CHALLENGES AND NEEDS FOR DAMS IN THE 21ST CENTURY

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FOREWORD

This bulletin is intended as a general document aimed at a wide technical audience involved with or affected by dams and reservoirs.

It has been prepared in response to comments from members and officers of ICOLD that ICOLD must be prepared for the challenges of global water management and requirements for power supply that are emerging and that will continue to arise in the 21st century.

The subject of this bulletin comprises the following four major categories of emerging challenges.

1. The great need, in many parts of the world, for additional fresh water resources and for additional electrical production (section 4);
2. The mix of energy sources needed to deal with the expanding energy needs world-wide; and the need for pumped storage hydro or other more expensive energy storage as the world develops more renewable and uncontrolled intermittent energy sources such as wind and solar power (section 5);
3. Climate change that has an impacts to on water supply, flood control, and energy production as the world progresses into the 21st century; and how dams and reservoirs might help mitigating or adapting to climate change (section 2); and
4. The need to deal with constraints to development and responses to climate change such as financing, environmental needs, and social responsibility (sections 6 and 7).

The Committee on Emerging Challenges and Solutions (COEC&S) acknowledged that, in many countries, the pace of dam construction is not fast enough to meet the present and future needs. COEC&S endeavoured to compile “Potential Solutions and Recommended Actions” that would foster new dam development and which are presented in section 8.

An outline of the main findings of the Committee is presented in section 1.

OUR 21ST CENTURY …

Prospective challenges and needs for dams and reservoirs in the 21st century require setting the stage and trying to delineate what our 21st century may resemble.

A CHANGING ENVIRONMENT – AN UNCERTAIN FUTURE

The 21st century is almost 20 years old. Though nobody dares to predict how it could turn out. Indeed massive changes are at work with unpredictable outcomes.

Demography and poverty – Despite a drop in fertility, the number of humans keeps increasing. This is especially the case in many countries where accommodating food and water needs is already a challenge. Despite great accomplishments in some countries, the fight against poverty is not over yet. In most countries, another challenge arose: population ageing.

Environmental threats – Demography and our addiction to economic growth have serious consequences for the environment. Energy, food and industrial needs are exhausting our planet resources – with mainly two consequences: climate change is reshaping our planet, and biodiversity is massively declining. The cumulated consequences at the end of our century are unpredictable to the point that some authors consider that the very survival of the human species is at risk.

Science and technology took a new turn during the last century. As of now, Bigdata + Artificial Intelligence + Neuroscience + Biosciences + Nanotechnologies develop and promise incredible novelties. The very next years might witness a deeper penetration of sensors, measures, data and worldwide connectivity – for the best, but also with the associated new cyberthreats. The next decades are much harder to anticipate. Various authors predict a “singularity”, and a gradual shift towards a post-homo sapiens era before 2100; an era with AI surpassing natural intelligence and/or life without ageing.

FRESH WATER: A PREMIUM RESOURCE

Whatever the big trends and changes during the 21st century, we could certainly bet that nothing will replace fresh water.

Yet fresh water is overused and too scarce – all year round in various regions or at some periods of the year in many others. In arid and semi-arid regions water scarcity combined with demographic pressure (locally in large cities or globally at a regional scale) is a major threat.

The need for fresh water might reduce if – thanks to science and technology - agriculture and industry drastically reduce their consumption. We may hope for a revolution there, but it might be unwise to rely on this. The base case scenario is that the impact of demography, economic growth and climate change will surpass the positive impact of improved agricultural methods, and that technologies will remain too expensive to balance this in most countries. Hence fresh water scarcity will probably intensify.

One classical solution to fresh water scarcity is artificial reservoirs.

Artificial reservoirs increase the amount of available fresh water. Not only do they increase the amount of freshwater available, they also store fresh water during floods to release it during dry spells. Artificial reservoirs have been used to alleviate water scarcity for centuries and are still required to handle our needs during the 21st century.

Yet we do not only need fresh water – but also fresh water with special quality. Apart from water stored in the ground, lakes or reservoirs, we need fresh water running in streams and rivers, carrying aquatic life and shaping streams and estuaries. Lakes, rivers, floodplains, and estuaries are habitats for an invaluable biodiversity which in turn provides invaluable and probably irreplaceable services to us. Natural and artificial reservoirs increase the amount of available fresh water but – as of now – they most often decrease the quantity and quality of running fresh water.

ELECTRICITY, WATER AND DEVELOPMENT … AND DAMS

Access to electricity and access to fresh water are essential keys to development and to fighting poverty. As stated in this report, many countries, and especially many countries where the human development index (HDI) is low, need better access to fresh water and much more electricity.

As of now there is no indication that new technologies may substantially reduce the per capita requirements for water and electricity. Hence the corresponding requirements for future volumes of water and electricity are impressive.

The history of development also underlines that it is not enough to provide water and electricity. The requirement is to provide cheap water and electricity.

Dams and reservoirs, among other tools, have succeeded in providing water and electricity in many parts of the world: reliable water – i.e. available also during dry spells; renewable, reliable and cheap electricity. It is important that dams and reservoirs could still be contemplated as a possible option when additional electricity or water is needed. In many countries and by many international NGOs, dams are, however, a priori disregarded, because of their impacts on the environment. In many countries, dam projects also suffer from a lack of proper financing mechanisms.

ICOLD: A RESPONSIBILITY

As stated above, our common future is very difficult to anticipate.

A lesson from the last millennium is that dams and reservoirs have played an irreplaceable role in the development of our civilizations. A lesson from the past century is that ICOLD has played a decisive role in helping our professional community to devise and build reliable, safe and cost-effective dams.

We believe ICOLD, as a professional organization, bears today an extensive responsibility.

ICOLD shall certainly keep focusing on technical issues related to dams. The progresses in dam safety have been striking, and should continue. The continued knowledge-sharing with professionals all over the world is still required.

ICOLD shall also fully acknowledge the impact of dams and reservoirs on biodiversity associated with fresh running water, and foster all actions dedicated to better understand and handle these impacts on water quantity and quality. This is our responsibility towards future generations. This is also a condition to regain acceptability for dams in many regions.

ICOLD supportive actions for dam development are very important for countries where dams are much needed – namely the poorer countries. ICOLD shall keep dedicating a large part of its actions to develop solutions for these countries.

Luc Deroo
Chairman
COEC&S

FIGURES; TABLES

1. BACKGROUND AND OUTLINE OF THE BULLETIN

1.1. BACKGROUND

To establish guidelines for the COEC&S, a series of meetings (workshops) were held in Bali 2014 during which several regional representatives presented the history of dams and energy, and the constraints to development and future needs for development in their regions.

The workshops concluded with a discussion, facilitated by Alison Bartle, and a panel of experts including Mr Francois Lempérière, Past ICOLD Pres. Berga, the then Current ICOLD Pres. Nombre, Mr Harry Blohm, and others. The panel urged the Committee to concentrate on identifying emerging problems and challenges and to recommend actions. The panel also emphasized that finding a solution immediately would not always be required. The recommended action may be the formation of a new committee or assigning the problem to an existing committee.

The panel of experts commented extensively on constraints to developments, particularly financing. Financing is a good example where ICOLD needs to restart the now defunct committee on financing or assign the task to an existing committee. The COEC&S has drafted suggested terms of reference (TOR) for an ad doc committee on project financing that is included as Appendix B.

The Committee on Governance of Dams (COGD) focused on some present challenges and needs and completed its work in 2007. In this report, the COEC&S will update the work of the CODG by utilizing statistics in the Register of Dams and other ICOLD bulletins, and will incorporate information on climate change from the Intergovernmental Panel on Climate Change (IPCC) and utilizing the work of the dedicated Committee of ICOLD and other professional organizations such as the International Hydropower Association (IHA) and the International Energy Agency.

1.2. OUTLINE

The following is an outline of the observations and recommendations compiled by the COEC&S. Facts, figures and more details can be found in the main text of the bulletin or in other bulletins.

1) The present overall pace of dam construction has disconnected from the world needs from water and electricity (see §2)

The world demand for water, electricity and flood protection is growing rapidly.

At the same time, the overall pace of construction is rather stable, both for hydropower (§2.1) and irrigation (§2.2).

Dams and reservoirs, as a solution among others, are not often the preferred option.

It is interesting to note that this situation is not universal. On every continent, there are countries with a strong dam activity and countries where activity is weak

- This is the case for hydropower dams (§2.3)
- This is also the case for irrigation and water supply dams (§2.3)

Many factors have an impact on the pace of construction. Some factors are justified (natural conditions, degree of already satisfied demand), others are less acceptable (social perception, political support, financing capacities).

