the Mechanical Consequences of Internal Erosion <i>CJ MacRobert (South Africa)</i>	2b-159
Investigation of Piping Phenomenon in Embankment Dams Utilizing Dams Risk Assessment <i>A Noorzad , F Bagheri , I Vaezi & M Gharavi (Iran)</i>	2b-169
The Filtration Stability Safety Assessment of the Dam Liptovská Mara after Grouting Curtain Reconstruction <i>E Bednárová, D Grambličková, M Minárik, J Škvarka & B Kopčáková (Slovakia)</i>	2b-179
Rehabilitation Works to Control the Foundation Internal Erosion and to Mitigate the Effects of Alkali - Aggregate Reaction at Dridu Dam <i>D Ștematiu, A Popovici, C Voinitchi & C Ilinca (Romania)</i>	2b-189
Quantification on the Probability of Dam Failure due to Internal Erosion Using Event Tree Anaysis <i>G Heo & C-K Chung (South Korea)</i>	2b-199
A 70m depth Cut-off Wall to Control Seepage on an Operating Clay Core Dam <i>AF Chraibi, M Benyahia, & A Mhirech (Morocco)</i>	2b-207
Importance of Geological and Geotechnical Understanding for Mitigation of Reservoir Leakage and Slope Instability Problems: The Case of Tendaho Reservoir <i>DN Abraha (Ethiopia)</i>	2b-217
Foundation Failure of Gheisaragh Dam, Causes and Solutions <i>SP Azar (Iran)</i>	2b-227
Evaluation of Grout Curtain Efficiency Due to Instrumentation Data Analysing <i>MA Toosi (Iran)</i>	2b-235
Design for Rehabilitation of an Embankment Dam for Seismic Safety Improvement <i>E Yıldız & F Gürdil (Turkey)</i>	2b-245
The Seismic Analysis of an Earth-Fill Dam on Thick Liquefiable Ground and Countermeasures against a Large Earthquake <i>T Kato, T Honda & S Kawato (Japan)</i>	2b-253

Pull Out Tests of 50-years old Rock Bolts <i>R Hellgren, FR Bayona, R Malm & Fredrik Johansson (Sweden)</i>	2b-263
Rock Treatment around Morning Glory Spillway Shaft of Sefidrud Dam <i>A Faghihimohaddess, H Abbasi & F Farhadi (Iran)</i>	2b-273
Baihetan Dam – China: Rock Mechanics Control of Columnar-Jointed Basalt <i>H Lianxing, Z Endi, F Yilin & L Shaojun (China)</i>	2b-283
Slope Stability Analysis of Jinping Dam using Limit Equilibrium Method and Finite Element Methods <i>WJ Herweynen & H Liu (Australia)</i>	2b-291
Condensed History and Samples of Water-stop's Development for CFRDs in China <i>F Minghui, L Yihui, L Chun, X Yao & H Jutao (China)</i>	2b-299
Brush-Coated Flexible Waterstop Structure of CFRD Joints <i>X Yao & S Zhiheng (China)</i>	2b-307
Mohale Dam Crack Stage 2 Rehabilitation <i>L Matete, S Mojela & T Maseatile (Lesotho)</i>	2b-313
Rehabilitation and Long Time Behaviour of Asphalt Concrete Faced Reservoirs and Dams <i>P Tschernutter (Austria)</i>	2b-323
Lessons from Geotextile Use in Embankment Dams <i>J-J Fry, GE Degoutte & D Poulain (France)</i>	2b-333
Selection of Liner Type for Raw Water Storage <i>DJ Hagen & AJ Botha (South Africa)</i>	2b-343
Adaptation of a Geosynthetic Clay Liner to a Cofferdam using a Decision Matrix <i>Ö Özen, H Kúsmez, E Üzücek & T Dinçergök (Turkey)</i>	2b-353
Controlled Demolition Techniques during raising of the Hazelmere Dam Spillway in KwaZulu Natal, South Africa <i>JR Brinkmann, AJ Botha & A Olden (South Africa)</i>	2b-361
Blasting for a Large Pollution Control Dam Directly Beneath Overhead Powerlines <i>CVB Cunningham (South Africa)</i>	2b-371
Talybont Dam Tunnel Pipework Repair Following Damage Caused by a Pressure Shock Wave <i>TA Williamson & AL Warren (United Kingdom)</i>	2b-381
Mohale Tunnel Dewatering System: The System still to be Commissioned <i>L Matete & E Mathaba (Lesotho)</i>	2b-391
Renovation of Långed Hydro Power Plant, Sweden <i>A Engelmarm Hofgaard & R Ascila (Sweden)</i>	2b-397
Raising of Clanwilliam Dam Design and Construction Considerations <i>P Barnard, H Swart, H Durieux & A Thobejane (South Africa)</i>	2b-407

Theme 3. Innovative river basin management including the optimisation of the operation of dams

Orange Senqu Shared International Basin: Importance of a Common Understanding of Water Resource Modelling Capabilities and Results for Decision Makers involved in the Planning and Operation of the System <i>HG Maré, CJ Seago & C Talanda (South Africa)</i>	3-1
Drought Management: The Case of Hluhluwe Dam, Kwazulu-Natal, South Africa <i>AS Sikosana & C Ntuli (South Africa)</i>	3-11
Analysis of Multiple-Target Optimized Regulation of the Three Gorges Reservoir under Changed Operating Environment and its Integrated Benefits <i>X Tao, Z Man & L Changchun (China)</i>	3-21
Cause-Effect Analysis of River Basin Management Options - Case Study of a Small Dam in Thailand <i>H Lohr & R Treitler (Germany)</i>	3-29
The Practice and Discussion on the Joint Operation of Cascade Hydropower Plants on the Upstream Catchment of Yangtze River <i>B Zhengfeng, X Ge & W Yuhua (China)</i>	3-39
Reservoir Operation Rule Changing to Maintain Sustainability of Gajah Mungkur Life Time, Central Java - Indonesia <i>DAS Kubontubuh, CD Yuliningtyas & N Hidayat (Indonesia)</i>	3-47

