International Conference on

HYDROPOWER AND DAMS DEVELOPMENT FOR WATER AND ENERGY SECURITY – UNDER CHANGING CLIMATE

ABSTRACTS

7-9 April, 2022
at **Rishikesh**

ORGANISED BY

New Delhi

INCOLD

THDC India Ltd.

Central Board of Irrigation & Power

Indian National Committee on Large Dams

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International Conference on

Hydropower and Dams Development for Water and Energy Security – Under Changing Climate

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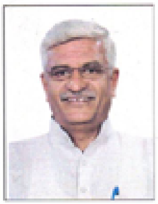

सत्यमेव जयते

जल शक्ति मंत्री
भारत सरकार
Minister for Jal Shakti
Government of India

0 4 APR 2022

Message

I am happy to know that Central Board of Irrigation and Power, INCOLD (Committee of the International Commission on Large Dams, India) and THDC India Ltd., is organizing International Conference on Hydropower and Dams Development for Water and Energy Security-Under changing climate from 7-9th April, 2022 at Rishikesh and participants visiting TehriDam.

Large population and fast-growing economy have led to a huge demand for water and electricity, including clean renewable hydropower in India. So far India has tapped about one third of its hydropower potential. With water and electricity demand in India expected to rise, a huge demand-supply gap is looming in the near future. Even though India has made some remarkable progress in energy sector in the recent years, still there is a need for implementing reforms and framing policies-both for water and energy security-towards a secure, affordable and sustainable water development and energy system to spur high economic growth. Climate change and global warming issues are compelling many countries to plan more and more for green energy sources.

I am sure during the 2 days deliberations the international and national dam and hydropower professionals will highlight the Government policies for sustainable development of dam and hydropower to meet the water and energy security requirement.

I wish the international conference for its success.

(Gajendra Singh Shekhawat)

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नवीन और नवीकरणीय ऊर्जा मंत्री
भारत सरकार
Minister of Power and
Minister of New & Renewable Energy
Government of India

सत्यमेव जयते

Message

India's power sector is one of the most diversified power sectors in the world. Sources of power generation range from conventional sources such as coal, lignite, natural gas, oil, hydro and nuclear power to viable non-conventional sources such as wind, solar, and agricultural and domestic waste. Electricity demand in the country has increased rapidly and is expected to rise further in the years to come. In order to meet the increasing demand for electricity in the country and power India's journey to becoming a $5 trillion economy, we are adding generation capacity constantly. Today the installed power generation capacity of the country stands at 3,95,608 MW.

Power Sector has witnessed tremendous growth over the past years in generation, transmission, and universal access to electricity. We have transformed our country from a power deficit to a power surplus country. We have ensured universal access and now we are spearheading the global journey towards Energy Transition. Renewable Energy capacity has increased from 35.52 GW in 2014-15 to 151.39 GW in 2021-22. In addition, around 68.97 GW is under installation. Indian power sector is undergoing a significant change that has redefined industry outlook. Sustained economic growth continues to drive electricity demand in India. Simultaneously, the competitive intensity is increasing at both market and supply sides (fuel, logistics, finances, and manpower). Our Prime Minister in COP26 announced 'Panchamrit' to tackle the climate change crisis, under which one of the key targets is for India to reach non-fossil energy capacity of 500 GW by 2030. Hydropower will have tremendous role to play in realizing his vision.

Hydropower is the largest source of renewable electricity today, with over 1,300 GW of installed capacity providing more than 15% of the world's electricity. The twin

Cont...2/-

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challenges of development and climate change mean that we need to both increase the total amount of electricity generated whilst significantly increasing the contribution of low carbon sources. The transition to clean energy is urgent and vital. Although much of this new renewable deployment will be led by wind and solar PV, their variable nature means that there will be a significantly increased demand for sources of flexible low carbon generation. Consequently, the International Energy Agency and the International Renewable Energy Agency both assess that to cost effectively keep global warming to below 2°C at least 850 GW of new hydropower capacity is needed. For the more ambitious Net Zero target (limiting temperature rise to below 1.5°C) the numbers are even greater, with at least 2,500 GW of capacity needed. Hydropower will therefore play a key role in future energy systems as an enabler of variable renewables, as well as a renewable energy source itself. By 2050 hydropower will be the dominant source of system flexibility.

Hydropower is not only clean but is also capable of providing flexibility and storage capacity that will be needed by an increasingly dynamic Indian power grid, requiring a substantial amount of power from generation sources that have quick start and stop capability and can offer grid balancing services. Highly flexible hydropower, with an ability to effectively store energy in its reservoirs and respond quickly to system requirements will have a vital role in the future Indian power system.

The present international Conference on 'Hydropower and Dams Development for Water and Energy Security – Under changing climate' on 7-9 April at Rishikesh by CBIP, INCOLD and THDC India Limited will deliberate on the various issues through the presentations by national and ICOLD international dam experts which will help the dam and hydropower professionals. I am sure that this Conference will help in implementing reforms and framing policies for both water and energy security – towards a secure, affordable and sustainable development to spur high economic growth. I am also confident that this conference will make significant contributions in meeting the water and energy security requirements and facilitate us in tackling climate change.

(R. K. Singh)

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MESSAGE

Water is key to sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations.

Considering the temporal and spatial variability of rainfall, water storages are necessary for water, food and energy security. Improved water storage is a driver for economic growth. Lack of adequate water storage causes large and avoidable economic losses from floods and droughts, and constrains long-term growth. The benefits provided by water storage in developed countries are reflected by their high per capita rates of water storage and consumption. The available evidence indicates significant economic returns accrue from improved water storage, although there has been considerable variation in performance. Multipurpose water storage, justified economically on returns from hydropower, may be used to provide additional benefits such as irrigation to support local livelihoods and improve food security.

Climate change has adversely impacted the rainfall pattern with increased variability. Improved water storage will increase resilience to climate change and support better water and food security in developing countries. In India, about 250 BCM of water storages have been created and about 100 BCM of storages are under construction. However, to meet the forecasted demand of about 1180 BCM of water by the year 2050, more storages are needed. This will require actions to improve both natural water storage in rivers, lakes, aquifers, wetlands and soils, as well as built storage.

It is important that development of water storage in the future does not repeat the mistakes of the past and social and environmental impacts are addressed properly. Future water storage projects must ensure pro-poor outcomes and proper compensation for people displaced by dams, or whose livelihoods are disrupted by changes in river flows. There is evidence that, with good planning, dams can deliver positive gender impacts through increased access to irrigation and water services.

Hydropower development has also played an important role in supporting economic growth in developed countries, which have developed most of their hydropower potential. India's hydroelectric power potential is estimated about 1,45,000 MW at 60% load factor, out of which so far 32% has been developed with an installed capacity of 41,423.6 MW. In addition, hydropower offers an important low-carbon energy solution to meet the massive unmet demand and provides reliable peaking power in developing countries.

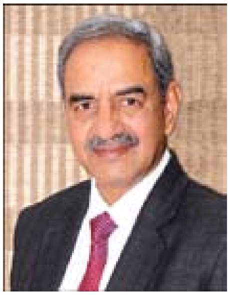
The present Iinternational Conference on Hydropower and Dams Development for Water and Energy Security – Under changing climate will deliberate on the various issues through the presentations by national and international experts which will help the dam and hydropower professionals for sustainable development and meeting the water and energy security requirement under changing climate.

It has always been the endeavour to provide a suitable platform to professionals for exchange of their thoughts and experiences, with a view to disseminate knowledge, which will help in accelerating the sustainable development of dams and hydropower.

I wish the conference all success.

Dr. R.K. Gupta
Chairman
Central Water Commission

MESSAGE



India ranks third globally with 5334 dams in operation which includes Bhakra, Hirakud, Tehri, Sardar Sarovar and many more mega projects. Around 411 dams are under construction in the country. The Dam industry in India has contributed significantly towards meeting the growing water and power demand of the country, yet India is facing increasing pressure on water resources due to population growth, urbanization and creeping effect of climate change.

Water is a resource that serves social and economic sectors, as well as the larger needs of the planet's ecosystems. Water security refers to the availability of water, in adequate quantity and quality, to sustain all of these together – without exceeding its ability to renew. Globally, growing population and urbanization have increased the pressure to meet the water, energy and food demands of larger population with higher expectations. As a result, both developed and developing countries seem to be racing against the clock to respond to the needs of societies in which resource inequalities continue to grow. Water is becoming scarcer and more polluted. Climate variability and change are imposing greater uncertainty than ever before.

Water security depends fundamentally on local contexts, meaning that broad prescriptions are of little use. Policymakers have to learn from one another about what has worked in similar contexts in case of specific formal and informal institutions, policies, legal frameworks and management strategies that have strengthened water security. It has proven more effective to integrate approaches and bring together different users around the needs of a geographic area, rather than to try and bring varied local situations under an umbrella of a single approach. This is why water security – and efforts to maintain it – look different everywhere.

Improving water security is essential for India's development. With total water demand in India expected to rise geometrically by 2030, a huge demand-supply gap is expected in the coming years. Poor water quality and lack of adequate access to sanitation are also major causes of disease and poor health. Efforts to achieve water security through multi-sectoral, coordinated policies and inter-disciplinary approaches will have multiple positive effects by addressing water challenges holistically, taking into account the needs of various sectors, such as energy and agriculture, that will require increasing water resources to satisfy population growth and growing demands. Such an environment will reflect the interconnectedness between sectors while respecting the needs for water by individuals and communities.

Friends, I am sure that the International Conference on 'Hydropower and Dams Development for Water and Energy Security -Under Changing Climate' being held at Rishikesh in hybrid mode from 7-9 April, 2022 will be very exciting and a memorable one after the removal of pandemic restrictions. We have emerged stronger after passing through these difficult pandemic times. This is an opportunity where professionals, academicians, scientists and planners working in the field of water and hydropower can get together in person for sharing of their personal and professional experiences.

I am also happy to inform that INCOLD is organizing the International Symposium on the topic "Dams for People, Water, Environment and Development from18-24th October 2024 at New Delhi which will provide an excellent platform for researchers, scientists, engineers, policy makers and young professionals working in the field of energy and water resources management around the world. This symposium will definitely act as confluence of brilliant minds and provide an interactive platform to share path breaking ideas on the theme of the symposium besides Special Workshops including the workshops of the ICOLD Technical Committees being organized for the water and power professionals.

I am looking forward to welcoming and meeting the national and international experts at Rishikesh.

I wish this Conference a grand success.

Warm Regards

Devendra Kumar Sharma
President
Committee for International Commission on Large Dams, India (INCLOD) and
Vice President
International Commission of Large Dams (ICOLD)

PREFACE

It is moment of pleasure to present the proceedings of International Conference on "HYDROPOWER AND DAMS DEVELOPMENT FOR WATER AND ENERGY SECURITY – UNDER CHANGING CLIMATE". The conference is jointly organized by Central Board of Irrigation and Power (CBIP) and THDC India Limited, under the aegis of Indian Committee on Large Dams (INCOLD) at Rishikesh from April 7 to 9,2022. The aim of this conference is to bring together a wide spectrum of Policy Makers, Scientists, Researchers, Engineers, Designers and Educators active in the field of Energy, Hydropower and Environment from across the world.

The response to the conference has been overwhelming. This volume includes a total of 70 papers submitted by national and international authors comprising of veterans as well as young professionals. It is heartening to notice the enthusiasm of upcoming generation of Hydropower professionals reflected through their high-quality innovative work, which is the highlight of this volume. The papers and articles contributed by the authors cover the policy framework as well as financial and legal and policy aspects in addition to the latest developments and case studies pertaining to the classical issues of design features, operation philosophy, sediment management, risk management, environmental and sustainability aspects. The contemporary issues such as development of Pumped Storage Schemes and their interface with Renewable Energy have also been adequately covered.

Each paper included in this volume has been reviewed by two members of the Technical Screening Committee, ensuring that quality contents and original contributions are incorporated in the proceedings. Constructive suggestions given by the Technical Screening Committee has brought about significant improvement in the contents and presentation of many of the articles, for which the committee merits commendation.

A large number of participants from different countries has registered for attending the conference as delegates and speakers. Stimulation discussions are expected to take place during the course of the conference. It is planned to bring out a supplementary volume containing the deliberations of the conference and important recommendations derived from the same.

I hope these proceedings shall prove to be valuable reference document, not only for the professional and technocrats but also for the policy makers, financers and contractors influencing the chain of development and progressive evolvement of hydropower sector. The conference shall leave us more enlightened towards appropriate handling of delicate balance between energy security and sustainability so that the world becomes a better place to live for the future generations.

I wish the participants spiritual serenity in Devbhumi Rishikesh on the banks of The Holy Ganges and the conference to be a successful and fruitful event.