2) Future needs for water, electricity, and flood protection are very high for two main reasons: Growth and Climate change. But, dams are not the only solution to meet the needs

Needs from Growth – both demographic and economic needs

Published prospectives for future water demand (water supply and irrigation) foresee a strong growth – even when not including the effects of climate change (§4.1 and 4.2)

- There is a strong need in countries which are today under-equipped and which do not entirely provide for the population needs
- The general improvement of life standards points towards changes in diet modes (more meat for instance) which leads to a higher demand for irrigation
- There are improvements in water management (drip irrigation, less leaks in water networks) that mitigate the needs
- Several major droughts have affected entire regions (§3.4)

Dams and reservoirs for water supply are an option among others (§4)

- Dams and reservoirs could meet this future demand in most countries – but there are also other means such as pumping underground water (though most aquifers are depleting), intakes on rivers, seawater desalination, and reuse of waste water

The electricity demand will experience a strong growth (see §2.1 and §5)

- Electricity production is expected to double before 2050
- Energy storage, induced by the development of intermittent energies, is expected to be multiplied by up to 10 before 2050

Dams for electricity production and storage are an option among others (§5)

- In many countries, dam reservoirs can provide cheap electricity and many valuable services. But there are also various other options (thermal plants or renewables)

- In many countries, dam reservoirs can provide energy storage. But there are also various other options (grids interconnection, batteries, smart grids and peak offsetting)

Because of the constant trend towards urbanization, which concentrates on human and economic assets, the need for flood protection increases (§4.4)

- Dam reservoirs can often provide flood mitigation, especially when purposely designed and operated
- There are also other means, with various degrees of efficiency, such as river flow capacity improvement, local protections like levees, better flood and post-flood management, land use regulation

Observation confirms that climate change increases the needs for water storage and flood protection

For water storage for municipal and industrial (M&I) and irrigation use (bulletin 169 and §3.3)

- In many countries, less rainfall occurs. In most countries, there is a higher rainfall variability; with more severe droughts.
- The prospective studies indicate that in many countries climate change will increase the demand for water.
- Almost everywhere, water storage helps adapting to the variability caused by climate change.

For electricity (§3.6)

- Hydropower, as low greenhouse gas (GHG) energy, helps mitigating climate change
- Reservoir hydropower is less sensitive than run-off river hydropower (bulletin 169 and §3.6)
- Hydropower can store energy, and can therefore handle the natural variability in solar and wind production which are the fastest developing carbon-free solutions (§5.2)

For flood management, mitigation or protection

- There will be needs for new protections to cope with the sea-level rise (§3.5)
- The future climate will probably be a more variable climate, with more extreme rainfalls in many regions (§3.5) even if this is not completely established.

For inland navigation

- Inland navigation is a low-CO2 solution, with a renewed interest (§4.5)

3) Since the needs are so high, why so little construction? Four main reasons

The impacts on the social and natural environment. Dams have positive and negative impacts – both of them sometimes strong or very strong – both of them difficult to quantify. The negative impacts have blocked numerous projects, mainly for the following reasons:

Dams alter rivers, yet rivers are one of the most important and fragile ecosystems. Reservoirs inundate vast areas, which also affects flora and fauna.

- With various negative impacts: Reservoirs alter the water quality; Dams constitute obstacles to fish migration; Reservoirs alter d/s flow regime (§6.2)
- And also some positive impacts: Reservoirs create new humid zones; Reservoirs purify water from some pollutants; Reservoirs may provide water for ecosystems during droughts; Reservoirs help alleviate poverty which is a threat to biodiversity (§6.2)
- With often probably an overall short-term negative impact on biodiversity – most species fail to adapt to rapid habitat changes (§6.2)
- The long-term impact can be positive because of the effect on poverty and because of the possible redevelopment of valuable ecosystems (§6.4)

Reservoir inundation is a source of GHG; this is most probably a secondary issue but which has to be sorted out (see Bulletins 169 and 171 and §3.7).

We keep struggling with the important issue of sedimentation (see bulletin 147)

- With impacts on the rivers and ecosystems downstream
- With impacts on the lifespan of the reservoirs

Whereas the overall social impact is usually strongly positive (water, electricity), reservoirs also have negative impacts on specific affected populations

- Population displacement; loss of land, cultural disruption
- Negative impacts on d/s users river when sharing of the water is not appropriate (Bulletin 171)

In many countries, public opinion objects to new dam projects

Dams have a mixed reputation: they are strongly supported by the public opinion in some countries, but are not supported in many others (§7.1.2).

A few international NGOs systematically oppose dam projects. But some of the most important NGOs have recently been more open to a fair appraisal (§7.1.3).

However, from many examples, once dams and reservoirs are in place, in the long run, they gain public support (§7.1.2).

Financing dam projects is complicated – more complicated than financing the alternatives (see Q96GR and §7.1)

Financing dam projects is more complicated than most other investments (§7.1.4)

- Unlike other alternatives, dams require long and sometimes costly investigations. These investigations are difficult to finance at an early project development stage when the decision to implement the project has not yet been secured.

- Dams, like many other projects that cannot be standardized, often experience costs overruns and extended schedules. That is a threat to financing.
- Dams generally provide long-term benefits. But many private investors and funders seek less than 10 or 15 years return on investment, which is rarely possible with dams. Dams then require public funding or guarantees that are not always easy to obtain.
- Reservoirs provide various critical services that are not or only remotely valued in terms of their real economic value (storage of water in case of droughts, storage of water for peak electricity demand, services to the grid).
- However, recently, some private investors decided to invest in dam projects considering long-term return on investment and considering the social benefits associated with the projects.

It is even more complicated in situations where they are most needed

- Private investment is even more difficult in countries where the need for dams is the strongest, because of the investment risks they bear.
- Private investment is almost impossible for irrigation and water supply – except for high-commercial value irrigation.
- Local communities in rural areas of developing countries will need small dams but can certainly not pay for them.

Hydropower from dam reservoirs provides a “better” (very flexible, reliable and allows management of power demands) electricity than other renewables. Yet this is usually not accounted for in the tariffs (bulletin 163)

- Hydropower from reservoir offers short-term frequency regulation and voltage support, and also spinning reserves.

- Energy storage by reservoirs and pumped storage might be critical for the grids to meet load and production variations.

In the competition with other projects, dam projects often loose even though dam projects have objectively significant advantages (Bulletin 171 and §5).

Competition with classical thermal plants

- Gas and coal power plants are being constructed at a very impressive pace. Several countries consider gas and coal their main option for future development.
- The thermal plant industry does a lot of research and development to become "cleaner" and also a lot of marketing to promote this.
- When there is a potential, hydropower projects should be in a position to compete (lower prices, less GHG). But thermal plants are much easier to implement: less risks and lower investment costs. This is the issue of short-term vs long-term benefits.

Competition with solar and wind farms

- The technical and economic development is impressive. The costs drop, especially for solar power.
- Hydro cannot compete with solar and sun. But hydro should find its place in a renewable energy mix:

- in countries where the resource is water rather than sun or wind
- everywhere in association with solar and wind (intermittent) to provide guaranteed power and grid stability, and to optimize solar-wind by storing some excess energy
- everywhere when other services are sought (water storage, flood protection, drought mitigation)

Competition with batteries (§5.4)

- Batteries are more and more considered for mass storage. They now compete with other storage means (diesel, gas or small pumping storage plants (PSP).
- Batteries and ultra-capacitors are easier to implement than PSP and can handle very short-term frequency variation. They are, however, not in a position to provide mass storage like PSP.
- Considering the high ecological footprint of batteries, it is important to keep improving small and medium scale PSP so that they can be cost-competitive for a large range of peaking power (MW) and storage (MWh).

Competition with desalinization plants

- Desalted water is more and more considered in various countries.
- The energy costs still make them less efficient than other alternatives when these alternatives are available.

Competition with direct withdrawal from groundwater or from rivers

- Direct withdrawal from rivers and the sometimes associated alluvial groundwater is an option, as long as sharing the river resources during the driest periods remains possible
- Withdrawal from deeper groundwater is often cost-effective, but usually not sustainable. Artificial repletion of aquifers is an option, but in rare circumstances only
- Dam reservoirs, though more expensive than direct withdrawal, might provide storage in dry seasons and spare over-used groundwater resources

4) Considering this big picture of needs and challenges: what does the future hold for dams?

Dams remain the only option to meet some needs

Irrigation, when there is no alternative (no groundwater and rivers that do not provide enough water during dry seasons)

Water supply when there is no alternative and the sea is too far

Large dams and reservoirs are often projects that are developed at a regional or country scale; there are no (or almost no) examples of countries that could develop without a minimum level of large reservoirs equipment.

There may be a “minimum level of equipment” of large dams in every region, in every country, that could provide:

- water in every season, at low cost
- guaranteed power, at low cost, in every season

This “minimum level of equipment” varies in every country, mainly depending on the climate context and wealth (the higher the living standard, the more possible it is to discard the dam solution and pay for more expensive options)

Meeting this “minimum level of equipment” could gain general approval, but is not without challenges:

- Financing. The return on investment for such projects is very long and the beneficiaries often do not have enough revenue to pay for them
- Sometimes inadequate benefit sharing, which could stir righteous opposition from local or international public opinion (NGOs)
- Sedimentation. In some countries, the lifespan of large dams is strongly affected by sedimentation and this loss alters the services.

