Global hydro community discusses future strategies at HYDRO 2020

PART ONE

The theme of HYDRO 2020, Strategies for Future Progress, was selected well before any knowledge of COVID-19, but became all the more relevant in the new global situation. Keynote addresses stressed the important role to be played by hydro, together with other renewables, in the post-COVID recovery period. In this first part of our overview, we report on the opening addresses and many of the 40 sessions, which as usual covered the multiple disciplines on which the safe and efficient development of renewable hydropower depend.

A global pandemic did not prevent the world hydropower family getting back together, even if virtually, for HYDRO 2020 On-Line, from 26 to 28 October 2020. Delegates from about 60 countries attended, and nearly 600 were on line in Central European Time; the conference stayed live beyond the normal hours and days, to enable others to catch up at different times. It was the only large-scale event for the hydropower industry during 2020.

During some of the discussion in the sessions, and particularly in the closing plenary talks, a number of people commented that it had in many ways resembled a live conference. When engrossed in deep discussion on some specific issues, it was possible to imagine being in the same conference hall together; the difference was that at times people were speaking live from places such as the Rogun dam site in Tajikistan, UEGCL's office in Kampala, Three Gorges in China, Hydro-Québec in Canada, CEPEL in Brazil, the World Bank in Washington, and numerous utilities, research institutes, consulting practices and universities worldwide. In the current situation many were speaking from homes, and some, participating from Australia and New Zealand, were chairing or joining Q&A sessions in the middle of their night.

As hosts of the conference, we were proud to have some of the world's most eminent experts in their respective fields as session chairpersons, and keynote or guest speakers. Together with others who had submitted the best abstracts, been welcomed to the original programme, and stayed with us despite the change to a virtual event, these people enabled us to embark on the adventure of an on-line conference with a reasonable degree of confidence. It also made it possible to offer the usual diversity of topics in 40 sessions, running in four parallel tracks.

As a result, and as the following session summaries show, the usual wide range of subjects were covered comprehensively, in sessions and workshops.

A number of speakers who had been accepted to present at the originally planned conference were not keen to pre-record talks, feeling this would not be worthwhile. While this provided an organizational challenge in the days before the conference, it enabled us to welcome higher level experts from some more remote parts of the world, who would have been less likely to be able to to travel to Strasbourg.

Plenary session

There were opening messages from ICOLD President Michael Rogers and Secretary-General Michel de Vivo, ICOLD Hon President and CHINCOLD Secretary-General Dr Jia Jinsheng, Renewable Energy Market Analyst at the International Energy Agency, Yasmina Abdeliliah, and Global Lead for Hydropower and Dams at the World Bank. Pravin Karki.

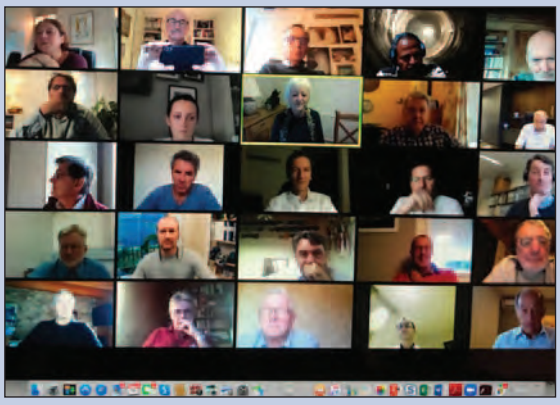
Together they outlined global challenges, but also had positive messages for the increasing role of renewable energy and water infrastructure in the post-COVID recovery period.

Alison Bartle, Publisher of *Hydropower & Dams*, welcomed delegates and, on behalf of the whole Aqua~Media team, expressed empathy with all those who had had their lives or work impacted by the pandemic in the past months, or worse, had sustained tragedy and loss. She also drew attention to the resilience of the hydropower industry throughout what had been such a challenging year.

In her opening address, she reviewed hydro development trends around the world, with some examples of major on-going projects, and then she made a comparison of hydro capacity and generation between 2010 and 2020, which showed a 64 per cent increase in hydro capacity in Asia, and 68 per cent increase in Africa. Hydro capacity under construction in Africa had increased almost four-fold over the ten years.

Bartle recalled statements in 2020 by key organizations influencing energy policy: AU Commissioner Dr Amani Abou Zeid called on greater development of the vast hydropower potential across the African continent, as part of the recovery process from the pandemic. IRENA had called for a 60 per cent increase in world hydro capacity by 2050, and for pumped storage capacity to triple [*Energy Transformation 2050 report*]. And IEA's *World Energy Outlook 2020* predicts that hydro, wind, solar, geothermal, bioenergy and marine energy could supply 40 per cent of global electricity by 2030.

Referring to the conversion of HYDRO 2020 to a virtual event, she felt that this event could not fully compensate for the necessary postponement of the live event planned, but in a year when there were no other



A planning meeting with the session chairpersons took place in October 2020, to discuss the format and organization of the HYDRO 2020 on-line sessions. Photo by Prof Anton Schleiss.

A key message from ICOLD President Michael Rogers in his opening talk was the responsibility of engineers to ensure the safety of critical water infrastructure.

choices, Aqua~Media had done its best to bring together regular participants as well as new ones, to provide a full programme, and that the on-line event should be regarded as a communication bridge between Porto and Strasbourg.

In his introductory speech, ICOLD President, Michael Rogers, commented that during 2020, peoples' lives had changed dramatically, as had our understanding of the future challenges. He said that conferences such as the present one underlined the resilience of the profession, and HYDRO 2020 was an opportunity to reaffirm professional values.

His key message concerned dam safety, which he regarded as a personal and moral commitment. He felt the conference was an excellent platform to share knowledge from past experience. He also underlined the importance of passing on such knowledge to future generations, adding that mentoring was another important responsibilty of engineers; he stressed that young engineers should not hesitate to consult and learn from others. They should work hard, and be humble.

He concluded by mentioning the value of collaboration between ICOLD and Aqua-Media, and paid tribute to *Hydropower & Dams* as a valued source of reference around the world.

ICOLD Secretary-General, Michel de Vivo, spoke of ICOLD's mission and activities, and mentioned in particular how the organization had had to adapt to the current situation. He mentioned that in lieu of the 2020 Annual Meeting in Delhi, the General Assembly would take place on line in November (see *H&D* Issue 6, 2020), and that INCOLD would hold a Symposium as a hybrid meeting in Feburary.

The subsequent meetings would be: the Congress in Marseille in June this year; ICOLD 2022 in Gothenburg, Sweden; ICOLD 2023 in Delhi, India; the 2024 Congress was still to be decided, but in November during the General Assembly, Chengdu, China, was selected; and, ICOLD 2025 will be in Shiraz, Iran.

ICOLD Hon. President Jia Jinsheng, referred to the challenges of 2020 and resulting uncertainties about the world economy. He stressed the need to work together to mitigate the impacts of the pandemic. Technical exchanges had not been possible earlier in the year, he said, which made HYDRO 2020 all the more important.

Jia felt that hydropower would have an extremely important role to play in the recovery period, adding that water infrastructure and hydropower should be regarded as a high priority. Areas of current focus for CHINCOLD, Jia said, were new technologies, and especially their application to safety; and also, strengthening collaboration to exchange knowledge of technology. In this respect, CHINCOLD had developed a cloud-based platform for international collaboration and knowledge sharing.

Yasmina Abdelilah, Energy Analyst at the Paris Headquarters of the International Energy Agency, presented some details from recent research by IEA which highlighted the major role which would be played by hydropower, both new schemes and upgrading, as well as pumped storage, especially over the next few years to 2025.

She referred to the role of hydro in helping to achieve carbon emission reduction goals, and in providing system flexibility, especially in integrating wind and solar power.

She predicted that about 100 GW more hydro capacity would come on line by 2025. During the same period, Abdelilah continued, around 104 GW of existing hydro capacity would become around 40 years old; together with existing ageing plant, this could total around 42 per cent of hydro capacity which would be in need of refurbishment and could be upgraded. This could represent the addition of an extra 24 GW of new capacity over the next five years.

In summary, Abdelilah said "robust growth is expected over the next few years", but she added that there were financial challenges in the regions which required new capacity most. She also referred to the numerous benefits of multipurpose storage schemes, but commended that insufficient remuneration for these hampered investment.

Pravin Karki, Global Lead, Hydropower and Dams, at the World Bank, began by adding his comments on the effects of the pandemic. The Bank, he said, estimated that globally around 60 million people would experience extreme poverty as a result. In the energy sector, there would be a disproportionate impact on the most vulnerable communities, for example in rural areas of developing countries.

Describing hydro as the dominant technology in the renewable energy family, Karki outlined the main drivers for future hydropower development.

The first concerned access to electricity. He noted that despite so much progress, more than one billion people still lived with no electricity supply.

The second concerned climate change, and the need to decarbonize, especially in the developing countries. As an example, he said that replacing the use of gas and diesel from the streets of Kathmandu would save many deaths from cancer or respiratory disease.

Karki stressed the value of storage schemes for their multiple benefits, and in particular pumped-storage schemes for the ancillary services they offered.

In terms of the synergy with other renewables, Karki said that a 1 MW hydro plant on a river in the Himalayas could help to integrate 5 to 6 MW of solar or wind power in India or Bangladesh. Scaling this up, 150 GW of hydropower in Nepal or Bhutan could help integrate 750 GW of wind or solar power across southern Asia.

In conclusion, Karki mentioned that hydropower worldwide provided around 2 million jobs, directly, and many more indirectly. Furthermore, site workers trained on hydro schemes, for example as an electrican or welder, could transfer those skills and thus contribute to the GDP of his/her country.

Parallel sessions

Sessions took place in parallel in four 'virtual conference rooms'. Each began with a general introduction from the chairpersons, followed by pre-recorded talks, and then questions and discussions conducted live as Zoom webinars. Speakers were on-line as a panel; delegates had the opportunity to submit questions on Zoom at any time during the presentations, which could be viewed by the chairperson, or they could speak spontaneously during the discussion webinar.

Because of the wealth of information from the sessions, we are dividing this report into two parts, and in this first part we cover the sessions focusing on future potential and opportunities, planning, cross-border developments, new approaches to finance and risk, as well as the technical sessions on many aspects of hydraulic machinery, the role of hydro and pumped storage (including a special session on the EU-supported XFLEX iniative), as well as civil engineering topics, including dam safety, design and construction, materials for dams, spillways, and tunnelling.

In our next issue, we will cover the discussions on social and environmental issues, climate, small hydro, hybrid systems, maintenance, uprating and safety of hydro plants, hydromechanical equipment, electrical engineering, as well as two special sessions hosted by the International Energy Agency (on climate, and hidden hydro).

We are grateful to all chairpersons for preparing summaries and comments on their sessions, which form the basis of the remainder of the reports.

Future perspectives

Potential and planning

A.R. Palmieri, International Advisor on Water Infrastructure, Italy

Contrary to what one would have expected, none of the six presentations in session 1, on Potential and planning, delivered the typical data on technically feasible, or economically feasible hydro potential. And that was good, because that information is periodically updated and reported in the *Hydropower & Dams World Atlas & Industry Guide*. It was also good because it allowed us to discuss some emerging topics.

Besides, it was pleasant to realise that the contributions were in line with the 'emerging trends' identified in ICOLD's Bulletin 171 'Multipurpose Water Storage'.

Enhancing the integration of renewables is an established trend, and that hydro is the enabler of intermittent sources is a fact on which more work must be done. Case studies were presented in the session from the developing world (Sebastien Sterl Vrije Universiteit Brussels, Belgium). The potential of regional power trading for a better management of transboundary river systems was also discussed (by Julien Harou, University of Manchester, UK).

Making the most of existing assets is another established trend, from large-scale rehabilitation and upgrading of portfolio of plants (Pedro Pinto, EDP, Portugal), to small-scale energy recovery from water supply networks (Anja Bekke, University of Pretoria, South Africa), thus confirming that all options should be contemplated in the supply of renewable energy.

Planning models for new projects were also presented. These were either based on hydrological data (Tim Ivanov, Consultant, Tajikistan) or rooted on extensive hands-on information on design solutions and cost-basis (Özgür Beser, Tractebel, Germany). These two contributions can be regarded as the essential building blocks of project planning: without water there cannot be any hydro (the role of hydrology), and no project can be seriously planned before its cost has been estimated.

While hydrological data is generally publicly available, reliable cost data are typically available only within large consulting firms and, in more detail, within specialized contractor companies. It would be beneficial to see more gathering of such databases by large public developers of hydro projects. That would provide such institutions with more control on cost estimates, bid evaluation, and contingency allocation. Better informed cost estimates can go a long way towards translating potential into planning, and to implement projects according to plans.

Maybe that could be a subject, although not an easy one, for future HYDRO conferences.

HYDRO 2020 took place in the middle of the COVID-19 pandemic and, notably, several contributions provided concepts, ideas, and solutions for the hydro business in a 'virtual' or remote mode. Most hydro projects contain work that can be tackled remotely. Leveraging new technologies to do so would be a winning strategy, even in a post-pandemic future, from both a cost and resource usage perspective. Combining hands-on experience with innovation (see the session on 'New technology and design approaches' in Part 2 of this report) should be regarded as the way ahead to advance the hydropower business in a resilient and effective manner.

Challenges and opportunities

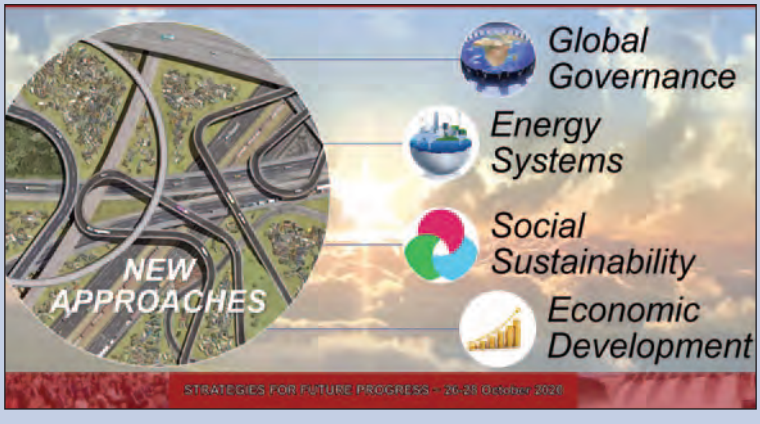
H.I. Aker, Dolsar Engineering, Turkey

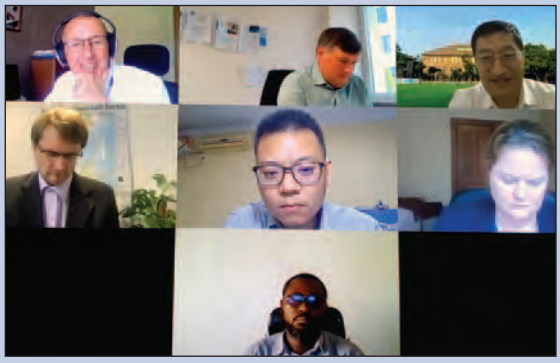
In his introductory speech, Chairman Irfan Aker pointed out that when the current pandemic was over, there would be new approaches as well as changes to global governance, energy systems, social sustainability and economic development. He quoted Albert Einstein who said: "In the middle of every difficulty lies opportunity", and he added that in his opinion, it was the right time to apply this thought.

N. Nielson from the International Energy Agency gave a presentation explaining the activities of the agency in detail, and he drew attention to some papers to be published in the near future.

H. Harreiter of Verbund Hydro Power, Austria, discussed past experiences from the perspective of his organization, and in comparison, reflected on experience during the COVID pandemic period, concluding

In his opening remarks to the session on Opportunities and challenges, Irfan Aker of Dolsar, Turkey, said that new approaches and changes would follow the pandemic. "Governments and investors should consider this an opportunity to focus on long-term national development plans", he said.





The session on cross-border projects, chaired by Jean-Michel Devernay (shown top left), stimulated much lively discussion between delegates and speakers from Asia, Africa and Europe. The session had input from the World Bank and African Development Bank.

with the lessons learned. He outlined the conclusions and opportunities as follows: the importance of increased public awareness on infrastructure;a boost for digitalization; the importance of systematic crisis prevention; and, the need for skilled and fully engaged employees.

A.C. Geber de Melo of CEPEL (Electric Energy Research Center), Brazil, gave a presentation summarizing the general situation of the power sector in Brazil. He mentioned that between 2008 and 2015, 47 public auctions had taken place, adding around 65 000 MW of new capacity to the grid system. He concluded that the main objective was to develop indicators of hydropower performance in relation to climate change, based on: mitigation measures, dam safety, electricity production, finance, water resources services, biodiversity protection and social issues.

P. Perazzo, from Carpi Tech, Switzerland, gave a paper co-authored with Venezuelan colleagues, which summarized the general situation in Venezuela, including hydrological basins, completed hydroelectric projects, additional hydroelectric generating projects and the next steps to be taken. He concluded that Venezuela needed to return to the development of hydroelectric infrastructure and other renewables to meet the future electrical energy requirements of all users, and that the country should keep an open mind, as its power and economic needs called for drastic improvements, and eventual minimization of fossil fuel-based generation.

Chhewang Rinzin, from Druk Green Power Corporation Ltd, Bhutan, explained that under the accelerated programme of hydropower development in Bhutan, the construction of three mega projects had been started, with a total installed capacity of around 3000 MW, but that as a result of inadequate understanding and the limited capacity to deal with geological surprises, only 720 MW could be commissioned by 2019. He added that there was a need to step up collective efforts for integrated management of watersheds and catchment areas. He concluded that to take Bhutan's hydropower sector ahead, the overarching consideration was how best the sector could benefit the nation and help to achieve the larger aspirations of its people for peace, prosperity and happiness.

The last speaker of the session was A. Gupta of SJVN Ltd, India. He said that since the end of the 12th plan (2012 to 2017), only 1221 MW of hydropower had been added in the country, whereas the capacity of renewable energy had doubled over the last four years.

He concluded that because of the associated large-scale socio-economic and environmental implications, hydropower projects were considered 'more than normal engineering ventures' and thus required special treatment. He added that the Government alone could not take entire responsibility for the growth of hydropower, but that all stakeholders, including the project developers, should come forward to sacrifice some interest, changing their perceptions, attitude, and mindsets to contribute towards growth of hydropower for broader national benefits.

Cross-border projects

J-M. Devernay, Consultant, France; (former Lead Hydropower Specialist at the World Bank)

After HYDRO 2017 in Seville, HYDRO 2018 in Gdansk and HYDRO 2019 in Porto, this was the fourth time a session specifically devoted to trans-boundary projects and regional collaboration had taken place at the Conference. Some papers addressed the subject under specific angles that were not, or were only incidentally, covered during the previous sessions.

The five speakers took the participants through a challenging but promising journey beyond borders, exploring how countries collaborate, or should collaborate, in the field of hydro and water projects for the benefit of their respective populations. They provided an updated insight into the current situation and future trends regarding this collaboration in complex environments, especially in Africa and Asia.

C. Egeruoh from the African Development Bank illustrated this challenge upfront by questioning whether transboundary projects in the developing world were a myth or a reality. He identified a number of barriers, including the tendencies of individual jurisdictions to have an expectation of self-sufficiency, national policies supporting local investments and the challenge of properly allocating environmental benefits. He suggested that integrating power systems without sacrificing local autonomy was the key to cross-border projects, and that projects should be driven by desirability and practicality to ensure success.

Dr R. Bucher from Tractebel Engineering, Germany, presented a case study in Africa which showed that while global investment in energy infrastructure has declined since 2014, investment in electricity networks has increased against that falling trend.

The 2 GW HVDC link between Ethiopia and Kenya will reduce the national need for balancing power, thus making the construction of a pumped-storage plant in Kenya less necessary than previously envisaged. This US$1.26 billion investment will make part of the electricity produced by the 6000 MW Grand Renaissance dam usable for the entire region of East Africa. Bucher also said that a flexibility option to mitigate the effects of stochastic generation from wind and solar PV is wide-area balancing with bulk energy transfer systems, as illustrated by the 960 km 500 kV AC overlay grid built in Sudan.

Fuqiang Tian from Tsinghua University, China, addressed the subject of cross-border collaboration from a more unusual angle, showing that multi-country cooperation is not only needed at the institutional or financial level. It also requires joint efforts in research, science and engineering, especially when it comes to successfully tackling the challenges of climate change mitigation and adaptation. Based on a case study of drought characteristics of the Lancang-Mekong river basin and the impacts of reservoir regulation on streamflow through China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, he recommended

the promotion of integrated structural and non-structural measures, to develop flood and drought forecasting at the basin scale, and to operate jointly the more than 40 × 10^9 m^3 of water stored in the reservoirs of the Lancang-Mekong river basin.

Wang Qiankun, from Global Energy Interconnection Development and Cooperation (GEIDCO), China, presented the results of a research programme which demonstrates that harnessing the bulk of the world's untapped hydro potential would require the development of cross-border energy and water infrastructure through enhanced regional cooperation. From examples in the Congo and Nile basins in Africa, as well as five river basins in Southeast Asia, he put forward some concrete proposals, including enabling and enhancing the role of regional institutions, improving cost-benefit sharing mechanisms, prioritizing integrated and coordinated planning at the regional level, and harmonizing technical standards and regulatory policies. He also recommended to crowd-in different financial resources with multilateral finance institutions playing a major role.

Along with the presentation by the African Development Bank, a response to that last comment came from Eileen Burke from the World Bank, who gave an overview of the Bank's past and current support to transboundary initiatives across the globe, in particular in Europe, Asia and Africa. She recalled that two-thirds of the world's transboundary rivers do not have a cooperative management framework yet. She also explained how the Bank is helping countries to plan and build joint investments, mentioning as an example the 80 MW Rusumo Falls project, shared between Rwanda, Burundi and Tanzania. In conclusion, she referred to the forward-looking 'Water Storage Global Study', which aims to collate, publicize and bring new approaches in water storage as a means of enhancing water security.

During the lively interactive discussion session that followed, many participants reiterated the need for trust-building and high level involvement from respective countries, and drew attention to the role that multilateral institutions can play in facilitating cooperation. Cross-border projects become desirable only when each country involved can develop a sense of ownership. It was also pointed out that many lessons could be learned from the Grand Renaissance dam's development process.

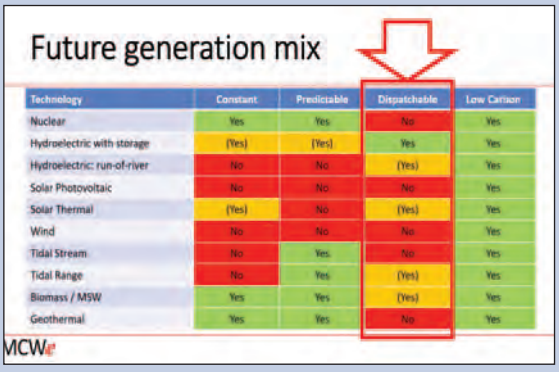
Finally, it can be said that the exchanges showed a growing awareness that dam safety should be a component of regional collaboration, in view of the cross-border impact of potential failure. The World Bank is supporting that trend.

New approaches to finance

M. McWilliams, McWilliams Energy, UK

The role of hydropower is changing: as well as providing clean energy, hydro is now recognized as an integrator for variable renewables, and is considered to be a key part of the solution to low-carbon power systems. However, there are still barriers to investment, and the green credentials of hydropower need sensitive treatment when dealing with the investment community. There remain questions about how to monetize non-energy benefits, and how to evaluate the benefits of hydropower.

The session explored these issues, discussing the services that hydropower provides, giving guidance on securing finance, and offering options for evaluating and monetizing hydropower benefits. Presentations were given on the following topics:



In the session on New approaches to finance, which he chaired, Mike McWilliams showed this outlook for the future global generation mix, with the characteristics of each source. "It is only hydro which can be switched on and off at short notice", he commented.

- Evaluating the benefits of hydropower (by chairman Mike McWilliams)
- Climate change and hydropower: potential impacts on the availability of finance for large hydropower projects in developing countries (by S. Markkanen and Dr Judith Plummer-Braeckman, University of Cambridge, UK)
- Institutional investment in hydropower (by Bernhard Miller, Hydropower Evolutions, co-authors from Simmons & Simmons, and Dr Judith Plummer-Braeckman)
- Financing hydropower in a world of cheap renewables (by N. Saporiti and J-F. Mercier of the IFC).

A common theme of the papers was that the traditional models for developing and financing hydropower are no longer applicable, and that new models are required. These need to take account of all the benefits that hydropower provides to the power system and host nation. As well as valuing the power and energy benefits, developers need to be compensated for ancillary services, socio-economic benefits and multi-purpose benefits provided by hydropower.

The results of research into the factors affecting the availability of finance were presented, giving an insight into what affects the decisions of financiers, including the perception of risk relating to hydro projects. Financiers are concerned about risk, including reputational risk. There is widespread recognition that hydropower is not adequately compensated for its role in stabilizing grids, and for its role in climate change adaption and resilience.

The particular concerns of institutional investors were discussed, considering the risk-reward profile of hydropower, and focusing on aspects that institutional investors find particularly problematic. The difficulties of mobilizing institutional investment stem from concerns about the complexity and sustainability of hydropower, and the perception that other renewable generation is less risky. Environmental, social and governance (ESG) credentials are becoming a major consideration for institutional investment. Increasingly hydropower is accepted as 'green' and as a contributor to several UN Sustainable Development Goals (SDGs), mitigating the sustainability concerns of investors.