R.K. Vishnoi
Chairman & Managing Director
THDC India Ltd. and
Chairman, Organising Committee

FOREWORD

Development of water resources is recognized as a key element in the socio-economic development of many regions in the world. Since water availability and rainfall are unequally distributed both in space and time, so dams are crucial for storage of water as viable alternatives. Besides generation of hydro power, dams play a vital role in satisfying the ever increasing demand for irrigation and drinking water, for protecting man, property and environment from catastrophic floods, and for regulating the flow of rivers. Dams have contributed to the development of civilizations for over 2,000 years. Worldwide, there are more than 60,000 large dams listed by ICOLD, most of which have a height of over 15 meters except a few with height between 5 meters and 15 meters but having storage above 3mcm. Today, in developing countries, the focus is on the state-of-the-art technology in planning, design, and construction as well as use of new materials for dams, which are essential for the sustenance of human life and also for poverty alleviation.

Climate change and global warming issues are compelling nations to plan more and more for green energy sources. Many countries are targeting to cut their thermal power generations in a phased manner and make greater use of solar, wind and hydro power to fill the gap. Hydropower is the second largest contributor of energy generated in India. However, so far the country has utilized only about 32% of its total 145,000 MW hydropower potential and therefore, tremendous opportunities exist for future expansion. The greatest hydropower potential in India exists in the three major transboundary river basins (Ganges, Indus, and Brahmaputra), but all these basins have experienced substantial changes in precipitation and air temperature affecting the availability of water required for hydropower generation. A majority of hydropower projects in India are run-off-the-river (RoR) schemes and in future also, in lieu of storage schemes, RoR schemes with diurnal storage may be preferable due to submergence, site conditions and other environmental issues. But in the climate change scenario, uncertainty in stream flow patterns may have a major impact in peaking power generations due to small pondage of RoR schemes. In order to mitigate this, RoR schemes require certain increase in pondage capacity.

Keeping in view the importance of the subject, INCOLD (Indian National Committee on Large Dams), CBIP (Central Board of Irrigation and Power) and THDC India Ltd. are jointly organizing a two-day International Conference on Hydropower and Dams Development for Water and Energy Security - Under Changing Climate from 7 April 2022 at Rishikesh followed by one day field visit to Tehri Dam for the delegates.

We have received overwhelming response from the national and international experts, who has contributed 70 technical papers, including keynote presentations are included in the proceedings volume, which will add new dimensions to the body of knowledge on the subject.

Central Board of Irrigation and Power and Indian National Committee on Large Dams are grateful to the authors of papers for the contribution made by them. Our sincere thanks are also due to Shri D.K. Sharma, President, INCOLD and Vice President, ICOLD; Dr. R.K. Gupta, Chairman, CWC and Shri R.K. Vishnoi, Chairman & Managing Director, THDC India Ltd. for their support and guidance in mobilisation of national and international experts for presentation in the conference.

It is hope that the deliberation of the conference would help in better understanding of the various aspects of sustainable development of dam and hydropower for meeting the water and energy security requirement under changing climate.

A.K. Dinkar
Secretary, Central Board of Irrigation & Power and
Secretary General, Indian National Committee on Large Dams

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PLENARY SESSION

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

ROLE OF DAMS IN MITIGATING THE IMPACTS OF CLIMATE CHANGE – INDIAN CASE STUDY

DEVENDRA KUMAR SHARMA
Chairman, HPERC, Vice-President ICOLD & President INCOLD

DR R. K. GUPTA
Chairman, Central Water Commission, Government of India

ABSTRACT**

India has distinct topological and geographical features which results in varying climatic zones ranging from the arid Thar desert in north-western part, humid areas in south-western region, central and north-eastern parts and Himalayan tundra in the northern regions. Further, there are diverse micro-climatic areas that spread across the vast sub-continent. A dominant and key feature of regional climate is Indian Summer Monsoons. The summer monsoon also exhibits a rich variety of natural variations on different timescales ranging across sub-seasonal/ intra-seasonal, inter-annual, multi-decadal and centennial timescales, which are evident from instrumental records and paleo-climate reconstructions. Results from studies simulating the past climate using paleo-climate proxies indicate that the changes recently observed in global surface temperature are unusual and the natural processes alone cannot explain the rapid rate of warming since the industrial era. The annual mean near-surface air temperature over India has warmed by around 0.7 °C during 1901–2018 with the post-1950 trends attributable largely to anthropogenic activities. Atmospheric moisture content over the Indian region has also risen during this period. The mean temperature rise over India by the end of the twenty-first century is projected to be in the range of 2.4–4.4 °C across greenhouse gas warming scenarios relative to the average temperature over 1976–2005. With the resultant increase in temperature and atmospheric moisture, climate models project a considerable rise in the mean, extremes and inter-annual variability of monsoon precipitation by the end of the century. With increase of extremes and inter-annual variability of monsoon precipitation, the role of dams becomes extremely important in mitigating the impacts of climate change. This requires formulation of new plans and strategies for management and operation of existing as well as future water resources projects. This paper discusses floods in Uttarakhand in June 2013, floods in Jammu & Kashmir in 2014, Kerala floods in 2018, floods in Satluj and Beas basins in August, 2019 and February, 2021 floods in Uttarakhand and impact of climate change on water security, water regulation, floods, hydropower and dam safety due to climate change.

** This paper has been accepted for publication in the 26th ICOLD Congress scheduled to be held in Marseille, France from 27th May to 3rd June, 2022.

RESERVOIR STORAGE – CRITICAL INFRASTRUCTURE FOR WATER SUPPLY AND FOOD SECURITY

DR. GEORGE W. ANNANDALE
President, George W. Annandale, Inc., Peoria, Arizona

The presentation reflects on sustainable development of reservoir projects ensuring water and food security for a growing world population exposed to the impacts of climate change. The world population is rapidly increasing, projected to grow from 6.9 billion people in 2010 to 9.1 billion by 2050, increasing demand for food by 70% and total demand for water by 55%. With irrigation water accounting for 70% of global water demand, the important role of this factor of production is emphasized. Grain yield from irrigated lands is approximately 2.7 times greater than that from rainfed farming, emphasizing the important role of irrigation to ensure food security in addition to water security.

The increased hydrologic variability associated with climate change points to a greater need for reservoir storage and dams in addition to the continued and growing necessity to develop this infrastructure to satisfy the needs of population growth. Despite this continued demand for more reservoir storage it is known that current net reservoir storage is globally decreasing, i.e., more storage space is lost to the effects of reservoir sedimentation than what is added through the construction of new dams.

Development of strategies to ensure a reliable supply of fresh water for both current and future generations requires a broad understanding of several interrelated topics of study, including sustainable development, climate change, sediment management technology, and economic analysis. The presentation reflects on these topics and presents recommended practices for future water supply reservoir planning. Insight into the true meaning of the concept of sustainable development reveals the important role civil engineers should play in providing infrastructure creating intergenerational equity, and reveals the need to change current development, design, construction and operational management practices for dams and their reservoirs. Creation and adherence to a professional code of ethics for dam engineers is necessary to emphasize the essence of relations between professionals and between professionals and society.

Session I

SUSTAINABLE DEVELOPMENT OF DAM AND HYDROPOWER

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

NEED FOR STORAGE DAMS FOR WATER SECURITY

VIVEK TRIPATHI
Director, CMDD(E&NE), Central Water Commission

KARAN SINGH SAINI AND MADHUKANT GOYAL
Assistant Director, CMDD(E&NE), Central Water Commission

Storing water has long been a cornerstone of socioeconomic development, particularly for societies exposed to large climatic variability. Nature has always supplied the bulk of water storage on earth but we are unable to harness the water by not creating enough storage. Today, numerous countries suffer from water storage gaps and increasingly variable precipitation, threatening sustainable development. There is a growing need to develop more water storage types and better management of existing storages. This paper argues that water storage should be perceived as a service, not just a facility. Ultimately, more important than the amount of water stored behind a dam or in a catchment area is the ability to provide a variety of services with a particular level of security at a particular time and place. The storage system must be designed and managed to provide the service standards of interest. This paper does not present new data or research, but provides an overview of the current knowledge and issues surrounding water storage and benefits of water storage infrastructure. It outlines the new constructive water storage agenda for the coming decades.

WATER-ENERGY-FOOD NEXUS: THE IMPORTANCE OF WATER

FELIX REINDERS, PR ENG
President Honoraire: International Commission on Irrigation and Drainage

Water gives life and is crucial to development all over the world. It waters the fields; nurtures the crops and stock; provides recreation; it support mines, industry; electricity generation and it provide life for plants and animals that make up ecosystems.

Runoff waters are a natural resource for nations and storing water is vital to develop economies. Water reservoirs give largely a guarantee of water supply for irrigation, domestic and industrial use. With 58 713 dams registered in the world, 13580 dams are for the sole purpose of irrigation and 6278 dams with a multiple-purpose that include irrigation.

The agricultural sector is by far the biggest user of water in the world accounted for 70% of the world's total water withdrawal. In Africa and Asia it is 85-90% of all the freshwater used is for agriculture. To satisfy global demand for food, by 2025, agriculture is expected to increase water requirements by 1.2 times.

Irrigated agriculture plays a major role in the livelihoods of nations all over the world and although irrigation is one of the oldest known agricultural techniques, improvements are still being made in irrigation methods and practices. During the last four decades, irrigation systems in the world made mayor advances in technology development and the uptake of irrigation increased by 81 percent from about 153 Mha in 1966 to more than 300 Mha in 2022. The expansion of irrigation in the next 40 years might however not be that extensive due to pressure on water resources as well as the impact of climate change.

The International Commission on Irrigation and Drainage roadmap "ICID Vision 2030" main drive is "A water secure world free of poverty and hunger" and in summary, it states as follows:

"Water, as the main input for food production, has played the most significant role in population growth and societal evolution over much of the recorded human history. By being a direct or indirect part of 7 out of 17 Sustainable Development Goals, water assumes inclusive dimension both as a natural resource for rural development and an essential input commodity for industrial and human life-style consumption."

ICID Vision 2030 for a water secure world free of poverty and hunger through sustainable rural development through its mission to facilitate prudent agricultural water management by encouraging interdisciplinary approaches to irrigation and drainage management is an expression of intent of the network to help various stakeholders in moving towards a 'World we Want'.

SUSTAINABLE SEDIMENT MANAGEMENT IN RESERVOIRS

MARTIN J. TEAL
P.E., P.H., D.WRE, WEST Consultants Inc. USA

Management of sediment in reservoirs is essential to ensure sustainable projects in which our (usually large) investment to create water storage is protected. While the concept is important for management and/or retrofit of existing projects to extend their lifetime, it is paramount for planning of new projects. The need for carryover storage to ensure continuous water supply and hydropower production during drought periods is well established. However, sedimentation of reservoirs reduces that available storage over time. To maintain storage and hence the return on our investment, sediment management techniques should be employed. A sediment management plan could contain a combination of methods to reduce sediment production in the watershed, route entrained sediments either around or through the reservoir, or remove deposited sediments through excavation or dredging. Techniques are reviewed in the presentation. Sustainable sediment management is part of sustainable development to "meet the needs and aspirations of the present without compromising the ability to meet those of the future." Climate change and the predicted increase in hydrologic variability heightens the importance of sustainable sediment management and maintenance of existing storage even more than at present. A life-cycle approach to projects should be taken to provide resilience to climate change impacts while ensuring intergenerational equity such that future generations will be able to enjoy the benefits of our investments.

CLIMATE RISK ADAPTATION AND MITIGATION IN INDIA: ROLE OF RESERVOIRS AND HYDROPOWER

NITIN BASSI
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India is growing so is the dependence on natural resources. Water takes a center stage whether it is meeting domestic, agricultural, industrial, or environmental demands from natural systems. As per the National Commission for Integrated Water Resources Development estimates, overall water demand in India will increase to 1,180 billion cubic metres (BCM) by 2050 [1]. This is an increase of over 67 percent of the 2010 levels. Among sectors, water demand for power generation, inland navigation, and maintaining aquatic ecosystem will increase by three-fold, for industries and domestic uses it will be more than double. As per the Council on Energy, Environment, and Water (CEEW) estimates, water consumption will increase by 3.2-6.5 percent per annum for the inland thermal power plants under various scenarios, ranging from renewable energy dominant to the fossil-fuel dominant economy, and they will continue to play an important role in India's energy mix [2]. Nonetheless, with an estimated requirement of 807 BCM in 2050, irrigation will continue to be the major driver of the water demand.