We believe there is a future for dams beyond the “minimum level of equipment”. The COEC&S recommends to support this opinion through the following:

Large dams provide essential services, but also have negative impacts on the environment. We could commit to maximize the services and minimize the impacts (see below).

Small dams provide essential services to local communities, but they are often too expensive for these communities. And we still struggle to find the correct engineering requirements for these dams – between the large dams' requirements and no requirements at all (§5 and Bulletin dedicated to "Low Hazard Small Dams").

We should keep developing new ideas that optimize water storage or electricity production and storage while minimizing costs and impacts. The competing technologies (desalination, thermal plants, solar and wind farms, marine energy systems, batteries) develop considerable research and development (R&D) efforts. Our profession does certainly much less (§8 and dedicated Bulletin under preparation by COECS).

5) Some solutions and recommendations

Develop projects that are exemplary

Dam projects require qualified owners and developers and supportive regulators, who will be able to handle the various issues and long-run planning of such projects' development, from the very beginning to the long-term operation. (§7.3)

- ICOLD could prepare basic guidelines for a dam developer or dam owner (guidelines that would be different for small and large dams) [Committee F?]

Continuing efforts to guarantee dam safety of large dams. (§7.2)

- Recommend to the "Dam safety" Committee that they prepare a series of "recommendations to regulators for safer dams". These recommendations could focus on non-structural measures (review of new projects by independent panels; periodic review of dam safety; surveillance of the first impoundment; written and tested flood instructions for every dam).
- Most fatalities today come from faulty operation of gated spillways. Research and a bulletin on this issue would be useful.
- Surface erosion (rock, earthfill covers) is an important issue that has not been dealt with so far.

This probably deserves a specific committee or a sub-committee of the committee on hydraulics.

Promote efforts to find a correct approach towards dam safety of small dams (bulletin under preparation by COECS). This approach requires distinguishing the low hazard small dams (LHSD) for which different conception rules can optimize the economy of the project.

- We need a simple tool to quickly assess whether a small dam is high hazard or low hazard.
- We probably need a different set of design standards for the smaller dams. This set could be specific to different regions with adaptation to local hydrology, geology, and topography.
- We need innovative solutions for these LHSD, to lower their cost and/or delay of construction although keeping or improving their safety and durability.
- We need improving the governance of LHSD, particularly in some developing countries, with a better implication of the owner, the designer, the operator and other stakeholders.

Projects that optimize the use of stored water and the use of flood storage volumes [see Bulletin 171]

- Promote the use of hydrological models for simulation and multipurpose operation of reservoirs. (§8)

Provide better data for better projects

In many regions, hydrological data are scarce and not sufficient to properly design the projects

- Hydrology – and especially run-off – is often poorly assessed because of a lack of adequate measurement equipment. Installing, operating and maintaining a reliable hydrological observation network are difficult and rewarding at medium term only. Measures in this direction, as well as regional-scale hydrological syntheses would help developing more robust economic models.

- International funding agencies could certainly help in financing such networks and regional-scale studies.

Small- and medium-size projects usually do not have enough resources to properly perform complete environmental impact assessments

- A classical means to solve this consists of preparing a “Strategic Impact Assessment” at a broad scale (usually a river basin or a sub-basin), which helps devising where and how dam reservoirs could be considered, and with which environmental and social specifications [see Bulletin 171].
- This would allow including the fact that environmental issues shall be balanced with the intensity of the human needs and that the income of the countries shall be considered. There cannot be a common standard for the whole world.
- Such studies should also be supported by international funding.

Suggest ways to maximize benefits from dam projects

Reservoir projects are essentially multipurpose, even if they are not designed this way (there are at least some “environmental” purposes even when not intended). They provide economic, social and environmental services that should be maximized.

- The projects’ acceptability, the image of dams and the services that our profession provides would be enhanced if we could every time take this multipurpose aspect into account.
- This principle is already set out in other bulletins (Bulletin 171) but needs to be more widely used.
- This is not only words and good intentions: it can be put into quantitative practice through hydrological modelling of reservoirs and operation rules.

Low head dams are specific structures, different from large dams. They require a specific design, construction and operation.

- Large progresses are possible to minimize costs, increase performances and enhance the safety and durability of small and low-head dams.
- ICOLD has published a bulletin on the issue of small dams that provides state-of-the-art guidelines mainly based on the experience of western countries, but these guidelines are not always perfectly adapted to the conditions of developing countries with their funding, human and material issues. There are strong opportunities for further research and innovation, especially for dams with low consequences in case of failure.

Flood mitigation dams are specific structures, different from large dams. They require a specific design, construction and operation.

- Progresses are possible to minimize costs, increase performances and enhance the safety and durability of flood mitigation dams.
- Our committee will include a specific section on dry reservoirs (with flood mitigation as a single purpose) in a specific bulletin.

Help financing or developing projects when they are good projects

Some hydropower projects are abandoned only because preliminary studies (technical and environmental) are long and costly, hence difficult to finance. This should be corrected.

- The better option would be to finance preliminary studies on public funds to allow their future development by private investors. In developing countries, funding agencies could play a role by taking charge of these studies: projects portfolio analysis, preliminary studies, strategic impact assessment.

Benefits from dams and reservoirs are for some of them non-monetary – although sometimes essential or even vital. Besides, dams have a long lifespan. These parameters are not considered in economical comparisons among alternatives. These facts imply that the projects should not be paid only by future revenues; they also deserve public financing – or at least a fairer comparison.

- The best tool to perform an unbiased comparison of alternatives requires a complete “life cycle assessment”, so as to value non-market costs and services. In that view, progress is possible in the development of shared methods to assess total costs. This should enhance the attractiveness of well-designed hydroelectric projects.
- ICOLD may try to develop such a tool – which is not an easy task.

Define appropriate and supporting feed-in tariffs that value the fact that reservoirs provide guaranteed power and grid regulation tools (frequency, voltage).

- It is certainly inappropriate to utilize similar kWh prices for predictable and stable HPP reservoirs electricity and for intermittent solar or wind production.
- This is a difficult issue that ICOLD can hardly cover. One possible action would, however, be to gather best-practice tariffs of various countries and disseminate them.

Promote funding that covers the 10 first years of operation

- In the case of public funding, the allocation should also cover a 10-year assistance to the owner, to ensure optimization and adequacy of the operation procedures, surveillance of the dam during the first filling and first years of operation, and assistance to and training of maintenance teams.

Help securing IPP projects in hydropower for both parties

- Contracts are often based on FIDIC rules, which provide a sound basis, but which could be further tailored to HPP projects.
- It would be useful to prepare specific “HPP additions” in addition to FIDIC red, yellow and silver books, including specific issues regarding the sharing of risks (with focus on what is dam-specific or HPP-specific: hydrology of floods and resources ; borrowed materials ; large tunnels ; etc.) and

including standard guidelines to determine fair and unbiased remuneration of the private investor.

<u>Objectively demonstrate the role of reservoirs in adaptation to climate change</u>

Promote regional hydrological models including climate change trends to assess the resources and needs at various time horizons

- The models should include the possible increase of drought frequency and seriousness. They may then assess the reservoir capacities required to handle climate change at various time horizons.

Keep working on the issue of GHG emission (TC "Environment" or "Climate Change"), with possibly two goals:

- Integrate the recent results from academic researchers for the assessment (§3.7).
- Secure best practices for future projects (§3.7).

<u>Keep working on the sedimentation issue (TC "Sedimentation"), and keep disseminating the results that are achieved in various countries, in terms of:</u>

- Soil and water conservation in catchments, which might be an option in some specific circumstances
- Hydraulic modelling of sediment transport
- Technologies: Flushing, Dredging, Sluicing, Bypassing…
- Management of the release of sediment d/s of reservoirs. What is the amount and quality of sediments that can be released to the rivers?

<u>Promote innovation and support new ideas beyond the strict domain of innovation for the design and construction of dams and appurtenant structures (§8)</u>

New type of reservoirs that solve some of the above-mentioned issues

- Off-stream storage
- Empty reservoirs for flood protection

- Underground dams

Reservoirs using sea water

- Seawater PSP
- Tidal basins for energy and coastal protection

New utilizations of reservoirs

- Solar-hydro or wind-hydro solutions
- Reservoirs with biodiversity as a primary purpose

Promote innovation to increase the services delivered by reservoirs

- Innovative solutions to raise reservoir operation levels (spillways, dam strengthening, safety of dams at very high water elevation)
- Innovative solutions to reduce evaporation
- Innovative solutions to remove sediments

Better resource allocation

- Innovative approaches in hydrological models, hydrometry, economic assessment, and governance of reservoirs [see Bulletin 171]

Promote innovation and expertise in the field of dam safety (§7)

- A better understanding of external erosion, first factor of dam failures
- A refined understanding and engineering of spillway gate operations
- Cyberthreats

Promote innovation and expertise in the field of freshwater biodiversity associated with dams (TC “Environment”)

- The scope of works probably exceeds the strength and capacities of one TC
- Innovation on a regional-scale approach because the environmental issues depend a lot on the regional climatic and physical conditions.