Operation of Citarum Cascade Reservoirs to Optimize Water and Power Requirement and Flood Control <i>M Khan, I Samoon & D Pranowo (Pakistan)</i>	3-53
Role of the Dams in the Strategy for Prevention and Reduction of the Destructive Consequences of Floods <i>I Asman, S Randasu & C Ban (Romania)</i>	3-63
Using Topographic Dams to Increase the Energy Production Potential and Flood Management <i>AAN Pourkiaei & S Emami (Iran)</i>	3-73
Challenges of Water Management in Trans-Basin Diversion Systems <i>B Kamaladasa & J Meegastenna (Sri Lanka)</i>	3-81
Modernisation of the LHWP Royalties Computation using Water Evaluation and Planning (WEAP) Tool to Determine Benefits Sharing <i>K Lepholisa, R Molapo & F Tlhomola (Lesotho)</i>	3-89
The Use of Cultural Ecological Knowledge, the Pranata Mangsa as Comparative Tool for Shifted Seasonal Pattern in Sermo Dam Operation, Yogyakarta, Indonesia <i>V Ariyanti, Aa Wicaksono, Tb Adji & A Anung (Indonesia)</i>	3-97
The Dams Master Plan for Kurdistan Region – Iraq. Getting the Job Done <i>C Popescu, P Mazilu, I Dragan, A Mihai, N Sirbu, R Sarghiuta & M Segarceanu (Romania)</i>	3-107
Technical and Economical Assessment of Large Dams Design Flood Selection in Iran <i>M Fadaeifard & S Daneshvar (Iran)</i>	3-115
Low Submersible Dams <i>F Lemperiere, M Hotakhanh & N Nerincx (France)</i>	3-125

Theme 4. Reservoir sedimentation and management

Sediment Management at Reservoirs and Hydropower Plants: New World Bank Technical Note <i>Gw Annandale, GI Morris, & P Karki (USA)</i>	4-1
Positive Effects of Reservoir Sedimentation Management on Reservoir Life: Examples from Japan <i>C Auel, SA Kantoush & T Sumi (Japan)</i>	4-11
Comprehensive Basin-Wide Sediment Management in Brantas River Basin, Indonesia <i>R Erwando, MA Satria, H Fahmi, RR Valiant & Harianto (Indonesia)</i>	4-21
Run of River Hydro - Latest Innovations in Diversion Dams and Sediment Exclusion <i>S Mottram, K Ainsley & E Scherman (Canada)</i>	4-29
Design of Run-Of-River Hydropower Schemes to Limit Sediment Diversion <i>M Van Heerden, & GR Basson (South Africa)</i>	4-39
Development of a Bedload Transport Measuring System for Sediment Bypass Tunnels in Japan <i>T Koshiba, T Sumi, D Tsutsumi, Sa Kantoush & C Auel (Japan)</i>	4-49
Dredging with Riverine Disposal to the Channel below the Dam for Supporting Sustainable Sedimentation Management of the Selorejo Dam <i>A Yhadhianto, F Hidayat, A Santoso, S Bachri & Harianto (Indonesia)</i>	4-59
A Practical Example of Change of River Bed Environment Downstream from Dam Reservoir by Sediment Replenishment <i>Y Musashi, Y Nakata, T Suzuki, M Oshima & S Demizu (Japan)</i>	4-67
Study and Practice on Sedimentation Reduction of Three Gorges Reservoir under the New Water and Sand Inflow Condition <i>B Zhengfeng (China)</i>	4-77
Study of Sediment Excavation in the Tail of the Three Gorges Reservoir based on Unsteady Flow-Sediment Model <i>X Tao & G Xiao (China)</i>	4-87
Research on Flow and Sediment Flux into the Three Gorges Reservoir and the Sedimentation Change Trend <i>J Zhongwu & W Huali (China)</i>	4-95
Sediment Control Interventions in the LHWP Muela Catchment <i>G Mokone, P Monongoaha & R Nts'Ohl (Lesotho)</i>	4-105
2D Hydrodynamic Modelling of Sediment Deposition Processes and Flushing Operation of Boegoeberg Dam, South Africa <i>O Sawadogo & Gr Basson (South Africa)</i>	4-113

2D Reproduction Analysis of Reservoir Sedimentation Caused by Flood <i>N Sorimachi, K Hashimoto & T Sato (Japan)</i>	4-123
The Response Law of Fluid Mud to Density Current in the Xiaolangdi Reservoir in the Yellow River, China <i>L Kunpeng, M Huaibao & W Yuanjian (China)</i>	4-133
Rehabilitation of the Kat River Barrage, Fort Beaufort, Eastern Cape, South Africa <i>BJ Kriegler, O Sawadogo & GR Basson (South Africa)</i>	4-139
HPP Vrhovo Operation under Reservoir Sediment Management <i>L Javornik, M Mikoš & A Kryžanowski (Slovenia)</i>	4-149
Sedimentation Problem at TNB Ringlet Hydroelectric Power Stations <i>R Radzi, A Hasnul & S Akib (Malaysia)</i>	4-157
Automatic Scour Gates to Keep Small Dams Free of Sediment <i>JF von Holdt (South Africa)</i>	4-167

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

Key Steps for Conducting Tailings Dam Breach Studies <i>AJ Strauss, V Martin, D Fontaine & J Cathcart (South Africa/Canada)</i>	5-1
Prediction of Potential Tailings Storage Facility Inundation Zones <i>M Rust & S Dressler (South Africa)</i>	5-9
Requirements for Stability Assessments of Tailings Dams <i>M Theron, M Rust & E Rust (South Africa)</i>	5-19
Common Practice and Innovations in Tailings Dams using Geosynthetic Tubes <i>MT Van Keßel, M Breytenbach & M Wilke (Germany/South Africa)</i>	5-29
Reliability of Tailings Dams with Possible Disturbance of the Impervious Elements and Seismic Impacts <i>V Glagovsky, S Golubev, S Sosnina, T Sinitsyna & N Yurova (Russia)</i>	5-39
Review of Finnish Tailings Dam Safety <i>JP Laasonen (Finland)</i>	5-47
Application of Rock-Filled Concrete on Tailings Reservoir Project <i>F Jin, Y Wang, H Zhou, M Huang & X Cui (China)</i>	5-53
Operation and Maintenance of Ash Dams in South Africa: Challenges and Shortcomings <i>PJ Gouws (South Africa)</i>	5-63