The question of why hydropower should be developed when solar and wind energy are so cheap was the subject of the fourth paper. It was explained that hydropower has many benefits over variable renewables, including reliability and dispatchability, much greater longevi-

ty, and the ability to provide flexibility services and to operate in a complementary manner to other generation. The role of IFC in financing hydropower was examined, and case studies were presented to illustrate the benefits provided by hydropower.

The question and answer session focused mainly on the valuation of hydropower's benefits: how they can be evaluated, where studies are being carried out and how compensation can be provided. There were differing views on how to compensate for ancillary services: some favour a market approach with compensation for individual services, possibly using an auction-style mechanism; others believe that compensation for these services within a capacity payment is the best way forward, providing that the payments adequately compensate for the project costs. A general consensus emerged that the benefits should be evaluated on a system basis, assessing the costs and benefits of hydropower and other competing technologies to the power system.

The interventions from the audience and the views of the panel provided a lively debate, and it is hoped that this will contribute to the understanding of decision-makers involved in establishing regulatory mechanisms and commercial contracts for hydropower implementation.

Dealing with financial risk

Dr J. Plummer-Braeckman, University of Cambridge, UK

The risk session provided a fascinating insight into the world of hydropower project insurance. Two speakers from Marsh JLT Specialty (Stuart Freeman and Matthew Kendle) explained the results of a survey of hydropower projects which showed that the loss ratio (the ratio of premium received to payments made) was well in excess of 100 per cent, with some reporting ratios of up to 300 per cent and above.

Market conditions are changing for infrastructure projects in general, but these significant losses experienced on recent hydropower projects are making these impacts more acute in the hydropower sector. Many insurers are seeking significant premium rate increases so that the sector can be profitable and sustainable. For the hydropower construction projects that Marsh JLT Specialty has arranged in the last 10 years, average pricing has roughly halved in the last six years, but the trend is now in reverse.

In view of the above, insurers are reconsidering the cover they provide. The types of restriction likely to be put in place include: not offering defects cover; constraints on delayed startup cover; limits to cover on elements such as temporary roads and landslide cover; and, limited ability to extend the project period with the same terms. This will increase risk exposure and cost for the future.

After reviewing typical insurance claims associated with hydropower (which had totalled more than US$2 billion over the past five years), Stuart Freeman and Matthew Kendle from Marsh JLT concluded with these four recommendations.

It was suggested that, to benefit from the broadest cover possible, and with the lowest prices and deductibles, contractors and developers would be advised to approach the insurance of projects even more carefully than before. In particular, projects should engage with insurance advisors early in the process, ensure that they have good quality information to provide to insurers, and take great care about the way in which a case is presented to insurers.

The session also considered a new risk assessment framework developed for large hydropower projects, and delegates heard details of the current approach to risk from two multi-lateral development banks (Omar Vajeth from the African Development Bank, and Patrice Caparossi from the World Bank). Each year the presentations on this subject area are growing in complexity and this looks to be a fruitful area for further research.

Contractual Issues

Peter Rae, P.J. Rae Consulting, Canada

This session comprised four presentations, followed by a lively discussion that explored a variety of opinions about the optimal approach to contracting for hydropower construction.

The use of engineer-procure-construct (EPC) contracts was discussed in two of the presentations (Kevin Candee of Aqua Energie LLC, USA, and chairman Peter Rae). EPC is often contentious for projects with a large amount of underground works or other risks that can require a large cost premium for potential contractors. However, the presentations described situations where EPC could be applied effectively. A key consideration is to assess risks that are carried by the contractor in an EPC contract, and then determine how they could be mitigated before the tender.

Limitations will arise in situations where there is a large amount of site risks that make the opportunity unattractive to contractors. Another important consideration in some cases can be the size of the project, and whether there is a pool of interested contractors available. This can be a constraint for small projects, as well as for large scale ones.

While EPC is often preferred by lenders and developers because of perceived allocation of risk, many projects are not well suited for EPC. Issues identified during the presentations include the lack of EPC contractors in the market for many smaller scale projects, and the difficulty of ensuring risk transfers. One issue is the management and financial capability of the contractors interested to engage in smaller hydropower projects.

Alternatives to EPC were then discussed in the context of smaller scale projects. Many small projects will be sensitive to costs, and cannot afford the large premium for an EPC contract. At the same time, funding for development costs is limited, so conventional mitigations with more investigations and design are not always possible. Several alternative models are available that can expand the pool of available contractors and allow the owner to optimize cost for development and the premium charged.

Applications of the new FIDIC Emerald Book contract form were discussed following a presentation of the main features, by Stéphane Giraud of EGIS, France. As a Design-Build contract, the Emerald Book can be applied for civil works where ground conditions are important, but also with a full project scope that

would be analogous to an EPC contract. The Emerald Book allows ground conditions to be managed by allocating the site condition to the employer and the construction methods to the contractor. The pricing mechanisms allow for a significant reduction in the underground risks for a contractor. Projects can be set up with the full scope, including engineering, procurement, and construction, assigned to the contractor.

Examples of the key challenges for projects in Nepal were discussed by G.P. Kayastha of Chilime Engineering & Services, Nepal, including project financing challenges, requirements for a bankable project, and the legal framework for implementation. The available development framework affects the contracting strategy, investment opportunities, and financing.

The session noted that there is no one ideal solution for a hydropower construction contract. Each project must be considered in the light of the political framework, site conditions, ownership, financing, market for supply and construction, and the scale of the development. A good understanding of how a project might be assessed in the construction marketplace is required to ensure that there will be a competitive pool of experienced contractors available. Given the options available, project developers can select from a range of possible contracting strategies, depending on their specific conditions.

EPC contracts are recognized as being a viable alternative for some projects, but they have limitations for very small or very large projects, and in cases where there are large site risks. The new Emerald Book provides a valuable tool for developers by enabling and EPC scope of work while allowing the key ground conditions risks to be managed in a manner that will reduce risk premiums for construction contracts.

The capability of the developer is important in being able to assess the site conditions and to develop the most advantageous contracting strategy. Capable developers are able to obtain project financing with more flexibility in the contract forms adopted.

Overall, the session provided a very good overview of good practice for development and contracting of hydropower projects. Common themes included the need for good project preparation to identify, eliminate and mitigate risks, and the need for contracts and procedures to manage change and resolve disputes quickly.

Hydro technology and pumped storage

Hydraulic Machinery - Research

Prof Dr François Avellan, Emeritus Professor, EPFL-LMH, Switzerland

Four research papers were presented in this session. All were reporting on extensive investigations based on numerical simulations, laboratory experiments, reduced-scale physical model tests and advanced monitoring of prototype Kaplan and Francis turbines. In most of the presentations, both experimental and numerical simulation approaches had been followed, emphasizing the importance of these basic investigation tools. The overarching objective of these investigations were to optimize the design for extended service life, enhanced efficiency and increased flexibility of the turbines.

Dr V. Hasmatuchi, Research Assistant at University of Applied Science HES SO Valais, Switzerland, opened the session with a presentation of his investigation of cavitation erosion monitoring techniques, based on a hydrofoil case study in the cavitation testing facility of HES SO Valais-Wallis. The objectives were to provide a toolset for cavitation detection and measurement in the highly perturbed environment of hydroelectric units in the powerplant.

Some of the speakers take questions during the session on Hydraulic machinery: research, which was chaired by Prof François Avellan, Emeritus Professor at EPFL-LMH, Switzerland, shown top left. Papers covered numerical simulations as well as laboratory testing.

Dr. H. Benigni, TU Graz, Austria, discussed the development of a new Kaplan runner for modernization of the 1965 Krippau run-of-river hydropower plant in his country. The refurbishment aims to achieve an increase of efficiency in the relevant operating range of the turbine through a runner replacement, while keeping the runner diameter value. Furthermore, the maximum discharge is to be increased from 120 to 135 m^3/s, and the annual production by 4 per cent. Extensive numerical investigations were carried out to achieve acceptable cavitation characteristics, in this case of turbine capacity increase.

Dr I. Kassanos, National Technical University of Athens, Greece, gave a talk on the reversible pump-turbine efficiency and fish friendly assessment of Deriaz versus Francis units. The assessment was done using flow numerical simulations. It was shown that both types of pump-turbine achieve similar efficiency and fish-friendly characteristics, except that the Deriaz features about half the probability of fish collision with the blades leading edge, compared with experience in the Francis reversible pump-turbine. This last result may be related to the smaller number of blades featured in the Deriaz impeller, in comparison with the Francis impeller.

O. Orešković, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia, and CEO at Veski, presented a case study of troubleshooting excessive vibrations experienced by a Francis unit after overhaul. Industrial standard instrumentation was installed, including a key phasor, relative and absolute vibration sensors, capacitive air gap probes and magnetic field sensors. The data processing of the measurements with an industrial standard software demonstrated two causes of the problem: First, the tilt of the thrust bracket bearing plane with respect to the horizontal; and, second, the stator-to-rotor eccentricity causing unbalanced magnetic pull to the electrical machine.

Hydro machinery: operational issues

Daniel Paschini, EDF Hydro, France/Myanmar

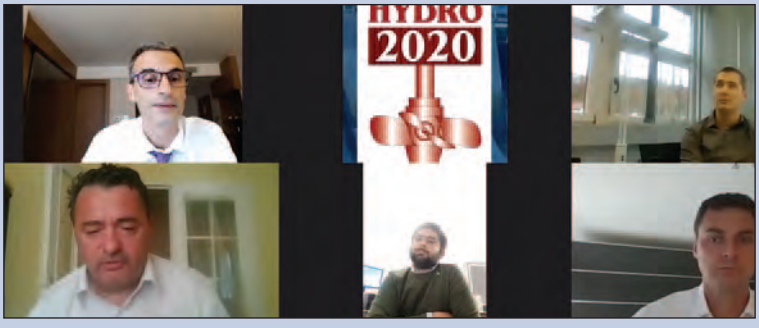
Operational aspects are key for a hydropower plant to last more than a century, as are design and construction aspects. While hydropower is a mature industry, improvements relating to operation are still ongoing,

as was shown in the four papers discussed during the session. Innovation relates not only to pieces of equipment but also to the methodology to install or monitor them, and the session made it possible to discuss various examples about penstocks, turbine runners, oil pressure systems and generators.

The first paper, presented by Jan-Hendrik Lott (API), dealt with fast and accurate alignment using 3D laser measurement technology. Measurement and alignment are indeed paramount when assembling parts of a unit. For example, a vertical-unit Pelton runner has to be set at a precise elevation with regard to injectors; in the same way, the bars of a generator have to be perfectly centered in relation to the unit axis, to avoid vibrations. Traditional methods use micrometers or cords, but Lott explained that laser measurements were now much more efficient because they give more precise results, they are carried out two to four times faster, and they make it possible to obtain a precise mapping of the various components. Replying to some questions during the discussion, Lott mentioned that the laser tracker could not operate under water. He also confirmed that the laser system could help control penstocks with regard to steel thickness loss, but this would also depend on the surface state.

The second paper was presented by Felix Lippold and Thomas Zeller from Voith Hydro, Germany. Voith has designed a new kind of oil pressure system (OPS) for hydro plants. These systems are necessary to open or close units' main inlet valves or guidevanes, and usually consist of pumps, accumulators and cylinders, controlled by oil distributors. The new development is a hybrid system. During normal operation, the system is based on an innovative closed-loop oil circuit with variable speed pumps. These pumps are hardly used thanks to the closed-loop circuit, which allows for up to 80 per cent energy savings. During emergency shutdowns, the system switches to a classical and safe open-loop circuit, using the tank and the accumulator. Voith has built and tested a 160-bar prototype of this hybrid OPS and proved that safe and reliable operation can be achieved using much less energy and oil. There were two questions at the end of the session, and in reply to one, Zeller said that this system has not been implemented yet but a first OPS was to be installed at a powerplant in the coming weeks. In response to the second question, Zeller said that Voith also studies electric actuators, but for medium to large hydro plants at least, OPS and cylinders were still necessary to ensure safe operation.

The third paper, introduced by Mohammad Zehab Ud Din (of the Mechanical Engineering Department of NIT, Jammu & Kashmir, India) was about assessing sediment erosion on Pelton buckets, using CFD. His work was based on the 23 MW Chenani hydro plant on Tawi river. The catchment area of the plant brings a large amount of sediment, with a hardness value greater than 7 on Moh's scale, which in turn induces spectacular erosion on buckets (the splitter and bucket tip) as well as the injectors (needle and nozzle seat). CFD simulations had provided a better understanding of the accurate location of hot spots, as well as the wear pattern, depending on various angles of impact, concentration, erodent size and shape factor. This analysis will be a useful input to Pelton runner designers to improve the geometry and coating of buckets to minimize the erosion without compromising the energy efficiency.



The second session on Hydraulic machinery dealt with operational issues, and was chaired by Daniel Paschini of EDF (shown top left). Topics included sediment erosion, flow measurement, and aspects relating to the installation and monitoring of equipment.

The last talk was by Pierre Roumieu of Compagnie Nationale du Rhône, France. He described how an ultrasonic flow measurement system had been set up at the 420 MW Genissiat hydro plant. For CNR, knowing the exact plant discharge was important because the flow is part of the cooling source of the Bugey nuclear plant downstream. After making field measurements using Doppler devices, and then using a CFD model, CNR had concluded that eight ultrasonic sensors were necessary on each of the six penstocks, to ensure an accurate measurement, within 1 per cent. (NB: the penstock length is equal to five times the diameter). In addition to the flow measurement, the system made it possible to compute the efficiency of the six Francis units, depending on the head, discharge and location (that is, centered or near the banks). Results showed a difference of up to 5 per cent for the two central units at the rated flow (100 m^3/s). These results helped optimize the powerplant and led to a large payback compared with the investment. Replying to a question, Roumieu underlined that the number of sensors to ensure a good accuracy depended on the straight length of the penstock (of course, the longer the better).

As a conclusion, innovations in electromechanical, SCADA and computer science help make better and longer-lasting hydro plants. Innovation is not only important for new powerplants but also for existing ones: it is paramount to maintain the existing powerplants well, in parallel with building new ones. These improvements are not only based on a purely economic rationale, but are also vital for additional important aspects like environmental protection or energy efficiency.

Hydraulic machinery: optimizing equipment

Prof. Cécile Münch-Alligné, HES-SO Valais, Switzerland

During this session on hydraulic machinery, three talks were presented around the topic of improving existing hydropower plants.

The first, entitled 'Challenges during the retrofit of the control systems at a 900 MW hydro plant with double Pelton turbine that operates as a synchronous condenser' was presented by M. Bühler of Reivax, Switzerland. His study reported on the refurbishment of the 900 MW Henry Borden high head hydropower plant in Brazil, equipped with 14 generators connected to double Pelton turbines. The project involved modernizing the speed control and automation systems of three generating units, which can operate as synchronous condensers. The production from this powerplant is relatively low today, as the plant's reservoir supplies drinking water to the city of São Paulo. The plant operates mainly in synchronous condenser mode, with the possibility of reversing operation and provid-

ing nominal active power to the system in less than one minute. After the installation of the new systems, several tests were carried out successfully such as a simulated isolated network test to challenge the reaction of the governor to control frequency. New diagnostic and testing tools were implemented to improve maintenance and to operate the units with a better view of all the processes, including centralized commands and the versatility of operation in the synchronous condenser mode.

The second paper 'Optimized energy production index of Itaipu' was presented by R.E. Oviedo, from Itaipú Binational. His presentation focused on the optimized production index (IPO) developed for the well known Itaipú hydropower plant. This very large plant is located on the Paraná river on the border of Brazil and Paraguay and is equipped with 20 Francis units of 700 MW. As a result of low inflow in 2019, it became necessary to optimize production. The IPO quantifies the amount of time the generating units operate in specified ranges of efficiency on the productivity curve, from 100 per cent at the optimal operation point, to 94 per cent at minimum and maximum power outputs. A grade between 0 and 5 characterizes a year: a grade 5 corresponds to a mean index equal to or greater than 99 per cent, while a grade 0 corresponds to a mean index of 94 per cent. The optimization is done by tracking the productivity curve during the short-term programming stage and during real-time operation. Thanks to this approach, an IPO higher than 99 per cent was reached with a grade 5 in 2019, although the inflow was very low. By comparison, the IPO, calculated retrospectively in 2016, was lower than 99 per cent, whereas the production was higher than 2019 because of the higher inflow. This new index makes it possible to characterize the valuation of the available inflow.

The last presentation was by M. Roque from EDP, Portugal, together with F. Von Locquenghien from Voith Hydro, Germany. They presented their paper 'Castelo do Bode HPP: Flexibility increase of an old Francis turbine'. This plant, on the Zêzere river in Portugal, is equipped with three Francis turbines with a maximum capacity of 53 MW. The study investigated the possibility of increasing the operating range of the machines from 0 to 100 per cent by carrying out site measurements, including strain gauge, vibration, pressure measurements and numerical simulations. In addition to multiple pressure probes and accelerometers, 32 strain gauges were placed on two blades where the flow and structural simulations predicted the highest and lowest stress. Transient and steady-state operating conditions were recorded, including multiple starts, stops and load rejections, to estimate the damage from the operating conditions normalized by the damage during 1 h at full load, as well as the residual life. The degree of utilization was assessed to be 3.16 per cent of 80 years of operation, and the main impact on the total damage was found to come from the start-stop cycle, whereas all steady-state operations only had a minor impact. Moreover, the runner of unit 3 had been rehabilitated with a full coating, to provide high resistance to wear and cavitation. After one year of operation, with extensive partial load, the protective coating showed very good behaviour, confirming the previous results.

The interest of optimizing the production and flexibility of hydropower plants, as well as the development of new services to the grid, is booming, reflecting the new role of hydropower in the electricity market.

In a session on optimizing hydraulic equipment, chaired by Prof Cécile Münch-Alligné of HES-SO Valais, Switzerland, a joint paper from EDP and Voith described increasing the efficiency of an old Francis unit at the Castelo do Bode plant, in Portugal, shown here.

The European XFLEX programme

Prof Dr F. Avellan, EPFL-LMH, Switzerland

After an introduction about the programme, the three phases of the H2020 European Project XFLEX Hydro were presented: innovation, demonstration and deployment. The project to extend hydro's power system flexibility (XFLEX Hydro) is an innovation action project funded by the European Union's Horizon 2020 research and innovation programme, under agreement No 857832, was explained.

Prof Dr François Avellan, Emeritus Professor of Hydraulic Machines at EPFL, opened the session with an introduction of the project and presentation of the Innovation phase. The main overarching objective of the project is to contribute to the decarbonization of the European electricity mix. Keeping in mind the 32 per cent target for renewables, to be achieved by a massive deployment of intermittent wind and solar energy sources, hydropower is a key enabler for the stability of the power system. The XFLEX Hydro project is an initiative, coordinated by EPFL, of a consortium of 19 partners, including three major European electrical utilities: Alpiq, EDP and EDF, three international hydroelectric equipment suppliers: Andritz Hydro, GE Renewable Energy and Voith Hydro, two consulting companies: Power Vision Engineering and Zabala Innovation Consulting, and 11 Research and Technology Organizations (RTOs): in France Armines, CEA and SuperGrid Institute; in Germany, Stuttgart University; in Portugal, CNet and Inestec; in Spain, UPC; in Switzerland, EPFL and HES SO; and, in UK, IHA. The project objective is to demonstrate the integration of advanced flexibility hydroelectric technologies at seven hydro powerplants, including all types of plant: pumped storage, storage and run of river. The XFLEX Hydro project began on 1 September 2019 and will end on 31 August, 2023 after 48 months. The overall cost of the project (including non-EU funded) is €18 million, of which the Commission grant amounts to €15 million (or 83 per cent of overall cost). This makes XFLEX Hydro the largest project related to hydropower to have been funded by the European Commission to date.

The Innovation Phase is two-fold, including: an optimal collection of data to estimate the Key Performance Indicators of a hydroelectric plant accurately; and, the specification of the 'smart power plant supervisor' dubbed SPPS.

Flexibility services and specifications is the scope of the work package WP2 led by Inestec. Specifying the

mapping of the ancillary services related to flexibility technologies which a hydro plant could provide to the electrical power system is key to assessing the opportunity to take part in new power markets. The resulting ancillary services will combine, for each demonstrator, information about the latest flexibility product, flexibility markets and innovative hydroelectric technology solutions that enhance the ability of hydro plants to respond to the power system's flexibility needs. An advisory board of transmission system operators is constituted to support the XFLEX Hydro project consortium in the performance of the work package WP 2.

Specification of the SPPS is the objective of the work package WP 3, led by EPFL. Today the practice of hydro unit control is to fix a limited range of operation based on technical constraints which exclude the needs of the grid. Typically, hard coded limits are fixed for the control set points according to the OEM specifications, and the safety requirements of the hydro plant's operation. Advanced digital techniques make it possible to have knowledge of the hydroelectric unit's behaviour, with respect to the operating set point. This knowledge, such as hydraulic performance data collected during the engineering development phase, reduced scale physical model tests, commissioning and operation, is mapped as a function of the operating range. Therefore, a multidimensional hill chart can be used to build a look-up table, to provide to the supervisor with a path to reach the set point and to assess the production, the wear and tear and the residual unit lifetime of the unit. The SPPS will act at an intermediate level between the SCADA level and the automatic generation control. The SPPS structure is designed to integrate the flexibility technologies such as variable speed, hydraulic short circuit, and battery hybrid. The SPPS will make it possible to control the unit of a flexible range of operation based on a multi-dimensional analysis, including grid energy and flexibility needs.

The Project Demonstration phase is then performed to demonstrate how integration of advanced flexibility hydroelectric technologies in hydropower plants can support the electrical system flexibility.

The objective of the Deployment Phase is to build methodology and tools to bring project results to their markets and to optimize the XFLEX Hydro Solutions.

Filipe Duarte, of the University of Porto, Portugal, and also Unit Director for Engineering and Optimization of Hydro Assets, EDP, Porto, described the variable speed doubly fed induction machine at the Frades 2 pumped-storage scheme, one of the six demonstrators of the XFLEX Hydro project. Frades 2 is a new plant in Portugal, built with two powerful 390 MW and advanced hydro generator sets. The objective is to demonstrate the potential of a DFIM variable speed pumped-storage plant to enhance its benefit to the grid further by: maximizing performance and increasing flexibility through the implementation of hydraulic short circuit operation to extend the power-plant range; implementing virtual inertia emulation and frequency control reserve (FCR), improving the maintenance intervals and minimizing outage times with the help of the SPPS implementation; and, improving the average annual overall efficiency while reducing the power consumption of auxiliary equipment by condition-based control.

The Vogelgrün plant in eastern France, one of the XFLEX demonstrator projects. Jean-Louis Drommi of EDF explained that as part of the XFLEX project, one of the Kaplan units at the plant will be hybridized with a small battery; both will work in tandem under the control of a specific power sharing algorithm.

Jean-Louis Drommi, Electrical Expert at EDF Hydro Engineering Center, France, presented the demonstrator of Hydraulic Short Circuit and SPPS at the Grand Maison pumped-storage plant in France, and the demonstrator for battery hybridization with a Kaplan unit at the Vogelgrün powerplant on the Rhine river in France.

Grand Maison is the largest pumped-storage plant in Europe, and is equipped with 12 units totalling 1800 MW of installed capacity, including four Pelton units and eight reversible pump-turbine units. It is a seasonal pumped-storage scheme, with an exceptionally large storage capacity for the headwater reservoir. The fixed speed, 850 m head, reversible multistage pump-turbines prevent the variation of power either in the turbine or pump operating mode. In the generating mode, the plant relies on the Pelton units to provide ancillary services to the grid, whereas in the pumping mode, no frequency support can be provided to date. Therefore, the demonstrator goal is to validate the hydraulic short circuit operation, to achieve fully automatic control of the units when operating in HSC.

Vogelgrün is a run-of-river plant on the Grand Canal d'Alsace (Rhine), very close to the city of Strasbourg. It is equipped with four Kaplan units totalling 160 MW. Considering the increasing need for grid frequency support, it is expert opinion that Kaplan turbines and their servomotors are expected to suffer additional wear and tear and fatigue stresses. The demonstrator is to use one existing Kaplan unit which will be hybridized with a small size battery; both will be working in tandem under the control of a specific power sharing algorithm. With one hybrid unit and one reference non-hybrid unit, XFLEX Hydro is to provide data to substantiate the wear and tear estimate, and to check the possibility of extended performance whether dynamic or energetic.

Chairman Prof François Avellan presented the Project Deployment phase of the XFLEX Hydro project. Demonstrator coordination and monitoring is the task to be performed in the work package WP 10, led by EPFL. The outcome of this work package is to specify the key performance indicators of the flexibility matrix, to enable a quantitative assessment to be made of the hydro flexibility technologies. Particular attention is paid to the extended operating range, fast start and stop, fast ramp-up/ramp-down, fast turbine-pump/pump-turbine transition, optimized maintenance intervals, extended availability, increased annual efficiency, and performance maximization and digitalization. Maybe the most important outcome of XFLEX Hydro will be, at the end of the project, the delivery of a public white paper proposing guidelines and standards to support hydro plant operators to achieve

enhanced flexibility services for the electrical power system.

Benefits, costs and deployment are the tasks to be performed in the work package WP 11, led by SuperGrid. To help decision-makers and support market uptake, flexibility benefits optimization tools (FLEXBOTs) will be developed and validated on each demonstrator business case. Cost models will be mapped against each technology, and the overall benefit of using a flexible technology assessed comprehensively. Market scenarios, in 'day-ahead' or over long-term timeframes, will be taken into consideration to help the investment decisions. These tools will provide a deep understanding for plant owners of their potential to provide flexibility services to the grid system.