At the National scale, the per capita water availability is already below the water stress threshold limit of 1700 cu m per annum. Even during normal rainfall years, significant parts of central and peninsular India experience water scarcity. This is mainly due to the large-scale spatial and temporal variability in climate and geo-hydrological settings. Most of peninsular India is underlain by hard rocks (consolidated formations) which have limited aquifer storage potential to receive recharge water [3]. As a result, well failures and water shortages during summers are common in such areas [4]. Considering that the present average freshwater availability (average annual utilizable is about 1,123 BCM) is further expected to be adversely influenced by climate variability and change, better planning of water resources development and management is required to provide water security during dry years and the period of seasonal water scarcity.

RESPONSE OF HYDROELECTRIC PROJECTS UNDER THE INFLUENCE OF CLIMATE CHANGE

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Hydropower is regarded as a low-carbon source of renewable energy and a reliable and cost-effective alternative to electricity generation by fossil fuels. However, its production is directly subjected to the effect of climate change (CC). Thus, this study focusses on the CC impact on the variation of discharge in the Karnali River and the subsequent effect in power generation in Mugu Karnali Storage Hydroelectric Project under study by NEA Engineering Company (NEC). Soil and Water Assessment Tool (SWAT) is applied in the Karnali basin to simulate the current and future hydrological regime. The model was calibrated for 2000-2005 and validated for 2007-2011. The future climate conditions at the basin are projected considering the outputs of five Global Circulation Models (GCMs) under two shared socioeconomic pathways (SSPs) for three future timeframes: 2021-2045, 2046-2070 and 2070-2100 (near, mid and far futures respectively) against the baseline period of 2000-2014. An ensemble of bias corrected GCMs under (SSP585) scenario shows the projected annual precipitation rises by 8.5% (7.9%), 14% (11.9%) and 9.6% (25.8%) in near, mid and far futures. For the same scenario for three future periods, the maximum temperature is projected to increase by 0.6°C (0.7°C), 1.1°C (1.7°C) and 1.6°C (2.9°C) respectively whereas the projected minimum temperature increases by 1°C (1.2°C), 1.9°C (2.7°C) and 2.5°C (4.6°C) respectively. Under these projected climate conditions, the annual streamflow is simulated to increase by 10% (10.6%), 17% (16.1%) and 14.5% (35.1%) in near mid and far futures. The reservoir simulation model is developed in excel spreadsheet to assess the effect in energy generation. Under the influence of climate change, the annual energy is projected to increase by 18.4% (21.9%), 26.2% (27.0%) and 22.1% (52.1%) in NF, MF and FF time frames respectively under SSP245 (SSP585) scenario. This study provides the insight on climate change influence on currently under study hydropower and will assist in planning climate resilient hydropower projects.

EVALUATION OF SEDIMENT MANAGEMENT TECHNIQUES OF DOKAN DAM ACCOMPLISHED WITH CLIMATE CHANGE SCENARIOS USING RESCON 2.2 BETA MODEL

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The storage capacity of dams is affected directly by sediment build-up. Drought, heavy rainfall, and catastrophic events in watersheds increase soil washout up to unusual and unbeaten records. Dokan Dam, as a strategic dam in Iraq, plays a vital role in water management with a strong firm with the even worse scenario of an actual predicted sediment rate of 3.8 M m^3/y. Sediment management is an essential process that enhances dam functions. Reservoir conservation model ResCon 2.2 Beta was used to predict and analyse sediment management techniques, taking climate change scenarios into consideration. The model gives a good and acceptable interpretation of the sediment management in both the watershed and the reservoir. Dokan reservoir is a sustainable reservoir within its long-term capacity. Up to four different techniques and 37 different methods were evaluated to reduce the sediment entering the reservoir for up to 300 years. Economic approaches are applied to calculate the basic parameters of sustainable projects. Satellite images, dam operations policy, inflow, and sediment data are used as inputs to calculate the aggregate net present value (NPV) and gross storage capacity. In terms of climate change, results show the watershed management technique is the best option to decrease the soil washout and sediment deposition in the reservoir with a NPV of 24.5 B $ assuming the unit price of water yield is 10 cents, and long-term gross storage capacity is 6.4 BM3. Dokan Dam can be sustained for the applied period in terms of water storage depletion provided there is no structural defect in the dam body. Check dams, reforestation, and vegetation of specific areas in watersheds are necessary to maintain the storage capacity of the dam as much as possible, up to 6 BM3.

Keywords: Dokan dam, washout, ResCon, sedimentation, net present value, watershed

MODEL STUDY FOR DETERMINATION OF EFFICIENCY OF A TYPICAL SILT EJECTOR

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After construction of a barrage in the main river Teesta in West Bengal, the off taking channel from one of its bank was designed to carry water and augment the discharge of a secondary river Mahananda. The discharge of the main river was heavily laden with silt. To control the quantity of silt, a Silt Ejector was proposed to be constructed in Teesta Mahananda Link Canal for getting silt-free water for irrigation. The design discharge of the canal upstream and downstream of the Silt Ejector was 438.91 cumecs and 382.28 cumecs respectively and the discharge through the Silt-Ejector was 56.63 cumecs. A geometrically similar model of scale 1:36 was constructed in Indoor Hydraulics Laboratory on the basis of design drawings. The model incorporated about 500 m long stretch, about 400 m upstream and about 100 m downstream of the Silt Ejector. In the model, the Silt-Ejector structure was made of thin Perspex sheets. The model was run with the design discharge and with discharges 70%, 50% and 30% of the design discharge. Four nos. of gauges were installed in the model at 360 m upstream, 75 m upstream, 22 m downstream and 100 m downstream of the Silt Ejector. Another gauge was installed in the escape channel. Velocity observations were taken at 324 m upstream, near the upstream face of the Silt Ejector and 80 m downstream point of the Silt Ejector. The observed model data were validated with respect to prototype data. Mustard seeds were used as silt-charge. The entire quantity of mustard seeds passed through the Silt Ejector into the Escape Channel for all discharges, except that of the 30% design discharge. This indicated that the efficiency of the Silt Ejector was good and satisfactory except for low discharge of the order of 30% of design discharge. No undesirable flow features were noticed at the entry of the Ejector.

Keywords : Silt Ejector, Escape Channel, Geometrically Similar Model, Sub-tunnel

NEED OF AN HOUR - POLICY FOR RENOVATION, MODERNISATION, UPRATING AND LIFE EXTENSION (RMU&LE) OF HYDROELECTRIC PROJECTS IN THE STATE THROUGH PRIVATE SECTOR PARTICIPATION ON LEASE, RENOVATE, OPERATE AND TRANSFER BASIS (LROT)

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Hydro-Electric Power, generation has many well recognised advantages. It is environmentally clean and renewable energy source with high degree of flexibility and reliability. In the overall economic interests of the State and the country, hydro potential has to be optimally harnessed and operated efficiently by constant maintenance, renovation and modernisation.

In this paper, it has been discussed that by undertaking timely RM&U & LE works, the existing generating plants can continue to operate for extended period of 20 to 25 years, with improved reliability and availability through PPP model on LORT basis. However, in the absence any policy guidelines for involving Private sector through PPP, the RMU&LE works have not been streamlined in the State yet. Attempt has been made through this paper to involve Private sector in RMU & LE work.

RIVER LINKING FOR HYDRO-POWER WITH PARTICULAR REFERENCE TO BRAHMAPUTRA-GANGA LINK

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National Water Development Agency (NWDA), under the Ministry of Jalshakti, Govt. of India, is executing the national perspective scheme (NPP) of linking Indian rivers through construction of 30 link canals -14 in the Himalayan region and 16 in the Peninsular region of India. Several merits and demerits of the scheme are discussed. Brahmaputra-Ganga (Link-1) is vital for utilization of untapped hydro-power potential of north east region (NER) which is 40% of the country's total hydro-power potential. 93% of hydro-power potential of NER still remains unutilized. Besides hydro-power, the link will be useful for transfer of excess water of Brahmaputra basin to Ganga basin for satisfying the water need of Bangladesh and drought prone areas of India in the Southern and Northwest part of India. The link will also help in navigation, water supply and lean flow augmentation-both for India and Bangladesh.

CLIMATE CHANGE AND WATER MANAGEMENT OF SINDH CATCHMENT

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The Sindh Catchment located in Ganderbal district of Jammu and Kashmir, India is one of the most important water resources. It is one of the main tributaries of the river Jhelum in the valley of Kashmir. It boosts the economy of the valley, through generation of hydroelectricity, irrigation for agriculture and tourism because of snow covered mountains which surround the valleys. Therefore, in the current study of Sindh discharge were assessed using a WEAP model, GIS tools and satellite images to determine the effect of climate change and to calculate present and future water demands under different scenarios for a modelling period from 2020 to 2030. The river Sindh is a perennial river and main source of of the river lies in the Machoi Glacier which is at an elevation of 4800m, east of the Amarnath temple and south of the Zoji La as due to global warming Himalayan glaciers are melting at an alarming rate to know the changes in glacier cover with time satellite images and meteorological data are used. The satellite images have revealed that due to global warming snow cover has been decreased. Because of changing weather pattern higher discharges are present in summer season and in winters there is shortage of water due to very low temperature water freezes, which affects demand in winters and there are also higher chances of flood in summer season.

SEDIMENTATION MANAGEMENT – A CASE STUDY OF CHAMERA STAGE-II & CHAMERA STAGE-III HYDROPOWER STATIONS, H.P., INDIA

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Sediment has been defined generally as solid particles which are moved or might have been moved by flow in a channel. It creates numerous problems for the engineers. Sediment in river water causes mainly loss of storage capacity of reservoirs and damage to turbines and other underwater parts in hydropower plants in addition to changing river regime increased flooding, sedimentation of intakes and loss in power generation due to sediment deposition in the reservoir, etc. All the reservoirs, big or small, created by constructing a dam across rivers is subjected to sedimentation which results in reduction of storage capacity. In storage schemes, with typically large reservoirs, the reservoir acts as a large settling tank and most of the sediment settles in the reservoir (reduction in storage capacity) and clearer water enters the intake and goes off to the power house. In run-off-the-river schemes, the river flow is diverted without creating a large storage to power house through water conductor system. During monsoon, a lot of sediment enters the power plant with water, causing erosion and damages of varying degrees of underwater components. The problem is more serious in case of hydro plants located on Himalayan Rivers as they carry a huge sediment both as bed load and suspended load during monsoon. The catchment area treatment which aims at preventing the entry of sediment in the reservoir gets mired in multiplicity of agencies having different target strategies and modes of execution. A sizeable work has been done by various individuals and organizations on the prevention, exclusion and management of sediment entering the reservoirs. The work of exclusion and management of sediment being largely of recent origin requires supplementation by drawing on experience from present practices so that better strategies for tackling the sedimentation problem could be evolved. This paper aims at sharing the experience of sediment management being practiced in two reservoirs in Himachal Pradesh, India.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

SEDIMENTMANAGEMENTFORRESERVOIR BASED HYDROPOWER PROJECTS

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The transportation of sediment by rivers is an inevitable phenomenon and the need of sediment management arises due to sediment transportation being intercepted by the hydropower projects. The handling of sediment is one of the major challenges facing the design as well as operation of hydropower projects. The concepts pertaining to origin, transformation and transportation of sediment particles in the hydrological system are important to be realized for development of efficient sediment management mechanisms in the context of hydropower projects. It is therefore worthwhile to relook at the principles of sediment transportation in the rivers and streams.

The sediment management in hydropower stations is either by allowing accumulation of sediment in the dead storage capacity of the reservoir or by removal of sediment by way of large desilting chambers followed by arrangements for silt flushing. The discussion in the paper is limited to sediment management in reservoir based hydropower projects.

The paper revisits some of the phenomena associated to the behavior of naturally occurring sediments under different flow conditions. A commentary on evolving technologies supporting the practices of monitoring and management of sediment in rivers as well as reservoirs is also incorporated. The unique structure developed for sediment management at Kol Dam Hydropower Station has been presented by way of case study.

EFFECT ON SEDIMENT TRAPPING & FLUSHING EFFICIENCY DUE TO SIZE VARIATION OF ORIFICES IN FLUSHING DUCT SLAB (HYDRAULIC MODEL STUDY OF RAMMAM-III HEP)

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Chocking of desilting chamber due to silt deposition results in flowing of silt laden water into the Headrace tunnel (HRT) and consequently results in erosion of turbine. Therefore, sediment trapping & flushing efficiency of the silt flushing arrangement is very important and is always established by physical model study. The paper describes results of three alternative physical model studies of desilting arrangement of Rammam-III Hydro-Electric Project (HEP) (3×40 MW), which were carried out by varying the sizes of orifices (openings) in flushing duct slab.