Theme 6. Strategies for proper surveillance of dams

Effect of Common Cracks on Structural Behaviour of Concrete Dams <i>M Westberg Wilde, M Hassanzadeh, M Janz & T Ekström (Sweden)</i>	6-1
The Behaviour of a RCC Dam Raised with RCC...10 Years on <i>CI Dankers & C Oosthuizen (South Africa)</i>	6-11
High Resolution Distributed Fiber Optic Temperature Measurement of Massive Concrete in Concrete Dams at an Early – Age <i>N Humar, S Milevski, D Zupan, A Vidmar & A Kryžanowski (Slovenia)</i>	6-21
Monitoring the Behavior Changes of an Unreinforced Multi Domed Buttress Dam during Rehabilitation <i>JL Schoeman & C Oosthuizen (South Africa)</i>	6-29
Long-Term Integrity Monitoring of a Concrete Arch Dam using Continuous Dynamic Measurements and a Multiple Linear Regression Model <i>P Bukonya, P Moyo & C Oosthuizen (South Africa)</i>	6-39
Identifying Behavioural Trends and the Development of Calibrated Finite Element Models for a Double Curvature Arch Dam <i>ZJ Prins, CN Mahlabela & P Moyo (South Africa)</i>	6-47
Notes on the Behaviour of a 65 Year Old Concrete Arch Dam affected by AAR (Based on Visual Observations only) <i>O Human & C Oosthuizen (South Africa)</i>	6-57
Safety Monitoring and Controlling System for Xiaowan Arch Dam <i>Z Lichun, Z Zhiyong & C Shenghong (China)</i>	6-67

Geodetic Deformation Monitoring System of the 185 m High Katse Dam in Lesotho <i>CJ Pretorius, S Mojela & T Maseatile (South Africa)</i>	6-77
Monitoring System of Cahora Bassa Dam....The Past, Present and Way Forward <i>EF Carvalho, BT Matsinhe & C Oosthuizen (Mozambique)</i>	6-87
The Application of Fuzzy Comprehensive Evaluation Method on Large Concrete Dam Safety Monitoring System Evaluation <i>C Wenbo, T Yuanyuan & Y Jin (China)</i>	6-95
Analysis of Potential Failure Modes and Re-Instrumentation of a Concrete Dam <i>R Malm, E Nordström, C-O Nilsson, R Tornberg & J Blomdahl (Sweden)</i>	6-101
Improving Longevity of High Embankment Dam Instrumentation <i>D Salehi (Iran)</i>	6-111
Behaviour Monitoring of Driekoppies Dam – 18 Years on <i>L Hattingh, C Zwane, L Nkozi, E Khoza & C Oosthuizen (South Africa)</i>	6-119
Surveillance of Lom Pangar Dam during First Filling of the Reservoir <i>T Guillemot, A Towa, M Lino, C Daux, L Vauloup & E Remy (France)</i>	6-129
Evaluation and Monitoring Response to Upstream Slope Failure at an Embankment Dam <i>JN Stateler & J Wormer (USA)</i>	6-139
Analysis Method for the Monitoring of Pore Water Pressure in Embankment Dams <i>AG Simon & T Guilloteau (France)</i>	6-149
Development of Emergent Monitoring System for Leakage from the Dam <i>T Higuchi, T Sugai, T Sato, & T Kayukawa (Japan)</i>	6-159
Seepage Control and Monitoring of Zirdan Dam <i>A Bagherzadehkhalhali & M Karimi (Iran)</i>	6-165
Application of Response Surface Method in Analysis of Hydraulic Structures <i>M Klun, A Kryžanowski & S Schnabl (Slovenia)</i>	6-175
Thermal-Hydraulic-Mechanical Coupled Analysis to Diagnose Condition of Earthen Dams and Reservoirs <i>B-H Choi & KT Chang (South Korea)</i>	6-185
External Deformation Monitoring of Five Rockfill Dams in the same Radar Satellite Data <i>H Sato, T Sasaki, T Kobori, Y Enomura, Y Yamaguchi, W Sato, N Mushiake, K Honda & N Shimizu (Japan)</i>	6-193
Surveillance of CFRD Built on Deep Alluvium Foundation <i>Z Xu (China)</i>	6-203
Performance Analysis and Safety Monitoring Key Points for Concrete Face Rockfill Dams <i>L Nenghui, Z Ganwu & L Denghua (China)</i>	6-213
Rehabilitaion of Seepage Monitoring System of Rockfill Dam for Dam Safety <i>L Jongwook (South Korea)</i>	6-221
Behaviour of the Spring Grove Dam During and After Construction <i>M Trümpelmann, D Badenhorst & J Nyakale (South Africa)</i>	6-231
Surveillance of Bedford and Bramhoek Dams <i>E Lillie (South Africa)</i>	6-241
Improving Seismic Monitoring in the Active East African Rift System for Detailed Seismic Hazard Assessments: A Case Study in Malawi <i>VA Dimas, PRN Chindandali & B Kendaragama (Australia)</i>	6-249
Outcomes of the Devastating Mw 7.8 April 2015 Nepal-Gorkha Earthquake and Establishing a Seismology Research and Monitoring Centre in the Kingdom Of Bhutan <i>VA Dimas, B Kendaragama & N Arora (Australia)</i>	6-259
Use of Hydrogeological Parameters in the Performance Monitoring of Dams and Their Foundations <i>W Riemer (Germany)</i>	6-269
Hydrologic Information Measuring Application based on Redundant System Framework <i>L Yu & Y Xiao (China)</i>	6-277
Inspection of Submerged Area with the use of an Underwater-Camera Surveying Vehicle <i>Y Sakamoto, S Akimoto, & K Kera (Japan)</i>	6-285
Monitoring of the Submerged Structures of Dams <i>E Isomäki & K Hänninen (Finland)</i>	6-295