- Reservoir physical chemical and biological cycles (including impact on human health). Improve our (scientific and technical) knowledge, and disseminate it, so that practical ideas of improvement may be sought.
- Biodiversity of reservoirs. How to get the most out of existing reservoirs in terms of biodiversity. This includes fish migration, birds, mammals, etc. (§ 6.4)

Promote innovations with impacts on costs and schedule

- Innovations that could speed up the projects in the development phase
- Innovations that could speed up the projects during implementation (e.g. speed up the construction during dry periods)

To get new ideas adapted to every region, obtain the input from representatives of every region, including the regions that are often under-represented

- The ICOLD board should devise ideas that could improve the attendance or the contributions from a larger set of countries
- The Committees should devise ways to make sure they can provide their input. That could be through sub-committees.

2. CURRENT TRENDS IN DAM CONSTRUCTION

Water demand is growing rapidly for M&I, irrigation and hydropower uses (see Sections 2.1 and 2.2). At the same time, several regions of the world are experiencing a decrease in the availability of water due to climate change. An aggravating factor is the expected increase in rainfall irregularity including, location, duration and magnitude (see Section 3).

One consequence of the increased demand for water and the irregularities of supply is that more storage is necessary which requires building new reservoirs and – according to the figures in Sections 3 to 5 – in large numbers and rapidly. However, there is no clear trend in that direction today.

In fact, the following paragraphs and figures in Section 2 present current trends that indicate that the pace of construction of hydropower, water supply and irrigation dams is slowing to the extent that present and future needs of populations will not be met. Section 7 of Theme A presents many of the reasons for this adverse trend of slow construction and development of dams. Consequently, the COEC&S strongly urges national committees of ICOLD to undertake efforts to change these adverse trends.

2.1. DAM CONSTRUCTION FOR HYDROPOWER

The demand for electricity will continue its rapid growth[1]. This growth will mainly come from non-OECD countries. Based on the average scenario, the demand for electricity is likely to increase from 18 000 TWh by 2011 to 38 000 TWh by 2050. The share of hydropower is about 16% today. Maintaining this share would mean doubling the hydropower production in 40 years. An additional 1 000 GW of installed capacity (25 GW/year) would be necessary.

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[1] International Energy Agency. (2014). Energy Technology Perspectives 2014 (ETP 2014).

Another driver for hydropower construction is energy capacity and energy storage construction storage that utilizes dams and reservoirs, and which allows operators to follow system energy load efficiently while also providing more reliability in the system. Consequently, it is important to track both to assess future trends. In Europe, for example, energy storage capacity reached 45 GW in 2011. The figure of 45 GW can be compared with the current electricity production in Europe, which is about 3 200 TWh. The share of available energy storage in Europe, related to power generation, is 14 MW/TWh[2]. The installed storage capacity worldwide in 2009 was 127 GW[3]. Compared with global electricity production, this corresponds to 7 MW/TWh. The world figure is lower than the European figure, which may be partly explained by the fact that Europe is more equipped with intermittent and unpredictable energy sources such as solar and wind. Extrapolation of these figures shows a significant need for energy storage at 14 MW/TWh; the global need would be above 400 GW in 2050. But this analysis is very approximate and the resulting forecasts of needs are largely uncertain, based on other considerations. The International Energy Agency[4] predicts significantly higher needs at 1 500 GW by 2050.

These combined figures indicate a need for some additional 35 GW to 60 GW per year.

According to the World Register of Dams (ICOLD), a recent acceleration in globally installed hydropower capacity associated with dams[5] is acknowledged. A total of 80 GW were installed in 10 years between 1998 and 2008 (8 GW/year) and 160 GW between 2008 and 2015 (more than 20 GW/year).

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[2] ICOLD. (2008). Dams for Hydroelectric Energy.

[3] Ingram, E. A. (2010). Worldwide Pumped Storage Activity, HRW-HYDRO REVIEW WORLDWIDE.

[4] International Energy Agency. (2014). Energy Technology Perspectives 2014 (ETP 2014).

[5] The figures from the World Register of Dams only consider hydropower capacities *associated with dams*. The current total world hydro capacity is at least 1 122.9 GW (generation 3 901.7 TWh/year), according to the Hydropower and Dams World Atlas, 2016. The World Register of Dams only reach 1 047 GW, part of which is being associated with projects under construction.

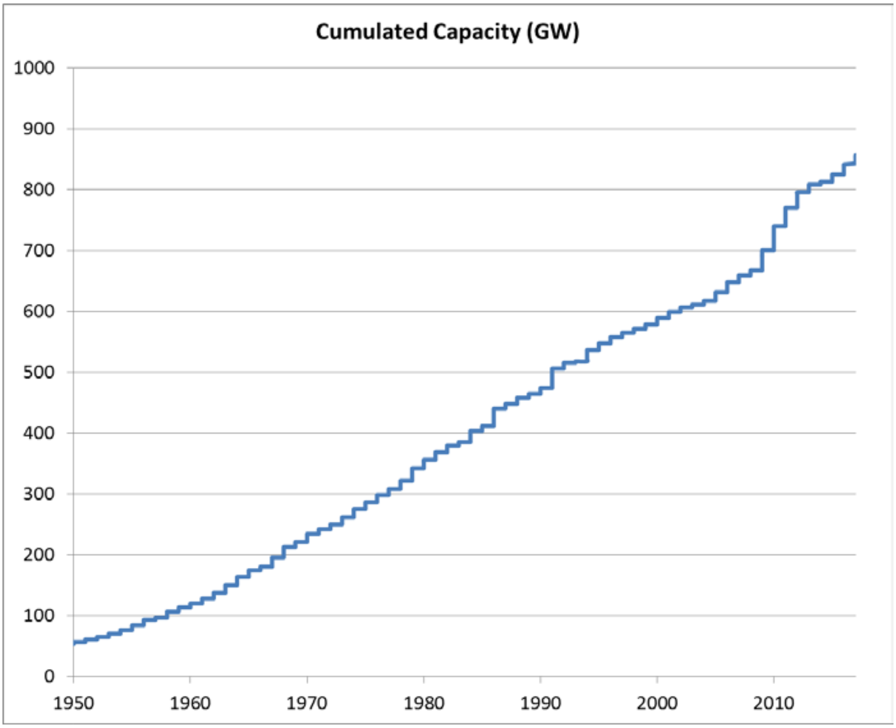
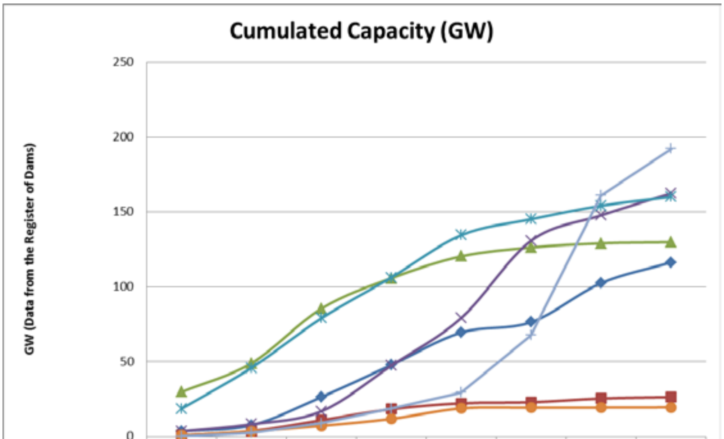


Fig. 2.1

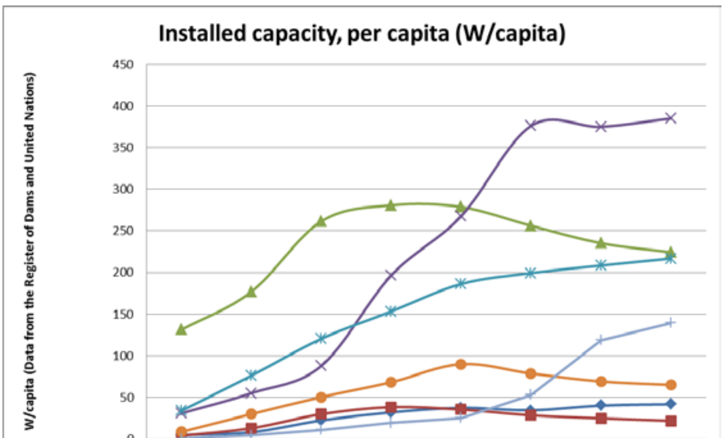
Installed capacity associated with dams (GW), World Register of Dams ICOLD (data slightly modified, total capacity probably underestimated)

Note: The World Dam Register data were extracted in December 2017. The graph above does not reach 1 047 GW, because it ignores 250 GW for which the Register does not mention a date of completion, i.e. projects under construction or projects already in operation but without a date of completion in the database.

The recent acceleration of the figure above is a result of an increased pace of construction in a very small number of countries: China, Turkey, and some countries of Asia. There is also an increase in Africa (Ethiopia, Angola, Cameroon, and Uganda, particularly), but the pace in Africa does not meet the expectations.