Rammam-III HEP, a run of river scheme, is under construction by NTPC Ltd in West Bengal, India. Hydraulic Model study of desilting chamber along with silt flushing tunnel has been carried out for assessment of sediment trapping & flushing efficiency of the silt flushing arrangement at Irrigation Research Institute Roorkee, India. Studies for desilting arrangement of Rammam-III HEP has been carried out on three alternative physical model by varying the sizes of orifices in flushing duct slab. As per the results of alternative model studies corresponding to 5000 ppm sediment concentration overall sediment trapping efficiency of desilting chamber increased from 75.5% to 84.3% from initial to final alternative. Further, for particles size greater than 0.2mm it increased from 81.6% to 90.2% due to increase in sizes of orifices of flushing duct slab with a increase in total area of all orifices from 0.298m^2 to 0.374m2 i.e. about 25.5%.

Sediment flushing efficiency also increased from 28.1% to 62.1% that too with a reduced flushing discharge i.e. from 2.345 cumec to 2.0 cumec (14.21% to 12.12% of 16.5 cumec total discharge passing through one desilting chamber). Silt deposition between orifices observed in models and worked out to proto reduced from about 1.0m to 0.6m. Choking of orifices observed in the models also reduced from 13 nos. to just one from the initial to final model. Further, no significant silt deposition was observed inside the flushing duct in the final model. However, in view of increased sizes of orifices, flushing discharge is to be controlled with partial gate opening installed on each branch silt flushing tunnel.

Keywords : Desilting Chamber, Sediment trapping, Sediment flushing, Hydro

Session II

DAMS AND HYDROPOWER DEVELOPMENT FOR WATER AND ENERGY SECURITY – GOVERNMENT POLICY

HYDRO POLICY FOR BOOSTING HYDRO POWER DEVELOPMENT

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Hydropower is a clean, green and non-polluting source of energy. The growth of hydropower has seen many ups and downs. Hydropower began to be used for production of electricity by the end of 19th century. World's first hydropower plant of capacity 12.5 kilowatts was developed on the Fox River in Appleton, Wisconsin, USA in Sept. 1882 and soon after development of hydropower in India also started with the commissioning of a 130 KW plant in Darjeeling in 1897. The growth of hydropower, world over, picked up momentum in the twentieth century with rapid innovations and changes in hydropower facility design.

At the time of Independence, the overall hydro capacity of India was 508 MW constituting about 37% of the total installed capacity in the country at that time. Upto 1960s, the increasing emphasis of the Govt. was on development of multi-purpose reservoir projects like Hirakund, Bhakhra, Damodar Valley projects etc. in order to have greater irrigation for better food security. This also led to significant development of hydro capacity and the share of Hydro in the overall system rose to almost 51%. The decadal capacity growth of hydropower became quite sluggish from 1970s and towards the end of 20th century. This was the time when concerns were expressed about the environmental and social impacts of hydropower development and hydropower projects began to be perceived as environment degrading which led to drying up of funds from international agencies and protests by NGOs against their development. Moreover after 1970s, environment clearance regime also became increasingly stringent due to world-wide focus on environmental, ecological and Rehabilitation & Resettlement (R&R) issues and activism against development of hydro projects by NGOs/ Environmental activists leading to slow-down of the sector.

In order to achieve quicker capacity additions to cater to large scale industrialization, the focus had shifted to the rapid development of thermal power in 1990s and as a result the share of Hydro Power in the Power Sector of India has progressively declined from a peak of about 51% in 1962-63 to about 12% now.

The beginning of the 21st century, has seen the world grappling with issues like increased global temperature on account of increased greenhouse gases being released into the atmosphere and consequently shifted focus on development of Renewables like Solar and Wind. With increasing global warming and huge peaking and balancing power demand in light of growing focus on renewable energy, there has been ever growing interest in hydropower development in the world and there is renewed thinking about hydropower projects especially the Pumped Storage Schemes for producing electricity.

POLICY LEVEL CHANGES INITIATED BY GOVERNMENT OF INDIA FOR DEVELOPMENTOFHYDROPOWERSECTOR IN INDIA

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Hydropower can play a crucial role in India's sustainable development and energy security as it meets the criteria of sustainability, availability and reliability. It is an environmentally benign, non-polluting source of power and is most suitable for balancing renewables. Despite so many benefits from hydropower and huge potential in country, the share of hydropower is not at satisfactory level in overall installed capacity of the country. The Government has accorded high priority to the development of the hydro potential and has time to time taken a number of policy initiatives to address the issues impeding the hydropower development.

This paper mainly focuses on the recent policy level initiatives taken by the Government of India to accelerate the development of Hydro Power Sector in India. Further, special focus has been given to the measures to promote hydropower sector through budgetary support for Flood Moderation component and Enabling Infrastructure i.e., roads/ bridges.

IDENTIFY AND HARNESS HYDROPOWER POTENTIAL IN NORTH EASTERN REGION

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Electricity is one of the key enablers for achieving socio-economic development of the country. The economic growth leads to growth in demand of power. Generation and capacity augmentation is the most vital for meeting the ever-increasing demand of power to achieve the targeted growth rate. Today, endeavor is being made to provide 24x7 adequate & reliable energy and reduce country's reliance on fossil-based energy by shifting to cleaner and renewable energy sources. Government has set an ambitious plan to have generation of about 175 GW by 2022 and 450 GW by 2030 (further increased to 500 GW as announced in the 26th Summit of the Conference of Parties (COP-26) at Glasgow, by the Hon'ble Prime Minister of India) from renewable energy sources. In addition, India also envisages to be Carbon Neutral by 2070.

The renewable energy sources of Solar and Wind power, however, generate intermittent and variant energy. As such, there would be growing need for energy storage plants for smooth integration of these renewables into the grid and to stabilize the electrical grid. Development of hydropower especially the pumped storage projects, in this regard, assume paramount importance since hydropower is a clean, green, sustainable, renewable, non-polluting and environmentally friendly source of power and promotes conservation of fossil fuel. It is blessed with numerous other advantages like its suitability for peaking and balancing operation due ability of these plants for instantaneous starting, stopping and load variation and improving reliability of power system. Hydro/ PSP projects also have very long life as compared to other energy storage sources and these are escalation free & cheapest energy in long run.

ALTERNATIVE DISPUTE RESOLUTION (ADR) MECHANISMS FOR HYDROPOWER PROJECTS

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Construction contracts of hydropower projects are prone to disputes due to the complexities involved in their development. Several Alternate Dispute Resolution Mechanisms are available today for the resolution of these disputes. This paper discusses these mechanisms and their relative merits and demerits over each other. It also records the experience gained by SJVN in dispute resolution during the development of the 1500 MW Nathpa Jhakri Power Project.

RESERVOIR TRIGGERED SEISMICITY SCENARIO WITH SPECIAL EMPHASIS TO THE HIMALAYAS

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Himalayas are one of the mightiest mountain ranges in the world with immense, untapped hydropower potential (to the tune of 90,000MW in India; The Hindu; Business Line-2020) due to several mighty rivers originating from its glaciers. On the contrary because of its unique geotectonic setup, Himalayas also comprise the highest seismic zone of the country (Zone IV and V). Irrespective of this the large untapped hydro potential has attracted several developers to venture into construction of some big hydropower projects in the Himalayas. Himalayas are home to some largest hydropower projects in the country like Tehri, Bhakhra Nangal, Salal, Chamera-I etc. running successfully for past several decades.

In the recent years, however, the environmental hue and cry against development of these projects has started raising its head. One of the reasons cited is the occurrence of Reservoir Triggered Seismicity due to the pondage of large dams in the highly seismic Himalayas. Till date however there has been no example of significant RTS in the Himalayas. Still to satisfy the fear psyche of the common public a systematic and scientific approach is needed to be adopted by the hydro sector for seismic monitoring. Factors influencing RTS include Pore Pressure, volume of reservoir, duration of RTS, type of faulting and b value correlation. The historical details of RTS occurrences worldwide cited in this paper have been meticulously compiled from various technical sources. These include RTS instances from Europe, USA, Australia and Indian subcontinent. Seismicity due to Koyna Reservoir along with possibility of RTS in the Himalayas has also been delved with in detail. The theory of RTS and why its plausibility in the Himalayas can be negated have been discussed on scientific grounds.

Pre and Post construction seismic monitoring studies for dams of height greater than 100m and reservoir volume 500Mm^3 indicative of RTS have been discussed in a systematic manner.

Keywords: Hydro projects, Dams, Himalayas, Reservoir Triggered Seismicity, Real Time Seismic Data Center.

FINANCIAL AND PRICING STRATEGIES FOR NEXT LEAP OF GROWTH OF HYDROPOWER IN INDIA

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Electricity is a necessary resource for all facets of our life. It is the basic human requirement and backbone to the socio-economic development of a country. Hydroelectricity is one of the crucial and clean sources of power. It plays a vital role fulfilling the power requirements during peak time and in ensuring the stability of the grid in the longer run. Keeping in view the Hydropower as clean energy, many countries have adopted power generated from Hydro sources as the primary source of energy.

In India, after Thermal power, hydroelectricity is the second 2nd source of energy and is endowed with a capacity of 85000 MW with a 60% load factor, ranks 6th in the world in terms of Hydroelectric Potential. However, despite having abundant reserves as well as the fact that India has aggressively expanded the Power generation capacity as compared to the situation in the year 1997-98, the total installed capacity of hydropower is still lagging as compared to the global peers, and the proportion of installed hydropower capacity to the total installed power generation schemes in the country has witnessed a decline, with large hydropower accounting for only 11.18% of the total installed capacity down from 46% in the year 1966.

To date, only 46.51 GW of hydropower capacity is installed. A total of 1,45,000 MW has been identified to date and out of this 98,490 MW accounting for 67.92 % is still to be harnessed as of 31.01.2022. Despite having clear advantages and compulsion of increasing the Hydropower for achieving the load balancing requirements still the development of Hydro Power in India is lagging as compared to the global peers. Figure 1 shows the installed capacity of Hydropower in India as compared to other forms of power generation.

Session III

ENVIRONMENTAL AND SOCIO ECONOMIC ASPECTS

DAMS – SAVIOR OF ECOLOGY AND MANKIND

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Food security has been the biggest challenge for mankind in the recent days. Climate change has posed many threats including extreme floods and draughts. Element of uncertainty of precipitation from quantity and timeliness points of view has posed a critical challenge before the water managers. Extent of severity of extreme events is on rise. Water management and flood management – both have become a matter of concern. How dams can play an important role in addressing paradoxical situations if reservoir operations are sensibly made is discussed in this paper with the help of a few case studies. Ecological challenges are also a matter of concern for all and how dams can also help conserve ecology besides serving the cause of mankind is attempted to be underlined.

Keywords : Climate change, Ecology, Extreme events, Food Security, Water conservation

ECOLOGICAL AND CUMULATIVE ENVIRONMENTAL CONSIDERATIONS FOR HYDROPOWER DEVELOPMENT IN CURRENT ENERGY TRANSITION SCENARIOS

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Hydropower is today the largest source of renewable electricity, with over 1,300 GW of installed capacity providing more than 15% of the world's electricity . The twin challenges of development and climate change means that we need to both increase the total amount of electricity generated whilst significantly increasing the contribution of low carbon sources. The transition to clean energy is urgent and vital. Forecasting future electricity systems is a challenge, but analysis from major international organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) is clear, if we are to tackle dangerous climate change, suggests that we will need far more renewable generation, potentially increasing by a factor of 10. Although much of this new renewable deployment will be led by wind and solar PV, their variable nature means that there will be a significantly increased demand for sources of flexible low carbon generation. Consequently, the International Energy Agency and the International Renewable Energy Agency both assess that to cost effectively keep global warming to below 2°C at least 850 GW of new hydropower capacity is needed. For the more ambitious Net Zero target (limiting temperature rise to below 1.5°C) the numbers are even greater, with at least 2,500 GW of capacity needed (around twice today's installed capacity). Hydropower will therefore play a key role in future energy systems as an enabler of variable renewables, as well as a renewable energy source itself. By 2050 hydropower will be the dominant source of system flexibility.

Hydropower is not only a clean energy but is also capable of providing flexibility and storage capacity that will be needed by an increasingly dynamic Indian power grid, requiring a substantial amount of power from generation sources that have quick start and stop capability and can offer grid balancing services. Such resources come online within a short span of time to bridge the gap on supply side arising due to variable renewable energy generation. Highly flexible hydropower, with an ability to effectively store energy in its reservoirs and respond quickly to system requirements but which to date has only been valued for energy served, will have even greater value within the future Indian power system.

One option to utilize surplus of hydropower in HP and further support integration of renewable energy sources is to create a bundled product, comprising large hydropower, solar and wind plants. Such a bundled product would create multiple benefits including provision of round-the-clock power supply to electricity consumers, decrease in overall offtake price supporting less competitive hydropower generation assets, increased grid stability, higher competitiveness in the Indian power market, and others. The other important role would be of Pump Storage Hydro (PSP) Projects with different options. As PSH projects are highly site-specific in their performance, costs and impacts, it is important to focus on the processes that lead to sustainable systems, not just on broad PSH performance and cost indicators. Increasingly, energy storage and flexibility solutions will be relied upon to support electricity systems with large amounts of variable renewable energy sources. Therefore, system needs should be the point of entry . It will then be necessary to understand the trajectory of the transition towards net zero carbon power systems and then to develop and implement an energy storage (and other forms of system flexibility) strategy leading to that goal.