Organization of Surveillance of Dams in Russia <i>EN Bellendir, EA Filippova & OA Buriakov (Russia)</i>	6-305
Implementation of a Dam Monitoring Management System in the Tagus River Basin Authority <i>S Hoppe & E Moreno Calle (Spain)</i>	6-311
Aloha: An Innovative System for Proper Surveillance of Hydraulic Structures <i>P-H Faure, F Zenss, V Gbiorczyk, V Degezelle & V Morisseau (France)</i>	6-319
New Ideas for Dam Safety Monitoring System Establishment in the Smart Basin <i>S Hui, Z Lan & L Qi (China)</i>	6-329
The Thinking about Dam's Safety Monitoring Based on the Full Life Cycle <i>C Gang & G Fawang (China)</i>	6-335
Implementation of Failure Mode-based Monitoring of Dams <i>A Isander, U Kuoljok, P Wilén & J Oestberg (Sweden)</i>	6-345
A Study on the Development of Performance Evaluation Method on Existing Dams in South Korea <i>KJ Hye, KY Soo, P Jiyeon, SC Shik & KH Ki (South Korea)</i>	6-347
Dam Safety Management in the Brantas and Bengawan Solo River Basins, Indonesia <i>Hariato, RV Ruritan, F Hidayat, F Sarifudin, K Windianita & MTB Raharjo (Indonesia)</i>	6-353
Suggestions for Dam Crisis Management Learned through the 2011 off the Pacific Coast of Tohoku Earthquake <i>H Okumura, T Matsumoto & K Koyama (Japan)</i>	6-361
Telemetry System as a New Approach for Dam Surveillance in Indonesia <i>M Anissa & DK Nofyar (Indonesia)</i>	6-371
The Use of Bio-Location in the Safety Evaluation of Dams <i>LC Hattingh & C Oosthuizen (South Africa)</i>	6-381

Theme 7. Sustainable hydropower development in developing countries

Important Policy Considerations for Hydropower Development in Developing Countries in an Era of Climate Change <i>GW Annandale (USA)</i>	7-1
Challenges in Development of Small Hydropower in Africa: A Technical and Financial Perspective <i>H-J Wright, BR Collet & H Hawarden (South Africa)</i>	7-11
The Rehabilitation of the Mt Coffee Hydropower Project in Liberia <i>WD Hakin, QHW Shaw, R Guimond & B Taraldsten-Brunes (Canada)</i>	7-21
Analysis of Future Hydropower Development and Operational Scenarios on the Zambezi River Basin <i>JP Matos, T Cohen Liechti & AJ Schleiss (Switzerland)</i>	7-31
Study Approach into the Hydropower Development along the Luapula River <i>SG Renecke (South Africa)</i>	7-41
LHWP Phase II Hydropower Feasibility, Further Studies <i>JR Sawyer & T Mochaba (Lesotho)</i>	7-51
Monont'sa Pumped Storage Scheme – Sustainable Hydroelectric Development In Africa <i>CF Logan (South Africa)</i>	7-61
Study on Hydro Power Potentials in Existing Major Reservoirs in Sri Lanka <i>WB Palugaswewa (Sri Lanka)</i>	7-71
Sustainable Hydropower Development in I.R. of Iran <i>S Salavitarab & A Salavitarab (Iran)</i>	7-81
Oiești Development Scheme Conversion <i>ID Iacob & C Abdulamit (Romania)</i>	7-91
Development of a Novel System for Improvement of Operation and Maintenance Works in Dams and Hydropower Plants in Iran <i>K Nasser, E Hassan & Yousefi Saied (Iran)</i>	7-99

Theme 8. Other

Ambarau Hardfill Dam - Appropriate Dam Technology for Central Africa <i>D Cameron-Ellis (South Africa)</i>	8-1
---	-----

The Cemented Soil Dam (CSD): A New Concept of Cemented Dam <i>M Lino, F Delorme, D Puiatti, P Agresti & F Lempérière (France)</i>	8-9
Simple RCC Dams for Developing Countries <i>F Ortega (Spain)</i>	8-19
RCC Mixtures Study for the Design of a Large Dam in Mexico <i>A Garduno-Gallo & M Montero (Mexico)</i>	8-29
Global Stability of High Gate Dam Based on Deep Overburden Layers by Geomechanical Model Test <i>D Bin, H Zhonghui & Z Lin (China)</i>	8-39
Design Features of Koyunbaba Concrete Faced Sandy Gravel Dam founded on Deep Alluvium <i>MH Askeroglu, H Kusmez & N Pelen (Turkey)</i>	8-49
Analysis of Factors Affecting the Stability of the Mosul Dam <i>ZA Aladwani, N Younis & AA Mahmood (Iraq)</i>	8-57
Research on Structural Safety Design of High Embankment Dams <i>B Li (China)</i>	8-67
Application of Monte-Carlo Simulation for Slope Optimization of CSG Dams using Fuzzy Uncertainty Set <i>A Noorzad, E Badakhshan, I Vaezi & M Gharavi (Iran)</i>	8-73
Geological Studies for Increasing the Operating Level of Karun1 (Shahid Abbaspour) Dam, Iran <i>A Barjasteh (Iran)</i>	8-83
Partial Factor Calibration Based on Non-Numerical Method of Gravity Dam Foundation Material <i>B Li (China)</i>	8-93
Criteria for the Selection of Dam Types in Areas of High Seismicity <i>M Wieland (Switzerland)</i>	8-101
Seismotectonic Modelling for Seismic Hazard Assessments in Low-Seismicity Regions of Africa: Western Africa <i>VA Dimas, UA Kadiri & B Kendaragama (Australia)</i>	8-111
Seismic Vulnerability Analysis of Tendaho Dam in Ethiopia <i>A Aman, T Mammo & M Wieland (Ethiopia)</i>	8-121
Seismic Safety Evaluation of a RCC Gravity Dam under Maximum Credible Earthquake <i>D Li, J Tu, S Guo, H Wang & W Wang (China)</i>	8-131
Seismic Responses of Conventional Concrete Gravity Dams on Weak Foundations <i>K Tayyebi, MS Gilani & M Ghaemian (Iran)</i>	8-141
Modeling of Earthquake-Induced Settlement in Embankment Dam by new Approach <i>D Behnia, A Noorzad, M Behnia & K Ahangari (Iran)</i>	8-151
Case Studies of Reservoir-Induced Geo-Hazards for the Jiansha River Hydropower Projects in China <i>E Zhai, Q Fan & H Jin (China)</i>	8-159
Some Lessons Learnt from the Failure of Earthfill Dams in Burkina Faso: Case Stories <i>A Nombre, E Somda & M Kabore (Burkina Faso)</i>	8-169
Regulatory Dam Safety Inspections and Evaluations in South Africa <i>CL van den Berg (South Africa)</i>	8-179
Eastern Nile Transboundary Cooperation on Dam Safety: Challenges and Opportunities <i>M Abebe (Ethiopia)</i>	8-185
Dam Safety Assessment of FAN Dams in Ethiopia <i>F Shiferaw (Ethiopia)</i>	8-193
Dam Construction Key in Future Dream of Water in Africa <i>Ei Ekpo (Nigeria)</i>	8-201
Dam Safety Regulations in Norway; Relationship between Rehabilitation Project Cost and Resulting Added Dam Safety <i>H Kjærås, L Basberg & Ø Lier (Norway)</i>	8-207
Evaluation of Dam Safety Using Limit States <i>J Riha & M Spano (Czech Republic)</i>	8-217
Risk-Informed Decision-Making in Dam Safety - Federal Agency Perspectives Based on 20 Years of Experience <i>N Snorteland, D Osmun, & BC Muller (USA)</i>	8-227