Communication and dissemination are carried out in the work package WP 12 led by IHA. Sharing knowledge during the four-year project will raise awareness of XFLEX Hydro and disseminate project outcomes to stakeholders. Target audiences include the hydro and energy industry, governments and markets, as well as the wider public. A programme of actions will deliver multimedia, news, branding and events to communicate progress and improve understanding. The www.xflexhydro.net website will become an online knowledge hub of the project, providing access to resources and published materials.

A lively question and answer session followed the presentations.

Operation and maintenance

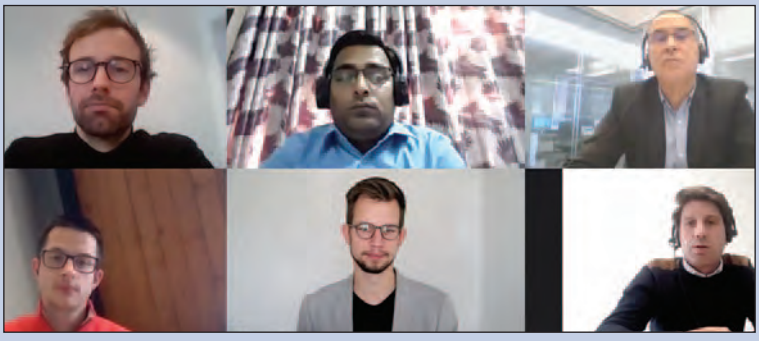
M. Oliveira, EDP Gestão da Produção de Energia SA, Portugal

Today the operation and maintenance of hydro facilities covers a broad range of disciplines and competences, from the purest technical aspects of the installations, equipment and systems, to the emerging robust digital tools and models, which have only become possible as a result of the current computational and connectivity capacities.

These new technical frontiers and the optimization of procedures are the tools that generation companies are using today to cope with internal costs in the light of decreasing market prices and the increasing pressures on regulation, while at the same time not jeopardizing safety, performance, availability or flexibility. The session on O&M addressed all these issues.

A presentation by Y-L Beck of EDF, France, described the internal organization and solutions implemented by his company to monitor its hydro facilities, and how curative maintenance and maintenance strategies could be optimized with a discerning segmentation of more than 200 hydropower plants, and different levels of digitalization. With fault modes defined and the installation of an appropriate number of sensors, potential faults could be avoided, allowing companies to estimate the significant reductions in its income losses. It was pointed out that this capability would enable the investment cost in the monitoring system to be recovered within three to six years. Based on these findings, EDF recommended that all hydro assets owners should to develop their own monitoring system.

Continuing on this subject, delegates heard from Dr Paul Webbe, that to achieve the same goal, his company, Voith of Germany, had developed a service based on proven data-driven analytical models, and with a multi-disciplinary team of experts in the various fields of hydropower, that would allow owners to plan their powerplants' maintenance based on the condition of the machinery, therefore optimizing the maintenance periods and cycles. Despite the specific tailor-made characteristics of each hydropower plant, the use of appropriate machine learning algorithms and combining this with expert knowledge, Voith's service would allow their clients to reduce downtime of the plants, reduce maintenance costs, and optimize operation. These two approaches for the same goal, with their relative advantages or disadvantages will, for sure, lead to intense and constructive discussions in the sector.



Manuel Oliveira of EDP, Portugal, (shown top right), chaired the session on Operation and maintenance. He commented in his introduction that O&M of hydro plants covered a broad range of disciplines, and ranged from traditional technical solutions to emerging digital tools, representing new technical frontiers. These were all covered well in the session.

The operation and maintenance of hydro plants in challenging environments, such as the Himalayan region, can impose tough discipline on daily procedures and practices, for example to mitigate sedimentation and silt erosion which could affect plant performance and revenues. J. Pani, of NHPC, the largest organization for hydropower development in India, gave a talk on what had been learnt, and best practices implemented at the company's 22 powerplants throughout the country, to guarantee the plants' availability, optimize maintenance schedules, manage sediment and silt effects, and to create an inventory to minimize generation losses caused by outages. There was special interest in the use of HVOF coatings for runners and guidevanes.

Assistant Prof Kaspar Vereider of Norway discussed the strategy followed by his company, Sira-Kvina, to develop a system for condition monitoring and predictive maintenance, combining data and opinions from experts. With these data and based on a risk assessment for each unit, machine learning algorithms would be able to predict future failures, he said. To achieve this, the previous standardization of components, descriptions of failures and faults, and the taxonomy to connect components with failure types and tests, were all essential to design the architecture for data acquisition and provide the optimum functionality and accuracy of predictions. Based on some proven case studies, Sira-Kvina has made a transition in its maintenance strategy, shifting from periodic maintenance to a condition-based maintenance regime, and thus expects to reduce its maintenance costs by 5 to 20 per cent.

Dr Ricardo Clementi, of STE Energy, Italy, presented the example of a small plant and several uses of machine learning techniques to predict future behaviour of the components and to detect deviations that could lead to failures. Special care with the preprocessing of the data, the algorithm training, the postprocessing of results to check the algorithm and the choice of the models is fundamental for the accuracy of results, he explained. He gave an example of the bearing temperature estimation and the intake debris accumulation detection to confirm the efficiency of these tools.

As a conclusion to the session, it could be observed that these new and emerging digital tools will help the hydro community to improve the efficiency and competitiveness of hydropower, and will help to enhance its specific role in the electricity sector. Last, but not the least, the combination of the experience and knowledge of experts in hydro technologies with the domain of these digital skills and tools is critical in this respect.

Pumped-storage projects

E. Guilleminot, Mott MacDonald, Singapore

Once again, this year the session on pumped-storage projects was successful. I take the opportunity to congratulate the speakers for their very interesting presentations and articles. They have demonstrated the varied work being undertaken in this area across the globe.

The first presentation highlighted what I see as a major part of our future, that is pumped storage and integration with renewable generation. The 250 MW Kidston project in Australia is the perfect case study to present the lessons learned to guide the new approaches to renewable energy systems. The site is a former mine and therefore has minimal environmental challenges. Some innovative form of construction adopting a steel frame and precast floor units for the powerhouse have been proposed by Mott MacDonald to manage the time and cost of construction.

Then Thomas Ihly of AFRY, Switzerland, reviewed the development of the Nant de Drance pumped-storage project, including the design features and technical characteristics of the 900 MW plant. He described the first filling, with a special focus on the monitoring that had been implemented. Leakage through concrete lining had been detected from a temporary gallery and adequately treated.

The third paper, given by Sanjoy Saha of NTNU, Norway, discussed the air cushion surge tank proposed for the 1300 MW Kuli pumped-storage project in Norway. This type of surge tank allows for an inclined headrace tunnel without a vertical shaft in the waterways; but it was pointed out that air leakage could be a challenge in cases when the geology was not good enough.

Civil works solutions to prevent rotor lifting at the Duge 200 MW pumped-storage plant in Norway were then described by Daniel Pace of EPFL, Switzerland. It is valuable to investigate this phenomenon to prevent disasters such as the one which occurred at the Sayano Sushenskaya hydro plant.

The next presentation, by Kateryna Fanina of Ukhydroprojekt, was about solutions to solve operation problems with the electrical equipment at the Tashlyk pumped-storage plant in Ukraine.

The Tashlyk pumped-storage plant in Ukraine. Solving operational problems with electrical equipment there was discussed by Kateryna Fanina of Ukhydroprojekt, in one of two sessions on pumped storage, which was chaired by E. Guilleminot, Mott MacDonald, Singapore.

The last talk, by Liui Jiajin of Power China Huadong Engineering, was about the core technology in pumped-storage development in China. In particular, vibration control analysis in pumped-storage plants was discussed. The various construction core technologies were described, including the large-scale vertical shaft boring machine. Some forward-looking research in Chinese pumped-storage development was presented, including the future for saltwater schemes.

Over the past 60 years, pumped-storage plants have been operated worldwide, and so it is important to highlight how our history and experience are helping with our future and innovation.

This conference is a good start for the International Forum on Pumped Storage Hydropower which has just been created as it will help to shape and enhance the role of pumped storage in future power systems, and to expand and transfer best practice and experience. These subjects should be developed further at the next conference.

Pumped-storage technology

Ralf Bucher, Tractebel Engineering GmbH, Germany

In this session, current large-scale developments were presented, and the role of pumped-hydro in renewables-based electricity systems was examined.

As an introduction to the session, the chairman drew attention to the recent trend reversals and global development projections. With record-low auction prices of less than €¢3/kWh, today in many countries, the cheapest way to produce electricity is by solar PV. In 2019, an important milestone was achieved when renewable generation increased by more than the increase in global electricity demand. This was the first time in decades that fossil-fuel-based generation had declined. Today, renewable technologies are dominating the global market for new capacity, and according to the International Energy Agency (IEA) in 2020, 90 per cent of new power capacity was renewable. Regarding pumped-storage, the installed capacity is expected to increase from 165 GW today to 300 GW by 2030.

In the first presentation, by Jake Ross from Snowy Hydro, we learnt about the Snowy 2.0 pumped-storage plant in New South Wales, Australia, with a design capacity of 2000 MW. The interest of the audience was directed towards the question of why three of the six pump-turbine units were chosen to be of the double-fed induction type. In the course of the discussion it was pointed out that this question is key during the design of a modern pumped-storage scheme equipped with pump-turbines. The selection of either asynchronous (adjustable-speed) or synchronous (constant-speed) motor-generator technology is crucial. Apart from the obvious operational advantages of adjustable-speed units, during the decision-making process a number of complex and wide-ranging questions have to be answered. The capacity rating of individual units is especially important for synchronous machines, as in the pump mode, a fixed amount of a continuous surplus of power in the grid is required. Load control in the pump mode is not possible. On the other hand, a large number of asynchronous units provokes superimpositions in the variable load operation range. For Snowy 2.0, the decision was taken to design the turbines in such a way that at a later stage, the fix-speed units could be changed to variable-speed, by replacing

the runners and (of course) the motor-generator.

The contribution by Praveen Dixit from Meil, India, focused on key aspects of the balance of plant equipment for the 500 MW Kundah pumped-storage plant in the southern Indian state of Tamil Nadu. The existing system comprises six hydro plants with around 600 MW of capacity that have been in operation since the 1960s. The new pumped-storage scheme will reduce peak demand deficit, and is planned to be commissioned by 2022-23.

A presentation by Dr Wolfgang Richter from Graz University of Technology, Austria, compared various storage technologies and outlined a case-study in Germany which showed how to achieve a 100 per cent renewables-based electricity system. For the year 2019, pumped-storage schemes and synthetic methane storage systems with re-electrification were compared, to investigate the specific impact on electricity production with loss identification and utilization time. The results underlined that pumped-storage hydro is the most cost-effective and sustainable energy storage technology, with the most efficient use of valuable power production from renewable sources, and thus has the lowest carbon footprint. Furthermore, the benefits of an asymmetric storage with the use of passive energy storage at existing hydro reservoirs, and the construction of new pumped-storage schemes, were highlighted. This solution was shown to provide the highest use of resources to avoid overproduction, and as being the most economic approach.

The final contribution, presented by Eliseo Marchesi from Studio Frosio, Italy, focused on small-scale pumped storage, and its contribution to smart grids. During the discussion, questions arose as to whetheryhu56t small pumped-storage plants would be suitable to stabilize mini-grids or solar-hybrids.

Regarding topics for future conferences, the increasing impact of variable renewable infeed will provide sufficient material for research and development. Concluding with some interesting figures in this context: In July 2020, the contribution by wind and solar in Germany was 54.1 GW at a national consumption rate of 54.1 GW. Half a year later, during the night and at low wind speeds, it was 1.3 GW (at a consumption rate of 60.1 GW). These are the challenges that power networks and pumped-storage face.

Civil engineering

Design and Construction

Michael Rogers, ICOLD President, and Stantec, USA

The presentations and discussion during this session at HYDRO 2020 centered around the civil engineering aspects of hydropower and dams. Civil engineering is a key component of our dams and hydropower industry, with critical infrastructure projects that develop 'Strategies for future progress' (the conference theme) in themselves, as well as in support of larger systems. The practical steps of civil engineering involve the planning, design, and construction of structures for new projects, as well as the refurbishment of structures for existing projects.

The session focused on the design and construction of some major hydropower schemes under implementation in Switzerland, Uganda, and Canada. A key focus of the session was the use of the maturing technology around the Building Information Modelling (BIM) project delivery method, including a representative project (the Schils powerhouse in Switzerland) that was constructed without paper drawings.

A session on Civil engineering – Design and construction, was chaired by ICOLD President Michael Rogers (shown top left). Project case studies from Switzerland, Uganda and Canada were discussed.

It is always exciting to see the civil engineering papers in these HYDRO conferences as they represent modern approaches to design and construction projects. This year's papers were interesting, with two projects from Switzerland where much work on the leading edge of hydropower is being accomplished. The Swiss energy strategy carries the lofty objective to abandon nuclear energy and to rely completely on renewable energy production by the year 2050. We know that the use of intermittent renewables, such as wind and solar, increases the need for renewable hydro production to sustain the grid balance of reliability for energy supply. In Switzerland, Hydroelectric powerplants currently represent around 60 per cent of the annual electricity production and the figure is growing. Globally, we are seeing an increase in hydropower productions by new construction, as well as refurbishing existing plants.

The paper presented by Mona Seyfeddine (Ecole Polytechnique Fédérale de Lausanne, Switzerland) showed a comparison of hybrid modelling techniques for a throttled surge tank, including numerical (one-dimensional and three-dimensional) and physical modelling. Each technique was shown to have different advantages and challenges. When combined and contrasted, a clear picture of the expected hydraulic performance of the complex system could be understood and predicted to support operational planning. It was good to see the strong relationship in our industry with academia, as Ms. Seyfeddine had used this project as part of her graduate thesis work.

The construction phase of the project cycle is always challenging, as changing conditions arise seemingly every day, or even every shift. The Schils powerhouse development presented by Gregor Heyer (AFRY Schweiz AG, Switzerland) showed the construction-phase advantages of the BIM project delivery process

The possibility to design and construct a project without paper was demonstrated in the talk by Gregor Heyer of AFRY, who spoke of the Schils powerhouse in Switzerland.

Marco Conrad of AFRY, Switzerland, chairing the session on Materials for dams, which covered RCC, CFRDs, geomembranes, and concrete dam rehabilitation.

Below: Prof Xu Zeping of IWHR, China, who gave a talk on CFRDs built with soft rockfill materials.

executed without drawings. It was encouraging to see the interest from contractors at this project, to move beyond paper plans to tablets and total stations in the field for construction. This paper outlined a comprehensive BIM process from planning through design and construction, and this no doubt represents the future of heavy civil construction.

The more conventional Waba dam rehabilitation project presented by Eric Tiedje (Hatch, Canada) illustrated a common problem of the modern inventory of dams: aging. The 18 m-high embankment dam was constructed in 1976 on a soft, sensitive marine clay that has settled in areas as a result of foundation compressibility. The rehabilitation project was a good opportunity not only to address the immediate settlement issues, but also to upgrade several other areas of the aging project, including instrumentation and monitoring improvements. Instrumentation and monitoring continue to be among the best tools for tracking the health of our aging structures.

Bill Hakin, Australia, spoke of the advantages of moving the design and construction of both new and refurbishment schemes to a digital delivery platform. He described this as a "single source of truth", accessible to all parties involved, anywhere in the world, in real time. from the conceptual stage of a scheme, through design and construction, to operation and maintenance.

The final presentation on the Nalubaale and Kiira hydro plants' upgrades showed a strong commitment to maintaining key hydropower facilities in Uganda. The combination of these two hydro plants and spillway discharge structures have an important function to control water level and discharges from Lake Victoria. Left unchecked, the aging projects threatened a loss of efficiency and capacity for the generation of clean and renewable power in the country. The authors, Peter Otto and Eng. Paul Tumwine (UEGCL, Uganda), presented a comprehensive review of the project drivers, including deterioration of the civil structures as a result of alkali-silica reaction, as well as the mechanical issues with the power generation equipment. A cost/benefit review of alternatives had been discussed as part of the process, to identify the most appropriate rehabilitation solutions. The implementation of these solutions will increase the reliability and longevity of these critical infrastructure projects.

In summary, the topic of BIM design and construction continues to be popular in the civil engineering track for this conference. I see this topic continuing to grow in affordability to owners, and acceptance in the industry, for those bold enough to take the next steps of evolution for heavy civil projects. I hope that we continue to see an expansion of this project delivery method at future conferences, including its use in developing countries, as discussed during the question and answer period of this session. The Q&A period also discussed the challenges of aging infrastructure that will continue to be a focus of our industry. I hope to continue to see innovations at future conferences that address aging hydropower projects to meet the design intent and assure dam safety.

It was an honour for me to be Chairman of this HYDRO 2020 session on Civil Engineering. I am very grateful to the authors and presenters who made this session a success, especially those who participated in the live discussion. I am also grateful to Aqua Media and the conference facilitators for a well run virtual conference.

Materials for dams

M. Conrad, AFRY, Switzerland

The session included four presentations. In the tradition of past HYDRO conferences, the topics were very diverse, covering roller compacted concrete dams, concrete faced rockfill dams, geomembranes and concrete dam rehabilitation and retrofitting.

Dr Malcolm Dunstan, MD&A, UK, gave a keynote talk on RCC dams worldwide. His database, which is also published in the annual *H&D World Atlas*, holds 936 large RCC dams (with a height of at least 15 m) of which 851 are complete and 85 under design and construction. A 'standard' RCC dam has emerged from the trends seen in the database over the past decade. This is based on the high-cementitious content approach (67 per cent of the volume of all RCC placed in dams to date) with a high workability, frequently super-retarded RCC that contains a low-lime flyash as a supplementary cementitious material (used in 67 per cent of all RCC dams). There could be conditions when such a dam is not the optimum, but it should be the starting point for the design of the great majority of RCC dams. The importance of the RCC speed of construction was emphasized as the key to RCC dam economy and quality. The original concept of RCC dams was to provide a simple method of construction. Unfortunately, some of this simplicity, referred to by Dr Dunstan as the KISS (Keep It Simple) concept, is being lost with some modern RCC dams, and most RCC dams are not being constructed as rapidly as they could be. A holistic view should be taken for design and construction of RCC dams, as every aspect of the design and construction impacts on other aspects. Investment spent upfront on the investigation of the design and construction of an RCC dam would always lead to economic benefits, Dr Dunstan said.

Prof Xu Zeping, IWHR, China, discussed technologies for concrete faced rockfill dams (CFRDs) built with soft rockfill materials. He stressed the importance of understanding the engineering properties of the soft rockfill and the deformation characteristics of the CFRD to control and improve the stress condition of the concrete face slab. Challenges with soft rockfill include significant particle breakage and an increase of fine particles after compaction, resulting in lower

rockfill permeability. Soft rockfill has lower shear strength, is more susceptible to weathering in a humid or open-air environment, and exhibits larger creep and a significantly longer time until deformation development stabilizes, compared with hard rockfill. Consequently, it should be used in the downstream part of the CFRD (zone 3C), where it should be arranged above tailwater level. A high permeability drainage zone should be provided upstream of the soft rockfill zone, and the outside boundary of the soft rockfill zone should be protected by hard rockfill. Soft rockfill is generally not recommended for CFRDs exceeding 200 m in height. Construction recommendations put forward by Prof Xu included the use of controlled blasting for soft rockfill quarrying and avoidance of stockpiling to prevent further weathering and weakening. Construction parameters, including the addition of water, should be optimized in embankment compaction tests, focused on minimizing particle breakage. As the fine particles concentrate at the lift surface, scraping of this relatively impermeable hardened layer (typically 10 to 20 cm) prior to placing the next lift is recommended.

Dr Alberto Scuero, Carpi Tech, Switzerland, addressed the topic of restoring the watertightness of existing canals, analysing various repair options and exploring the advantages geomembrane liners have over more traditional liners, thanks to their elongation properties, their low hydraulic roughness, and their engineered long-term durability. He took the example of the 7 km-long Lorona canal in Indonesia as a recent case history of a geomembrane installation in the dry, which had been fully lined within only seven weeks. The selected PVC geocomposite had been considered superior over an HDPE lining, based on the combination of geomembrane and anchoring system, factor of safety, precedent performance under high-velocity flow, and life cycle cost. The installation of a geomembrane lining under full canal operating conditions was discussed, with two project examples where an innovative PVC geocomposite mat had been used, with a ballast layer incorporated. The technology had been validated in a pilot project at the Ismailia canal in Egypt in 2016. An upcoming project, it was reported, was the sealing of a section of the Grand Canal d'Alsace near Kembs, France, for which the PVC geocomposite mats are entirely prefabricated including a distributed fibreoptic monitoring system and grouting pipes for ballast filling.

João Conde Silva, National Laboratory for Civil Engineering, Portugal, discussed different repair, rehabilitation and retrofitting measures for concrete dams, using cement-based materials. The various intervention levels were introduced, addressing replacement of deteriorated concrete, overlays as the strengthening layer and complete dam cross section enlargements to increase stability. The diverse methodologies were illustrated by case histories, and it was concluded that the successful remediation projects typically implemented a combination of different methodologies to extend the dam service life.

Dam safety - 1

Dr A.K. Hughes, Dams and Reservoirs, UK

An illustrious group of speakers joined the session. Michael Rogers, ICOLD President, talked about ICOLD's role in enhancing dam safety; the World Bank's perspective to dam safety was described by Felipe Lazaro, and Past ICOLD President Jia Jinsheng talked about cemented material dams and their safety.

Past ICOLD President Anton Schleiss spoke of what he called 'the seven commandments associated with the first filling of a dam', and ICOLD Vice-President D.K. Sharma informed the conference about the World Bank-supported DRIP initiative in India, aimed at rehabilitating a large number of dams to enhance safety.

Michael Rogers highlighted the importance ICOLD placed on the issue of dam safety, demonstrated by the recently published (October 2019) World Declaration on Dam Safety, and ICOLD's continuing commitment to improving the safety of dams through knowledge transfer and worldwide collaboration in more than 100 countries. However, he highlighted that despite ICOLD's efforts, incidents and accidents continued to occur, endangering the lives and in some cases killing people downstream.

He drew attention to ICOLD's 'Pillars of Dam Safety': namely structural integrity/routine surveillance and maintenance; instrumentation/monitoring, design for intrinsic risk/changing natural hazards; and, emergency planning. Rogers stressed the importance of sharing lessons learned; he said: "We have an ageing stock of structures and also professionals" and thus it was necessary to have a sufficient pool of trained personnel.

Statutory regulators were also highlighted by Rogers as having a significant role in ensuring dam safety.

Felipe Lazaro, Senior Dam Specialist at the World Bank, told delegates that the Bank tries to ensure safe dams, to contribute to a resilient and sustainable economy and social development, through the adaption of good international practice. He cited 201 active and pipeline projects involving 1715 dams, mainly in Africa, East Asia and Latin America. They included new schemes, but also rehabilitation and upgrade projects, including the Kariba, Tarbela, Nurek, Fierza and Komani dams.

The Bank provides technical support and quality assurance, Lazaro said, and has distinguished between large and small dams. New dams involved a review by an independent experts' panel, he said, as well as dam safety plans covering construction, supervision, instrumentation, operation, maintenance and emergency preparedness. Periodic inspections after completion were also required, he added.

A recent strengthening of the dam safety management systems had included a lowering of the threshold for large dams (3×10^6 m^3) from 10 to 5 m, the inclusion of small dams which could cause 'safety risks' and the introduction of a proportional risk management approach, Lazaro reported. A new 'Good Practice Note' for dam safety is to be available soon for Bank staff and borrowers.

Jinjigou dam, under construction in China, one of several examples of a cemented material dam, presented by Dr Jia Jinsheng. He spoke about the characteristics of CMDs, including safety against overtopping, and the possibility to be built on non-rock foundations.

Dr Andy Hughes, UK, (top left) chaired the first session on dam safety, which included talks by ICOLD President Michael Rogers, Hon Presidents Jia and Schleiss, Vice-President D.K. Sharma, and Felipe Lazaro of the World Bank. India's World Bank-supported DRIP initiative, and lessons from the Xe Pain-Xe Namoy failure in Laos were among the topics discussed.

Jia Jinsheng, Honorary President of ICOLD, presented on the subject of 'Investigation on dam safety and progress in cemented material dams'. His talk highlighted that there have been more than 2000 failures in the USA and 3000 in China, and that most failures still occurred as a result of overtopping. More than 93 per cent of China's dams are embankment dams which can be subject to overtopping failure.

Jia explained that cemented material dams had first been proposed in 2009 as a 'safe' dam against overtopping which could be built on a 'non-rock foundation'. His presentation highlighted that any materials could be used, and so variations included cemented sand and gravel, cemented artificial sands and gravels, cemented rock and soil; the structures could be built on virtually any foundation.

Examples of dams, dykes and cofferdams were given, involving some very high structures, many of which had been overtopped without failure. Certainly, it seems a form of construction to be considered, he said.