Above considerations of bundling hydro and developing PSH calls for implementing agencies to look at

projects quite objectively w.r.t site-specifics and consider sustainability from cumulative perspective and not be defined by a simplistic classification. Some key factors to consider for options assessment and project optimization needs to be pre identified and can be integrated to include associated environmental functions and sensitivity, safety issues and social aspects with an intent to avoid, minimize and mitigate impacts . Such arrangements will also foresee a change in the operation of hydro power. The operation of hydro will take shape as per the protocol of bundling of power which to honor peaking requirement or use of other source and thus may operate at different time of hour than is practiced currently. Similarly, PSH environmental impacts would be related to type of technology adopted and site location. A sustainable hydro development in above scenarios therefore requires considerable thought process of impacts from cumulative perspective and mitigation so proposed should be forward looking towards sustainability of assets.

Cumulative impacts are impacts that result from the successive, incremental, and/or combined effects of an action, project, or activity when added to other existing, planned, and/or reasonably anticipated future ones. For practical reasons, the identification and management of cumulative impacts are limited to those effects generally recognized as important based on scientific concerns and/or concerns of affected communities. The CIA would provide a description of the existing environment and social fabric in the area affected by the project and any decommissioning / rehabilitation of existing infrastructure, construction, operations and future decommissioning proposed. All potential cumulative impacts on environmental and social values are to be investigated and analyzed. The CIA would present an evaluation of the potential cumulative environmental and social impacts using an accepted risk-based methodology and their impacts on VECs and describe proposed measures to avoid, minimize or offset / compensate the expected, likely, or potential impacts. All prudent and feasible alternatives must be discussed in detail and the reasons for selection of the preferred option must be clearly given.

The world Bank Group has identified CIA good practice and suggests that CIA is evolving and there is no single accepted state of global practice. What is important is that during the process of identifying environmental and social impacts and risks, developers or project sponsors (a) recognize that their actions, activities, and projects— their developments —may contribute to cumulative impacts on valued environmental and social components (VECs) which other existing or future developments may also have detrimental effects, and (b) avoid and/or minimize these impacts to the greatest extent possible. Furthermore, their developments may be at risk because of an increase in cumulative effects over ecosystem services they may depend on. Good practice requires that, at a minimum, project sponsors assess during the ESIA process whether their development may contribute to cumulative impacts on VECs and/ or may be at risk from cumulative effects on VECs they depend on.

A useful preliminary approach for developers in emerging markets the conduct of a rapid cumulative impact assessment (RCIA). The RCIA can be an integral component of the ESIA or a separate process . It entails a desk review that, actions, or business activities potentially subject to a CIA. Cumulative Impact Assessment and Management in consultation with the affected communities and other stakeholders, enables the developer to determine whether its activities are likely to significantly affect the viability or sustainability of selected VECs. The proposed approach recognizes that, especially in emerging markets, the many challenges associated with managing a good CIA process include lack of basic baseline data, uncertainty associated with anticipated developments, limited government capacity, and absence of strategic regional, sectoral, or integrated resource planning schemes. Given the many challenges, it is recommended to: (i) follow a six-step RCIA process, (ii) engage stakeholders as early as possible and throughout the decision-making process, and (iii) clearly record the fundamental reasoning behind each important decision made, supporting it with as much technical evidence as possible.

Integrating above approach with project cycle preliminary feasibility or detailed project report stage makes investment much viable and allow proponents to avoid delay and resource loss. This is a best feasible and appropriate approach by including ecological, health, safety, social and cumulative impacts in the development of hydro projects upfront for resource efficiency.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

ROLE OF TEHRI DAM IN ABSORBING THE FLOOD DURING THE UTTARAKHAND DISASTER-2013

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India is a land of rivers and mountains. Total land area is crisscrossed by rivers and they are significant to our culture, religion and spiritual life. A large population is dependent on rivers for their sustenance. The rivers are lifeline for habitation along the rivers but in case of extreme hydrological events (floods), they cause disasters along their course. Large reservoir based hydro projects are needed in each and every river basin to conserve the high runoffs (floods) for safety of habitation along the rivers and releasing afterwards in a regulated manner. Technological advancement has improved the implementation and O &M of large dams to the extent that public perception about the safety of large dams has changed now. Tehri dam project built as a mega project on river Bhagirathi in one of the largest river Ganga Basin of India is one such an example. It is a multipurpose scheme designed for storing surplus water of river Bhagirathi during monsoon period in its reservoir and releasing the stored water after monsoon period from the reservoir through power house to fulfill the irrigation and drinking water requirements of population in the downstream while providing 1000MW peaking power to Northern grid. It is not only providing the water for consumptive use of downstream population but also safeguarding them from the fury of recurrent floods. Prior to 2013, Tehri dam mitigated the impact of floods during the monsoon of 2010 and 2011 but during June-2013 flood of Uttarakhand, Tehri dam played a crucial role by averting a further rise of 2.5 to 3.0 m in water level of river Ganges at Haridwar which was already creating havoc along the banks from the flood waters of another river and any further rise would have increased the havoc manifolds.

MONETIZATION OF HYDROPOWER DAM PROJECTS

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The world is shifting its focus from conventional energy sources to renewable energy sources such as hydro, solar, wind etc to decarbonise the energy for mitigating the climate change. Hydropower projects provide many additional benefits other than electricity and these may be broadly classified into two services -Energy Management Services comprises energy generation, ancillary services etc. and Water management services incorporates services viz irrigation, water distribution and greenhouse gas emission etc. These services, if monetised will provide a more robust approach for analysis in terms of viability. This paper is about monetising these benefits and the case of Tehri Multipurpose dam based Project has been studied. To monetise energy management services, Linear Optimization Technique has been applied on GAMS software and the value obtained for these services are found INR 4.20 per kWh. The overall value of water management services is found out INR 5.58 per kWh. Thus, the overall monetised value for the Tehri Hydropower project is assessed to be INR 9.78 per kWh out of which major portion of the benefits comprises of water management services.

BHAKRA NANGAL PROJECT – HARBINGER OF PROSPERITY IN NORTHERN INDIA

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After independence of India, most of the irrigated area went to Pakistan and food grain shortages started after World War-II became very acute. In 1950s, India started importing food grains. This situation was further aggravated by the wars of 1962 and 1965 with neighbouring countries. Failure of monsoon in 1965 and 1966 forced India to heavily import food grains. Reliable irrigation provided by Bhakra and Nangal dam projects of Bhakra Beas Management Board (BBMB) led to massive gains in production of food grains in Punjab and Haryana as well as increase in productivity which was much higher than the country as a whole. Bhakra-Nangal Project has been a major source of green revolution in this part of the region. In addition, it is also a source of drinking water to all major towns in the states of Punjab, Haryana, Chandigarh, Delhi and parts of Rajasthan. This project also supplied electricity to the northern States of the country. This paper deals with food, water and energy security, flood control, rural electrification and other benefits from BhakraNangal project.

DAM, ENVIRONMENT AND DEVELOPMENT

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Subansiri Lower Hydro-electric project (2000 MW) is India's largest Hydro Power project presently under construction by NHPC Ltd. at Arunachal Pradesh/ Assam is a gateway to clean energy development in the North-eastern region. The project is actively engaged in providing direct employment to more than 7500 local population and contractors manpower engaged in construction activities in addition to numerous indirect employment opportunities to the population in the local region. The project is also providing benefits of river bank protection downstream of the Subansiri Lower River up to the confluence of mighty Brahmaputra River thereby protecting the river banks and providing security to the local populace downstream of the river. In addition the project has undertaken various skill development programmes for the sustainable development and livelihood of local population in long run. Although the project which was started in 2003 had encountered various hurdles both geological as well as agitation by anti-dam protester, however, the benefits imparted by the project is unparallel by way of uplifting the lives of stakeholders, boom in commercial activities and uplifting of lifestyle on economic scales. The project will further keep on providing direct as well as indirect benefits even post construction stage also in addition to free power to the states, creating huge corpus of funds for local area development as well as opening new avenues for commercial activities and industry in future.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

OPTIMISATION OF FILLET SIZE IN A RECTANGULAR DUCT AND A RECTANGULAR OPEN CHANNEL

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Optimum size of fillets at the corners of a rectangular duct or a rectangular open channel carrying water to minimize the hydraulic head loss has been worked out. For all the cases viz. a rectangular open channel or a rectangular duct running full or not running full, the optimum size has been found to be 0.24R where R is the hydraulic mean radius.

NON-STRUCTURAL MEASURES FOR FLOOD MITIGATION AND SUSTAINABLE DEVELOPMENT OF A COUNTRY

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Flood causes enormous loss of life, throws normal life out of gear, leaves large scale destruction of property and crops, disrupts essential services and other developmental activities, creates hue and cry, chaos and loss in confidence in the people and thus costs the country's exchequer crores of rupees every year. The sustainable development of a country is adversely affected by the fury of floods. It is not possible in a developing country to ensure foolproof structural protection to the people owing to economical constraints. In such cases, non-structural flood control measures may be explored. Some of the non-structural measures are proper flood defence education, efficient drainage system and environmental hazard reduction, river control and monitoring of hydraulic structures, floodplain management, flood proofing, watershed management and anti-erosion strategies, flood relief management, flood forecasting and warning, setting up of flood control stations, flood insurance, economical strategies, etc. Computer-mediated communication systems, geographic information systems (GIS), remote sensing, electronic decision support systems (DSS) and risk-analysis techniques have developed substantially and show great promise for supporting sustainable flood mitigation. Deserted houses, inundated fields, disrupted services, damaged properties, crops and floating carcasses of dead animals show the devastation of floods which have catastrophic impact on country's sustainable development. Sustainable development is process-oriented and does not focus on a static world order. As such, flood management involves a constant search for ways to incorporate mitigative concepts into development decisions to reduce our vulnerability to natural hazards like floods for today and tomorrow.

Keywords : Flood defence education, floodplain management, flood forecasting and warning, disaster preparedness, flood mapping and damage assessment

Session IV

DEALING WITH NATURAL HAZARDS AND RISKS

EXTREME PRECIPITATION EVENTS AND HYDROLOGICAL IMPACTS OVER THE HIMALAYAN REGION IN A CHANGING CLIMATE

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Human activities since the nineteenth century have contributed to substantial increases in the atmospheric concentrations of heat-trapping greenhouse gases (GHG), such as carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), and fluorinated gases. Carbon dioxide is the main long-lived GHG in the atmosphere related to human activities. Burning of fossil fuels, deforestation, and land use changes, among other human (anthropogenic) activities, have led to a rapid increase of atmospheric CO_2 levels from 280 parts per million during 1850 to more than 416 parts per million in February 2020. The series of assessment reports of the United Nations Intergovernmental Panel on Climate Change (IPCC) provides unequivocal evidence for the role of anthropogenic forcing in driving the observed warming of the Earth's surface by about 1^{o}C during the last 150 years. Consequences of this warming have already manifested in several other global-scale changes such as melting glaciers, rising sea levels, changing precipitation patterns, and an increasing tendency of weather and climate extremes. These changes are projected to continue through the twenty-first century, as the GHG concentrations continue to rise. Robust attributions and projections of regional-scale changes to anthropogenic forcing are inherently more complex than global-scale changes because of the strong internal variability at local scales. For example, the IPCC Fifth Assessment Report (AR5) reported large inter-model spread in the climate change response of the Indian monsoon precipitation, Indian Ocean regional sea-level rise, Himalayan snow cover, and other aspects of the regional climate system. In this context, this book presents a comprehensive assessment of climate change over the Indian region and its links to global climate change. This assessment report is based on peer-reviewed scientific publications, analyses of long-term observed climate records, paleoclimate reconstructions, reanalysis datasets and climate model projections from the Coupled Model Intercomparison Project (CMIP) and the COordinated Regional climate Downscaling EXperiment (CORDEX). This book is the first ever climate change report for India from the Ministry of Earth Sciences, Government of India, and its preparation was led and coordinated by the Centre for Climate Change Research (CCCR) at the Indian Institute of Tropical Meteorology (IITM), Pune. The aim of this assessment report is to describe the physical science basis of regional climate change over the Indian subcontinent and adjoining areas.

A salient feature of this report is the inclusion of introductory results based on the CMIP Phase 6 (CMIP6) projections of the IITM Earth System Model (IITM-ESM)—the first climate model from India, developed at the CCCR-IITM, that is contributing to the Sixth IPCC Assessment Report (i.e, IPCC AR6) to be released in 2021.