Application of Risk Analysis in Membrío Dam (Spain) to Inform Safety Investments <i>M Setrakian, I Escuder-Bueno, A Morales-Torres & D Simarro (Spain)</i>	8-237
A Description of the Application of a New Quantitative Dam Safety Risk Screening Tool to assist a Remote Northern Community in Making Risk Informed Decisions on the Dam Safety Risks and Remedial Actions <i>CR Donnelly, K Jamieson, CDSS Perkins & M Orton (Canada)</i>	8-245
Risk Issues and Mitigations for Very High Concrete Arch Dams <i>M Safi & M Gharavi (Iran)</i>	8-255
Dam Hazard Analysis using GIS and Nationally Coordinated Emergency Preparedness Plans <i>M Jewert, G Sjödin, M Hautakoski & M Björk (Sweden)</i>	8-265
Evaluation of Life Safety Criteria for South African Dams <i>S Reynolds & C Viljoen (South Africa)</i>	8-275
Is the S-Shaped Curve a General Law? An Application to Evaluate the Damage Resulting from Water-Induced Disasters <i>M Chen, J Ma, F Zhou, Y Hu, J Li & L Yan (China)</i>	8-285
The Main Technological Innovative Practice in Construction of Jinping I hydroelectric Project <i>W Jimin, D Shaohui, Z Jiang, H Shuhong & J Xuelin (China)</i>	8-295
Use of a Cushion Layer to Reduce the Cost and Installation Time of a Vibrating Generator Foundation and Spiral Case: A 3D Nonlinear Study <i>SM Yousefi & T Dell (Canada)</i>	8-305
Application of Data Driven Models in River Flow Forecasting <i>A Khazaiepour & M Shourian (Iran)</i>	8-315
The Ntabelanga and Lalini Dams Conjunctive Scheme – A Water Food Energy Nexus <i>SV Johnson, M Mugumo, AJ Pepperell & T Moore (South Africa)</i>	8-323
Feasibility Study for Foxwood Dam, Eastern Cape, South Africa <i>J Hampton, L Spasic-Gril, J Bristow & R Gilbert (United Kingdom)</i>	8-333
Analysis of Vulnerability to Climate Change in terms of Water Supply for San Jose Hydroelectric Project (Bolivia) <i>MF Villazón, D Inturias, P Pardo, O Zarate & G Rodríguez (Bolivia)</i>	8-343
Value Add of Remote Sensing in the Planning of Dams in Africa <i>DR De Witt & R Nel (South Africa)</i>	8-353
Gate Operation of Small Dams for Flushing the Pollutants Accidentally Released into the Nakdong River <i>MJ Kim & KS Jun (South Korea)</i>	8-361
A Quantitative Approach to Optimizing the Fuel Consumption of Dump Trucks in Earthmoving Projects to Decreasing Emission <i>D Bahadorbeygi, NH Alaei & ER Azar (Iran)</i>	8-371

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

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

Sam Mottram¹, Keith Ainsley¹ and Egbert Scherman¹

1. Knight Piésold Ltd., Vancouver, Canada

PRESENTER: SAM MOTTRAM

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.

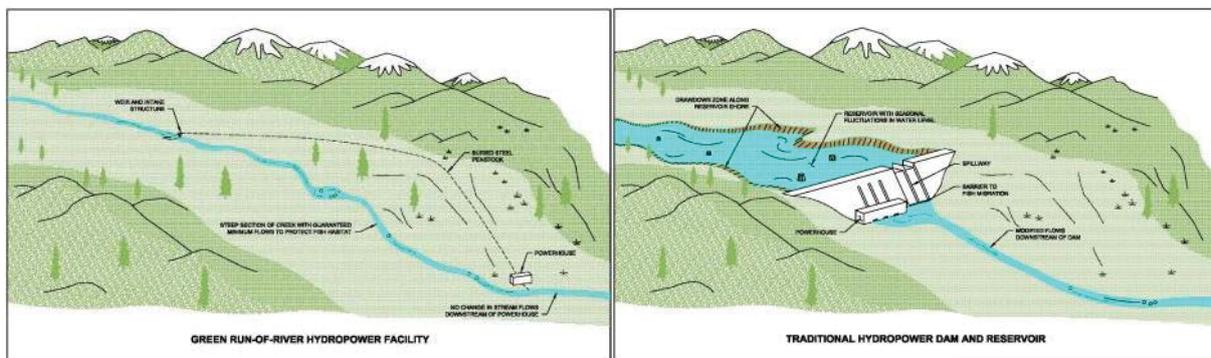


Figure 1. Schematic Layout of Large Dam and Run- of-River Hydroelectric Facilities