	1950	1960	1970	1980	1990	2000	2010	2015
Asia exc. China	3	7	26	48	69	76	102	116
Africa	1	4	11	18	22	23	25	26
North America	30	49	85	106	120	126	129	130
South America	3	8	17	47	79	131	148	162
Europe	19	46	79	106	135	145	154	160
Australasia	1	3	7	12	19	19	19	19
China	0	3	9	19	29	68	161	192



	1950	1960	1970	1980	1990	2000	2010	
Asia exc. China	4	8	22	32	37	34	40	42
Africa	4	13	30	38	35	28	25	22
North America	131	177	261	281	279	256	235	224
South America	31	55	87	196	267	376	375	385
Europe	34	76	120	153	186	199	208	217
Australasia	8	30	50	68	90	79	69	65
China	0	4	11	19	25	53	119	139

Fig. 2.2

Hydropower installed capacity associated with large dams (from ICOLD Register of Dams)

The hydropower installed capacity per capita is growing in China and Turkey as well as in some parts of Africa, stable in Europe, South America and Asia, and decreasing in North America and Australasia.

The graphs above show spectacular differences in the degree of hydropower equipment across the world.

The differences come from the share of hydro within the mix (more than 50% installed capacity in South America and less than 6% in North America) and also from the degree of development of the electrical installed capacity (2.25 kW/capita in North America, 0.13 kW/capita in Africa).

Globally, the share of hydro in terms of electrical installed capacity has decreased.

Table 2.1
Share of hydro in terms of electrical installed capacity (source: ICOLD World Register of Dams and US Energy Information (EIA) data)

	Asia exc. China	**China**	**Africa**	**North America**	**South America**	**Europe**	**Australasia**	**World**
2000	11.2%	20.9%	21.2%	13.4%	70.4%	13.4%	28.3%	17.3%
2010	10.0%	16.6%	18.4%	10.5%	55.6%	11.4%	19.7%	14.5%
2015	8.8%	12.7%	15.2%	10.1%	47.9%	10.5%	15.7%	12.8%

This trend can be considered problematic, since the overall electrical capacity must grow to meet demands, and hydropower helps to reduce the carbon footprint associated with climate change. The shift to non-hydropower capacities is partly in favour of renewable energy (sun, wind) and mainly in favour of fossil fuels.

2.2. DAM CONSTRUCTION FOR IRRIGATION

Table 2.2 below provides indications on the estimated trend of irrigated surfaces without climate change, and without change in agricultural practices[6].

Table 2.2

Evolution “without climate change” of irrigation withdrawals, Food and Agriculture Organization of the UN (FAO) 2011

Year	1960	2005	2050
Irrigated area (millions ha)	141	287	318
Water resources withdrawal for irrigation (km^3)		2600	2900

UNESCO presents a more complete picture, including various scenarios of economic development[7]. Under these scenarios, the increase in withdrawals for agriculture would range from 20–40% ("sustainable development" scenarios) to more than 100% ("market-based" scenarios).

The projections for 2050 are uncertain for several reasons:

- Climate change affects the demand for irrigation because of the change in rainfall patterns and the change in evapotranspiration (ETP is increased by the rise in temperature, but reduced by the greater CO_2 availability).
- Changes in agricultural practices may in some cases optimize the use of water.
- Changes in diets may lead to a shift towards more water-demanding food production. The development of biofuels points in the same direction.

[6] Food and Agriculture Organization (FAO) of the United Nations. (2011). *FAQ Water Reports: Climate Change Water and Food Security*. Rome, Italy. Retrieved from http://www.fao.org/docrep/014/i2096e/i2096e.pdf.

[7] UNESCO. (2012). Water footprint scenarios for 2050 – Research Report Series No. 59.

The trend for dam construction for irrigation purposes is unclear today. According to the World Register of Dams (ICOLD), the construction pace of dams that are primarily used for irrigation remains below what it was between the 1960s and 1980s.

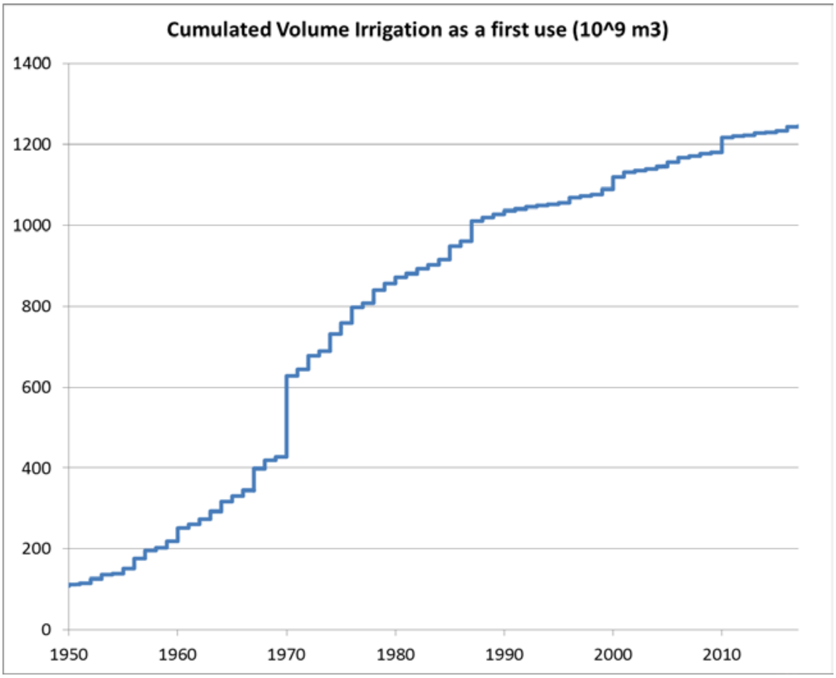
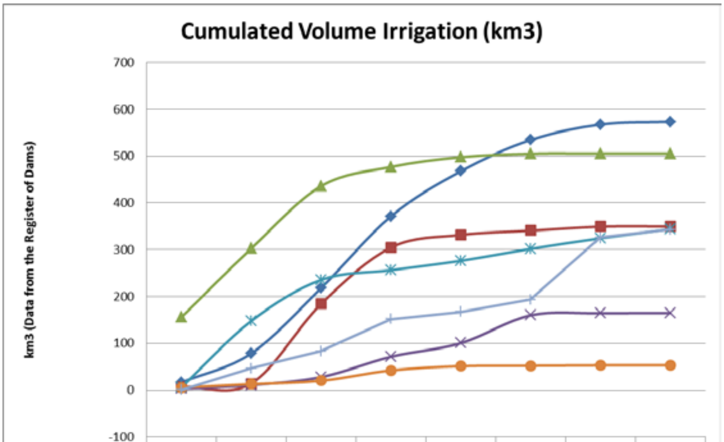


Fig. 2.3

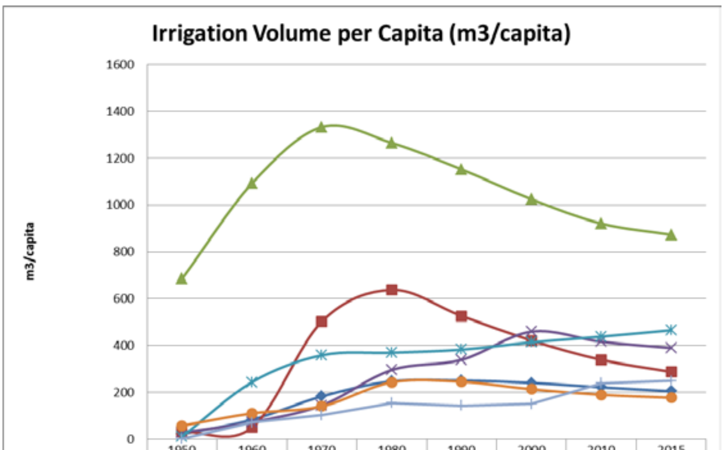
Cumulated storage capacity of large dams with irrigation as a first purpose (World Dam Register ICOLD – data slightly modified by the author)

(*) Not accounting for loss by sedimentation

An analysis by regions confirms that the rate of construction of new irrigation reservoirs has decreased throughout the world.



	1950	1960	1970	1980	1990	2000	2010	2015
Asia exc. China	16	78	218	371	468	535	568	574
Africa	7	14	184	305	332	341	349	350
North America	156	302	436	477	498	505	505	506
South America	3	11	28	71	100	160	164	164
Europe	6	148	236	256	276	302	324	344
Australasia	6	13	20	42	51	52	53	53
China	0	46	83	151	167	193	326	343



	1950	1960	1970	1980	1990	2000	2010	2015
Asia exc. China	21	83	183	248	251	240	221	205
Africa	31	49	503	637	526	422	339	287
North America	685	1092	1333	1265	1152	1024	921	873
South America	29	73	145	296	339	459	416	389
Europe	11	244	359	369	382	414	438	465
Australasia	58	110	140	243	245	213	190	177
China	1	71	102	154	144	151	240	249

Fig. 2.4

Storage capacity of large dams with irrigation as a first purpose (from ICOLD Register of Dams)

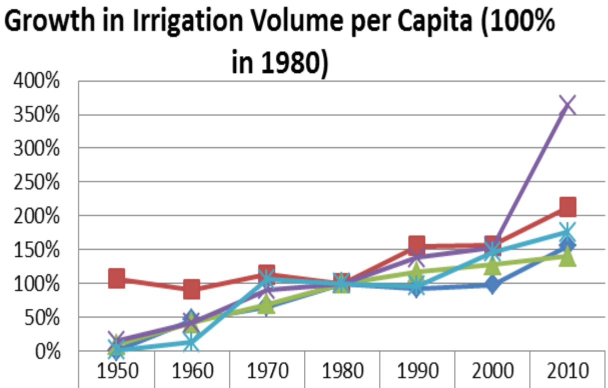
According to this figure, there are only two regions where the irrigation volume from large reservoir keeps pace with the population growth, namely China and Europe.