A COMPARATIVE MODELING STUDY OF GLACIAL LAKE AND ASSOCIATED GLACIAL LAKE OUTBURST FLOODS AT DUGAR HYDRO-ELECTRIC PROJECT IN CHENAB RIVER BASIN

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Glacial lakes are common in the upper reaches of glacierised basin such as basins in Himalayan regions. They are formed by storage of melting water from snow and glacier ice. Most of these glacial lakes are dammed by unstable lateral or end moraines. These lakes normally drain their water through seepage. But as the global warming has increased the pace of melting of snow and glaciers, some glacial lakes are getting bigger in size and accumulating more water with time. Such bigger glacial lakes holding large quantity of water, if breached, discharges huge amount of stored water instantly causing flash floods, known as Glacial Lake Outburst Floods (GLOFs). It could create havoc in downstream areas. Hence GLOF must be taken into account while planning, designing and constructing any infrastructure in downstream. Specifically, water resource projects shall be of prime concern for experts involved in water sector as they are situated on the stream path and could breach leading to further catastrophe and financial loss. In the present study, glacial lakes, that may pose a threat for under planned Dugar Hydro-Electric Project (HEP) in Chenab basin, have been identified. By criticality analysis, three glacial lakes have been selected as potentially dangerous based on their water surface extent and distance from project site. The water surface area of one glacial lake was found to be increased by 81% from 2014 to 2020 using remote sensing analysis. The increase in lake size also led to increase in GLOF by 50% at project site. The motive of this study is to assess the increase in GLOF due to increase in lake area. This study tries to impart a sense of understanding to the water resource community regarding the expansion in both glacial lakes and resulted GLOF and try to present a road map for various future researches.

Keywords : Glacier retreat, Glacial lake expansion, Glacial lake outburst flood (GLOF), Hydrodynamic channel routing, MIKE-11, Dam break

ENVIRONMENTAL FLOW ASSESSMENT FOR RIVER VALLEY PROJECTS

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Water is an essential component of life. Water, energy and transport are the basic components for social prosperity and economic growth of any country. In a developing economy like India as the economic growth and social prosperity is advancing, the demand for water resources projects is also increasing. Consequently, rivers and their ecosystems are coming under immense pressure due to storage, diversion and abstraction of water for various consumptive and non-consumptive uses. So far, we have exploited river basins for various uses, mostly without considering the water requirements of the living systems themselves. Therefore, it is critical to balance the requirements of various human uses and ecological needs in a river system from a basin-wide perspective. In this regard river flows of a certain quantity and quality called as environmental flows (E-Flows) are needed required to maintain the river in desired environmental condition or predetermined state where there are competing water uses. The criteria for estimating environmental flows requirements should imitate the spatial and temporal flow patterns of river flow, which affect the structural and functional diversity of rivers, and which in turn influence the species diversity of the river. All components of the hydrological regime have certain ecological significance. High flows of different frequency are important for channel maintenance, bird breeding, wetland flooding and maintenance of riparian vegetation. Moderate flows are critical for cycling of organic matter from river banks and for fish migration, while low flows of different magnitudes are important for algae control, water quality maintenance and the use of the river by local people. Therefore the element of flow variability has to be maintained in a modified E-Flows regime. The present paper describes the importance of environmental flows, methodologies for environmental flow assessment and methodology adopted for the assessment of environmental flow for a reach of river Ganga between Haridwar to Unnao.

***Keywords* -** Flow Regime; Riverine Ecology; Hydraulic Variables, Habitat Simulation

RECENT ADVANCES IN FLASH FLOOD FORECASTING OF SOUTH ASIA

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Flash floods are typically associated with high-intensity rainstorms with short response time. They have the potential to severely impact and damage communities in different climatic settings especially in a densely populated region of South Asia. Recent years witnessed an increased effort to understand the dynamics of Flash floods with the availability of high resolution hydro-meteorological and topographical data. Despite their scientific significance and social impact, the fundamental processes triggering a flash-flood response are yet not fully understood.

The operationalisation of flash flood guidance services is one such attempt to integrate the hydrological mechanisms causing hill slope run off in response to intense rainfall causing Flash Floods over the watersheds of Indian region. The core of Flash Flood Guidance (FFG) System is the real-time integration of hydrological model that pre-calculates the FFG value by combining the input from the diagnostic hydro-meteorological variables with the estimated rainfall from numerical models. Based on FFG values, it generates both Risk and Threat perception of a Flash Flood over a watershed, within 24 hours and 6 hour interval respectively. FFG is the amount of rainfall needed over a prescribed area, for a given duration to bring small streams to bankfull flood conditions (see Sweeney, 1992; Sweeney & Baumgardner, 1999).

Though still evolving, efficacy of South Asia Flash Flood Guidance System at operational level is validated by many accurately forecasted Threat and Risk potentials of various Flash Flood events in the South Asia region during SW Monsoon season of 2020. This study summarizes the operational schema adopted in South Asia, evaluates the performance with a recent case study over South India and further scope of improvement with the existing system.

Keywords: Flash Flood, watersheds, threshold runoff, FFG, soil moisture, bankfull.

DECISION SUPPORT SYSTEM: EARLY FLOOD WARNING SYSTEM, MAPPING & RISK ASSESSMENT

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In the recent past, extreme events such as flash floods and droughts are increasingly causing significant damages in terms of human lives, property loss, irrigation productivity, etc. across India. This might be due to erratic behaviour of climatic pattern, land use changes, population burst and subsequently increasing water demand. These circumstance lead to water governance crisis and resource management could become under substantial pressure. Drivers such as demographics and uncertainties further increase the stress on water resources planners and managers. There is a major constraint and a prime cause for lapses in efficient water resources management for non-availability of reliable, real time information from the water infrastructure. The traditional fragmented approach has to give way for adopting more holistic approach for sustainable water resources management.

In spite of the large investments made in dams and reservoirs across India, most of the hydraulic structures are still being operated on the basis of experience, rules of thumb or static rules established at the time of construction. Manual calculations on flood forecasting and water supply, manual operations of dam spillway gates and canal gates. The prevailing limitations of analytical applications of rainfall and hydrological data in the catchment areas, which are crucial for flood forecasting, reservoir management and water use planning. The regulations of water through dams, canals and other hydraulic structures are having vital during monsoon as well as dry seasons. Technology is led and provided by governmental agencies and most countries are blind to data and its use. Businesses are reactive to extreme weather events, water, crop and cannot link business to expected impact. 90% of businesses cannot understand what water, crop, extreme weather events like, flood & drought data means for them. Existing providers gives repackage Models; Simulations; forecasts; – lack of accuracy, resolution, and limited and Could not overcome the multi vertical complexity of extreme events impact. Also, they provide services (not sustainable solutions oriented services). They Provide solutions based on raw data and not actionable/decision making business insights. The fact is 85% of the globe doesn't have reliable real time and forecast weather and hydrological data. Due to the advancement in IT technologies in the field of water resources engineering can be used for real-time inflow forecasting to mitigate flood and regulate water efficiently by functioning short-term and long-term reservoir operations. For real-time applications, forecast information on reservoir inflow is used to optimize short-term benefits by minimizing spills and maximizing the economic value of water for hydropower production and other water uses. The use of Cyberinfrastructure Requirements for Climate and Hydrologic Information Development, such as :

Dashboard Platform present the data in intuitive/compelling ways

- Real time Data
  - Coordination of work across an organisation
- Sensor data, GPS locations, social media, etc.
- Other Data
  - GIS server
  - Online content & Services

Following Disruptive Technologies for Climate & Hydrologic Information Delivery integrates above features into global hydrological forecasting models and decision support systems.

UAV-BASED MULTI-LAYERED DATA COLLECTION METHODS AND DEFECT DETECTION ALGORITHMS FOR PREDICTIVE ANALYTICS

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Traditional inspection procedure for condition assessment of dam structures is laborious, dangerous, time consuming, capital intensive and highly dependent on subjective skill level of a human's judgment. This leads to comprehensive project expenditure incurred by the dam owner.. The primary focus of the authors is to present an improved defect detection and quantification software paired with a novel Unmanned Aerial Vehicle (UAV)-based data collection technology to detect and quantify surface and subsurface defects such as delamination, voids, cracking. The data is collected in-terms of Light Detection and Ranging (LiDAR), optical images, infrared images, and acoustic signatures which is further combined together to quantify surface and subsurface defects in concrete dams. Furthermore, the condition-based life cycle assessment on a time-scale allows owners to make cost-efficient business decisions to plan and execute the maintenance repair schedule using the risk modelling methods to extend the lifespan of the structure rather than replacing the entire structure. This approach also grants building predictive deterioration models using the historical performance which can be utilized for asset management. This paper demonstrates a case study of the technology when applied on concrete structures in USA and Canada to detect and quantify surface and subsurface damage.

IMPACT OF SOFT WATER ATTACK ON DAM CONCRETE OF HYDRO POWER STRUCTURES IN THE HIMALAYAN REGION – CASE STUDIES

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To full fill country's irrigation and power requirements various large capacity dams have been constructed on major rivers in last 70 years. The long term sustainability of these structures is largely dependent on hydro-environment and the capacity of these structures to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. These are therefore the major factors to be considered during the designing and construction of the projects for enhancing their sustainability. Quality of water plays an important role in the production of concrete. The chemical reactions between cement and water enable the setting and hardening of cement, resulting in a binding medium for the aggregates and development of strength. Concrete can be made which will perform satisfactorily when exposed to various atmospheric conditions, to most waters and soils containing chemicals, and to many other kinds of chemicals. There are, however, some chemical environments under which the useful life of even the best concrete will be short. To make concrete durable, it is a must to understand the mechanisms of various factors affecting the durability of concrete to come to the remedial measures in an economic way. Understanding these conditions permit measures to be taken to prevent or reduce deterioration. The aggressiveness of a water is dependent on the pH value, the total dissolved salts , the degree of hardness, soluble chlorides, sulphates, carbonation, temperature and alkalinity etc. Aggressive water may deteriorate concrete structures to a great extent if proper precautions are not taken at the time of construction and/or during the life span of structure . A number of hydroelectric projects around the world are suffering due to

attack of aggressive water on concrete / metallic equipment and a lot of economy in involved in the process of repairs and rehabilitation of such project. The review paper present the typical aggressive water quality issues encountered during our investigations. Central soil and materials research station involved in the water quality investigations of the various projects of the Himalayan regions and found the common issues related to soft water attack on concrete structures. Presence of low salt content in glaciers flow makes Himalayan river water soft in nature which in turn not good for concrete structures. Some outcomes of our studies related to Tehri dam H.E. project (THDC), Uttarakhand, Nathpa Jhakri Hydro power station, NJHPS (SJVN) Project, H.P and Baglihar H.E. Project, J & K are presented here for reference.

Keywords : Soft Water Attack, Aggressivity; Durability, Leaching of lime; Seepage; Hydro-environment.

RELATION BETWEEN BED FORMS AND FRICTION IN ALLUVIAL CHANNEL FLOW IN THE CONTEXT OF SEDIMENT TRANSPORT

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This paper reports development of a relationship between friction factor of bed with ripples and the size and other geometric properties of these bed forms. The objective of the present study is to establish a relationship of these bed forms to theory of resistance to flow in lower flow regime. Such a relationship has been established between the ripple friction factor and the parameter modified relative roughness. An empirical relationship has also been developed for computation of area average mean velocity of flow using experimental flume data.

Keywords : Alluvial Channel, Bed Forms, Friction Factor, Relative Roughness, Sediment Transport

HI-TECHNOLOGY INITIATIVE QUANTIFYING THE IMPACT OF CLIMATE CHANGE ON WATER SECURITY AND ENERGY RESOURCES

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Growing evidence of the effects of climate change on the planet has led to increasing interest in determining its potential impact on various sectors of the economy such as the hydropower industry, which has played a significant role in renewable and clean energy in the overall world energy supply in recent years. Every continent suffers from water scarcity and security; it is predicted that by 2030, nearly half of the world's population will experience high water stress conditions, and these will likely impact energy security. Unfortunately, while climate change will continue to have considerable impact on water and energy resources, the majority of our communities have little or no resilience to changing climate. Therefore, it seems necessary that various sectors of a community including the private sector, the public sector, and civil society work together to develop innovative approaches to mitigate the impacts of climate change on these essential resources.

We (ISOBARS and FAMS), are a specialist in including the effect of climate change in the estimation of the resource and production of the wind, solar, hydroelectric power, hydrology, risk assessment, the uncertainty in said production, the expected useful life of renewable assets and operation and maintenance (O&M), through a methodology based on projections of climate change, big data, own mathematical models, meteorological and oceanographic models and the application of supercomputing infrastructure (HPCC).