Prof Anton Schleiss, Honorary President of ICOLD spoke on the "Seven commandments to respect to reduce the failure risk of embankment dams during first filling of a reservoir". These 'commandments' were based on an investigation of the failure of Saddle Dam D at the Xe Namnoy, Xe Pian project in Laos. They could be summarized as follows:

- Observations and tests from boreholes cannot give a full picture of the mechanical characteristics for safe dams.
- When interpreting in-situ test results, the level of soil saturation should be considered in comparison with the situation after impoundment.
- The first filling is among the most critical phases. Experienced dam monitoring specialists have to be permanently on site to be able to detect anomalous behaviour and take timely action.
- Access to critical infrastructures (including saddle dams) must be ensured even during extreme meteorological events.
- During first filling, the contractor and surveillance team should be prepared to take emergency measures.
- Any reservoir must have discharge facilities able to control the level of the reservoir during first filling, and the capacity to lower the level in the case of an emergency.
- There should be an emergency action plan covering all threatened areas, in case of failure of any component (for example saddle dams).

Dr D.K. Sharma, Vice President of ICOLD, spoke on the 'Dam Rehabilitation and Improvement Project in India (DRIP I, II and III)' assisted by the World Bank. The project started in 2011, and Phases II and III begin this year (2021).

Sharma said that India has about 5400 large dams, with 293 being more than 100 years old, and many being older than 25 years. However, there is no legal framework for dam safety and a dam safety bill has yet to be passed by the Upper House in Parliament. There were a number of different safety systems in different states, he explained, as well as various technical standards and regulations. Between 1991 and 1999, the 'Dam Safety Assurance Rehabilitation Project (DSARP)' was carried out over four states, involving the rehabilitation of 33 dams.

Sharma then described the DRIP Programme, the objective of which is to improve the safety and operational performance of dams, covering 198 dams. This was a huge undertaking, he said, covering the rehabilitation and improvement of dams and instrumentational strengthening and also revenue guidance at sites, as well as project management covering 687 dams.

A lively Q&A session followed, demonstrating the continuing importance of the topic of dam safety.

Dam safety - 2

Michel Lino, ISL, France

Dam safety continues to be one of the most important topics for the dam engineering profession. In 2020, ICOLD issued a very important World Declaration on Dam Safety which calls for a personal commitment from all dam engineers in favour of dam safety. However, some significant dam and spillway failures have occurred during the past year such as Toddbrook auxiliary spillway in UK, Tiware dam in India, and Sardoba dam in Uzbekistan, among others. Dam safety improvement around the world is a long-term challenge, and we should do our best to achieve this goal in our day-to-day practice.

There were five presentations dealing with various aspects of dam safety.

Dr Peter Mason from the UK, as a member of the independent governmental review team, reported his forensic approach to establish the technical reasons for the collapse of the Toddbrook reservoir auxiliary spillway which had occurred in August 2019. Mason showed that the direct cause of the failure had been the dynamic pressure generated by the impact of the flow against the rock embedded in the chute slab, so-called stagnation pressure. This is something that the USBR has extensively investigated, as it has been a perceived chute failure mechanism 'on numerous occasions'. However, the failure occurred in the context of poor design (no upstream cut-off from the crest slab into the clay core below, inadequate chute slab thickness, inadequate rebar in chute slab poor joint details between sabs, no under-drainage) and poor maintenance (extensive vegetation growth in joints and cracks). The removal of imbedded stones had been recommended in 2008 but had not been implemented. That is also a lesson.

To finish with Toddbrook, it is worth noting that the crest was basically not affected during the failure, in spite of some inadequate details. Lino pointed out the upmost importance of crest design to guarantee safe behaviour in the case of high reservoir levels.

Camila De Goes Silva, of Intertechne Consultores, Brazil, described the dam break studies performed for the Tucuruì plant in Brazil. Tucuruì is a very large reservoir impounding the flow of the Tocantins, Moju, Guamá and Pará rivers. The dam break computational simulations had required a cartography base of nearly

70 000 km^2, prepared with information from aerial survey of 35 cities, 283 cartographic survey points and 67 topobathymetric sections along the rivers. In addition, the inundation area is influenced by tidal conditions.

Nazli Palamut Kemaloğlu, of Dolsar Engineering, Turkey, described a GIS-based approach for the prediction of dam break flood hazard. From the return of experience of various studies, she said that the use of GIS in both hydrologic and hydraulic models has a potential to reduce the time and resources required for developing dam break analysis. Recommendations were given to select 1D, 2D or 3D modelling, and on the different software packages available.

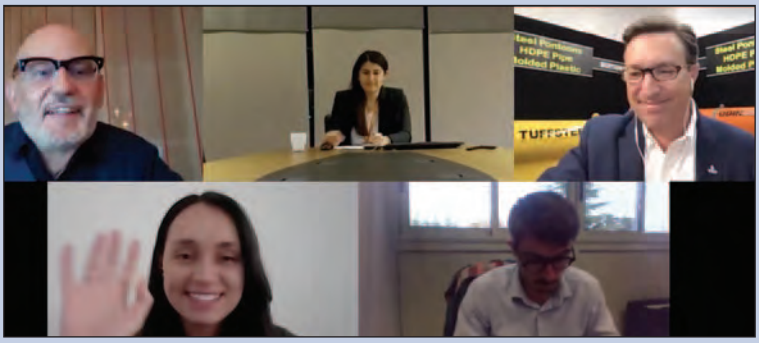
Yoann Jobard of SITES, a French company specializing in monitoring civil engineering structures, explained how site inspections could be digitalized using drones, sensors and data processing techniques. Digital twins' generation for surveillance of dams was already an available technique, also applicable to surge shaft, intake tower or headrace tunnels. Cracks of up to 0.7 mm width had been detected.

Paul Meeks, President of Worthington Products, USA, reported on the development of a debris deflection and capture barrier above the new Kamuzu barrage on the Shire river, to protect the three hydro plants that provide 98 per cent of Malawi's electric power. Although it was not the main theme of the presentation, the Kamazu barrage case draws attention to the risk of surface spillway clogging by debris. This is a very serious problem, and some significant incidents were recorded in the past years in France and in Europe. An efficient debris barrier can be a response to mitigate this risk.

Prof. Anton Schleiss acknowledged that for a large reservoir, control of the reservoir level by bottom outlets is not easy, and could be very costly, and that a gated spillway makes it possible to control the reservoir level in the upper elevations. Lino added that, on the other hand, non-gated spillways have high safety performance (no risk related to gate blockage) and that a mix between free and gated spillway sections is a good practice for flood management and reservoir level control for high elevations.

As a conclusion, the key lessons to take away from the presentations and discussions could be:

- Ageing of our dams increases the concern about dam safety: this is one lesson from the failure of Toddbrook auxiliary spillway. Of course, the design was poor and the maintenance insufficient. However, ageing progressively increased the failure risk.
- Emergency Preparedness Plan is one of the pillars of dam safety. It drastically reduces the number of victims in the event of a disaster. Two presentations showed that tools are available but that carrying out these studies for large dams with a huge reservoir is a complex task. The pertinent data necessary to assess the inundation map are numerous and not easy to collect, especially in case of a very large reservoir. Calibration of the hydraulic model is not possible because the dam failure flood is not of the same order of magnitude as the natural river floods.
- The presentation from SITES refers to another major pillar of dam safety: instrumentation, monitoring and visual inspection.Technology gives us powerful new tools to improve our knowledge and monitoring of dams and hydraulic structures under safe and efficient conditions.
- The safety of gated surface spillways is a major concern and a mix between free and gated spillway sections appears to be good practice.



The second session on safety was chaired by Michel Lino of ISL, France (shown top left); talks included findings of the expert report on the Toddbrook failure in the UK, by Dr Peter Mason (see also pp64), as well as dam break studies, the use of drones for monitoring, and debris deflection.

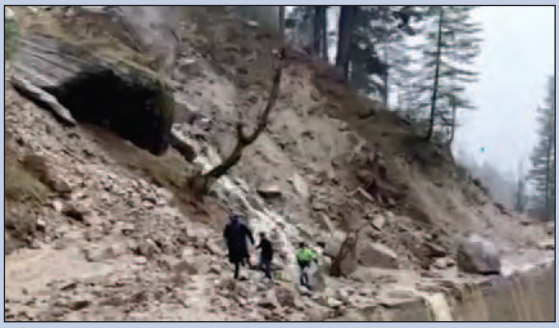
Challenging sites

Prof John M. Reynolds, Reynolds International Ltd, UK

Mountain environments are of increasing interest to hydropower developers for their high rainfall, steep gradients, and well defined river valleys through which the run-off is channelled. As regards hydrology, these locations are highly attractive, but they also present a wide range of physical and environmental challenges. These are often exacerbated by physical remoteness, dynamic geological conditions, active seismicity, seasonal extremes, and, increasingly, by the effects of changing climate with more frequent extreme weather events. Such regions are prone to flash floods, landslides, and other forms of slope instability, often being triggered by major rainstorms or earthquakes. When these events happen, they frequently result in a range of physical responses that can cascade together, compounding the consequences, greatly affecting riparian communities, and environments, and causing major damage to vital infrastructure downstream.

In other situations, a physiography suitable for hydropower development may have geology and topography that present their own challenges. The presenters of the three papers addressed such challenges and how they have affected their respective projects, or require very detailed and highly specialized analysis.

The first paper, presented by Olivier Julien, Tractebel Engineering, France, described working with challenging geological and access conditions at a hydropower rehabilitation project in northwest Tunisia. During an inspection, a 50 m segment of a 6.8 km-long, 3.2 m-diameter water transfer tunnel had been found to have been badly damaged. Loss of support for voussoirs and progressive deterioration of the tunnel lining had occurred from the dissolution of halite in the surrounding marl bedrock. This was also ductile and subject to squeeze from the pressure of thick overlying bedrock. The collapse of the tunnel had been narrowly avoided, and urgent remediation had been required to provide sufficient stability so that the tunnel could continue to be used. The owner of the scheme was supposed to have undertaken routine inspections of the facility every five years, but there were no records of any such activity for the 15 years the scheme had been in operation. The paper described how the remediation had taken place and the associated challenges had been overcome. However, because of the damage and of the installation of necessary repair works, which reduced the tunnel diameter, the discharge had been reduced to one third of its initial capacity.



Avalanches and landslides were among many challenges facing the 48 MW Jaggran II project in a remote area of Pakistan; an old feasibility study inherited by the consultants had not taken account of many physical features of the site, or social aspects, such as the presence of graveyards in the area.

The second paper, presented by Georg Reitzner, ILF Consulting Engineers, Austria, described the challenges associated with the implementation of the 48 MW Jaggran II hydropower plant in northeast Pakistan. During the construction, several issues had become apparent which had had significant impacts on the overall design and construction of the scheme, and had resulted in a 22 month delay to the overall programme. Problems encountered included: having to accommodate the presence of a previously unidentified graveyard and undertake major redesign work; and, inadequate geological investigations. In 2010, a major flash flood following heavy rainfall had occurred, and this had brought down large amounts of debris, including 5 m-diameter boulders. Despite this event occurring in 2010, its consequences had not been addressed in the feasibility study produced the following year. Other issues affecting the project included landslides, long periods where the site had been covered by deep snow, and an access road that was inadequate to cope with heavy traffic loads.

As a result of all the redesign work and the long period of delay to the construction, the overall costs had spiralled to between 1.5 and 1.8 times the original values. This also included charges on additional loans that had to be taken out over the extended construction period.

The third paper, presented by André Alegre, a PhD student intern, Instituto Superior Técnico of Lisbon, Portugal, described seismic and health monitoring of the 170 m-high Cahora Bassa dam, in Mozambique, along with the results of non-linear seismic analysis undertaken for the structure. This has been under continuous dynamic monitoring since 2010, thereby presenting a rare opportunity to investigate the behaviour and performance of the dam in relation to its seismic design. The software used in the study had been developed as part of the research and had been validated against experimental data, comparison with analogues of other similar dams, and through independent analytical procedures. The period of observations had also included the occurrence of a low magnitude earthquake 30 km away. Non-linear seismic analysis considers static loading. However, in a seismically active area, earthquakes can result in seiche waves, as could landslides impacting into the reservoir; both types of events could result in overtopping and also additional dynamic loading to the structure. It had been assumed, but not confirmed, that such scenarios had been considered in the original dam design.

It was apparent from the first two papers that common issues included inadequate geological investigations and unrealistic assumptions about how benign upstream catchments are in relation to project development timeframes and costs. There have been a great many, examples where substantial additional costs have been incurred by such issues. There appears to be widespread failure to account for the increasing adverse effects of climate change on upstream catchments or regional effects from large earthquakes triggering multiple simultaneous landslides and associated events. With more severe flooding, much larger sediment loads with large boulders (>5 m diameter) may result in severe damage to infrastructure; dam and spillway designs should be adjusted accordingly. There are guidelines on how to incorporate integrated geohazard assessments into hydropower projects, such as those from The World Bank [Climate Change Resilience and Disaster Risk Management Guidelines, 2017]. Developers and their consultants may ignore these at their peril.

Design, construction and rehabilitation of spillways

Dr Peter J Mason, Damsolve, UK

Spillways feature as a regular session at the HYDRO conferences. This reflects the continued interest in them, and the challenges involved in not only designing them, but also constructing, inspecting and maintaining them. Even now, failures occur on a depressingly regular basis, with Oroville in the USA in 2016 and Toddbrook in the UK last year being just two notable examples. Worldwide there have been many more, and this shows why we must continue to exchange experience on these structures, to try to minimize and ideally avoid, problems in the future. In that sense the spillway papers presented at HYDRO 2020 did not disappoint.

There were five papers in the session, including one describing the failure mechanism at the Toddbrook dam, mentioned above. It was presented by the Chairman, Dr Peter Mason. It attracted much interest and was repeated in the second session on dam safety. It demonstrated the importance of an impartial forensic approach when investigating failure. Physical evidence and testimony had been gathered by the independent governmental review team and then the events and the failure sequence had been carefully analysed to see which scenario best fitted the evidence available, Mason explained. It had been concluded that the key failure mechanism would have been crack injection caused by stagnation pressures developing on the chute. These had occurred where flows had impacted on rocks embedded on the chute invert. The water injection had effectively liquefied and washed away large sections of the underlying embankment fill on which the chute was sited. The paper also noted many possible contributory factors, including a poor original design, some construction deficiencies and less than adequate maintenance.

Three papers dealt with various aspects of innovation. In doing this they demonstrated why spillway design continues to be an ever-involving aspect of engineering science, and the importance of exchanging ideas at regular meetings such as HYDRO 2020.

A paper by Brian Leyland of New Zealand dealt with protecting spillway gate operation from electronic hacking. This topic is bound to gain increasing interest when one considers the ever-extending electronic inter-connectivity in the world coupled with the implications of maliciously opening a set of gates and releasing a major flood downstream, or of maliciously closing gates during an incoming flood event and perhaps overtopping the dam. The paper discussed both

In his introduction to the session on spillways, which he chaired, Dr Peter Mason (shown bottom left) referred to the fact that failures still occurred to spillways on a depressingly regular basis; Oroville and Toddbrook were two recent examples. He stressed the value of continuing to exchange experience regularly at the annual conferences.

the importance of choosing an appropriate type of gate, such as one which could operate hydraulically depending on reservoir level and independently of power, or if that were not possible, the appropriate signal circuitry to prevent maloperation by unauthorized electronic intruders.

Stephan Gloimüller of AFRY presented a paper on the Nam Theun 1 hydropower project currently under construction in Laos. This includes a 187 m-high, curved, gravity RCC dam, which features a major gated crest spillway capable of discharging a 30 200 m^3/s flood. Flows pass via spillway chutes to six flip buckets, set in pairs at differing elevations. These target jets to impact the riverbed downstream, with the whole arrangement verified by hydraulic model testing. However perhaps the most significant feature for other designers would be the considerable seismic amplification of the peak ground acceleration (PGA) that occurs at crest level. This is not only because of any frequency resonance of the dam, but also the hydrodynamic interaction between the gates and the reservoir. The large load generated is then transferred to the trunnions and so to the spillway piers. It implies that any such arrangements require quite elaborate non-linear finite element modelling and that perhaps where such arrangements exist on current dams, those designs may need to be revisited.

The advent of roller compacted concrete for dam construction has led to an increasing number of concrete dams formed with stepped downstream faces. These are then often used for the passage of floods. At the base of the steps, a stilling basin is still required and designs for these generally follow classic guidance or such works. But classic design guidance always assumes that flows entering the basin will be from a smooth chute and not the more turbulent flows associated with stepped chutes. The work presented by Dr Ivan Stojnic illustrated that such an approach might underestimate the length of basin required and also the extent of hydrodynamic pressure fluctuations that need to be accommodated. The resulting research and conclusions have also been summarized in paper published in Issue 5 of the *International Journal on Hydropower & Dams* and readers are encouraged to consult that for further information and details.

A final, project-based, paper concerned the Ruzizi III project currently under development in East Africa. It borders three countries, Burundi, Rwanda and the Democratic Republic of Congo (DRC), and follows the existing Ruzizi I and Ruzizi II projects upstream and from which it receives outflows. The spillway developed for the project comprises a labyrinth weir placed on a curve and with flows then converging down a progressively narrowing chute before being discharged from a terminal flip bucket. Interestingly, the spillway design resulted from lessons learned on the previous projects. An ungated crest was selected to overcome the risk of gate malfunction, and to be independent of operator intervention; note the parallels with the paper mentioned above by Bryan Leyland. Another factor against the adoption of gates was the highest seismicity of the region; in this case note the link with lessons from Nam Theun I. Above all, the paper illustrated how a carefully considered review of constraints and other relevant factors can lead to a final best and appropriate solution.

Discussions on all papers were extensive, illustrating the considerable interest that this topic retains.

Tunnels and underground works

Dr Gerald Zenz, TU Graz, Austriia

The art of engineering hydraulic structures requires the contribution of specialized disciplines, and some of these relates to the design of power waterways, tunnels and underground works. With the increasing need for flexible energy for net regulation and electricity storage hydro, especially high-head hydropower plants, is a mature and well established technology. With the knowledge which has progressively been gained on underground works, represented within various international societies such as the International Tunnelling Association and the International Society of Rock Mechanics, geologically challenging, large cross-sectional areas can be excavated, while maintaining the highest safety standards.

Together with the detailed knowledge of the hydraulic behaviour of pump-turbines and huge oscillating water columns in power waterways, this provides the basis to build large-scale high-head pumped-storage schemes, which ideally serve for our future needs.

Within this first session on tunnels and underground works, some aspects of these structures were presented and discussed.

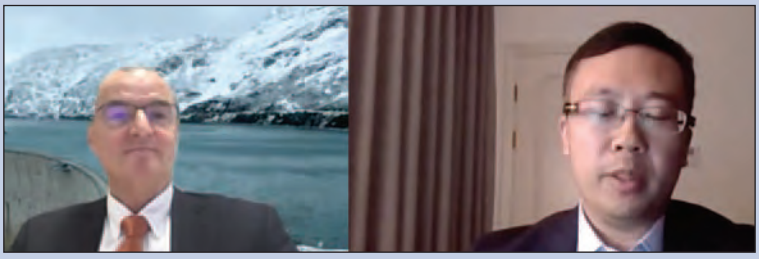
The first talk was given by Régis Blin of Smartec SA, Switzerland, and was entitled 'Structural monitoring of full length tunnels'. With the help of continuous fiberoptic monitoring along an entire tunnel length, and not interfering with normal tunnel operation, the tunnel's safety assessment was shown and explained. This presentation later attracted a number of questions.

Kang Lyu of Power China asked about the long-time behaviour and the experience gained with this technique. In reply, Régis referred to the experience gained by Smartec over more than 20 years. To gain appropriate measurements, he stressed the need for a rigid fixing system of the cable on the rebars in concrete.

Wolfgang Richter asked about monitoring experience for power waterways. Régis replied that experience was available on penstocks and motorway tunnels; however, experience in tunnels used as power water ways, under water pressure from inside and/or outside, was not yet available from the projects which had been presented, but could be in the near future.

Darren Edson asked about availability of redundancy on measurements between the continuous measurements by fiberoptic cable and discrete measurements. The reply was that to get optimum results, the length would be divided into several sections, or additional cables would be used to have redundancy in measurements.

The second contribution to the session was given by Kang Lyu of Power China Huadong Engineering



Dr Gerald Zenz of Austria (left) chaired the first session on Tunnels and underground works; he noted in his introduction that based on experience today, geologically challenging, large cross-sectional areas could be excavated while maintaining the highest safety standards.

To the right is Kang Lyu of PowerChina Huangdong Engineering, describing excavations for the huge surge chambers for the Baihetan scheme.

Corporation Ltd, and it dealt with the design of the huge and complex surge chambers at the Baihetan hydro plant in China.

Eight cylindrical tailrace surge chambers had been designed, each with a height of about 130 m and a diameter of 45 m, in challenging geological conditions, creating an essential part of the Baihetan scheme.

Wolfgang Richter asked about the general layout considerations for the surge tanks. Kang replied that the design had been based on the most conservative assumptions for emergency closure within 10 s.

Prof Anton Schleiss asked about minimum/maximum in-situ principle stresses and their orientations, as well as about the lining design concept for internal and external water pressure. Kang replied that at the right bank, the in-situ principle stresses varied from 26 to 15 MPa and had a ratio of about 1.7, which was of special interest for the layout of the excavation support.

Geotectonics had caused a horizontal orientation of the minimum in-situ stresses. The entire excavation was supported by reinforced concrete, he said. For the design load on the lining, this was considered as completely watertight, and therefore the design assumption was on the conservative site.

A further interesting contribution relating to underground works was presented by Demirhan Ünlü of Dolsar Engineering, Turkey, with the title 'Design aspects of the grid diaphragm walls under the circularly located buttress weir'. The general system layout was detailed during the presentation; for the foundation of the weir on the Göksu river, a raster of diaphragm walls into bedrock with a depth of approximately 35 m had been designed and described in the presentation.

Prof Anton Schleiss asked about the purpose of the cutoff wall (suggesting it was probably to block all of the seepage) and how the resulting uplift pressure was monitored. Ünlü replied that the design assumption was to reduce the seepage, and in addition to monitor the uplift pressure with piezometers; results were not yet available.

Finally, it should be mentioned, as the HYDRO 2020 conference took place online, some of the authors of accepted papers were unfortunately not prepared for presentation in the requested pre-recorded form; this was an unsatisfying aspect. But of course, it has to be accepted as the prerecording requires specific exercise and skills, normally not part of every-day engineering work.

It is much appreciated that Aqua-Media made the online presentations available to an even broader audience, especially to our students at the universities. These students normally would not have the opportunity to attend such an interesting conference. This knowledge transfer and capacity building is of great value to the students.

Tunnels and underground works

Laurent Mouvet, CEO, Hydro Operation International, Switzerland

This session followed one on the same topic chaired by Prof Gerald Zenz. In the first session, three case studies were presented and discussed, with very interesting challenges and innovative solutions. The second session dealt more with technical concerns and new developments to improve and make more efficient and sustainable underground hydropower structures.

The first presentation given by Dr Ersan Yildiz, Tractebel Engineering, Germany, was entitled 'Rock support design and 3D numerical modelling of the powerhouse cavern for Forbach project'. The Forbach pumped-storage project is an extension of an existing plant. It includes a 123 m-long cavern with an 18.9 m span and a maximum height of 42 m. The underground cavern is located in a granite rock mass with generally very favourable conditions. However, a 3D analysis showed that two planes of weakness cutting through the cavern could have a considerable impact on the intersection areas in terms of increased deformations and the extent of yielding zones.

Prof Schleiss asked about the fracture density and RQD values of the rock. He also asked if the scale effect influences the dilatometer tests. Yildiz replied that the RQD was high, generally 90-100 per cent and always above 75 per cent in sound rock, and around 40-60 per cent in local weaknesses. Of course, the dilatometer tests were affected by the scale effect, but the measured stiffness modulus was coherent with the value obtained with empirical approach. Prof Schleiss then also asked why vertical walls had been chosen. The reply from Yidliz was that as the rock quality was so favourable, the numerical model demonstrated that the gain for curved walls was negligible.

The second presentation was by Dr Giovanna Lilliu of Renesco Holding, Switzerland. She discussed design practice and new possibilities for composite membrane linings in pressure tunnels and shafts. This type of lining reduces water losses and head losses in tunnel flow, she explained. It isolates the groundwater table from the water flow in the tunnel, and thus guarantees the chemical and mechanical integrity of the rock. Thus, the durability of a project is increased. Until now, a 'rule of thumb' approach has been used for the design of such linings. Some further investigations and research are currently being carried out on numerical modelling, laboratory testing and to evaluate the influence of friction on the flow conditions.

Prof Schleiss remarked that in hydraulic tunnels, the lining suffers an initial tensile stress because of the curved situation, which should be added to the stress caused by the opening of the crack. Prof Miroslav Marence, co-author of the paper, answered that the analytical model presented was simplified and should be followed by a more complete numerical model, including the geometry and stress condition of a hydraulic tunnel cross section. He also mentioned that the shape of the crack was very simplified, and some additional research needs to be carried out to consider more realistic crack shapes.

Chairman Laurent Mouvet, asked about ageing of the membrane and if there was any specific requirement to monitor and inspect the membrane. The reply was that the procedure for monitoring was to extract a test specimen from the lining. There was great experience in monitoring geomembrane linings in traffic tunnels, where access was easier. It was generally acknowl-

edged that the lifespan of these linings was around 100 years. However, if the membrane was covered in hydraulic tunnels, the conditions were favourable, as the exposure to major environmental stress conditions was limited.