2.3. DAM CONSTRUCTION IN SELECTED COUNTRIES

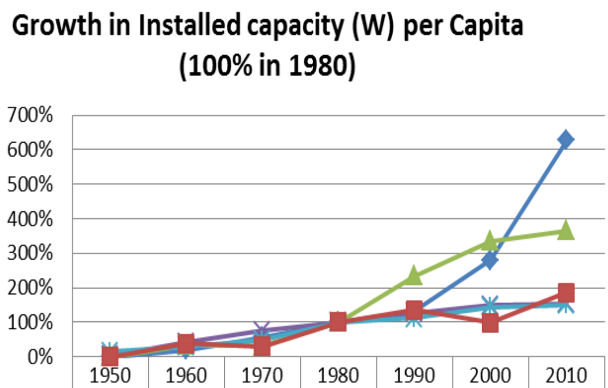
The discrepancy between the needs (demand for electricity, demand for water resources) and the rate of the dam construction is a result of various constraints that are presented in Section 7.

These constraints are not perceived with the same intensity all over the world. Several countries engage in the construction of new reservoirs. This is clearly the case of China. This is also the case of other countries all over the world, representing various conditions of location, level of development or water availability.

The figures below illustrate this affirmation, by showing various countries with a positive trend in either reservoir volume for irrigation or hydropower installed capacity.



	1950	1960	1970	1980	1990	2000	2010
China	1%	46%	66%	100%	93%	98%	156%
Algeria	107%	91%	114%	100%	155%	156%	212%
Japan	10%	42%	70%	100%	117%	128%	141%
Portugal	15%	42%	91%	100%	139%	154%	364%
Ukraine	2%	14%	106%	100%	97%	147%	176%



	1950	1960	1970	1980	1990	2000	2010
China	0%	21%	58%	100%	133%	280%	627%
Turkey	0%	33%	32%	100%	235%	335%	366%
Portugal	3%	42%	75%	100%	128%	150%	155%
Brazil	16%	31%	49%	100%	112%	144%	151%
Ethiopia	0%	39%	30%	100%	137%	100%	186%

Fig. 2.5

Some countries with positive trends of large dam construction during the last decades

In a perfect world, the rate of development of dam construction would be linked to a fair appraisal of resources, needs and comparison of alternative solutions. In fact this is not the case. The rate of dam construction is mostly influenced by (1) the availability of financial facilities, and (2) the level of political and social inclination or reluctance to build dams when compared with other solutions. See Section 7.

The map below illustrates the present dam activity. It is a compilation of all large dams built after 2000, or that are under construction and included in the ICOLD Register database.

The purposes of these dams are summarized in table 2.3 (one multipurpose dam would be counted several times in this table).

Table 2.3
Purposes of dams built after 2000

Type of usage	Number of dams
Hydroelectricity	1243
Water supply	727
Flood control	518
Irrigation	1694
Fish farming	35
Recreation	95
Navigation	43
Other	215

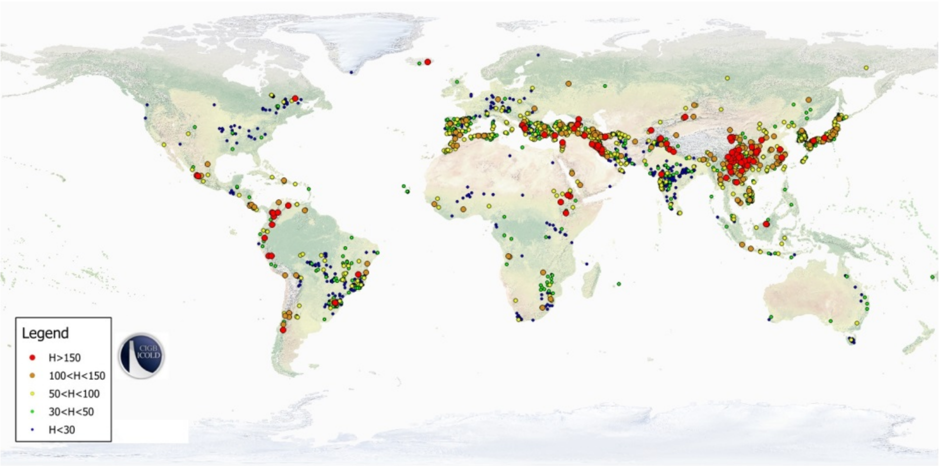


Fig. 2.6
3 687 dams built after 2000 or under construction
Data from *France/CFBR – ICOLD/Committee O* – Patrick Le Delliou - 16/03/2018

This map only hardly coincides with maps of present or future water deficit index, or maps of hydropower potential or maps of population growth. Multiple factors intervene; among them, the political factors certainly explain most of the variations.

3. CLIMATE CHANGE

3.1. SCOPE AND EXTENT

The ICOLD Committee on Global Climate Change (COCG) produced a Bulletin in November 2016 that presents the facts and uncertainties associated with climate change, illustrates how this will have an impact on dams and reservoirs, and presents some recommendations. The COCG based its work on the consensus findings of the IPCC.

The IPCC Working Group III, in its report entitled *Summary for Policy Makers – Climate Change 2014: Impacts, Adaption and Vulnerability* [8] offered the following observations:

- “In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans.”
- “In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (medium confidence).”
- “Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes with varying degrees of success.”
- “Adaptation is becoming embedded in some planning process, with more limited implementation of responses (high confidence)”

Climate change, regardless of its cause, requires that impacts to water supply, energy and other dam purposes be dealt with by

[8] Intergovernmental Panel on Climate Change Working Group III. (2014). *Summary for Policy Makers – Climate Change 2014: Impacts, Adaption and Vulnerability***.** Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf.

ICOLD and its technical committees. As stated by the COCG, these impacts may be strong, and not entirely predictable.

Besides, these impacts may cumulate with other changes in the need for fresh water and electricity. Research by others indicates that: “Between now and 2035 worldwide energy consumption is expected to double.”[9] Also, many experts predict that the global population will increase to about 10 billion by 2050. [10] The worldwide population is currently utilizing current energy and water resources at levels that will create shortages now or soon. These demands will continue to grow with the population growth and with changing economics and centres of population. Water usage in developing countries is likely to increase by 50% by 2025, while usage in developed countries is projected to increase by about 18%. Energy and water resource management will be a global challenge for decades to come.

Dams and associated hydropower are responses to the need for more and better water resources and energy management. However, climate change has affected and will continue to affect global hydropower production and water resources management.

Taking account of climate change is a three-dimensional issue:

- impacts (of variable natural conditions on structures and projects);
- adaptation (of people and environment to the new conditions);
- mitigation (of climate change).

[9] International Water Management Institute. (2011). *Climate Change & Water.*
[10] Nexus of Water and Energy. (2011). Facts *& Figures.*

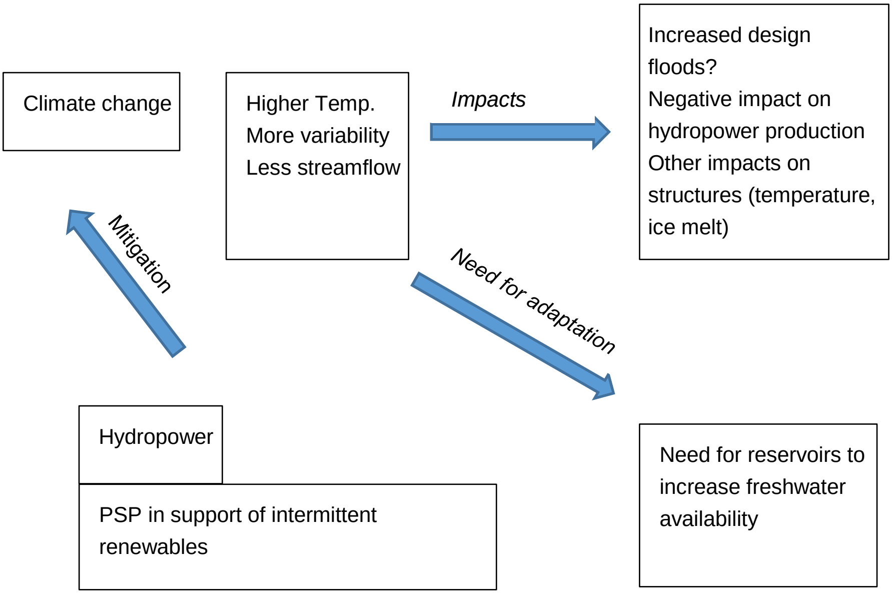


Fig. 3.1

Three dimensions of climate change issues: impacts, adaptation, mitigation

Each region of the world will face challenges resulting from climate changes including floods, drought, rapid glacial melt, increased temperatures, and variability in timing, location, and amount of precipitation. Increased temperatures have been observed with scientists stating that 2014 was the warmest year since reliable record-keeping started in the 1800s. The NOAA (U.S. National Oceanic and Atmospheric Administration) and NASA announced that 2106 was the warmest year since modern record-keeping began in 1880 and that 2017 was third; 2017 is the 41st consecutive year with temperatures above the 20th Century average. All of these factors will influence water supply and hydroelectric generation, as well as dam safety.