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

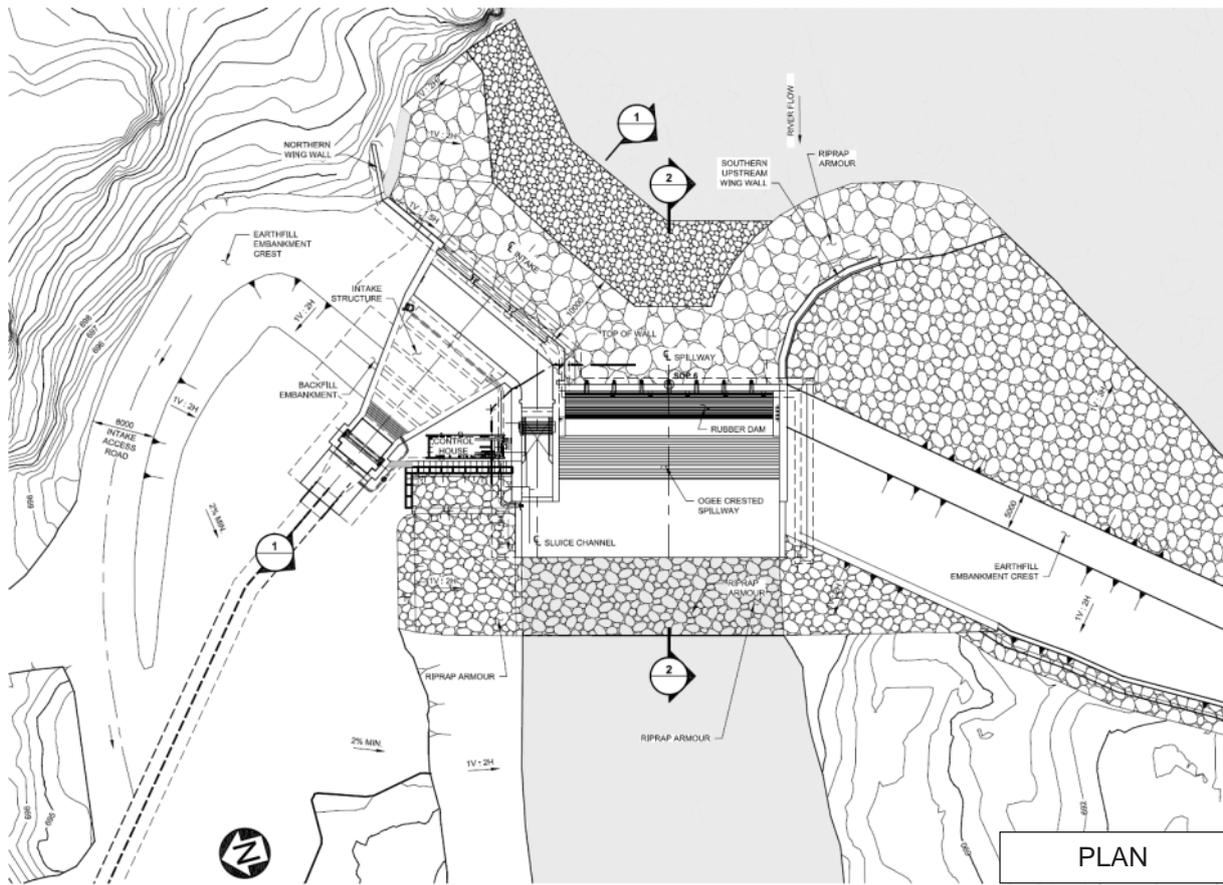
Given the right site conditions with large flat upstream reaches, some run-of-river intake facilities can be designed and constructed such that the upstream reservoir can be used as a settling basin for a larger fraction of mobilized sediment that arrives at the facilities intake. The relative size, 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.