The third presentation was by Eng. Francesco Raggi of ELC-Electroconsult, Italy. His talk investigated the hydraulic-mechanical interaction around a pressure tunnel undergoing cracking; the case study he described was an Indonesian hydro project. He compared the results of an analytical approach solution with an FEM numerical method for the design of the reinforced concrete lining. The latter made it possible to reduce the transversal steel bars significantly with respect to the analytical solution.

Prof Schleiss congratulated the authors of the paper on the development of the model. However, he asked if the solution had been checked against analytical solutions, such as the one he had developed (in 1997). Eng. Raggi confirmed that the solution had been checked with an analytical solution, but could not give further details as he had not been involved in that part of the project.

The last presentation was by Sindre Log of the Robbins Company, USA, demonstrating the efficiency of compact hydro tunnelling for small hydro projects in Norway. Given the increasing interest in small hydro projects with tunnels waterways, and the fine-tuning of effective designs for rock tunnels at steep inclines, there is a huge potential for continued projects all over the world, and specially in developed countries with favourable and well known rock conditions.

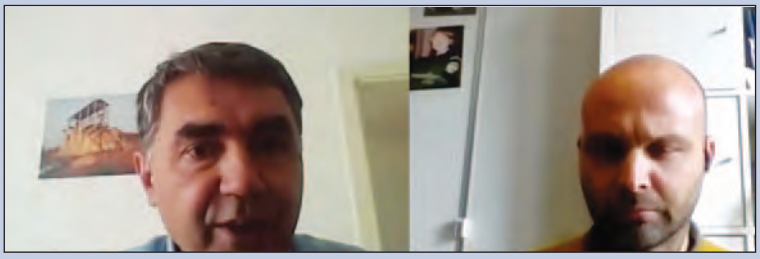
Chairman Laurent Mouvet commented that the small TBM equipment presented fantastic opportunities for the development of small hydropower schemes. However, this applied to cases with good and well known geology, as the possibility for intervention in the case of a geological incident was limited, or could ruin the benefit of the solution. That means that the cost of preliminary investigations should be high. In reply, Log stressed that the case studies presented were all located in Norway, where the geological conditions were very favourable. That is certainly a key condition.

A delegate from Studio Pietrangeli, Italy, asked about the minimum diameter to be considered. One of the case studies in Norway has a diameter of 1.8 m, which should certainly be considered as the minimum diameter to be recommended. Smaller sections would lead to greater technical difficulties. Small boring machines have been developed for almost horizontal profiles. The application to hydropower, which requires up to 30 per cent inclined galleries, can be developed further.

Prof Schleiss pointed out that the case studies presented had not required any lining, which was specific to the Norwegian geological conditions. He queried how damaged geological zones could be dealt with.

Log replied that with this size of diameter, the boring machine had some capacity to cross geologically damaged zones. However, the preliminary geological investigation was very important, he added. He pointed out that at some projects, the lower part of the tunnel was steel lined. Log also mentioned that a proper geological inspection should be carried out after the excavation, as the water pressure could lead to some local damage if not properly treated.

Dr Kamal Laksiri raised the question of costs. Log replied that this was difficult to answer, as in many cases, the project could not be constructed in any other way. Generally, the cost of projects using this technology was competitive, he said, but this should be analysed on a case-by-case basis.



Chairman Laurent Mouvet of Switzerland, shown far left, responds to a question during the second session on Tunnels and underground works.

On the right, speaker Francisco Raggi of ELC, who discussed the hydraulic-mechanical interaction around a pressure tunnel undergoing cracking, taking an Indonesian scheme as a case study.

Pravin Karki, World Bank, asked if there was any experience of remote inspection of hydraulic tunnels during the COVID-19 pandemic. While the speakers could not comment specifically on that topic, it was suggested that remote sensing could be a solution for certain parameters, but sensors should be installed in advance. It was mentioned that as long as the inspection was carried out by a sole inspector, there would be no risk related to COVID contamination in hydraulic tunnels. The problem could relate, however, to travel for international experts.

The chairman thanked the four speakers for their valuable presentations and for the effort of recording their talks in advance. He also expressed his appreciation for the high-level questions submitted to the speakers and the discussion. He also congratulated the Aqua-Media team for the perfect organization of this virtual event.

River and reservoir management

Prof Bogdan Popa, Polytechnic University of Bucharest, Romania

This session comprised four presentations and some lively discussion.

In the opening speech, the chairman thanked the participants commenting that, even in the difficult times of the pandemic, they had prepared very interesting presentations relating to: the importance of flood control on a huge river in Venezuela, a probabilistic forecast for the Rhône river, France; estimations for a poorly gauged basin in Nigeria; and, some influences of the Iron Gates dam on the Danube river.

The first presentation, by Pascual Perazzo, from Carpi Tech, Panama, was entitled 'Flood-control of the Lower Caroni', this river being the most important source of renewable energy in Venezuela. On the last 100 km river reach, before the Caroni reaches the Orinoco river (which is the third largest in world as regards discharge), there is 15 000 MW of installed hydro capacity at only three plants, for which the spillways are dimensioned for a discharge of 30 000 m^3/s. The scale of the development is huge, and the authors underline the major implications related to flood control caused by natural issues, as the different times at which floods occur on the Caroni and on Orinoco rivers, on the one hand, and by the poor maintenance of some existing hydro units and the delayed construction and rehabilitation of an intermediate hydropower project, on the other hand. After reviewing operational problems over last five years which impacted the national power system, the authors concluded that rehabilitation of the hydropower system would take several years but it could solve the problem of electricity need in Venezuela.

Discussion during the session on River and reservoir management, chaired by Prof Bogdan Popa of Romania (shown top left). The session had included talks on the Lower Caroni river in Venezuela, the Rhône in France, Iron Gates I on the Danube bordering Serbia and Romania, and the estimation of discharge in a poorly gauged catchment area in Nigeria.

The second presentation, 'Hydrometeorological probabilistic forecasts on the Rhône river in France', had been prepared by specialists from Compagnie Nationale du Rhône (CNR), France, and was presented by Sabrina Celié, an engineer specializing in forecasting. After a short introduction of CNR, noting that the company produces electricity only from renewable energy sources (hydro solar and wind), and highlighting the need for forecasting, the authors introduced the short-term, the mid-term and the long-term (seasonal) hydrometeorological chains and the connection between the tools. Among the conclusions were the importance of developing different tools for different purposes, and good communication between teams; as regards future perspectives, the most important, Celié felt, is related to the development of an optimization tool to combine hydro, wind and PV production, taking uncertainties into account.

The third paper, 'Estimation of discharge and determination of catchment-Area ratio exponent in a poorly gauged basin in Nigeria', was presented by Olatubosun Fasipe, from Energy Commission of Nigeria. This very well referenced scientific paper, prepared together with Prof Izinyon as part of PhD thesis, presented a methodology based on the Natural Resource Conservation Curve Number (NRCS-CN) method, GIS-based spatial tools and high-resolution DEM, developed to determine the hydropower potential of ungauged rivers in Nigeria. The most important issues underlined by the authors included the major challenges faced to obtain adequate hydrological data, and the need for predictions based on the targets assumed for small hydropower development up to 2025.

The last presentation, given by Catalin Popescu, and co-authored by specialists from Hidroelectrica SA, the Technical University of Civil Engineering of Bucharest and University Politehnica of Bucharest, discussed 'River segmentation and riverbed lowering in Romanian reservoirs'. The case study presented was Iron Gates I dam on the Danube river, built jointly by Romania and Serbia. The presentation was related to morphological changes in the downstream riverbed. The operating conditions based on the test models had required uniform loading of all discharge fields. Nevertheless, during more than 40 years of operation, different discharge durations had been recorded, as well as flows through the spillways which caused uneven depths of erosion. Another cause for the uneven distribution of erosion was found to be the different erosion properties of the bedrock downstream of the dam.

The Iron Gates 1 dam on the Danube; Catalin Popescu of Romania discussed morphological changes in the downstream river bed.

Some comments and questions followed the four talks. One delegate asked what the environmental flow requirements for hydropower on the Danube and Rhône rivers were, and what impact and challenges these created for powerplant operation. The reply was was that there were no problems for the large run-of-river hydro plants, as the environmental flow was also used for hydropower production. It was mentioned later that one problem could be upstream fish migration, but the chairman pointed out that these dams, which break up the connectivity of rivers, required all the parties involved to work together to identify and discuss such problems, so that the solutions could be found.

A second question was addressed by the chairman to Sabrina Celié and was related to optimizing hydropower plant operation, when CNR also operated wind and solar PV plants. She replied that this optimization of hydro plant operation was a part of an optimization of the whole system of CNR's plants. The optimization tool was being developed to combine hydro, wind and PV production and taking uncertainties into account. The chairman commented that it must be a huge challenge for CNR to operate such a large power system consisting of three major renewable energy sources and so many powerplants. Celié agreed and underlined that it was a big challenge to estimate the energy production for the day ahead market.

Two questions were addressed to Olatubosun Fasipe. One was whether there were concrete plans for the Government to use the results of the paper to build flood mitigation structures or small hydropower plants in Edo state, since flooding and electricity shortages represented a general problem there, and the answer was positive. The second question was about the intentions of the Government to prepare people in the area of electricity generation since there was a lack of manpower; the answer was also positive.

Although this was a small session, with only four presentations, it covered important rivers in Europe and throughout the world. There were discussions on impressive hydropower developments, some with huge problems arising from political issues, examples of very modern and well instrumented plants, and river basins poorly gauged, which require new intelligent methodologies to obtain hydrological data to estimate their hydropower potential estimation.

It was an excellent session, with a variety of aspects related to river and reservoir management.

The second and concluding part of this report will be published in H&D Issue 3.

Global hydro community discusses future strategies at HYDRO 2020

PART TWO

The first part of this report, published in our last issue, focused on many of the technical sessions of HYDRO 2020, conducted on line in October 2020. That included the sessions on hydraulic machinery, pumped storage, and civil engineering, as well as potential opportunities for future development, especially during the post-pandemic recovery period. This part focuses on small hydro and hybrid systems, as well as a number of topics relating to the environment (including climate, sedimentation and fish protection, for example), and sessions on powerplant upgrading and safety, and innovation

More than 160 international speakers, and around 600 delegates from all parts of the world who logged in to HYDRO in real time, to participate live in the sessions and discussions provided a rich exchange of knowledge and experience, on the usual broad range of topics. This second part of our overview report includes two sessions organized by the International Energy Agency (IEA Hydro), on climate, and on 'hidden hydro', and another on the EU-supported HYPOSO programme.

Two sessions on small hydro and a training workshop (adapted from the usual full-day event to an on-line tutorial) took place, as well as a session on the very topical issue of hybrid projects, where hydropower is working in synergy with other renewables. Much attention also focused on environmental and social issues, as always. The on-going importance of powerplant safety, including cyber security, was also covered in a number of discussions.

HYPOSO, small hydro and hybrid schemes

The HYPOSO project

Dr Veronica Minaya, Escuela Politecnica Nacional, Ecuador and Prof Bernhard Pelikan, University of Life Sciences – Vienna, Austria

A special session of HYDRO 2020 was dedicated to a recent EU Horizon 2020 project, known as HYPOSO, being implemented by a total of 13 partners. HYPOSO (Hydropower solutions for developing and emerging countries) aims at supporting the European hydropower industry, while fostering sustainable development in selected target countries in Latin America and Africa, namely Bolivia, Colombia, Ecuador, Cameroon and Uganda. The HYPOSO objectives will be achieved by a combination of tools: market analysis, surveying hydropower potential; having an overview of political and legislative frameworks, smart financing, capacity building, replicable pre-feasibility studies and finally bringing together representatives of the European hydropower industry and their counterparts, and politicians from the target countries.

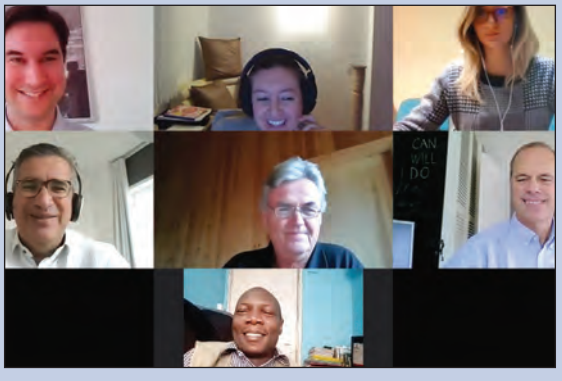
The first speaker in the session, Ingo Ball of WIP Renewable Energies, Germany, gave an overview of the background of the project, the project structure (seven work packages), the objectives (mapping, framework analysis, capacity building, case studies, online platform and B2B workshops), the first results already achieved, and an outlook on upcoming activities.

The second speaker, Prof Petras Punys of Vytautas Magnus University, Lithuania, gave an informative overview of the frameworks for hydropower development in the selected target countries. Any hydropower development is severely impacted by regulations and conditions. Besides the traditional research activities based on publications, the collection of information has been done based on two questionnaires. The first one focused on market data (industrial and economics), policy data (legislation, concession regime, support mechanism), financing, education and research needs. The second sought to identify R&D projects in the hydropower sector. The detailed information present by the speaker showed the great variety of results among the target countries, and gave an impression of the overall position of SHP and specifically the needs to improve the situation.

The third presentation was given by Beatrice Baratti, of Studio Frosio, Italy, which is responsible for the elaboration of 15 pre-feasibility studies, three in each of the target countries. These studies will serve as replicable cases, and the necessary basis for the implementation of the plants further on. To fulfil the requirements of the project (inclusion of local stakeholders, representativeness, replicability) the identification and selection of the sites was a crucial and sensitive phase of the process. In the first step, a questionnaire was used to identify ten potential sites. To rank the proposed sites, an assessment tool was developed. To make the final of three sites, a series of criteria like economic attractiveness, regional electricity demand, ecological impact, availability of grid connection but also expectations of the community and others, will be applied. For these sites, pre-feasibility studies will be then be carried out.

The final step, because of COVID-19 restrictions, was a webinar, during which the various views and interests of the stakeholders were expressed, finally leading to the expected result, in this first stage for Cameroon. All the other countries will follow.

The fourth speaker, Miroslav Marence, IHE-Delft, Netherlands, presented the educational part of the project, entitled 'Knowledge and capacity development in the hydropower sector for developing and emerging countries'.



The session devoted to the EU Horizon 2020 project, HYPOSO, which included talks on the objectives and tasks of the project, and was followed by reports by representatives of the target countries.

The Mbakaou Carriere 1.4 MW hydro plant, to be completed later this year; an example of a small hydro scheme in Cameroon described by Joseph Kenfack.

The aim of capacity building within the HYPOSO project is strengthening key stakeholders in strategic development, design and engineering, implementation, operation and maintenance of sustainable hydropower. A second target is the identification of research needs in the field of hydropower.

The speaker pointed out the necessity for a 'Knowledge and Capacity Development system' (KCD), which will be applied within the project. Part of this system will be a 'moodle' platform (open-source learning management system) containing all the educational material and not only available during the course and project period, but also being a long lasting source of contacts and information for the target countries, and for other interested stakeholders.

The fifth presentation was given by Tasniem Jawaid, representing EREF, the European Renewable Energy Federation. His presentation focused on activities promoting the European small hydropower industry. One of the activities carried out was the development of the first comprehensive dataset of the European small hydropower industry. The author also demonstrated and explained the newly built HYPOSO platform, available for the target countries to advertise European hydropower industry.

To support the capacity building activities within the HYPOSO project, a handbook on European small hydropower technologies and solutions is to be created. This promotional tool will include the latest innovations, underlining the strength and international leadership of the European industry. This handbook will be disseminated beyond the EU from 2021 onwards and will be available in English, French and Spanish to support the engagement and activities of European companies outside Europe.

In the second part of the session, the project partners of the target countries presented country reports.

Cameroon

Joseph Kenfack, of Solar Hydrowatt, Cameroon, presented the small hydropower and framework conditions for his country. Cameroon is the country with the fourth highest hydro potential in Africa, with 948 MW already developed and 20 GW remaining untapped. it has poor power system reliability; its electrification rate is around 90 per cent in urban cities and 20 per cent in rural areas and a national average of 68 per cent. In 1929, commissioning of 750 kW of small hydro in Malale, Western Cameroon, was under the British administration. The large hydropower sector was developed from the early 1550s until 1988. Four hydropower plants were operated by 1961: Then Foumban (128 kW), Dschang (260 kW), Bekili (1 MW), and Yoke (3.3 MW); however, all these power stations were abandoned in the 1980s. Between 1988 and 2017, no construction of hydro plants took place in Cameroon, therefore leaving the door open for other energy projects, such as thermal power stations, to take the lead and alleviate the energy deficit. In 2017, a new era opened up, with a partial commissioning (80 MW of the planned 205 MW) of the Memve'Ele powerplant. Future projects will be developed to solve electrification needs and to ensure economic development and increase power generation. This will be based on renewable energy sources as much as possible, to mitigate climate change effects. Kenfack stressed that the HYPOSO project is a big opportunity for Cameroon.

Uganda

Dan Marlone Nabutsabi, on behalf of the Hydro Power Association of Uganda Ltd (HPAU), presented the small hydropower and framework conditions in Uganda. The country has a total area of 241 551 km^2, a population of 44.2 million, and a per capita energy consumption of around 215 kWh. Uganda has a total installed generation capacity of 1252.4 MW with a 12 per cent average annual growth rate (2018/19). According to the electricity regulatory authority ERA, power generation increased from 872.2 MW in 2012 to 1246.3 MW in 2019. About 80 per cent of energy in Uganda comes from hydropower generation, and the remaining 20 per cent comes from thermal, solar and other sources. In 2018, the total generation in the country was 3638 GWh, with hydropower contributing more than 80 per cent. The technically feasible potential of Uganda is 20 833 GWh/year and the economically feasible is 12500 GWh/year. There are four large hydro plants in operation today: Nalubaale (180 MW), Kiira (200 MW), Bujagali (250 MW), and Isimba (183 MW); the latter was commissioned in 2019. Small hydro plants are defined as those with installed capacities of up to 20 MW. Total national small hydro potential is about 400 MW; by 2019 there were about 20 operational small plants, with a total capacity of 145.3MW. More than 50 potential small hydro sites have been identified on Uganda's rivers, with a total potential of 210 MW. There is a huge opportunity for investment in the country geared towards leveraging the knowledge, understanding, capacity and skills in hydropower design, development, operation and maintenance. Future projects aim to solve capacity building needs within the government institutions, particularly related to the planning, design and construction of hydropower plants. Uganda's vision for 2040 is to have electricity generation as one of the key strategic interventions for socio-economic transformation of the country.

Bolivia

Andrés Gonzales Amaya, senior Lecturer at San Simón University, Bolivia, spoke about the hydropower sector in his home country. Bolivia has an area of approximately 1×10^6 km^2 and 11 million inhabitants. The country has great potential for hydropower generation as a result of the extensive combination of high gradient slopes and rivers and approximately, 90 per cent of its population has access to electricity in urban areas, and 80 per cent in rural areas. Most of Bolivia's electricity is covered by the non-renewable thermal sources of natural gas combustion turbines, with an installed capacity of around 1500 MW. The leading source of renewable energy is hydropower, with a total installed capacity of 734 MW. The hydro plants in Bolivia generate about 2500 GWh/year. There are 31 hydropower plants in operation or under construction, and about 10 active companies related to the medium/small hydropower sector in Bolivia. The main barrier to small hydro development is the lack of incentives from the national government in both organizational structures and financing mechanisms. The future research projects to be developed include studies relating to hydrology, the assessment of (multipurpose) projects, the implementation of new technologies, and studies on socio-environmental and economic impacts.

Colombia

Carlos Velasquez, General Manager of the Latin American Center on Small Hydropower-CELAPEH, gave an overview of Colombia's hydropower. He said that the country has a population of about 50 million, and an area of 1172×10^3 km^2. The country has a total installed hydropower capacity of 11 771 MW, and hydro production of 58.3 TWh/year, allowing for access to electricity for 97 per cent of the population. Colombia is reported as having the sixth highest hydropower potential in the world. Hydro accounts for around 66.6 per cent of generation in the country. The country's large hydro plants have a total installed capacity of 10 830 MW (92 per cent), medium-scale plants have a capacity of 498 MW (4.2 per cent) and small hydro totals 442 MW (3.8 per cent). Colombia has a fully open market to private participation, and the registered participants in the electric sector are classified based on four main activities; generation (87), transmission (13), distribution (37) and commercialization (109). The small hydro potential in the country equivalent to around 5000 MW and there are around 50 small and medium-sized hydro projects under construction or planned. The main barriers for hydropower development are the lack of political/economic incentives, limited manufacturing capacity for small hydro components, as well as a lack of specific expertise and facilities for small hydro equipment testing and applied research. Colombia also has poor capacity building facilities and programmes for the design and construction of small hydro plants and the associated works. The HYPOSO project represents a bright perspective for the future in this country, in terms of providing useful tools for site identification and assessment and to provide help in increasing social acceptance of small hydro.

Ecuador

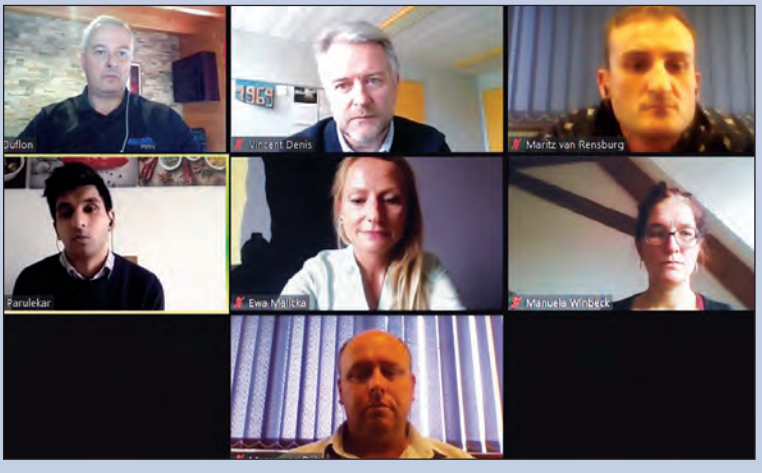
Prof Verónica Minaya, Senior Lecturer at the Escuela Politecnica Nacional in Ecuador, reported on small hydropower and the framework conditions in Ecuador. She pointed out that it is a small country, with 17.3 million inhabitants, and an area of about 284 000 km^2. Until 1961, the supply of electricity was dominated by private companies and municipalities, and the population was supplied by thermal plants (60 per cent) and hydroelectric plants (40 per cent). The Ecuadorian government, through its power sector, has committed to achieving a cleaner energy system through the development of renewable energy projects. Ecuador's hydroelectric potential indicator is higher (0.74 GWh/year/km^2) compared with other countries such as Austria, Norway (0.66) and Brazil (0.15). Based on the Government's assessment of hydropower potential, Ecuador has six major river basins that are geographically distributed in two main regions: Pacific and Amazon. Ecuador has 31 hydro plants in operation with an installed capacity of 4973 MW and 41 small or mini hydro plants in operation with an installed capacity of 102 MW. The cost of new hydro capacity is around US$ 2500/kW. Since 2011, all renewable energy projects must contribute a portion of the income per kWh generated to social and community projects. The principal barriers to small hydro development are: the lack of detailed data on the economic/technical potential of small hydro; and, technical capabilities and knowledge to ensure the effective integration of small hydro technology into the power system. To resolve these problems, it is important to define a more comprehensive strategy on small hydro implementation, and to encourage future public-private partnerships. The projects under construction and planned are the future hydropower prospects to increase the capacity of electrical energy. Around 40 small hydro schemes, with a total capacity of 225 MW, already have completed final designs.

Small hydropower 1

Vincent Denis, Mhylab, Switzerland; Pierre Duflon, Andritz Hydro, France

This session was co-chaired by Vincent Denis and Pierre Duflon, who studied and graduated together in Hydraulic Machines and CFD from the Swiss Federal Institute of Technology in Lausanne (EPFL) Switzerland in 1992, and since spent parallel careers in the Small Hydro business, Vincent mainly at Mhylab and Pierre at Andritz Hydro, all over the world.

Dealing with small hydro is always a challenge, as the projects can be as complex as large ones, but without having the same financial resources. This leads people active in this field to multidisciplinary and new



The panel of speakers in the first session on small hydro, co-chaired by Pierre Duflon and Vincent Denis, shown top left and centre.

Some examples of low head small hydro plants in Poland, with capacities of less than 1 MW, referred to by Ewa Melicka in the small hydro session.

developments, demonstrating that innovation remains a prerequisite for the success of small hydro projects. These new developments do not only focus on cost reductions, but also target rural and remote area electrification or the exploitation of hidden hydro, in addition to classical applications.

As discussed in the papers presented during the session, the development of so-called simple technologies need powerful and updated calculation tools or experimental means. As simple does not means cheap and low quality, one must remember that simplicity should be the result of a well structured engineering process, applying specific solutions and implementing specific knowledge to develop reliable, sustainable and profitable small hydropower projects.

The session focused on some non-classical solutions for rural and remote area electrification or exploitation of hidden hydro to solve local issues. The focus was put on the use of sometimes complex calculations and specific technologies to achieve a simple, reliable and cost effective product for specific applications, far away from a simple downsizing of larger hydro units.

Challenges that are facing the small hydro field are not only technical but also political and economic, as demonstrated by E. Malicka from the Polish Association for Small Hydropower Development (TRMEW). Her presentation focused on the complex situation faced by small hydro plant owners at the end of the support period in Poland, which is also a topic in many countries. The core of the equation is how to conciliate river protection, green energy production and economy.