The Middlebury College study[11] noted that: “Though all countries are susceptible to the effects of global climate change, developing countries are inherently more vulnerable to the effects of climate change because they have fewer disposable resources to spend on

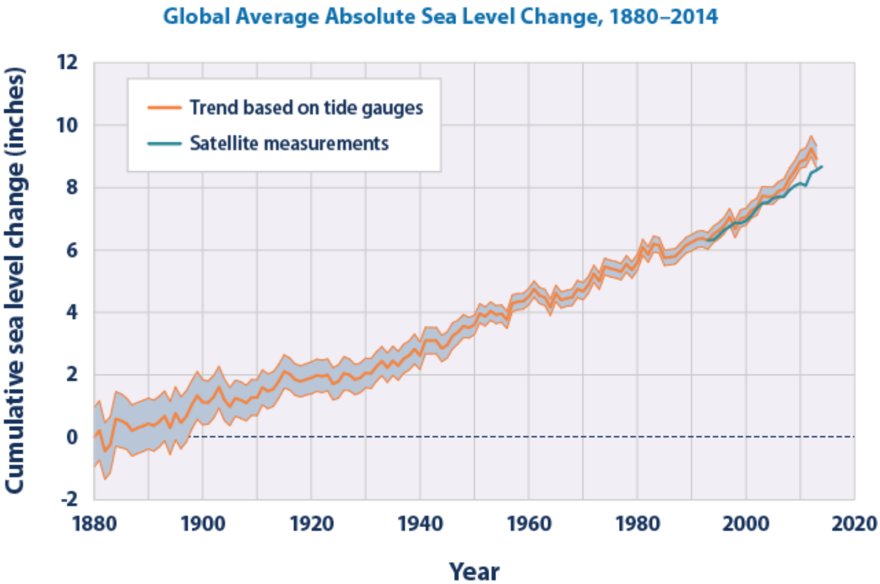
[11] Middlebury College Environmental Studies. (2011, Fall). Senior Seminar, Hydropower Vulnerability and Climate Change 2011.

unexpected extreme weather events and on adapting to long-term alterations.”

3.2. CLIMATE CHANGE ALREADY HAS VISIBLE EFFECTS

Climate change is not only a threat for the future, it already has visible consequences.

Some of the global consequences have been monitored for decades; this is notably the case for the sea level rise and the melting of ice pole caps (see below).



Data sources:

- CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2015 update to data originally published in: Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. Surv. Geophys. 32:585–602. www.cmar.csiro.au/sealevel/sl_data_cmar.html.
- NOAA (National Oceanic and Atmospheric Administration). 2015. Laboratory for Satellite Altimetry: Sea level rise. Accessed June 2015. http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_timeseries_global.php.

For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at www.epa.gov/climatechange/indicators.

Fig. 3.2
Sea level rise

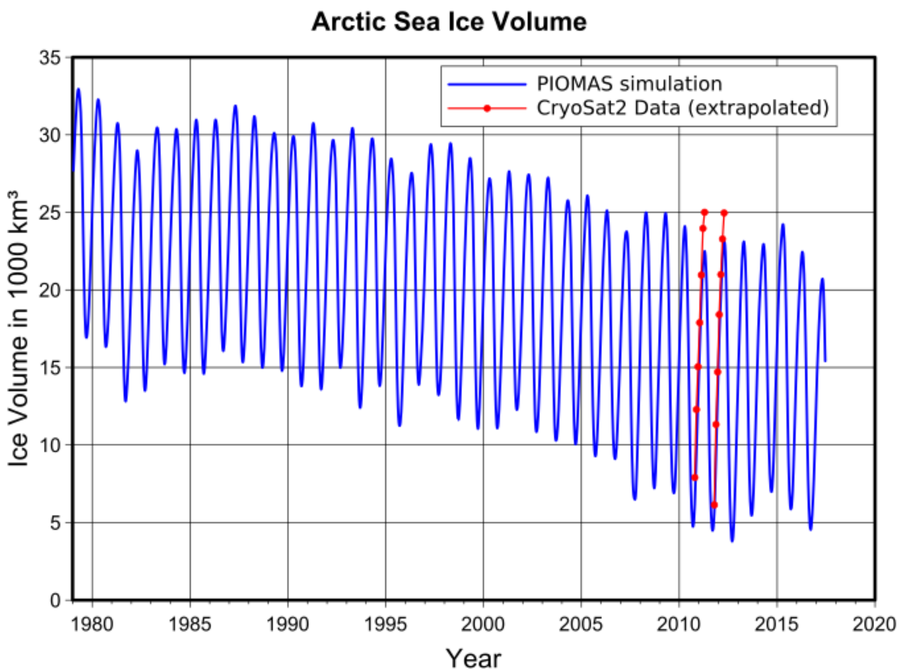


Fig. 3.3

Arctic sea ice volume change - Data sources: based on published data of Polar Science Center, University of Washington; published through wikicommons.

However, the most direct impact on human livelihood might relate to continental water. More severe and more frequent droughts are reported in various regions, as reported below.

3.3. DROUGHTS

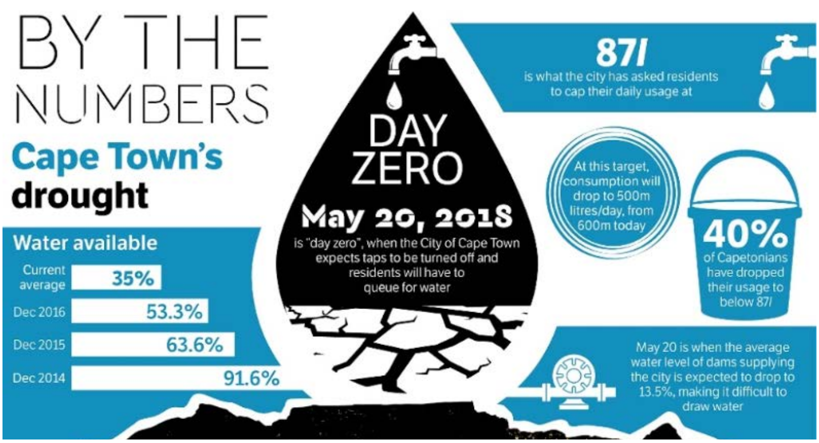
Major droughts have occurred during the recent past years. Whether they are related to climate change or to natural climate variability is probably impossible to assess. Whatever their cause, they have had severe impacts.

One out of many droughts is illustrated here. It attracted some attention worldwide because it hit Cape Town, the second largest city in South Africa to the point where water supply could have been suspended.

The Cape Town 2018 drought

South Africa included as part of the larger Southern African Development Community (SADC) experienced a regional drought from 2014 to 2016 which had affected about 41 million people across the region. The 2015–2016 El Niño event has resulted in the worst drought in much of southern Africa in 35 years. It will take a number of years for the region to recover owing to the magnitude of this drought. The countries which were most affected include Angola, Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe. [1]

In addition, special mention must be made of the Western Cape which relies on winter rainfall contrary to the rest of South Africa, and more specifically Cape Town, which is the second largest city in South Africa and which experienced water supply shortages that escalated to the level of a disaster. This was because 2017 was one of the driest years in recent decades and followed two successive dry winters. Such multi-year droughts are infrequent, perhaps occurring as rarely as once in a millennium. The most stringent water restrictions were subsequently implemented in Cape Town, namely Level 6B water restrictions (during February 2018), which asked residents to limit daily usage to 50 litres per person. [1] There is good evidence to expect similar, possibly more severe, and likely more frequent drought events in the future requiring more resilient water supply infrastructure.



[1] Regional Inter-Agency Standing Committee (Riasco). (2018). Response plan for the El Niño-induced drought in Southern Africa. May 2016 – April 2017.
[1] City of Cape Town. (2018). Residential water restrictions explained retrieved from http://www.capetown.gov.za/Family%20and%20home/residential-utility-

services/residential-water-and-sanitation-services/Residential-water-restrictions-explained.

The Cape Town “day zero” crisis could possibly hit other cities. As illustrated by this excerpt from the Times of India, the fact that climate change might severely affect water supply is now generally accepted.