We help chart the course for companies in the renewable energy sector, helping them to identify and mitigate the risk that climate change represents. The owners, operator, investors, insurance companies, and developers must understand and mitigate all the risks before deciding to proceed with a renewable project. Project risks that might affect the project's profitability in the short, medium and long-term usually originate during the initial development stages. Our climate advisory hi-technology initiative can evaluate the project's technical feasibility through a technical due diligence during which the risks probability of occurrence and their potential impact on the project would be detected. On the other hand, this risk is hardly addressed in financing operations for renewable projects, in cash flow generation projections, in the design stages of renewable projects, or the costs derived from operation and maintenance (O&M). Our risk assessment can help to identify and take corrective actions to mitigate are:

- Weather related climate change risk
- Technical risk
- Market risk
- Operational risk
- Business and strategy risk
- Political/ regulatory risk
- Economic/Financial risk

In present paper, we have enumerated our experiences through for quantifying the impact of climate change on water security as well as energy resources.

Session V

PUMPED STORAGE DEVELOPMENT - CURRENT TRENDS AND FUTURE CHALLENGES

PUMPED STORAGE DEVELOPMENT – CURRENT TRENDS AND FUTURE CHALLENGES

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India has ambitious international commitments to increase share of renewables in its installed capacity generation to 50% and achieve 500 GW of non-fossil fuel-based energy capacity by the year 2030. India has taken lead in the world's renewable energy revolution to achieve these climate targets. With Ambitious goals, concerted strategies, and a collaborative approach these emission reduction targets can be met. Wind and Solar, have become one of the lowest cost sources of renewable energy, however, their inherent variable, uncertain and intermittent nature presents a huge challenge for integrating large Renewables, while maintaining the grid stability.

The increasing Renewables capacities coupled with ever changing dynamic demand curves lead to sub-optimal utilization of the existing base-load assets. Flexible Energy Generation Assets that have a capability to supply both Base Load & Peaking Power efficiently and economically are the need of the future and the necessary solution to address the dynamically evolving energy needs of India. Energy storage represents a huge economic opportunity for India. In the present scenario, the increasing energy demand of the country can only be met sustainably by developing the much required Pumped Storage Projects (PSPs) - Flexible Energy Generation Assets.

Pumped Storage Project are known as 'the Water Battery', which is an ideal complement to modern clean energy systems, as it can accommodate for the intermittency and seasonality of variable renewables such as wind and solar power. PSPs present a viable solution to integration issue of large RE capacities being planned to be added to National grid. While battery storage solutions are still evolving, integrating Wind & Solar with time tested and proven Pumped Storage solutions presents an optimal, economically viable & scalable solution to supply Power with both base load and peak load capabilities. Pumped Storage solutions provide the necessary scale (large volume of energy storage) and have a long life cycle resulting in low cost of delivered energy over the life of the projects.

Pumped storage projects account for over 95 per cent of installed global energy storage capacity, well ahead of lithium-ion and other battery types. The International Hydropower Association (IHA) estimates that pumped hydro projects worldwide store up to 9,000 gigawatt hours (GWh) of electricity.

It is envisaged that in future the focus will change on the type of hydropower, a shift will occur from run-of-river to pumped storage combined with 'other alternative renewable energy resources' to ensure energy security. The future of Pumped Storage in India is bright despite several hurdles in development. The paper discusses Pumped storage development – Current trends and future challenges.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

CURRENT TRENDS AND FUTURE CHALLENGES AND POLICIES TO PSP GROWTH

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Global concerns towards climate change and commitment for net zero carbon emission in CoP21 and now in CoP26 has brought a paradigm shift in the energy sector. In past decade world has witnessed a drastic transition from conventional fossil fuel to renewable resources to meet its energy needs. India alone has seen a six fold growth in its renewable capacity addition (solar and wind). However, renewable resources have their own challenges and have set forth the need of energy storage. Storage of abundant renewable energy available during low demand time for its usage at a later stage is the only answer to intermittency and variability associated with RE sources.

Presently Pumped Storage Technology and Battery Storages are the major commercially viable solutions for long duration and short duration storage. Pumped Storage Plant (PSP) is quite old and proven technology and has provided a cost effective solution to varied energy needs for decades. Globally, PSPs account for 90% of grid scale energy storage needs. With advancement in semiconductor technology and improvement in power ratings of switching devices like IGBTs/IGCTs, Pump storage technology landscape has transformed a lot. Earlier fixed speed machines were being used in PSPs for power regulation in generating mode but now with variable speed technologies using advanced power electronics based VSI systems, power regulation can be provided in both generating as well as in pumping mode that too within specific range of speed and head variations. Thus new variable speed technologies provide added flexibility, better outputs and efficiency for the same head variations and configurations. Further advancements taking place in the domain are ternary set PSPs and hydraulic short circuit operation with single turbine and separate motor & generator connected to single shaft. This configuration provides maximum flexibility in operation wherein pumping and generation can be done simultaneously. PSPs installed so far are on river streams where both reservoirs are on the main water stream whereas now the focus is shifting towards off stream PSPs where one or both reservoirs may be away from main river stream. Off stream PSPs can save time and cost of construction as well as the minimum environmental footprints .In this paper, current trends and existing policy frameworks across the globe have been discussed. Based on the developmental model of PSPs around the world vis a vis prevailing challenges in India, necessary policy and regulatory framework has been suggested for faster development of PSPs in India.

Index Terms—Energy Storage, Pumped Storage Plants, Renewable Energy.

PUMPED STORAGE DEVELOPMENT EMERGING CHALLENGES AND AVAILABLE OPTIONS – CASE STUDIES

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Rapid depletion of fossil fuels together with associated adverse impacts on climate will result in large scale induction of renewable energy into the system in near future . These energies are abundant in nature but are intermittent and varying in nature. The output from these sources may not be in sync with the requirement in real time. Hence there is an urgent need for the large energy storage to ensure system reliability. However, the concept of Pumped Storage Projects is relatively new in India. Given its nature, almost all the Pumped Storage Projects have inherent challenges in planning, design and thus, require specialized expertise, knowhow and manpower from its concept to commissioning. There are only few pumped storage projects in India which have been designed, commissioned and running successfully in India. In this scenario well planned Pumped storage projects could play a vital role in mitigating above emerging issues.

In Indian context, there is an ambitious plan of 175 GW renewables generation as per various projections. But at the same time we are also looking at retiring many old Thermal plants while Hydro Sector passing through tough times and not looking promising in near future. Development of projects with large submergence and associated land acquisition has become increasingly difficult proposition. Moreover many good sites identified earlier have now become unavailable over a passage of time due to various reasons such as new notification of National parks, Wild Life sanctuary etc. All these factors indicate that there are multiple challenges in development of land intensive projects having reservoirs. Hence Identifying sites for Pumped storage projects which essentially have two reservoirs become even more challenging.

In this context , this paper underlines the importance of exploring all the attractive available sites. It is also equally important to exhaust all possibilities for installation of large Pumped storage projects within existing projects having reservoirs to the extent possible. Since installing Pumped storage project within existing operational projects is a complex proposition and requires in-depth study to integrate both existing and new projects in such a manner that over all project benefit can be maximised. In such cases all possible technical combinations need to be studied and necessary trade offs amongst the priorities of existing and new project needs to be made in judicious manner. Three case studies with different possible options for installation of Pumped Storage project are also presented.

Keyword : Hydropower Storage, Pumped Storage, renewable integration, Energy Storage

NEED OF PARADIGM SHIFT FOR PUMP STORAGE DEVELOPMENT

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India is the third largest producer and consumer of electricity globally, with annual electricity production between 1200-1300 TWh. The Indian power grid is one of the largest synchronous power grids in the world. During last decade, electricity production in India grew at an annual growth rate of about 5% excluding last two years. The Electricity Act, 2003 delicensed power generation activity, which gave impetus to generation capacity addition and led to rapid coal-based generation capacity expansion during 2007-2017.

As of December 2021, the installed generation capacity of the country stood at 393 GW, comprising 235 GW of thermal, 151 GW of renewable (Wind, Solar, Hydro, and Biomass), and 6.78 GW of nuclear. India witnessed a peak electricity demand surpassing 200 GW in 2021. As per study carried out by Central Electricity Authority (CEA), the storage requirement of 41 GW by 2030 has been forecasted and thus energy storage is getting much awaited attention in the country [9].

With the ambitious decarbonisation target of the Government of India, in Nov'21, at the COP26 Climate Conference in Glasgow Prime minister raised the nationally determined contribution (NDC) target of non-fossil energy capacity to 500 GW by 2030, from 450 GW earlier that India will achieve net zero carbon emissions by 2070.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

PUMP STORAGE PLANTS IN HIMALAYAN AND NON-HIMALAYAN REGIONS OF INDIA - PROSPECTS AND CHALLANGES

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A significant grid transition is underway in India, as it gears up to meet its pledge of taking up the share of non-fossil energy capacity to 500 GW by 2030. This large-scale RE capacity addition, known for intermittency /variability in generation, may have large scale implications on the reliability and stability of the Indian power system. This in turn, requires sufficient availability of balancing power and storage solutions to smoothen the integration of renewable into the grid.

There is no easy and effective way to store energy that can be used during peak demand. While battery technologies are progressing, it's not yet possible for the quantum of energy that hydro-energy plants are producing to be stored in batteries.

That's where Pumped-Storage Projects (PSP) comes in. In the mix of different energy storage techniques, Hydropower and PSP is gaining ground as a reliable, time-tested technology, particularly suited for load management.

This water is pumped from a lower elevation reservoir to a higher elevation reservoir. The PSP schemes act as a giant battery (also called Water Battery) as it can store energy as per availability of cheap power and then use it for producing energy when it needs during peak hours.

In view of above, Ministry of Power, Govt. of India has emphasized time and again that all Hydro PSUs should study and identify the exploitable Pumped Storage schemes.

TWO WAYS TO BENEFIT FROM THE USE OF MATHEMATICAL OPTIMIZATION FOR REVISING RESERVOIR OPERATING RULES – A CASE STUDY OF THE BARGI AND TAWA RESERVOIRS IN NARMADA RIVER BASIN

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Mathematical Optimization can introduce significant benefits to reservoir operations in India. One example demonstrated on Tawa reservoir shows the ability to develop and utilize dynamic real-time rule curves based on the current conditions in the field and statistical analyses of previously developed optimal solutions. Another example on Bargi reservoir shows how to improve the existing reservoir operation by combination of optimization algorithms and short-term runoff forecasting models. Both options are demonstrated on case studies conducted on the reservoirs in Narmada River Basin. Optimized operations show a potential to increase monetary benefits by a factor of 4 times in total on Bargi reservoir, where the planned increase of irrigation water supply to the tune of 6.7 times compared to historic operation would result in a reduction of generated hydro power by only 30%. Other large reservoirs in India would benefit from conducting similar analyses.

Session VI

DAM SAFETY MANAGEMENT

OVERVIEW OF DAM SAFETY ACT 2021

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Dams have always played a key role in fostering rapid and sustained industrial, agricultural, urban and rural growth and development, which have been the key priorities for the Government of India since independence. Over the last seventy years, India has invested substantially in infrastructure necessary to store surface runoff in reservoirs formed by large as well as small dams with associated appurtenances. In terms of large dams, India ranks third in the world only after USA and China. Although almost every state of India has large dams, the major chunk is situated in Maharashtra, Madhya Pradesh and Gujarat.

ENGINEERING CHALLENGES AND SAFETY ASPECTS OF TAILINGS DAMS

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Dams constructed to contain tailings are different than dams constructed for hydropower generation; primarily because tailings dams contain solids and liquid and are raised over time. This presentation will provide some insights to the engineering challenges associated with tailings dams that may be of interest to hydropower dam designers. Over the past 10 years, there have been significant advances in tailings dam engineering and safety that also may be of interest to the designers of hydropower dams.

IMPACT OF CLIMATE CHANGE AND TIME-DEPENDENT HAZARDS ON DAM SAFETY

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This paper is concerned with the impact of climate change and other hazards on the safety of large dams. It is typical for most hazards from the natural environment, man-made environment and site-specific and project-specific hazards that they depend on time. Similarly, the safety criteria are also changing with time. Therefore, dam engineers have always been concerned with such changes and climate change is no exception. Because of these changes, which cannot be predicted at the time a dam is being built, safety evaluations have to be carried out periodically. Well-designed, well-constructed and well-maintained storage dams that satisfy current safety criteria have a long lifespan and therefore safety assessments must be carried out repeatedly. The reservoir may have a similar lifespan as the dam, but the use of the stored water will change with time and the useable reservoir volume may decrease due to sedimentation, whereas the basic function of the dam remains unchanged. The main hazards due to climate change that are addressed in this paper are floods, floating debris, mass movements and debris flows into the reservoir, which may endanger the safety of a dam. To account for all these time-dependent changes a resilient dam should be the solution, i.e., the dam should have certain reserves beyond the safety flood or safety evaluation earthquake. Mass movements are among the main climate change hazards for dams, but strong earthquakes can trigger many more landslides and rockfalls than the worst meteorological events. This means that certain hazards are more critical than climate change. Due to changes in safety standards in design codes, the design loads have been increased continuously for weather-affected loads and actions when climate change was not an issue.