M.L. Van Rensburg from the University of Pretoria, South Africa, presented a very technical paper on the CFD development and prototype testing of a Darrieus type turbine and its application to a vertical axis setting, the idea being to propose a simple technology that could be installed in many remote areas with very low head. The technology was aimed at harnessing the kinetic energy of the river.

Y. Parulekar from the University of Strathclyde, UK, described the application of CFD in the design and improvement of the performance of a breast-shot waterwheel, which could be an interesting alternative to classical turbines if they would not be economic in view of the specific conditions of the site or would be too complex to operate and maintain.

M. Van Dijk from the University of Pretoria, South Africa, focused his presentation on a very specific application of energy recovery from drinking water pipelines to supply power to distribution centres by using the small amount of the pressure contained in the system and avoiding the construction and potential vandalism on the transmission lines or solar/wind generating equipment in remote areas.

Finally, F. Frey from DIVE Turbinen, Germany, presented the design concepts and application of their submerged axial-type unit with permanent magnet generator and variable speed for a 2 × 2.15 MW project in southern Kazakhstan. It was interesting to consider how designers are looking for solutions that allow a reduction of the civil work and on-site erection time.

After the presentations, a 25 minute Q&A session was moderated by the co-chairmen and numerous interesting points were raised and answered by the presenters. The dynamics of the discussion were very good, showing the strong interest of the audience for original and simple solutions, but also for the challenges that any small hydro operator is facing days after days.

A common feeling was that the people were less afraid to type the questions online, which would be then directed by one of the chairmen to the appropriate speaker, than to raise their hands in person in the room! As co-chairmen, we believe that it was a very interesting and successful experience given the circumstances, with some lessons to be retained for the next years, even if we all hope to meet in person next year in Strasbourg. Many thanks to all presenters, attendees and also to the organizers for the efforts put into the event and its perfect technical and social management.

Small hydropower - 2

Prof David Williams and Gordon Black, Learning Hydro Ltd, UK

The second session on small hydro delivered five excellent and diverse presentations. First, Prof Leif Lia of the Norwegian University of Science and Technology presented '900 new small hydropower schemes in Norway installed since 2000'. He described how a very positive and clear policy statement from the Norwegian Government in 2000 had resulted in the rapid development of small-scale hydropower schemes across the country, and how this was continuing. What was striking was the fact that small hydro makes up 8 per cent of the total production of Norwegian electricity. Lia also described the reasoning behind the turbine selection process which results in Francis and Pelton turbines being combined in powerhouses to maximize the energy being produced from the available head and flow. Another interesting feature addressed was the use of contra-rotating propellor blades on a single Kaplan turbine.

The second presentation was delivered by Alexandre Allain, Project Manager with BG Consulting Engineers, Switzerland, on the topic of 'Design challenges of a new high-head scheme in France'. High head indeed, with some 730 m of head and with a design flow of 1.8 m^3/s to generate 11 MW. He talked us through the designs of the five sections of penstock as it came down the mountain, reflecting the increase in pressure and pre-existing features and geology. He also explained the selection of a two Pelton turbine solution to maximize efficiency over the flow range.

This was followed by a talk by Olatubosun Fasipe, Senior Scientific Officer at the Energy Commission of Nigeria, on the topic of 'Assessment of the small hydro potential of the Oyanmi sub-basin using remote sensing and GIS techniques'. The detailed technical analysis showed that it is indeed possible to estimate the small hydro potential and aid the selection of suit-

able sites for hydropower projects using remote sensing data paired with GIS. This is of particular value where there is a complete absence of measured hydrological data and topographical mapping, and thus will allow speedy evaluation of potential candidate small hydro sites in many rural locations.

The fourth presentation was delivered by Nadine Yaolire from the Ministry of Water and Sanitation, Burkina Faso, with the title 'Small hydropower: Opportunities for household and rural electrification in Burkina Faso'. She explained that there are some 1000 dams in Burkina Faso, none of which are used to generate electricity. Her work is leading an investigation into how they might they be adapted to produce electricity for local communities. So far, she said, some 58 candidate sites had been identified, and eleven of these are to have full feasibility studies carried out. The presentation included the examination of the Comoe dam, as an example, which has the potential to deliver 880 kW. However, the main barrier appeared to be the cost of the connection to the grid, which turned out to be half the total cost of the project. Yaolire is now seeking a lower cost approach, perhaps avoiding the grid entirely and supplying directly to local communities.

The final presentation of the session was given by session co-chair Prof David Williams, Director of Learning Hydro and visiting Professor at The University of Edinburgh, Scotland. His topic was 'A potential revival for Shetland Mills?' He explained that many years ago in Shetland, Scotland, small water-powered mills had been used by the locals to grind oats. He illustrated the resource, the simplicity of construction and operation, and the appropriateness of the technology to the local population at the time. Using the example of flour shortages arising from the lockdown imposed in March 2020 as a result of COVID-19, he posed the question: "Should small rural hydropower mills around the world be considered for redevelopment for the benefit of local communities?"

There was no shortage of questions, and we quickly ran out of time.

Small Hydropower Workshop

Gordon Black and Prof David Williams, Co-Directors of Learning Hydro Ltd

This workshop, attended by about 40 delegates, was based on the one-day events run at Aqua Media International's conferences in Europe, Asia and Africa. Normally, it is known as 'Design a small hydropower scheme in a day" which was unfortunately not possible in the on-line format. Instead the session served as a 'taster' for the actual workshops which it hoped can be included at AFRICA 2021 at Lake Victoria, Uganda (13-15 July) and at HYDRO 2021 in Strasbourg, France (25-27 October).

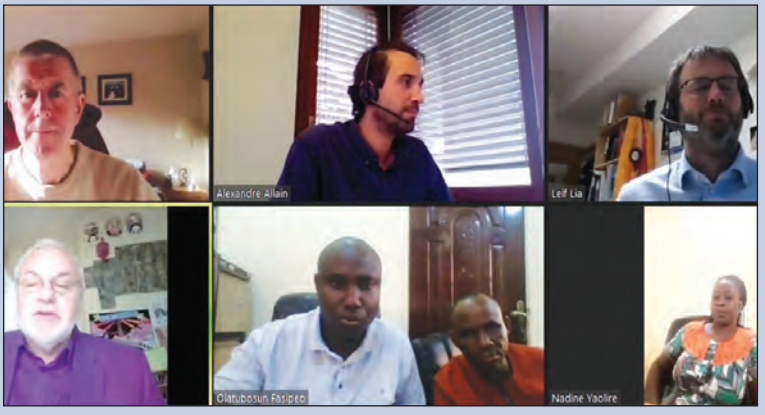
The four presentations covered:

Course introduction and aims

1. To provide a basic understanding of the types and principles of small hydropower generation.
2. Appreciation of the turbine types available.
3. Insight on the practicalities of building a complete scheme, including, intakes, penstock, powerhouses and grid connection.

Hydro scheme features: A review of the component parts of a project

Overview of the major components followed by more detailed descriptions and illustrations of:



Discussion during the second session on small hydro, which was co-chaired by David Williams and Gordon Black.

- *Intake*. Diversion structures with screening, compensation flow devices, forebay structure and fish passes.
- *Penstock*. Materials available and their properties, jointing and laying
- *Powerhouse*. Basic requirements and designs.
- *Tailrace*. Various designs and important properties.

Hydropower elements: Description and measurement of the main elements:

- *Flow rate*. Catchment area, measurement/gauging, hydrology and flow duration curve.
- *Head*. Net and gross head, measurement.
- *Power*. Rated generated output of the turbine and generator .
- *Energy (AAEP)*. Annual average energy produced by a hydro scheme.

Water turbine options

A review of the various types of turbine available and their applications, and how turbines are classified (specific speed), and selected.

- *Turbine types*. Impulse, reaction and hybrid and their ranges.
- *Reaction turbines*. Propeller (Kaplan and fixed blade) and Francis.
- *Impulse turbines*. Pelton and Turgo impulse.
- *Hybrid turbines*. Crossflow, Archimedean screw.
- *Turbine selection*. Specific speed and efficiency comparisons.

Full-day workshop

The normal full-day workshop, which takes place regularly at the in-person conferences, includes more presentations on:

- *Classes of schemes*: Storage and run of river, and from mills to pumped storage, tidal and kinetic.
- *Practical design*: Positioning of the intake, powerhouse and tailrace to optimise on head and flow (catchment area) and consider channel and/or pipe routes.
- *Electrical components*: Generators, controls and switchgear.
- *The business case*: Scheme design process, land ownership, general costs, income and risks
- *Case studies*: Three completed projects in different parts of the world described to indicate the similarities and differences between small hydro schemes.

It also incorporates an exercise in which participants, working in groups, design a hydro project using maps and local flow data provided, and then select a suitable turbine and calculate the annual average energy production for the selected site.

Floating solar panels on a reservoir in Portugal, an example of schemes dicussed in the session on hybrid renewable energy systems (photo by courtesy of EDP).

Hybrid renewable energy systems

Dr Kamal Laksiri, Ceylon Electricity Board, Sri Lanka

This, session focusing on the development of renewable energy sources, included five presentations covering cases from Portugal, China, Ukraine, Switzerland, and Mali. The session began with opening remarks by the session chairman, giving an introduction to renewable energy sources and the requirement and the importance of hybrid development of renewable sources for optimized benefits. He emphasized the importance of the topic in today's context of sustainable development.

Today, with growing attention on emissions reductions associated with global warming, countries around the world have established their expected targets for renewable energy generation over the coming years.

It is well recognized that because of the inherent characteristics, like intermittency, of the solar and wind resources, their optimum efficiency and the output cannot be achieved when they are developed in isolation, and this is where the hybrid energy systems come in to play. A hybrid energy system, usually consists of two or more renewable energy sources used together to provide increased system efficiency, as well as greater balance in the energy supply.

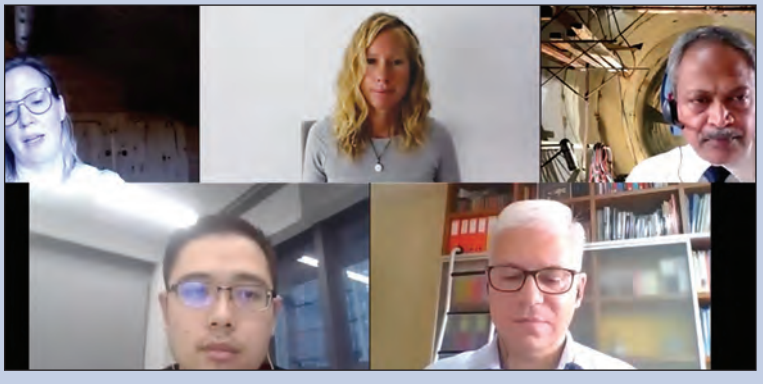
Renewable energy hybrids are the solution to a reliable, affordable and dispatchable integration of renewable energies, solving critical needs. From the combination of hybrid solar and wind power, to a hybrid of wind and hydropower, these renewable systems can provide vital stability to the grid.

The importance of taking advantage of hybrid systems is increasing today, and there is a substantial demand for such solutions to reduce cost and improve efficiency.

The first presentation in the session, entitled 'Where sun hits water', by Bente Brunes, Lead Hydro Specialist at the World Bank, presented a study based on solar power. She highlighted the importance of solar hybrid, particularly floating solar panels, in meeting the following objectives:

- maximizing the renewable energy generation utilizing the same infrastructure;
- ability to take the full advantages of synergies between hydro and solar;
- increasing reliability and resilience in generation; and,
- providing energy storage coupled with variable renewable energy.

Additional tangible benefits in such a solar hydro hybrid systems, she added, were: having one operator, one substation for grid connection and no land acquisitions; and, a lower levelized energy cost. The interesting case of Manantali hybrid system in the Senegal river basin, Mali, was presented as a case study. Bentes highlighted the role of the World Bank in the new solar -hydro hybrid developments.



The panel of speakers in the session on hybrid renewable energy systems, chaired by Kamal Laksiri of Sri Lanka, shown top right.

The second presentation, by V.T. Mendes from EDP, Portugal, described a study on a hydro, solar and wind hybrid system. His presentation was based on the Cavado river system which is a system with a six-reservoir cascade in northern Portugal, experiencing the highest rainfall in the peninsula. The opportunities for a hybrid system had been considered, he said, with the planned wind farms in the region, and in view of grid connection saturation currently experienced. The new Portuguese legislation for hybrid systems, which came into force in 2019, has also created new opportunities for hybrid development.

Mendes also introduced EDP's own model, HYDROSIM which is being used in assessments, and gave details of simulation studies which have been carried out. He concluded the presentation by stressing, among other things, the need of wind-hydro hybrids as a solution to grid expansion requirements amidst the limitations in the Portuguese grid.

The next presentation, by Yuri Landau of Ukrhydropoject PRJSC, Ukraine, described the Lastovsky hybrid system, incorporating pumped storage, wind and solar, which is planned to supply the Carpathian region of Ukraine. This region, with significant wind and solar potential, has favourable conditions for pumped-storage development. Landau gave a detailed account of how the Lasovsky power complex in the Carpathian region has been planned to incorporate a 155 MW pumped-storage scheme, a 1.4 MW small hydro plant, 60 MW of wind power and 34 MW of floating solar plants; other infrastructure developments will be included in the project, such as health and tourist centres, which will improve the socio-economic level of the region.

The fourth speaker, Yao Chenchen of PowerChina, described a study on pumped-storage development enabling the integration of wind and solar power to the grid in Eastern China. The need for this has resulted from a lack of primary energy sources such as hydro, oil and coal and, the rapid development of wind and solar power in this region. He presented details of the assessment conducted, which had shown the recommended on-grid wind and solar capacities as 60 and 65 per cent of the installed capacity, respectively. The study also revealed the reasonable ratio of wind power to pumped storage and large-scale solar power to pumped storage as 3:1 and 5-7:1, respectively.

The last presentation of the session was by Annelen Kahl of Sunwell, Switzerland. She spoke about the possibility of using solar panels on reservoir slopes, based on a pioneer project by Axpo in the Swiss Alps. Currently two-thirds of electricity production in Switzerland is from hydro, and the balance is from nuclear. As per the information, Solar PV has a highest potential to replace nuclear. She explained how Sunwell had assessed and mapped the solar power potential within the country. The software and data developed could be used to plan a solar PV plant at any location, she said. She also described a case where solar PV panels had been installed in the Alps. The panels had been installed on the surface of a dam built several years ago. This demonstrated that the installation of solar PV at the existing dams and reservoir slopes can be a smart solution.

The session ended with interesting questions and discussion on the five presentations and also on some other issues relevant to hybrid systems.

Climate and environment/social aspects

Climate and hydrology

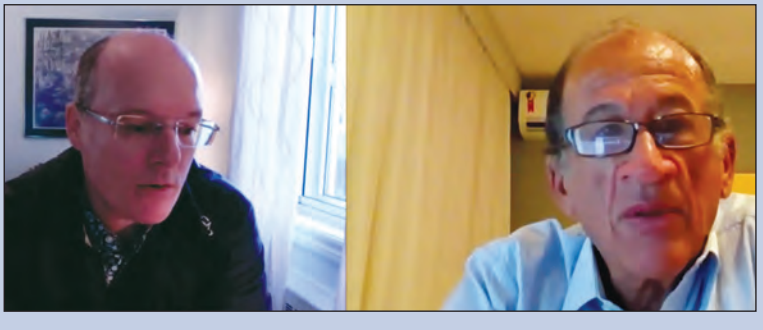
Dr J.M. Damazio, CEPEL, Brazil

Outputs of hydropower projects are essentially sensitive to climate and hydrology and these disciplines play an important role in the management of hydro plants. Appropriate consideration of climate and hydrology in the planning, design, building, and operation of hydro schemes are necessary to guarantee the success in the achievement of the numerous well known and proven qualities of hydropower. These are: reliable low life cycle electricity generation costs; low disaster risks for workers and the general public; role in improving network stability; provider of large-scale and economically viable energy storage; enabler of integrated renewable developments; and, supplier of flood control and drought management services. Climate change poses new challenges for hydropower management. GHG emissions from hydro reservoirs constitute a new water quality issue to be considered in the planning and in the operation management of hydro projects. Future shifts in frequencies and intensities of extreme hydrological events indicated by scientific studies of climate change are incorporated in the decision-making framework of the planning of hydro systems. So are the contributions of hydro regulating reservoirs in reducing the vulnerability of power systems and increasing of adaptability and resilience of surrounding ecosystems and communities.

This session focused on the various aspects of climate and hydrology in the planning, design, building and operation of hydropower plants.

The first paper, Adaptation and resilience to current and future climate for hydropower, by chairman Dr Jorge M. Damazio, discussed recent developments in an R&D project regarding performance indicators and associated requirements for the demonstration of climate adaptability and resilience of hydropower plants, which is currently being undertaken at CEPEL (Electric Energy Research Center) with the collaboration of IEA Hydro, and the monitoring of invited institutions (IEA, Engie Brazil, IHA, Federal University of Rio de Janeiro and University of São Paulo). The R&D project adopted seven assessment themes (Mitigation, Dam safety, Electric energy production, Finance, Water resources services, Biodiversity protection and Social issues) and framed the performance indicators in a general approach for the management of climatic variability, including current and future climates. The application of the approach for each theme was planned to involve up to five steps: assessment of theme vulnerabilities of hydropower; definition of performance indicators and associated requirements; risk analysis for climatic variability for the current climate regime; risk analysis of future climate regime (only carried out if, in step 1, relevant extra vulnerabilities in future climates have been identified); and, development of climate variability risk management plan.

The second paper (Inflow modelling under changing environmental conditions upstream the Regional Rusumo Falls hydropower project) by Dr Rudolf Faber, of AFRY, Austria, described changing inflow modelling and energy generation analysis in the context of the hydropower feasibility and detailed design studies for the regional Rusumo Falls hydro plant, currently under construction in the boundary region of Rwanda, Burundi and Tanzania, within the framework of the Equatorial Lakes Subsidiary Action Program (NELSAP) on behalf of the three countries. One of the two main inflowing rivers, the Nyabarongo-Akagera river, since 2014 has been changing its course near to Lake Rweru. Before 2014, the river passed close to the lake. The new river course now re-directs flows through the lake (avulsion), so the hydropower plant is eventually fed by the lake outflow instead of the river flow. These changing environmental conditions may alter and reduce the inflows to the hydropower plant and its power generation in the future. A detailed coupled water balance and energy modelling system was developed to process data collected from previous and recent studies, including field bathymetric surveys, discharge and water level measurements, installations of water levels gauges, loggers, sediment sampling and analysis, morphologic analyses, and screening of possible mitigation measures. The main objective of the modelling system is to provide reliable hydrological 30 years inflow time series to the hydro plant of pre-and post-avulsion conditions. These series are used to compute daily energy generation for both conditions, serving as a decision support for potential further mitigation options. A coupled modelling approach was used, including a main system semi-distributed model of the water balance for the 30 600 km^2 upstream basin and a hydraulic sub-system of the Lake Rweru area (125 km^2) covering the avulsion-lake-outflow region. The paper also discussed the model expansion to investigate future inflow and energy generation under climate change influence, and its use embedded in a fully operational inflow forecasting system, providing timely information on energy generation and evolving flood and drought conditions.



Left, Alain Tremblay of Hydro-Québec, Canada, who discussed studies on greenhouse gas emissions from La Romaine reservoir; and, session chair, Jorge Damazio of CEPEL, Brazil, who also gave the first talk in the session.

The third paper (Greenhouse gas emissions from La Romaine hydroelectric complex, Québec: Integration of carbon fluxes from terrestrial ecosystems), by Alain Tremblay of Hydro-Québec, Canada, addressed the extensive studies on reservoir GHG emissions for the cascaded hydropower system which is under development by Hydro-Québec in the La Romaine watershed. The paper reported preliminary results and discussion on the quantification of CO_2 and CH_4 exchange at the land-atmosphere interface in an ombrotrophic peatland, representative of the ecosystems within the watershed. Continuous automated flux chamber measurements had been installed and were operated on four microform covers during the growing seasons from 2018 and 2020. The results indicated that peatland ecosystems in Romaine are sources of carbon dioxide and methane for the measured period. The paper also highlighted that the period during which the budget was conducted was not representative of the annual carbon budget as the primary productivity peak (spring and early summer) was missed, and the conducted measurements occurred when CH_4 emissions would be expected to be the highest. The paper raised numerous questions from the audience about the Hydro-Québec programme on GHG emissions from hydro reservoirs, confirming the interest in the subject.

It can be concluded from the discussions in the session that the development of instruments to consider climate and hydrology in the management of hydro plants is an exciting area in constant evolution in response to new possibilities for data acquisition and new challenges.

The role and value of hydropower in mitigating risks in a changing climate (IEA session)

Atle Harby, IEA Hydro, Norway

The common main problem statement in all presentations during the session was that managing reservoirs for power generation can conflict with the needs for flood control and drought management. The talks highlighted the need for collaboration and cooperation to manage this potential conflict. The session included a number of examples of how this could be done, including a discussion on the available tools to help operation and decision-making. Another key message was the increasing importance of hydropower reservoirs in the future, where both climate change and increased integration of variable renewables from wind and solar power, will increase the need for water storage to multiple use.

Seven speakers presented their work during this session.

The first presentation gave a brief overview of the activities and achievements in the joint task of Annex IX and XII about valuing hydropower services in the IEA Technology Collaboration Program on Hydropower. One part of valuing hydropower services is about the value flexible hydropower operations are providing to support renewable energy integration. Another part, which is the focus for this session, is about flood control and drought management provided by hydropower operations. The objectives of the task are:

- understanding the role of hydropower operations in minimizing or mitigating risks associated with a changing climate with focus on flood and drought control;
- assessing the value that hydropower operations provide in minimizing or mitigating risks associated with a changing climate; and,
- disseminating results and findings in conferences, meetings, workshops and through relevant media.

A couple of workshops have been organized, a report of case studies from around the world is soon ready and there are plans to produce a White Paper. The following session presentations are all case studies from the IEA Hydro task on flood control and drought management provided by hydropower operations.

The Columbia river basin in the Pacific Northwest of USA and Canada has 250 dams and 150 hydropower plants. Nathalie Voisin of PNNL (Pacific Northwest National Laboratory), USA, presented on some of the challenges in managing such a large system of rivers, reservoirs, hydro plants and other user interests, as well as having complex ownerships, management agencies and stakeholders. To develop consistent long-term planning among water uses, she pointed out, collaboration is needed between agencies, which is achieved through a 'river management joint operating committee'. Such a committee will be engaged in consistent modelling and analysis of the river reservoir regulation and operation, taking into account both flood control and drought management. Agencies also collaborate on climate change research, and on characterizing its impact on the amount and timing of runoff. Voisin concluded that for a successful adaptation to global change, coordination between institutions and agencies on objectives, as well as modeling and analysis tools, were needed to set up an adoptable multi objective optimization approach.

The Paraiba do Sul river basin is located in an important industrial region of Brazil. The river basin includes four reservoirs and eleven hydropower plants. Jorge Damazio of CEPEL, Brazil, explained that water from the river is diverted for water supply towards Rio de Janeiro, and it has a strong impact on low flow conditions in the Paraiba do Sul river. Severe droughts have occurred twice downstream of the diversion point, but the catchment has also experienced floods upstream. Increased water demand and climate change could increase the challenge. However, decades of multipurpose operation of upstream hydropower regulation reservoirs had proved to be valuable in increasing the availability of basin water resources and reducing vulnerability against droughts in the basin, and in the two metropolitan nearby regions of Rio de Janeiro and São Paulo. Valley vulnerability against floods had also been enhanced by appropriate allocation of flood control storage in the hydropower regulation reservoirs.

Cornelia Häckl, of Uniper, Germany, discussed how the operation of the hydropower plants on the Lech river in Germany balance natural inflow variations with conflicting interests between touristic activities and flood control and energy production. The main challenge, she explained, was to maintain high water level in the artificial Forggensee, which is a popular touristic destination, and at the same time have enough space to store snowmelt runoff in early summer. The hydropower facilities are also used to secure a minimum environmental flow in the Lech and the downstream Danube river during dry periods, both for ecological and navigation reasons. Häckl also highlighted challenges related to climate change, which is predicted to decrease the annual runoff and increase the inten-

sity and frequency of severe high flow events. She concluded that we need more reservoirs like the Forggensee with high flexibility to encounter new challenges.

The East Telemark hydropower system in Norway comprises 33 hydropower plants and many reservoirs in the upper area of the catchment. The areas and towns in the lower part of the catchment are exposed to flood damage. Prof Ånund Killingtveit, NTNU, Norway, presented a modelling system for all powerplants, reservoirs and river reaches, to forecast potential floods. The model has been used to identify flood risk, to predict events. There have been many large flood events recently, with a major media focus. Without such a modelling system, it would be difficult to establish optimal operation of the reservoir and balance the needs for power generation and flood protection. Using the model system to simulate various operation strategies had been crucial to help select the operation during several flood events since 2008. Killingtveit concluded that using such tools could help to reduce conflicts and manage flood events better.

Arun Kumar, of ITT Roorkee, India, gave a talk on the Dibang multipurpose storage project, for flood moderation and hydropower production in his country. The Dibang river contributes about 8 per cent of the flood volume in the Brahmaputra river. There has been significant damage from floods in this region over the past eight years, Kumar said. The new reservoir will be able to store and dampen a flood with a 100-year return period. A new regime in India provides governmental funds for the flood moderation component of reservoir development. Kumar concluded by showing that the flood moderation component cost was very small in comparison with the cost of annual flood damage.