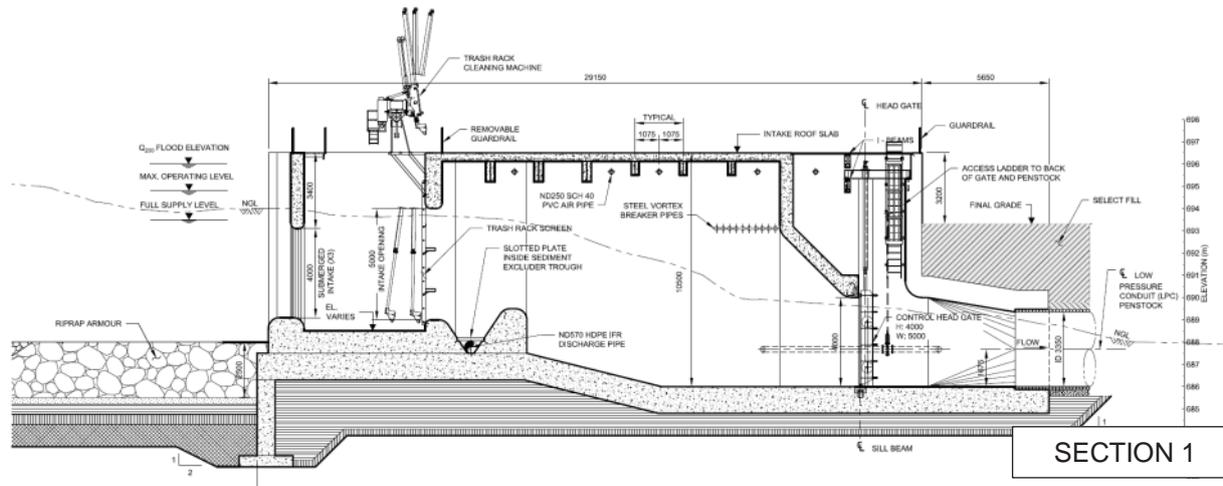


Figure 2. Rutherford Creek 49 MW Hydro Project - Inflatable Rubber Dam

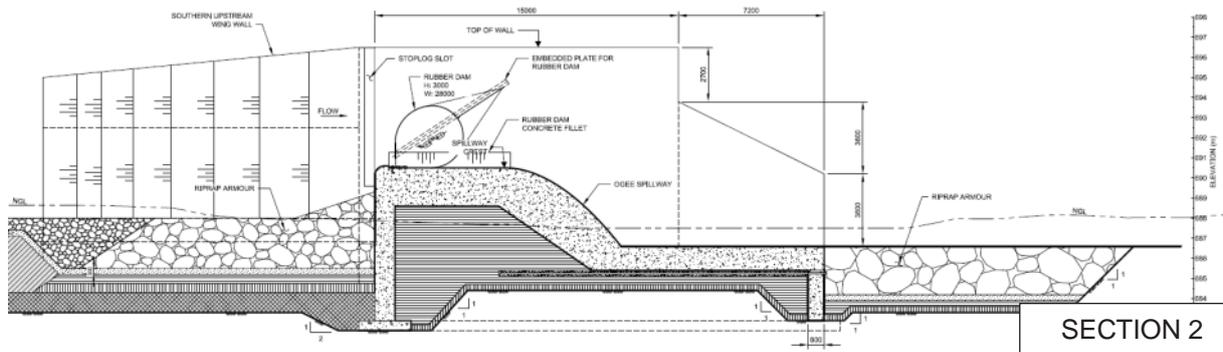
Knight Piésold has completed the design of several intake structures that utilize reservoir de-sanding to aid in the reduction of sediments from entering the hydroelectric facilities. Throughout the detailed design key considerations are taken into account with respect to the size and location of such 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.



PLAN



SECTION 1



SECTION 2

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 m³/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 m³/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.

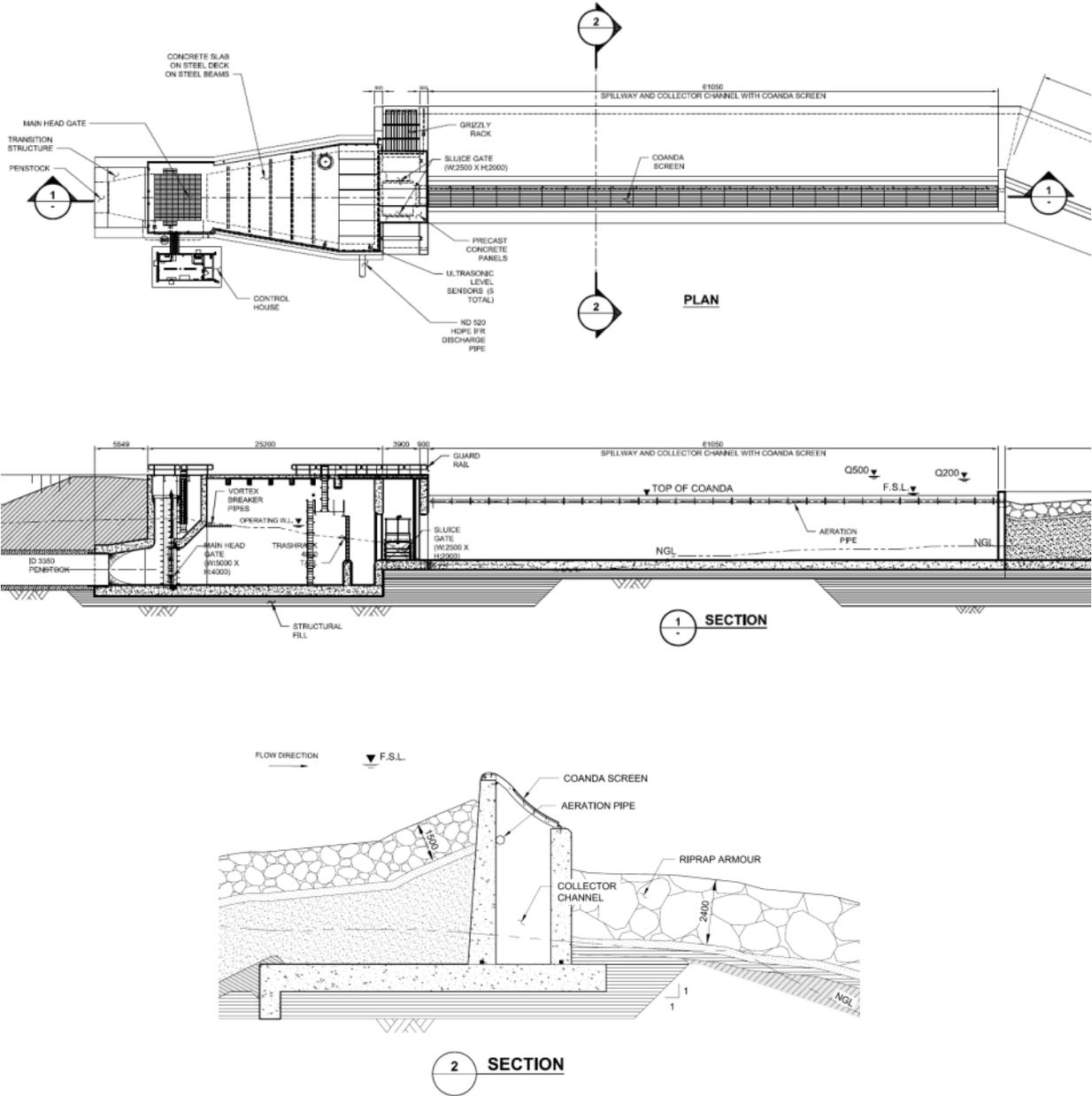


Figure 5. Typical Layout and Cross Section of a Coanda Screen Intake

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.