INITIAL PLAN, CHALLENGES AND DESIGN SOLUTION FOR COFFER DAM OF PUNATSANGCHHU-I H.E. PROJECT BHUTAN

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The nature and scope of design engineering are such that the problems and projects we deal with are a never-ending source of both challenge and excitement. In most cases we do very well in defining the problems and developing suitable solutions resulting in successful completion of projects. In a significant number of cases perhaps the unexpected or surprise outcome might have been anticipated and well tackled, Coffer dam of Punatsangchhu-I project (PHEP-I) is one such case. PHEP-I is a Run-of-River Scheme in Wangdue-Phodrang district of Bhutan. The Project contemplates construction of a 130m high Concrete Gravity Dam across Punatsangchhu River to divert 385.54 cumecs of water through a 9 km long, 10 m diameter Headrace Tunnel to an Underground Powerhouse for generating 1200 MW power under 357.68 m gross head.

In the DPR, the Upstream coffer dam was proposed as colcrete type dam of 21m height with design discharge of 1960 cumecs, adopted for 1 in 25 years monsoon return period, as per standards practices for the construction of concrete dam. The diversion arrangement consists of twin concrete lined 10m diameter tunnels of 2724m total length located on the left bank of the river. During tendering stage and after detailed investigation it was found that the bearing capacity is on the lower side to withhold the stresses and that the deepest rock is 60m deep, hence, the dam type was changed to rockfill type with clay core and jet grouting to avoid seepage through foundation. However, as soon the works were about to start, a cyclone named

"AILA" hit the area in May'2009. Punatsangchhu River received maximum ever recorded discharge of 2430 cumecs due to cyclone AILA. This made designers to revisit the entire diversion arrangements and specially the upstream coffer dam. In the revised design, upstream coffer dam height was increased from 21m to 29m, type of dam was changed, and diameter of diversion tunnels increased from 10m to 11m. This led to other sets of associated problems like-schedule delay, stresses within safe bearing capacity of the foundation with increase in height, settlement and seepage issues, junction of cut off wall etc.

Considering the frequency, magnitude and severity of the problems, an integrated and innovative Coffer dam comprising of both colcrete & rockfill type dams with 100% deterministic solution to stop seepage was thought, designed, and implemented by the designers. Initial planning, nature's surprise and associated challenges with design solutions are discussed in this paper.

Keywords : River diversion, Coffer Dam, Rockfill dam, planning.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

IMAGING OF DEEP KARST USING THE MULTI-ELECTRODE RESISTIVITY IMPLANT TECHNIQUE (MERIT) CASE STUDY OF A DAM IN FLORIDA

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Based on the current state of technology for detection of internal erosion in earthen dams the need exists for a technique that can provide reliable and accurate information of all potential dam failure modes. The current geophysical methodology for detection of internal erosion struggles to provide accurate information on location and size of internal erosion, deep karst and foundational seepage. Many dams enter a critical state before internal erosion and potential remedial actions are evaluated and taken. This approach is extremely costly and is typically due to the lack of early detection capability and the inability to perform preventative measures early in the internal erosion process.

This paper focuses on a unique approach with application of geophysical implant technology in mine tailing dam used of cooling pond. The case study site lies within karst geology of central Florida.

A water budget analysis performed by the consultant of three piezometers in the colling pond dams indicated the current amount of unaccounted for loss that may be flow into developing karst features was at least 4548 to 7944 MLPY. The threat of a sinkhole to the cooling pond is the potential loss of pond water by destabilizing one or more of the exterior dikes and/or by draining it into the underlying aquifers.

The Multi-Electrode Resistivity Implant Technique (MERIT), a geophysical technique that utilizes of small implant devices that are places inside the dam itself near the foundation, was selected based-on experience of the consultant with these techniques deep image capabilities. Three arrays of fifth six (56) implants and arranged in an array along a 335m length of the dam at 6m spacing and depth of 11.6m. The geophysical implants were combined with fifth six (56) surface electrodes for any array of 112 electrodes total.

MERIT achieved an optimal imaging that resulting in three 2D geophysical profiles

- Full image extent of all three profiles of subsurface coverage area of 25,460m for each 335m long array
- Three stratums were clearly identified at depths along with the material type and subsurface position as confirmed by three Standard Penetration Test boring completed to 150 to 180 feet at each of the piezometer locations under investigation.
- Details depositional contact of stratum 3, the limestone formation, was clearly mapped in the MERIT images at depths of 30m
- Paleo karst/sinkhole throats of located at depths of 30m and 30m across were clearly identified in MERIT images of P-12 and P-13
- A complex paleo karst/sinkhole was clearly identified in P-05 location at depth of 30m
- In all three MERIT images paleo karst/sinkhole features can be clearly see extending to the depth of the geophysical survey of 76m.
- While the level of effort and cost to install implants is higher than surface geophysical methods the greater ability of results of MERIT resulted in more complete understanding of deep karst features size and depth that can be more precisely located and measured.
- Since implants are permanently installed the consultant future plans include 3D imaging long term monitoring using the MERIT system.

ESTIMATION OF GLACIAL LAKE OUTBURST FLOOD (GLOF) FOR PLANNING AND DESIGN OF HYDROELECTRIC PROJECTS IN THE HIMALAYAS

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India is blessed with immense hydroelectric potential and ranks 5th in exploitable hydro-potential in the global scenario. As per assessment made by Central Electricity Authority (CEA), India is endowed with economically exploitable hydropower potential to the tune of 1,48,700 MW of installed capacity. As of March 31, 2020, India's installed utility-scale hydroelectric capacity was 46,000 MW, about 12.3% of its total utility power generation capacity. Considering the global warming issues due to pollution from thermal power plants, hydroelectric energy and solar energy shall be a better alternative to ensure India's energy security. Many hydroelectric projects are proposed in those parts of the Himalayas in India, where the glacial lakes are also present in the project catchment.

The Indian Himalayan region is the key to securing green energy to meet the ever-rising energy requirements of a country like India. Indian economy is growing at a fast pace, and at present, it is the sixth-largest economy in the world with a GDP of about 3.05 trillion dollars. To keep pace with this growth, India has to develop its untapped hydro-potential in the Himalayan region. It poses a conflict of interest between economic development and environmental conservation. Global warming, fragile mountain cryosphere, threats of landslides, GLOF, avalanches, and other flash flood events are severe challenges for the safety of river valley projects and mountain communities. The glacial lake outburst flood study is vital to address the challenges of associated risks with flashflood.

International Conference on Hydropower and Dams Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India

IMPLEMENTATION OF SUSTAINABLE DAM SAFETY MANAGEMENT – A CASE STUDY OF TWENTY PROJECTS IN HIMALAYAN REGION

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Infrastructure projects such as dams are national property – constructed for the development of the national economy and in which large investments and other resources have been deployed. With the increase of population & economic growth, higher demands of water and energy are to be substantiated with the construction of safe dams for sustainable water development and energy system. The safety of the dams is an important aspect for safeguarding the national investment and needs to be examined for continued accrual of benefits as well as to protect the d/s reaches from any potential hazard and ensuring public confidence.

With the passage of time, the number of older dams is increasing and so is the probability of dam failures. Advancement of modern technologies / methods of survey & investigation, geological & geotechnical investigations, design, construction, invention & adoption of new materials, improved operation & maintenance, and rehabilitation, the incidents related to dam failures has reduced significantly. However, new challenges such as climate change and global warming are rising which needs to be addressed in a timely and proper manner to respond positively to these increasing social expectations for higher safety levels and allay any unwarranted fear on dam safety issues.

Himalayan Rivers carry large quantity of sediments during monsoon requiring frequent repairs due to erosion of hydraulic structures like spillway glacis, piers and stilling basins. Erosion of hydraulic structures takes place due to progressive disintegration of solid by cavitation, abrasion and impact. Repair materials and methodologies need to be adopted depending upon identified 'Erosion conditions' of the project components. In NHPC, Performance of materials such as High Performance Concrete, Cementitious mortars (R4), Epoxy compounds and Steel-liners etc. was evaluated during dam safety inspections for various erosion conditions, on numerous dams on Himalayan rivers, to identify the best suited material based on international guidelines/codes, to optimize the cost and frequency of repair and enhance the safety aspects (1).

The safety of dam is to be integrated at various stages of hydropower development viz. conceptualization, planning, design, construction, maintenance and operation in a framework that ensures effective mitigation of the effects of natural and manmade adverse situations or emergency especially to avoid loss of human life.

PREPARING EVACUATION PLAN FOR DEVELOPMENT OF EMERGENCY ACTION PLAN – A CASE STUDY OF KONAR DAM

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Dams are important structures that serve multiple purposes. Failure of a dam is characterized by an abrupt uncontrolled release of stored water and would lead to catastrophic consequences in most cases. Preparation and implementation of an Emergency Action Plan (EAP) for a dam is crucial to minimize such consequences. For an effective EAP, planning for evacuation becomes a vital component. Guidelines for Developing EAPs for Dam, Central Water Commission (CWC), 2016, recommends using inundation maps for evacuation planning. As these maps are to be used by the Disaster Management Authorities (DMAs), simplicity and clarity of evacuation plan is essential. As per the guidelines, DMAs are to be provided with multiple inundation maps for planning evacuation which might not be convenient for them, especially during an emergency.

The paper discusses about the simplified evacuation plan prepared for EAP of Konar dam. The information provided in multiple inundation maps, individually showing time of arrival, velocity, depth and maximum water level corresponding to the flood waves, were clubbed into one single inundation-cum-evacuation-map for each failure scenario, with all relevant information, using GIS platform. A separate evacuation table was also prepared to supplement the information shown in prepared map. The author proposes preparing simplified map for distribution to the DMAs rather than multiple inundation maps in an EAP document.

Keywords : Dam failure, Inundation maps, Emergency Action Plan (EAP), Evacuation plan, GIS

ADVANCED GEOPHYSICICAL TECHNIQUES FOR DAM AND CANAL NETWORK SAFETY ASSESSMENT

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Water is a crucial resource for economic growth and sustenance of a country. A large number of dams have been constructed all over the country to store water. To take this water to end consumer points, a large network of canals exists. With time, dams and canal networks deteriorate. To realize continued economic benefits, it is imperative that these structures are not only functional but also safe to operate. In Indian context, maintenance of these structures is neglected. As the same time,a large amount of water is lost through leakages and seepages. Repairs, wherever undertaken, are often a haphazard firefighting measure. The visual and functional manifestation of structural deterioration in these structures happens much after internal weakening. Due to sheer size of dams and canals, it is very important to precisely pinpoint location and cause of seepage and leakages so that targeted and cost effective repair and rehabilitation measures can be undertaken.

Paper discusses various geophysical methods utilized for investigation of dams and canal networks. The primary motivation for using geophysics is their versatility and low cost, as a tool for mapping and pinpointing zones of deterioration in dam structures and identification of seepage zones in canals/water channels.

DAM SAFETY MANAGEMENT IN INDIA

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India has already gone through at least 41 dreadful instances of dam collapse in the past with the recent collapse of Annamaya Dam in Andhra Pradesh in November 2021. The first such failure was recorded in Madhya Pradesh during 1917 when the Tigra Dam failed due to overtopping where reportedly about 1000 people lost their lives. India's worst dam disaster was the failure of Machu-II (Morbi) Dam in 1979, because of overtopping during a flood. About 1800 meters of earth-fill embankment were washed way reportedly killing more than 2,000 people. Approximately 150,000 people were affected by the flooding that submerged Morbi in 1.8 to 6 meters (6 to 20 feet) of water and hit 68 villages along the Machu River in Morbi and Malia counties. Approximately $15 million in crops were damaged or destroyed in the disaster; 12,000 houses were destroyed and about 7,000 others partially damaged. In many advanced countries, particularly America, United Kingdom, Australia, Canada, Switzerland, France, China etc., dam safety legislations have been enacted for the purpose of regulating and ensuring the dam safety. Owing to India's sizeable number of dams – of which substantial proportions are ageing – legislation on the dam safety has been desired by various forums to ensure the safety of the dams in the country. In order to address various dam safety challenges in India, Indian Parliament has recently enacted the Dam Safety Act, 2021. With this, India, for the first time, has a law for the safety of its dams. . The provisions of the Act will lead to empowerment of the dam safety institutional set-ups in both the Centre and the States and is also expected to help in standardizing and improving the dam safety practices.