The final speaker, Audun Botterud of the Argonne National Laboratory, USA, gave an overview of the ongoing work at IEA Hydro on producing the report 'Valuing Hydropower Flexibility in Evolving Electricity Markets'. The report includes a brief description of fundamental system flexibility needs, a large section of the results from a survey of flexibility services in current systems in 15 countries, some case studies and perspectives on future electricity markets. The report will conclude by suggesting solutions, good practices, evolving trends and the implications for hydropower. Botterud concluded his talk by underling the fact that hydropower's value to the grid flexibility will increase with the integration of more variable renewables, the need for investment incentives for reliability and flexibility, and the importance of international collaboration and cooperation.

Environment

Prof Markus Aufleger, University of Innsbruck, Austria

The environment is a huge issue. It spans all scales, from specific local issues to climate change, which is changing the world so dramatically.

Worldwide, our society is facing enormous challenges. In addition to our current health problem, we must make the transition to a clean energy future. Here, hydropower will play a major role. Hydroelectric plants have the potential to generate sustainable, clean and extremely long-lasting value. An outstanding feature of hydropower plants and dams is the fact that the associated measures are highly interdisciplinary and often ideally suited to take on other

Discussion among the panel of speakers in the session on Environment, chaired by Markus Aufleger, shown top left.

tasks as well. This can have many positive effects. For example, reservoirs can also be used for water supply, flood protection and to secure new sources of income. However, they can also lead to destruction, ecological problems, injustice and major social tensions. It is now paramount that we proceed with great care and based on the best expertise in the planning, construction and operation of hydropower plants. The World Bank and other international funding agencies play an enormously important role in this. Senior Environmental Specialist at the World Bank, P. Dogra, spoke of environmental and social sustainability in hydro development, in the session. He stressed that during the major scale-up of renewable energy as part of the clean energy transition, it was essential to foster inclusive and sustainable growth while also addressing climate change. He reviewed both opportunities and challenges for hydropower, in this respect, in terms of technical, environmental, social and financial aspects. He underlined the need to strengthen the knowledge base of environmental issues, to recognize the need for consultation and benefit sharing with communities, and to focus on integrated planning, at national and local levels, and with planners and designers.

Through standards and values, institutions such as the World Bank, can and must ensure that hydropower and dam projects are socially and environmentally compatible. This responsibility and this connection is also clearly visible in the vast majority of larger projects with international participation. However, in some regions of the world the smaller projects without the involvement of larger international partners are more critical in this context.

The next smaller, but still very large scale issue, concerns large natural catchment areas (for example, transborder river basins) and in a related way interconnected energy supply systems (electricity networks). Here, many important system parameters in different areas are interdependent. Dams and bedload retention measures in the upper reaches of a river basin can cause problems of degradation in the lower reaches. Fluctuating energy production from solar and wind energy can be compensated by peak electricity from storage plants at other locations in the same energy supply system. Despite the diversity of the systems, the availability of good and reliable data, and the improvement of the various network structures, are of the utmost importance. Data from various sources (satellites, in-situ, modelling) and also technical measures (for example improvements in bedload management or making powerplant technology more flexible) can help in a significant way.

The common objective of the measures discussed should be to limit the ecological consequences for river ecology and greenhouse gas emissions in the

long term by improving the management of systems. The hydropower community plays a major role in both 'networks'. In this respect, it must assume a responsibility that goes far beyond the role of a local hydropower operator.

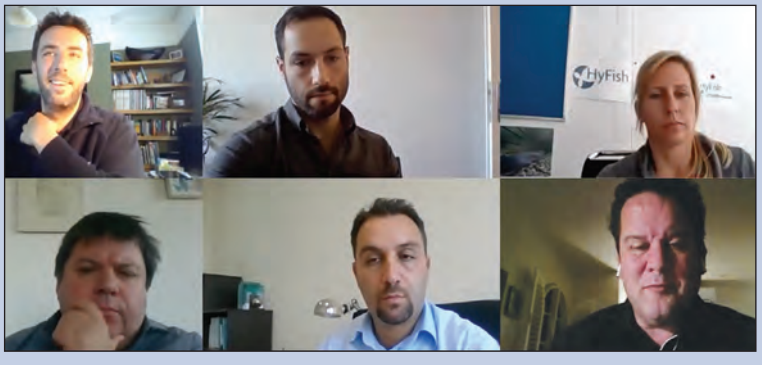
Dr Thomas Heege, of EOMAP GmbH, Germany, described the HYPOS decision support tool, an example of the use of multi-source data for hydropower planning and sediment management. He stressed the value of satellite-based measurements, outlining the information which was particularly relevant to hydro planning, and underlined the importance of how data were processed. The development of HYPOS, he explained, had been part of an EU-supported project with input from NTNU, Stucky, CNR-IREA, and SMHI. He gave details of the various data sources which had been used, and the capability of the system as a planning and design tool.

Heege reported that the HYPOS on-line portal was already accessible, and he outlined the data which were available to assist project planners.

Orkan Akpinar, of Schluchseewerk, Germany, who is also Secretary-General of the Alpine Hydropower Association (AGAW), described a study undertaken by AGAW on hydropower's flexibility in the context of the energy transition. The paper had been co-authored with representatives of the Austrian utilities Verbund, TIWAG, Illwerke AG, and Uniper Kraftwerke. AGAW also includes members from Switzerland and northern Italy.

After discussing challenges of the energy transition, Akpinar reviewed the benefits offered by hydropower as an integral part of the process, by providing grid stability; he outlined the current status of hydro in the Alpine countries, and necessary actions to strengthen its development.

Environmental protection at local project scale plays a very special role. The aim is to reduce potential negative impacts of hydropower on rivers through innovative approaches, but also by improving traditional technologies. Among other things, this can be achieved through improved powerplant layouts, additional anti-pollution measures, or improved bedload management. An innovative type of powerplant, Hydroshaft, recently commissioned on the Loisach river, was described by Bertalan Alapfy of Hydroshaft, Germany. Co-authors were from the Technical University of Munich, Germany, demonstrating that close cooperation between universities, research institutions, authorities and operators can be the basis for important development steps in this respect. The willingness and courage of the hydropower plant operators to place their trust in innovative approaches is particularly important and not at all self-evident.



Dr Tobias Coe (top left), who chaired the session on fish protection, invites questions during the panel discussion.

We need hydropower for our future. We need vital river systems for our future.

Hydropower and fish protection

Dr Tobias Coe, Fishtek Consulting, UK

This session covered a fascinating range of topics in the field of hydropower and fish protection. The impact that a hydropower scheme has on fish populations within a river is often one of the principle and most extensively discussed environmental aspects of hydropower development. The papers within the session covered a wide of specific methods for avoiding and mitigating the impacts of a hydropower scheme on fish. Aspects of particular importance discussed within the session were as follows:

- It is possible to improve the ability to pass through a vertical slot fish pass for small and/or weak swimming fish by installing brush blocks within the fish pass. Similar work has been carried out previously, however this work builds on this and helps demonstrate how fish passses can be optimized to pass weak swimming fish species. The recent field study was presented by Dr Serhat Kucukali, of Hacettepe University, Turkey.
- Turbines can be specifically designed to be more 'fish-friendly' by reducing the volume ratio. The lower the volume ratio, the more 'fish-friendly' the machines will be. This was demonstrated in the talk on downstream fish migration in a Kaplan turbine, presented by Dr H. Benigni, of the Technical University of Graz, Austria. He described an application at the largest capacity hydro plant on the Drau river.
- Fish can be prevented from going through a screened intake (even if they are physically able to fit through the screen) by generating an electrical field from anodes fixed to the the screen or to the bars of the screen themselves, using short DC pulses. This was the subject of a presentation by Barbara Brinkmeier, of the University of Innsbruck, Austria. She demonstrated that there are significant applications for these results at hydropower intake screens, as an alternative to fine screens, which are expensive to install and maintain. The system she described is now to be applied at a Swiss hydro plant, following a pilot scheme which was installed at the Leinau scheme in Bavaria in 2020.
- The number of migratory obstacles within a watercourse does not necessarily have a direct impact on the fish status/ecological condition of that watercourse, and good ecological status is possible, even with large numbers of migratory obstacles present. Additional factors may also be limiting or impacting a fish population, resulting in poor ecological condition. These were among the messages in a presentation by Philipp Wallner, from the University of Life Sciences, Vienna, Austria, who spoke of the influence of migratory obstacles on the econological status of the water bodies of Upper Austria.
- At large dams, an alternative solution to traditional fish passes is the Whooshh fish passage system. One of these systems, with six tubes, was used to help salmon pass a large landslide that blocked salmon migration on the Fraser river. The technology was described in a presentation by Michael Messina, of Whooshh Innovations, USA. He described some recent case studies where the Whooshh had been

installed; one was at the Chief Joseph dam on the Columbia river, USA; He demonstrated the operation and remote control of the system, with a video presentation. The other case, in August 2020, was to enable the passage of thousands of salmon when a landslide occurred which blocked the Fraser river in BC, Canada, in 2020. Messina concluded that the technology for fish passage was "ripe for innovation", as he felt many systems in operation were now outdated.

• Construction of the Baihetan hydropower station in China caused a shift in the fish species present in the Jinsha river. According to the presentation by Huang Bin, Deputy Director of PowerChina Huadong Engineering Corporation, it was found that the efficiency of the fish passage facilities at the dam could be improved by using a net wall to direct fish to the facility. The presentation included details of four methods which had been used to study the fish distribution and cluster characteristics downstream of Baihetan, to enable a selection to be made for the fish pass facilities, and the site for them to be located.

The session presentations summarized key learnings on a wide range of topics, and also highlighted several areas which future conferences could focus on. Of particular interest is the general topic of downstream migration, as this is often still an issue for fish populations within a river. Future sessions could focus on the technologies being developed both to exclude fish from passing through turbines, and the alternative passage routes being designed for them; and, the work being carried out to make turbines more 'fish-friendly'. The latter topic would be made even more relevant if substantiated by results from trials passing live fish through turbines, particularly at large and/or high-head hydropower schemes.

For fish moving the other way, an increasingly important topic is how to pass highly diverse fish assemblages upstream at a hydropower dam in areas like Southeast Asia, Africa, the Balkans and Caucasus. There has been a large amount of work in this area in other parts of the world (for example, South America); however, the applicability of lessons and information gained elsewhere needs to be investigated further on river systems in areas of the world where hydropower is currently undergoing a rapid expansion.

Social aspects

Dr Stephen Sparkes, Statkraft, Norway

The selection of papers and presentations for this year's session reflected the diversity of the scope, geography and range of themes that constitute 'social aspects'. Social components continue to attract keen interest, not only among social scientists, but generally among hydropower planners, engineers, financial experts and not least environmental experts, with whom there are many overlapping themes.

The keynote address to start the session was given by Dr Cecilia Tortajada, Senior Research Fellow, from the Institute of Water Policy, Lee Kuan Yew School of Public Policy, Singapore. The topic was. 'Resettlement: What have we learnt?' Dr Tortajada reviewed the present state of affairs, including the challenges faced by developers because of resistance by impacted communities and organized opposition to dam projects. The lack of data on resettlement, limited case studies and no overview of new initiatives, such as benefit-sharing, are the cause for a lack of progress in the past, she felt. However, there have been a number of key developments recently, such as updated handbooks (from IFC) and the World Bank source book which outlines ways to apply safeguards.

Educational facililties developed as social benefits of the Theun Hinboun Extension Project in Laos, as discussed by Stephen Sparkes.

My own presentation entitled 'Long-term planning with government to optimize socio-economic development opportunities for hydropower' served as an example of recent improvement in how to address sustainable development from the early stages of planning, using the example of the Theun-Hinboun Expansion Project in Laos. Examples were given from a number of key themes illustrating how impacts had been estimated, and how outcomes of mitigation in planning documents had needed adjustments and modifications during implementation, achieve positive outcomes in the form of setting up new biodiversity-conservation zones, maintenance of improved infrastructure and services, achieving sustainable livelihoods and income levels, and establishing long-term programmes to support vulnerable groups.

Another example of applied best practice was presented by Zoee Hillson from Sarawak Energy. This dealt with establishing partnerships and ensuring that social benefits reached the 54 impacted indigenous communities of the Baleh hydropower project. By using an extensive consultation, disclosure and consensus process with communities, programmes had been designed and implemented jointly in a culturally sensitive manner. Programmes included improved health and education, employment opportunities and skills training, cultural programmes and essential support during the COVID-19 pandemic.

The challenge of monitoring environmental impacts in relation to e-flow, impacts on aquatic ecology and generation was the theme of the next presentation, by Giovanni Frosio, Italy, using the example of the Allein hydro plant in northern Italy. This study has developed indicators for the downstream river impacted by generation, by combining the results of the various flows and releases on aquatic ecology. The aim was to find a balance between generation needs and the environment, so that energy production did not severely change the natural environment.

The final presentation, by Lucy Goodman, a researcher from the University of Cambridge, UK, had the provocative title of 'What's the dam fuss? Understanding and unpacking opinions on large dams'. After examining how dams were perceived and debated, she said, it had become clear that there were two main views: for and against hydropower dams. So, a series of statements have been developed and tested (work is still ongoing) to have different groups rank answers along a spectrum, from 'strongly agree' to 'strongly disagree'. A diversity of responses have been resulting, she said, but with only a few consensus

points agreeing that dams impact biodiversity and developers seldom correctly assess environmental impacts, and disagreeing with dams being avoided for religious reasons, or that they should be a geo-political tool to acquire control over rivers. I encourage readers to contact Dr Goodman if they would like to participate in the ongoing research.

Sedimentation management

Prof Anton Schleiss, Emeritus Professor, EPFL-LCH, Switzerland

The management of sedimentation is a must for designers and operators, to ensure the sustainable use of reservoirs and therefore also the sustainability of electricity generation from storage hydropower plants. Since sediment yield into reservoirs will increase as a result of climate change, the challenge of sedimentation management is becoming more and more important. Urgent mitigation measures are already required today at many existing reservoirs. It should be mandatory that new reservoirs are designed taking into account resilience against reservoir sedimentation. The reasons and the processes involved in reservoir sedimentation have been well known for a long time. For designers, owners and investors there is no excuse not to take into consideration sustainable and preventive measures, when designing new reservoirs. The design requirements for sustainable sedimentation management may even influence the overall layout of storage hydropower projects. This was highlighted by Sultan Alam (1928 – 2017), the late worldwide recognized sedimentation expert, who stated in 2002 "It is important to consider alternative project arrangements to delay the sedimentation process, reduce the risk of damage and improve economic feasibility and sustainability".

It is known that today's global annual mean loss of reservoir storage capacity as a result of sedimentation is already higher than the increase in capacity by the addition of new reservoir volumes for irrigation, drinking water, and hydropower. Depending on the region, about 1 to 2 per cent of the capacity is lost annually. This is catastrophic, as the tremendous and vital investments made in the last century will already be wasted by the middle of this century if urgent mitigation measures are not implemented. As already mentioned, a large portfolio of technical and operational mitigation measures against reservoir sedimentation are available and have been applied successfully at many reservoirs. Nevertheless, finding the best solution is a difficult task and requires highly innovative engineering competence, and a scientific understanding of the processes involved. Unfortunately, awareness about the urgency of the sedimentation problem is still lacking, not only in many existing storage hydro schemes, but also in new projects. Back in 2005 Sultan Alam warned: "There is an urgent need to pay more attention to the problems related to sediment management at hydro projects in many areas of the world, and in particular in the Himalayan regions of Afghanistan, India, Nepal and Pakistan". The costs of the required mitigation measures may be high for certain projects, but they are paid back very fast since they ensure sustainable use of storage, and consequently flexible electricity generation in future.

Prof Anton Schleiss, top right, chairing the session on sedimentation management.

The session addressed many critical issues of sedimentation management, and the challenge of finding the most efficient and sustainable mitigation measures. In a keynote lecture, Prof Sameh Kantoush from Kyoto University, Japan, spoke of the paradigm shift for sediment management at the river basin scale, and illustrated this with several examples in Japan. The key issue at rivers basin level is the involvement of all stakeholders when defining the most effective sediment management strategies, Prof Kantoush said. He described the challenges starting from the upper part of the catchment area down to the tributary of the river into the sea, with the corresponding major impacts caused by sediment retention in reservoirs. He also gave a comprehensive overview of sediment management techniques implemented at Japanese reservoirs. He stressed that the concept of dead storage, often used in the past, should be considered today as a poor concept, in terms of sustainability as well as waste of investment. Retrofitting works, involving the installation of sluice gates, at the Yamasabara and Saigo dams were described, with the very positive impact on river morphology evolution and biotope restoration in the Mimi river downstream. Japan has long experience with the operation of sediment bypass tunnels, which was illustrated with the example of Asahi dam. Finally, Prof Kantoush spoke of the successful extension of the lifetime of the reservoirs in the Kizu river system, with the help of asset management. Prof Kantoush's keynote address highlighted clearly that sedimentation management at dams is also an ecological requirement, to maintain river morphology and biotope richness downstream of dams, thus ensuring sustainability of floodplains.

Reto Bachman, from Rittmeyer AG, Switzerland, described an advanced monitoring system for suspended sediments conveyed by penstocks into the powerhouse, which are a potential risk for abrasion damage to the turbines. Suspended sediment monitoring in penstocks makes it possible to extend the lifetime of turbine runners by stopping operation at a certain concentration threshold. The acoustic discharge measurement system presented allows for a correlation to the particle concentration and is combined with an automatic warning system from a certain concentration threshold.

The active continuous controlled release through powerhouses of fine suspended sediments, which often represent the major part of the sediment yield in reservoirs, has become a field of great interest. These fine sediments are transported in deep and long reservoirs by density currents along the reservoir bottom. Thus, periodically, a large amount of fine sediments can reach the dam, and after only a few decades can

affect the operation of bottom outlets and power intakes. Based on recent developments, turbidity currents can be managed, that is, retained in the reservoir, whirled up by an innovative water jet mixing device and then released continuously through power waterways, or vented through low-level outlets during flood events. In combination with such innovative sediment release techniques, the real-time monitoring of critical particle concentration is essential.

Vicky Ariyanti, from the Ministry of Public Works and Housing, Serayu Opak River Basin Organization, Indonesia, addressed the particular challenge of sedimentation management at hydropower dams in volcanic river basins. Based on several case studies in Indonesia, she explained how for each river basin and type of volcano (frequency of lava flows), sedimentation rates, as well as the study methods used, had been investigated and compared. The results are very useful as a reference in determining appropriate methods for sedimentation management at hydropower reservoirs in other volcanic river basins.

After some questions to the speakers, a discussion began among about 30 people from all over the world, connected through the conference. New technologies based on satellite data for the estimation of sediment yield into a reservoir was considered as important and promising. In the case of cascade dams along a river, the synchronization and coordination of flushing was considered as an important challenge.

It can be concluded that, in general, whenever possible, any reservoir intake at a hydropower plant should be combined with a flushing device located just below, to ensure regular release of sediments and thus the sustainable operation of the reservoir. However, there is still a long way to go until any new dam in the world will be built, or any existing dam will be retrofitted, avoiding problems of sedimentation entirely.

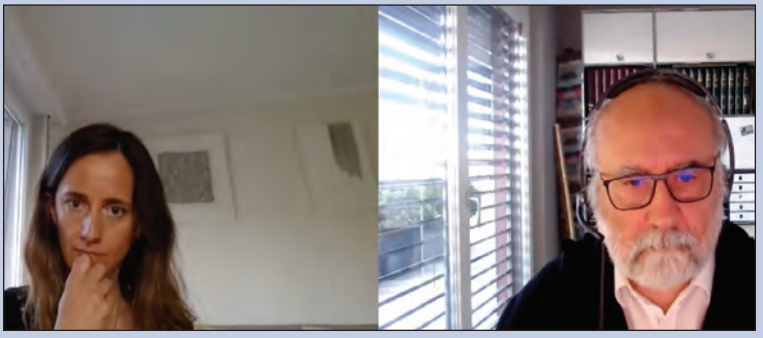
Maximizing hydro opportunities and plant safety

IEA Session: Overcoming the barriers to the development of hidden hydro opportunities

Prof Dr François Avellan, EPFL-LMH, Switzerland

Three papers were presented in this session. All the research papers reported on experience of pilot small hydropower plant sites.

Daniel Biner, University of Applied Science HES SO Valais, Switzerland, a doctoral student, opened the session with a presentation of 'Duo Turbo', the new drinking water network energy technology to harvest the energy dissipated by pressure release valves. First, he drew attention to the energy potential of drinking water networks. In the case of Switzerland, small hydro plants, with a gross capacity of less than 10 MW, supply 10 per cent of the domestic hydroelectricity generation, contributing 3.4 TWh/year. An additional potential of 460 to 770 GWh/year can be expected by 2050 from small hydro plants in Switzerland. Drinking water supply systems, especially in Alpine regions, where pressure release valves dissipate hydraulic energy surplus, could provide a significant part of this potential. The Duo Turbo system is aimed at drinking water networks with a 5 to 25 kW capacity range. The system features two axial counter-rotating runners. Each runner drives a wet permanent magnet rim generator with independent speed regulation. This compact design enables a serial installation to cover a wide hydraulic power range. Two pilot drinking water systems have been equipped with Duo Turbo prototypes and, since their successful commissioning in 2019, and with outputs of 26 MWh/year and 27 MWh/year, respectively, no unexpected outage has been observed and more than 50 per cent of the electricity has been fed to the grid.



Left, Prof. Cécile Munch-Aligné and session chairman Prof. François Avellan, during the IEA session on 'hidden hydro'. Prof. Munch-Aligné also chaired one of the sessions on research for hydro machinery.

Prof. Cécile Münch-Aligné, Head of the HES SO Valais 'Hydroelectricity' research group in Switzerland, presented a paper on the production flexibility return of experience in the case study of the 14 MW Gletsch-Oberwald run-of-river plant, featuring two 288 m-head Pelton turbines commissioned in 2017. This work was carried out within the framework of the SMALL Flex Project, to demonstrate how small hydro plants can be flexible and provide winter peak energy as well as ancillary services, while remaining eco-compatible. A storage capacity of 2500 m^3 was identified in the settling basin and forebay reservoir, while 30 per cent of the headrace tunnel capacity, corresponding to 6400 m^3, is considered for further storage capacity. A Hydro-Clone® advanced monitoring system has been installed to monitor pressure fluctuations during transient and off-design operations of the powerplant. Two campaigns of tests were carried out: first, the use the settling basin and forebay chamber to assess the methodology to predict the production programme, the monitoring system and the impact on the alluvial area; and second, the use the top part of the headrace tunnel with the settling basin and forebay chamber to assess the storage capacity of the hydro plant in safe conditions.

Dr Elena Vagnoni, a Scientist at the EPFL Technology Platform for Hydraulic Machines, gave the last presentation in the session. She presented analysis results of statistical tests (MARS) surrogate modelling of the operation time history of a 40 MW Kaplan unit at the Vogelgrün run-of-river plant in eastern France. Good prediction of the powerplant's performance and other monitored variables had been achieved. Furthermore, analytical functions had been derived which made it possible to optimize the algorithms. Further developments of regression models are envisioned to avoid local minimum new data coming from numerical simulations, and reduced scale model tests will complete the training and tests set to enable the extension of the power plant operating conditions and provide flexibility to the power system.

Innovation in hydropower

Luc Deroo, ISL, France

Five presentations were given, from Spain, Austria (two), France and Canada. Four of these addressed the key issue of digital transformation, and the last reflected on new options for hydropower reservoirs.

A number of systems based on new technology for the design and monitoring of hydraulic works were discussed in a session on innovation. It was chaired by Luc Deroo, shown top left.

E. Palmieri, from HydroCloud, Spain, presented Hydro Cloud, which is a cloud-based system for the collection, storage and analysis of dam instrumentation and monitoring data. He underlined the fact that cloud-based applications could reduce reliance on maintaining in-house systems, by offering the opportunity for cost-effective storage and the management of monitoring data for dam owners. (See also a full paper on this system in *H&D* Issue 1, 2021).

P. Reiter, from SeamTec, Austria, also discussed the benefits of cloud-based data technology. His presentation explored how plants could be networked online, with regard to planning, central maintenance, cost, optimization, monitoring and control. Two major aspects were described: maintenance process in the cloud; and, cloud-based control of hydropower plants.

B. Hollauf, of Verbund, Austria, presented an overview of a five-year investigation programme on hydropower digitalization, which had been initiated by his company. The innovation programme 'Digital Hydropower Plant' had been launched in 2017 and was ongoing, and involved practical testing of promising digitalization technologies. Three selected examples of the innovation programme were presented:

- process monitoring using anomaly detection models;
- digitalization of hydrographic surveying activities; and,
- generator inspection system using AI for image recognition.

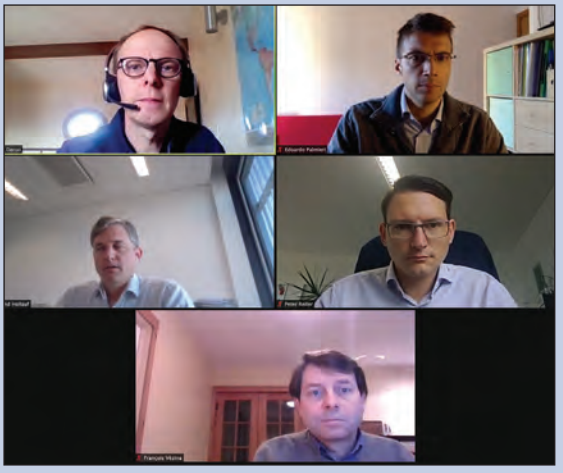
According to Hollauf, this programme showed that a sustainable approach to digitalization could create value in a wide range of areas.