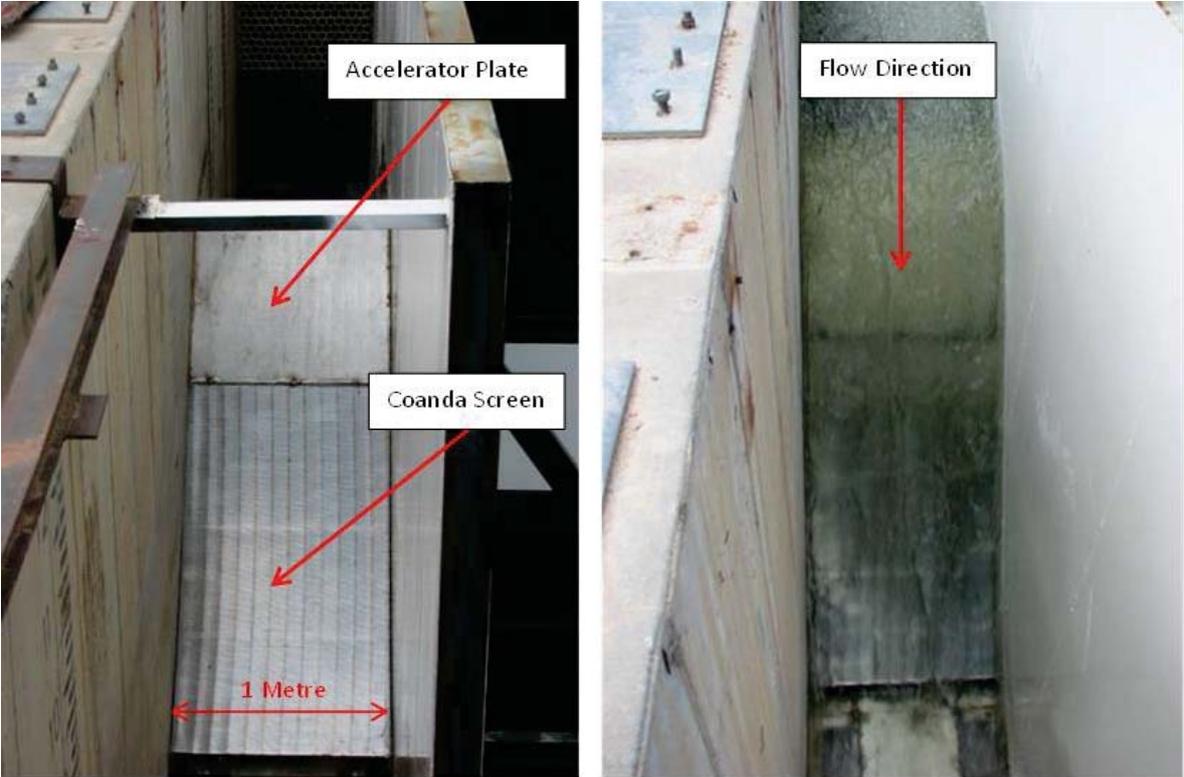


Figure 6. Full Scale Coanda Screen Model

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 m³/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 sediment, 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 m³/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 m³/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 m³. Figure 7 below illustrates the general arrangement of the Kokish River intake.

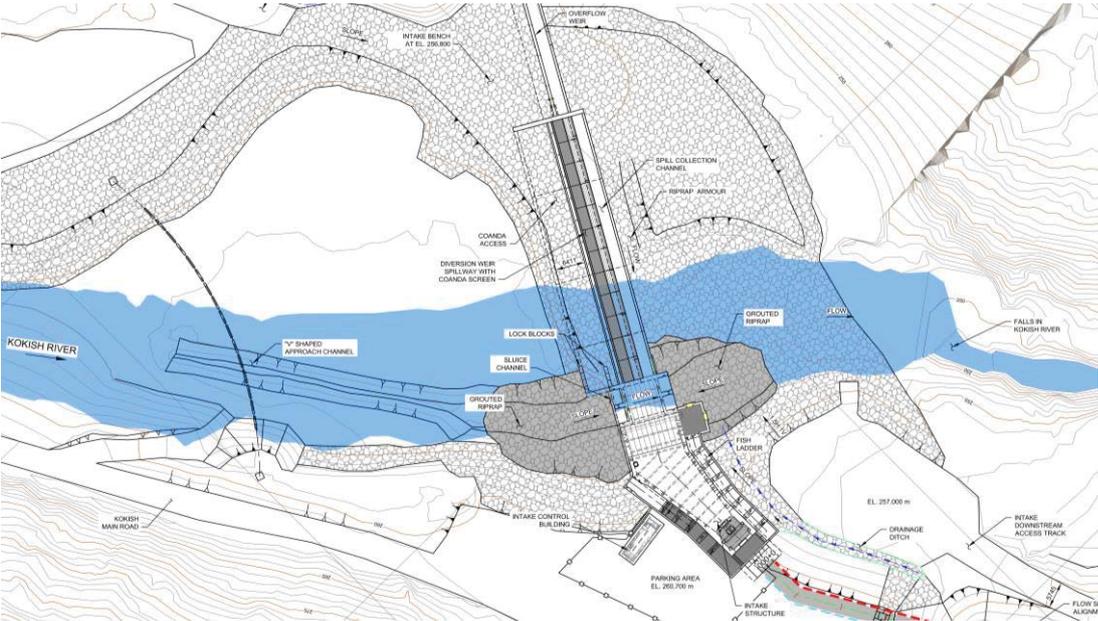


Figure 7. Kokish River Intake General Arrangement

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

Knight Piésold Ltd. and their Clients, whose projects are referenced in this paper, as listed below, have provided permission for this paper to be published.

- Alterra Power Corp. (www.alterrapower.ca)
- Innergex Inc. (www.innergex.com)
- Peter Kiewit Infrastructure Co. (www.kiewit.com)
- Elemental Energy (www.elementalenergy.ca)
- Brookfield Renewable Energy Partners (www.brookfieldrenewable.com)

5. REFERENCES

Sam Mottram, Brian Hughes and Nancy Simms (2009). *Run-of-River Hydroelectric Projects – Intake Design Considerations Based on Physical Hydraulic Model Study Results*. Published as part of the proceedings of Waterpower XVI 2009 Conference.

M.Robertson, N.Reid, C.Marti and B.Hughes (2003), *Rutherford Creek Hydroelectric Project – Sediment Exclusion at Main Intake*.