F. Vezina gave an overview of HydroSPACE, a tool being developed by his team at Hatch, Canada, with the purpose of providing a quick and precise outline of Francis turbine powerplant projects. HydroSPACE automatically generates 3D models of the hydraulic passages and concrete geometries. First experiences show that the tool enhances significantly the quality and the efficiency of the preliminary design work carried out in the preparation of feasibility studies.

F. Lempérière, from Hydro Co-op, France, presented an update on his current research, with a focus on twin dams, emerald lakes and off-river reservoirs. The potential of twin dams was illustrated by two spectacular examples: at two of the largest African artificial lakes (Kariba and Aswan), installing twin dams could multiply by 50 the present power production. More generally, Lempérière indicated that large pumped storage powerplants could have a bright future, as long as their construction costs remained low enough, and he showed how innovative options could be used to reach a target of around €1.5 billions/MW.

A discussion followed, on the gains that digitalization could bring to the hydro industry, and on whether these gains could come from a new generation of software, from automation, from IoT, or from artificial intelligence. According to the speakers, gains could be expected, especially for hydropower plant operation and predictive maintenance. But most believed that we should not expect game-changing technologies with a deep impact on the industry.

Several attendees had questions about twin dams, on the sizing of the pumps, turbines and reservoirs with respect to the solar powerplant peak power, and on the potential impacts associated with the submergence of



new areas upstream of the upper dam. The preliminary sizing of the twin dams' equipment, being used by M. Lempérière in his computations, results mainly from a day/night balance for typical solar irradiance conditions. Naturally, the installation of a new dam results in more land submergence. But it has been verified that (in the case of Aswan and Kariba) the corresponding areas are mostly inhabited; besides, and more generally, the efficiency of this additional land submersion, in terms of GWh/ha, is far better than for traditional hydropower reservoirs.

The session of course only provided a limited sample of all the opportunities for innovation in the hydropower and dam industry: some other new concepts, designs, construction methods, and contract and financing methods were also presented during most of the other conference sessions. But these do not always receive the attention they deserve. In the chairman's opinion, research and innovation is a must: our industry is challenged by various alternative options, and it would be wrong to consider that hydropower is a mature technology with limited options for further improvements. Innovations through digitization (IoT, artificial intelligence) in water management optimization, in biodiversity appraisal and support, in hydro operation hybridized with solar and wind, in reservoir and powerplant predictive maintenance, for example, could bring a lot of value and lead to better projects. Innovations in new materials, new designs, new investigation methods and in financing methods (that take into account the long service-life of hydro reservoirs and the external services they may bring) could substantially decrease project costs and make them more competitive.

Hydro plant uprating and refurbishment - 1

H. Obermoser, AFRY, Switzerland

Hydropower is a very old science. Powerplants have been constructed for more than 100 years. That means the equipment becomes old and unreliable, concessions expire and are ready to be renewed. The need for electricity increases periodically: in some countries more, in others less. Confronted with the question of whether to de-commission a hydro plant close to the end of its useful life, or rather to invest early enough to extend its lifetime, there should be no doubt about the answer. To assure a safe and reliable production of electricity, the rehabilitation of existing hydro plants has become a major factor in the hydropower world.

Three interesting papers were presented in this HYDRO 2020 session, underlining the need for rehabilitation. They showed the possibilities of how to refurbish the plants with the aim of extending the life of the equipment, to increase its capacity, and they demonstrated difficulties in compiling exact specifications, and impediments in execution of the work.

The first paper "Contracting-out rehabilitation of hydroelectric plant" was presented by John H. Gummer, Hydro-Consult Pty Ltd. He discussed the various steps in the contracting-out processes, including feasibility studies, specification, bidding processes, contract administration and quality assurance. He gave examples of several contracted-out rehabilitation projects worldwide in which he has been involved. He underlined the need for evaluation of the extent of rehabilitation work, done by either a manufacturer, the owner of the plant, or a consultant. He demonstrated that the initial investigation would be best led by an independent consultant, all the more if financing is from an international agency.

Defining the extent of the work contains risks which must be determined and can be characterized as follows. 'Known knowns' are established by visual examination, inspection and evaluation, and so on. They will always be included in the specification and in the contract. 'Known unknowns' include all elements in which problems might exist, but cannot be proven without prohibitive dismantling and testing. These types can be accommodated in the specification with optional prices. 'Unknown unknowns' are the substance of time and price contingencies. They are unpredictable surprises, waiting at any time around each corner.

In the normal course of events, an estimate will be made based on the final specification of the work to be done. The budget should then be determined from the estimate plus a certain contingency.

Gummer discussed the contract, bidding and funding, that is, the type of contract, the best number of contracts, the qualification of contractors, the commercial clauses and the type of funding. For rehabilitation projects with a lot of insecurities, the best type of contract, he said, is a lump sum turnkey contract, based on FIDIC standards, with an experienced contractor. During the execution, a strong and experienced project management and quality assurance is essential, he stressed.

The second paper 'Refurbishment of CNR's low head Rhône turbines: Feedback on experience at Beaucaire hydropower plant', was presented by T. Foggia, Compagnie National du Rhône.

He presented the scope of the refurbishment and the characteristics of the design optimization for this hydro plant on the river Rhône. A modernization programme began in 2015 to replace the original runner blades, to increase the rated discharge and the overall efficiency. A specific blade design has been developed and tested with a semi-homologous model. Only the runner blades, the discharge ring and the rotating hub are in exact homology with Beaucaire. CFD computations have been carried out to assess the effects of the geometry differences on the behaviour, particularly for the distributor and the draft tube.

However, at high load, and over a wide range of head, a strong and cyclic noise was noticed which was soon suspected to be caused by cavitation. It seems clear that the cavitation occurs in the runner passage and when the blades reach their upper vertical position. The type of cavitation is yet not clear but it is likely to be attached to the runner.

The refurbishment of Beaucaire unit 3, with a new blade design, has been proven to achieve the expected guarantees in terms of output and relative efficiency within the usual uncertainty range. Vibration levels are low at the turbine and generator guide bearings, but displacement values on the upper discharge ring are high. Yet, the unexpected noise generated by the cavitation remains of concern. The mechanism causing this phenomenon has been deduced from various measurements on site. A better knowledge of the dynamic process of the onset of cavities and collapse would require further observations from fully homologous reduced-scale model testing.

The third paper 'Refurbishment and model testing of turbine governing systems for the Belmeken pumped-storage plant, and the Sestrimo and Momina Klisura hydro plants' was presented by Mr. I. Miskovic from Končar – Power Plant and Electric Traction Engineering Inc Zagreb, Croatia. These three plants form the Kriva reka river cascade, in Bulgaria, with a total installed capacity of 739 MW.

The work includes the replacement of the excitation system, turbine governors and spherical valves. In addition, at Belmeken and Sestrimo, new nozzles, deflectors, and mechanical braking systems were replaced, and at Momina Klisura, the guidevane control mechanism, penstock discharge valve and spherical valve. The main aim of the refurbishment is to modernize the system, increase reliability, and improve the response of the powerplants in primary and secondary frequency regulation. Miskovic outlined the design of the governor system and relevant subsystems, as well as the plant emulation platform built to verify accuracy during factory testing.

Model testing was carried out on the control cubicles of the turbine governors, spherical valves and mechanical brakes. Models of the hydropower plants were developed using the Matlab/Simulink software environment. The models used simulated all subsystems of the powerplant which effect the operation of the turbine governor, that means, water supply, nozzles and deflectors, guidevanes, penstock discharge valve, turbine, generator, hydraulic unit, parts of unit controllers and other auxiliary systems. Using a test system, a comprehensive test of the entire turbine governing systems was achieved. (See also an article based on this paper on pp50-54).

The turbine governors developed for all plants successfully passed the factory acceptance tests and are currently on site at the commissioning phase. The emulation platform with the model of the turbine and

Discussion time during the first session on hydro plant uprating and refurbishment, chaired by Helmut Obermoser (top left). Beside him is John Gummer, who gave the leading talk in the session.

Prof Leif Lia (top left) who chaired the second session on upgrading and refurbishment, taking questions about the presentations

powerplant proved to be invaluable, both during the development of the control software and for the verification during the factory acceptance tests.

Hydro plant upgrading and refurbishment - 2

Prof Leif Lia, NTNU, Norway

The session was the second of two covering the topic, and contained three quite diverse papers, not exclusively on the upgrading of powerplants. There were participants from various disciplines, from electrical and mechanical engineering, to civil and environmental engineering. Presenters came from Austria, Brazil and Norway.

Peter Strohmer of ILF Consulting Engineers, Austria, presented a paper about experience gained from the commissioning of several powerplants. With his background in mechanical engineering, he had picked up various shortcomings in the commissioning process. He categorized the process by three possible descriptions: well organized, semi-organized and poorly organized. He then demonstrated how these three categories influenced the stages in the process, such as:

- the use of measurement equipment;
- checking the capacity of auxiliary systems;
- measurement of relative efficiency by differential pressure; and finally,
- the documentation.

After sharing his experience of practical implementation, he gave a list of very useful recommendations for successful commissioning. These were aimed at success for the owner, supplier and those who run the commissioning process; much of the focus was on reports and documentation.

The next paper focused on two specific projects, the Ilha Solteira and Jupia hydro plants in Brazil. The authors, Rafael Castilha and Afonso Rafael da Silva, from Intertechne Consultores SA, Curitiba, Brazil, shared their valuable experience on the challenges of upgrading these two large powerplants with capacities of 3440 MW and 1550 MW, respectively. The two plants are extremely important for the power supply of Brazil, and both have been in operation since the early 1970s. An upgrading project, organized through international contracts, had been planned and carried out for the two plants. The main challenges, such as the application of new and old technology, and cultural aspects between the participating companies during the process, were highlighted. This was considered particularly useful, as Brazil has several large projects to be upgraded in the near future, as well as participating in international projects.

A promising study about the retrofitting of old non-powered dams for hydropower production had been carried by Nora Rydland Fjøsne of Norway, as her Master's study. She presented the concept of retrofitting with and without reconstruction of the dam itself. To demonstrate the reality of the concept she had taken the case of the Guadalquirvir river scheme in Spain, where there are 65 dams in operation for various purposes. The water resources and thus the hydropower potential had been simulated by the commercial tool WEAP. Total costs of exploiting the available potential were calculated based on international price levels and the cost of capital, and compared with the potential benefits, ending up with a schematic expression of the levelized cost of electricity (LCOU). Even taking into account the limitations in the study, there seemed to be a potential for environmentally friendly retrofitting of non-powered dams. It is not clear why this potential has still not been fully utilized, and further investigations were recommended.

Before the end of the session, a number of relevant questions were posed by delegates directly relating to the topics presented. All questions were posted in the 'chat' and were presented orally by the chairman, and answered by the panel of presenters.

Enhancing powerplant safety

Ole A. Westberg, Consultant, Norway

It is only very seldom that serious accidents occur at hydropower plants. However, when they do occur, the consequences can be disastrous. Therefore, investments in powerplant safety measures are crucial, to minimize injuries to personnel, environmental contamination as well as loss of assets.

Underground powerplants are more exposed to accidents, because of the high concentration of energy produced and transformed by oil-filled step-up transformers, mostly located underground.

Three of the speakers focused on cyber security, a topic which has been on the programme of the annual HYDRO conferences over the past six years.

All session presentations fully met expectations, and a number of questions at the end of the session were answered satisfactorily, leading to a good discussion.

The first talk, entitled 'Concept for integrating access and data transfer from the critical infrastructure', was co-presented by Michael Hein and Christoph Kukovic, of Verbund, Austria. Verbund is the leading Austrian electricity company, producing 90 per cent of the country's hydropower; it is also the largest hydro producer in Europe. The company will be establishing an OT cyber security laboratory in the coming year, and there were exhibitors at the conference ready to discuss this.

Attacks on the IT- and OT-infrastructure of electricity companies, both technically, and on administration departments, are increasing, and cyber attacks are becoming a more and more serious cause for concern. These attacks are an effective and relatively low risk method of paralysing companies. The European Network and Information System Security Directive (NIS Directive) has been brought into force to define a uniform standard for cyber security, to establish this standard by national laws, and to verify its effectiveness. For this purpose, national laws have been passed and the necessary structures and requirements that directly affect the operators of these networks, as well as information systems must be defined.

Pavlo Popruha, Chief Expert of the Scientific Research Department at Hydrotech Project Ltd, Ukraine,

gave a talk on the automatic system for monitoring the safety of hydraulic structures of the Dnieper hydro plant cascade in his country. He reported that he was currently working on the development and detailed design for the installation of the instrumentation at the hydraulic works, including the development of technical documentation and programmes for field inspections.

Various aspects of the major Dnieper cascade, consisting of six powerplants, have been described at the HYDRO conferences several times before. The hydraulic works in this cascade are among the most significant engineering structures in Ukraine, from the point of view of their economic, social and environmental value. The main activities to ensure their safety include the organization of effective monitoring of the hydro plants, comprehensive assessments of their technical condition and operational reliability, and the development of measures to ensure reliable and safe operation.

To improve integrated approaches to risk management of the structures, a hydraulic safety management system was developed during the 2000s, to ensure reliable operation and minimize the risk of accidents, introducing modern technologies at all stages (design, construction and operation), as well as to prevent the possibility of incidents, and reducing consequences.

Andreas Klien, of Omicron Electronics GmbH, Austria, gave a talk warning of how attackers could target sub-stations to cause a blackout. He demonstrated this by presenting a 'live hack of a substation'.

This is possibly the first report from an attack of a substation. An unknown hacker group penetrated 12 substations. An OFF-command was sent to all circuit breakers in all the substations. The attack was preceded by a rejected blackmail attempt for 100 Bitcoins. The origin of the perpetrators is unknown, and investigations are still ongoing.

After password phishing, the attacker had access to all personal files, files on network drives, email accounts, and site documentation including network diagrams and much more.

In spite of very good security measures by the company, a multi-factor authentication for remote access had not been implemented. The company had not installed monitoring to detect break-ins, either.

Gates and penstocks

Bryan Leyland, Leyland Consultants, New Zealand

This was an interesting session with some very important papers.

The first presentation was by Luc Boulat of Tractebel, France, who described how his company had solved the seemingly impossible task of repairing the gate rails in a low-level outlet without shutting off the flow, by lowering a window frame arrangement which had sealed off the gate slots from the flowing water. They then had just sufficient space for workmen to replace the gate rails. A remarkably ingenious and successful project.

The second presentation, by Maria Nerodyk of Ukrhydroproject, Ukraine, described a process to optimize the design of the very large diameter penstocks for the Kaniv pumped-storage station in her country, where they had had to deal with extremely cold winter temperatures. The costs and benefits of a number of options had been considered and finally buried steel penstocks encased in concrete had been selected.

Speakers in the session on gates and penstocks, which was chaired by Bryan Leyland; he was moderating the discussion at around 03.00 hrs, New Zealand time.

Beatrice Baratti of Studio Frosio Srl, Italy, then discussed how a simplified risk assessment procedure originally designed for penstocks has been extended to canals and tunnels. This was a follow-on from a paper presented at HYDRO 2019 in Porto which had described a simplified procedure for penstock risk assessment.

F.O. Mescigil of Dolsar Engineering Inc, Turkey, then discussed a diversion weir for a river in Pakistan and the design process that had led to the selection of a number of radial gates.

He was followed by a very important paper on penstock rehabilitation by Julien Swach of Electricité de France. He described EDF's approach to penstock rehabilitation and the various tools and concepts they had developed to evaluate penstock condition, and to provide cheaper and better upgrades. Anyone involved in penstock upgrading should, most definitely, read this paper.

The final presentation was by Denis Funk, of Flexim GmbH, Germany, who added to our knowledge of ultrasonic flow measurement options, techniques, and installation methods. An important presentation and paper for anyone contemplating penstock flow measurement.

Electrical engineering and grid systems

Prof C. Urban Lundin, Uppsala University, Sweden

From the presentations during the session, we were reminded about the importance of adhering to international standards when working with high currents. This calls for continuous educational efforts to ensure that the required knowledge is securely anchored in the relevant organizations. We were happy to see that innovations still make their way to powerplants in terms of auxiliary equipment. A presentation about the Baihetan powerplant emphasized that hydropower is still an engineering art, where sites have to be developed based on their individual characteristics, and site challenges must be addressed properly.

Five papers were presented, with topics ranging from a magnetization system to powerhouse designs for ultra-large-scale plants.

The paper presented by A. Merina and O. Torsteinrud, of Voith Hydro, presented a new brushless excitation system, exhibiting fast response. The main thing

Prof Urban Lundin (top centre), who chaired the session on electrical engineering and grid systems, leading the Q&A and discussion.

is to replace the rotating diodes in a brushless system with a thyristor and the required ignition cards and electronics. Such a system also presents two methods to change the voltage applied to the field winding: a slow one from the stator magnetization level, and a faster one changing the firing angle of the rotating thyristors.

Questions such as cyber security and wirelessly communicating between the static and the rotating part were discussed. The main benefit was reported to be merging the low maintenance needs of a brushless system with a response time similar to a static magnetization system.

W.M.M.S. Wanigasekara, of the Mahaweli Authority, Sri Lanka, presented a feasibility study for island operation of a subsystem of a power grid in his country. Hydropower is known to be able to provide all system services needed to operate a stable grid, and this proved true even in transient conditions in the case studied case. One key component was looking at the seasonal accessibility of, and different usage of, water which can enable or hinder the Islanding capabilities.

Two presentations from Hitachi ABB Power Grids related to generator circuit breakers. P. Gugale discussed how combining monitoring systems, and precisely controlling the exact moment the circuit breaker interrupts the current, can substantially reduce contact erosion, and extend the lifetime of the circuit breaker, thereby providing an economic incentive for installing more monitoring systems.

A. Walczyna stressed the importance of looking at return currents and current paths, for these currents in isolated phase busducts. He also emphasized the importance of following the standards of insulated phase busducts and generator circuit breakers, knowledge that seems to have somewhat eroded. The most common error is to apply too many connections to earth from busbar enclosures, which hinder the stopping of return currents within the enclosure.

Huang Xioagan of PowerChina Huadong Engineering Engineering Corp, China, presented details of the main electrical connection of what will be the world's second largest hydropower plant, Baihetan in China. Challenges of site accessibility and the very large installed capacity of 16 000 MW requires careful engineering to ensure safe operation. The powerplant sits in a deep ravine in an alpine environment, so line ice-melting has to be utilized. Various options for the powerhouse connections were discussed, as well as the line charging of the 500 kV transmission lines connected to the left and right bank powerhouses. The units use both electrical and mechanical braking.

There was a lively discussion after the presentation, among speakers and from delegates on line.

Closing session and concluding remarks

As Aqua-Media's first on-line international conference drew to a close, several invited speakers presented comments on the programme, and some remarked on how much they had appreciated getting back together for discussions on hydropower, and reconnecting with friends, in a year which had generally not allowed for such communications.

ICOLD President Michael Rogers commented, in his closing remarks, that HYDRO 2020 had been a historic and innovative conference, which all would remember; he had been reminded how much he had missed seeing friends. He continued that he had been particularly happy to participate in the various civil engineering sessions, and noted that at the end of one of the dam safety sessions, a very good question had been put to the panel by Dr Andy Hughes: "Dam safety seems pretty straightforward; we all know the basics, yet dams continue to fail. What are we doing wrong?" ICOLD Hon President Anton Schleiss had replied, drawing a parallel with the pandemic. He pointed out that we also all know the basics of how to keep safe and well, and to take extra precautions at this time; yet the pandemic was spreading at an alarming rate.

Concluding his comments, Rogers expressed the wish that all would keep in mind the fundamentals of safety; at present for keeping in good health, and on returning to work, for keeping dams safe.

Niels Nielsen, Joint Secretary of IEA Hydro, reminded delegates of the three key issues which Yasmina Abdullah, of IEA Headquarters in Paris, had drawn attention to in her remarks during the plenary opening:

- new schemes to go ahead in developing countries, and the associated challenges of finance;
- modernizing existing, ageing, plant; and,
- the need for more reservoirs for storage, and pumped storage, to provide generation flexibility.

All these were in the long-term context of climate change, and the short-term context of COVID 19. All also related to the theme of the conference 'Strategies for future progress'. Nielsen then outlined the role of the various IEA Hydro Annexes, which related to valuing hydro services; adapting to climate change; fish protection; managing cascade developments; decision making for modernizing plants; and exploring opportunities to develop hydro at existing infrastructure.

Jean-Michel Devernay, former Lead Hydropower Specialist at the World Bank, and now a consultant, had chaired the session on cross-border projects, and he commented that this year's session had been one of the best, or possibly *the* best, ever; he added that the virtual format had had practically no impact on the presentations and discussions. Five excellent speakers had taken delegates on a journey across borders, and given a valuable insight on where we stand on tackling challenges, and capturing benefits, of regional and inter-regional collaboration. Keys to success, which had emerged from discussions, were: project desirability and practicability, and also mutual trust between the countries involved. This was not always given, Devernay commented, but could be built, for example by sharing data, joint planning of future systems and transmission lines, and the future use of water resources. The session had reflected the crucial role of the multilateral finance organizations in supporting and facilitating this process.




Some of the speakers in the closing session. From left: Michael Rogers, Jean-Michel Devernay, Alessandro Palmieri and Dr Judith Plummer-Braeckman.

Alessandro Palmieri, former Lead Dam Specialist at the World Bank, and now an Interanational Advisor on Water Infrastructure, commented that in the session he had chaired on potential and planning, none of the speakers had delivered data on technically and economically feasible potential, and that, he said, was good, as the *H&D World Atlas* was available to find that information. Instead the session had reflected trends towards multipurpose developments, and also hydropower's role as an enabler of intermittent renewable energy sources. Two speakers had discussed planning models, which Palmieri said would have been built based on the extensive databases of large consultants. He commented that it would be great for the large public developers of hydropower to have such databases, as it would give them more control on cost estimates, bid evaluations, and contingency allowances. He suggested that this could form the basis of discussion at a future conference, although it was not an easy topic.

Dr Judith Plummer-Braeckman, who had chaired a session on risk, said there had been fascinating contributions, particularly from insurance brokers. They had shed light on how projects should be packaged and presented, to enable them to obtain insurance, and also when developers should and should not try to obtain insurance. She drew attention to the contributions from multilateral development banks in the session, and commented that they did a splendid job in supporting developing countries to manage risk.

Steven Usher, Deputy Editor and ESG Manager at Aqua-Media, gave some closing remarks on the E&S sessions; he commented that at this unusual event, there had been a comforting consistency in the quality of the presentations in these sessions.

One speaker had focused on the importance of early engagement of developers and host governments, to deliver social and economic development. There was clearly a need to align project interventions within the framework of government plans.

Another speaker had explored the connections and divergencies between social benefits of hydro projects and the broader framework of climate change. She had noted the long-term framework for climate change, and said this should be reflected in the long-term planning of social objectives.

A speaker from the World Bank had drawn attention to the significant costs which could be incurred by project delays caused by inadequate environmental management, but he pointed out that this could be a result of a lack of institutional capacity, indicating that there was a strong need for institutional strengthening.

Usher then announced that a new session on environmental and social governance of hydro organizations was to be introduced at the hydro conferences, with a focus on how these activities could help organisations to position themselves better to avoid risk and improve access to, and terms of, investments.

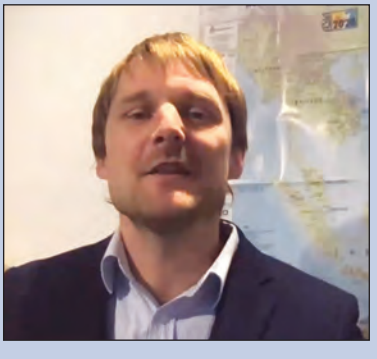
In her talk bringing the conference to a close, Aqua-Media Director Alison Bartle commented that all participants had absorbed a lot of information about many aspects of hydro planning, development and operation. She added that the Aqua-Media team, in the past weeks, had also learnt a lot about adapting to changing conditions. She commended the speakers and delegates from 56 nations who had been willing to support the event, and share their expertise and experience in this 'new adventure' of virtual HYDRO 2020.

As many had agreed, at some moments it had almost been possible to forget that hydropower colleagues were not together in the same room, as specialists discussed topics with the usual degree of enthusiasm.

The conference had been designed as a 'communication bridge' between Porto last year, and Strasbourg next year, and discussions had taken delegates from the current situation and challenges, to future perspectives for hydropower, particularly its role in the post-pandemic recovery period. The conference had underlined the importance of safety, and of collaboration across borders, and some papers had reflected the future great possibilities offered by new technology, both for future design and construction, and for monitoring the safety of existing hydraulic works.

Her closing words were to wish the 'hydropower family' well in keeping safe during the pandemic, and to express the hope to meet in person in Uganda in July and Strasbourg in October. She thanked all participants for their input, and for supporting this 'adventure' in challenging times.

In lieu of meeting later as usual for a farewell dinner, she toasted the virtual participants with a non-virtual glass of wine.




Steven Usher, who gave concluding remarks on the E&S sessions; and, Alison Bartle, who raised a glass of wine to the participants of the virtual conference, as she thanked them for their input.