THE TIMES OF INDIA

Water taps may completely dry up in India, warns study

PTI | Apr 12, 2018, 10.05 PM IST

LONDON: Shrinking reservoirs in India, Morocco, Iraq and Spain could result in water taps going completely dry in these four countries, a study based on a new early warning satellite system has warned.
According to the developers of the new satellite early warning system for the world's 500,000 dams, shrinking reservoirs in India, Morocco, Iraq and Spain could spark the next "day zero" water crisis, The Guardian reported.

The system has named countries where shrinking reservoirs could lead to the taps completely drying up, the study said.

Fig. 3.4

Climate change impact on water resources is now a widely acceoted fact

3.4. ASSESSMENT OF THE IMPACT ON WATER SUPPLY

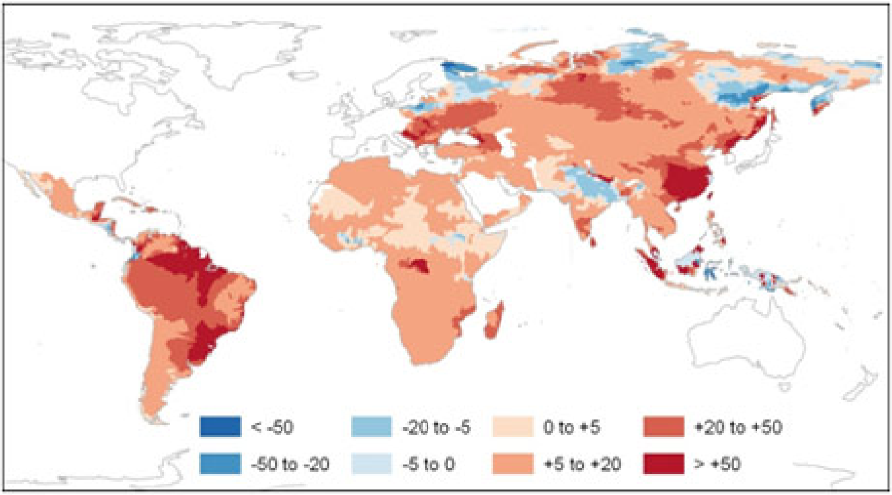


Fig. 3.5

Projected percentage change in water deficit index 2030

The water supply in both developed and undeveloped countries will be influenced by climate change. The World Bank notes in its report on Water and Climate Change[12]: "For poor countries that have always faced hydrologic variability, climate change will make water security even more difficult and costly to achieve." Also, climate change will likely create water shortages and "Many developing countries of the developing world will have to cope with droughts and/or the growing risk of flooding (Figure 3.1). Currently 1.6 billion people live in countries and regions with absolute water scarcity and the number is expected to rise to 28 billion people by 2025."

ICOLD is well aware of the relationship between water supply and energy, as both often require dams and reservoirs to manage their efficient use and availability. However, as we proceed further into the 21st Century, the development of more small dams of which the principal purpose is water supply may be the most practical and financially viable option to help ensure water supply reliability.

However, impacts to water supply reliability are not the only impacts that are water related. The World Health Organization (WHO) notes in its policy paper Vision 2030[13] :

- ”Climate variability is already a threat to water supplies and sanitation”
- “Floods are normal occurrences that continue to cause shocks for affected populations”
- “On a smaller scale drinking water infrastructure can be flooded and put out of commission for days, weeks, or months.”
- “Where flooding of sanitation facilities occurs … the flooding may distribute human excreta and its attendant health risks …”

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[12] The World Bank Group. (2015). *Water and Climate Change.*

[13] World Health Organization. (2009). *Summary and Policy Implications – Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change.* Retrieved from http://www.who.int/water_sanitation_health/vision_2030_9789241598422.pdf.

- “Droughts occur unpredictably, worldwide. In many places they are likely to become more frequent and widespread with climate change.”

Droughts are a major driver for water supply storage and infrastructure. However, as noted above, poorer countries respond less rapidly to this need because of limited financial resources. In the case of both developed and undeveloped countries as noted above, the practical solution for storage may be more “dams”. For example the construction of small dams was accelerated during the 2000–2010 period to help respond to the devastating drought in the Midwest region of the USA (Figure 3.2).

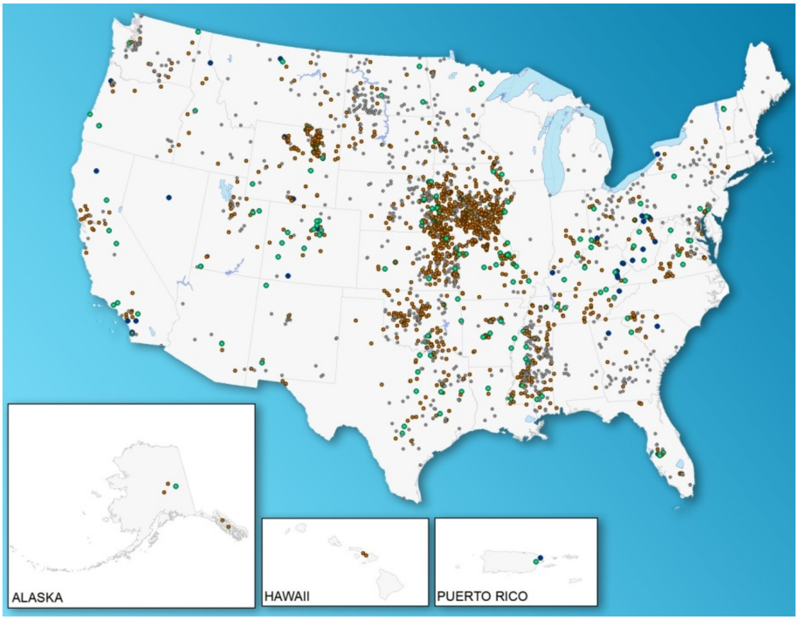

Fig. 3.6
Small dam construction after 2000

3.5. IMPACT ON RISK OF FLOODING

As noted in Section 3.2 above, each region of the world will face challenges resulting from climate change that will cause increased flooding and variability in timing and location of precipitation. This regular flooding could be devastating.

In an article in the September 23, 2014 issue of the New York Times entitled "Flooding Risk from Climate Change Country by Country"[14] (Figure 3.3), the authors state that:

"Across the globe, about one person in 40 lives in a place likely to be exposed to such flooding by the end of the century, absent significant changes." This statement results from a new analysis of sea levels and flood risk conducted by Climate Central. The analysis is based on more detailed sea-level data than have previously been available. Climate Central, a news organization and research group released this information in September 2014. The analysis defines regular flooding as a flood at least once every three years.[15]

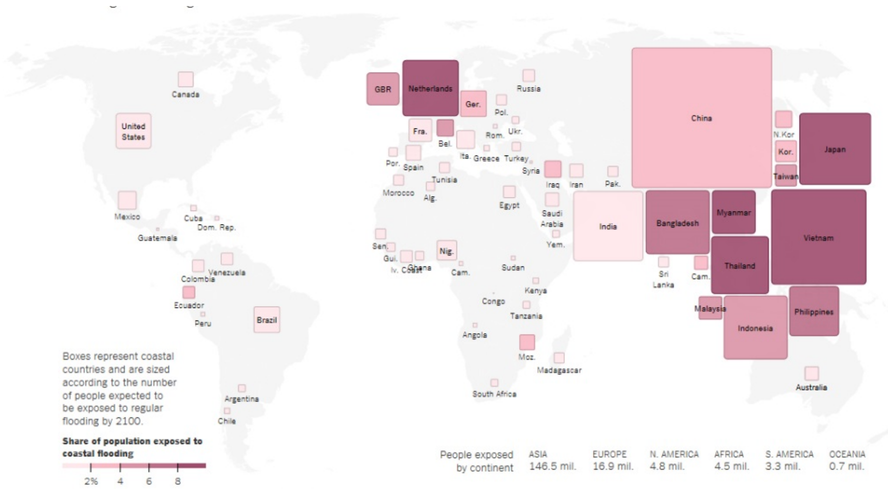

Fig. 3.7
Exposure to flooding by country

While this New York Times report from Climate Central seems to emphasize the effects of sea-level change, sea-level increases coupled with high precipitation and run-off events most often create

[14] Aisch, Gregor; Leonhardt, David; Quealy, Kevin. (2014, September 23). Flooding Risk from Climate Changer Country by Country. *New York Times*.
[15] Ibid.

the worst devastation to both urban and rural locations. This is particularly true for low-lying countries, such as the Netherlands, Japan, the UK, Pakistan and Vietnam that are exposed to the sea. Vietnam, for example, is aware of the flood risks and is committed to constructing more dams and dikes dedicated to mitigating and controlling floods. However, as noted later in Section 7 of this bulletin, financial constraints are a limiting factor in the construction of flood control and management projects.

ICOLD has historically considered dams one of the principal defences against flooding from high surface water run-off through storage of a portion of the run-off. However, some of its member country committees, US Society of Dams (USSD) for example, have now added a committee on levee design and maintenance to also deal with flood protection. ICOLD may want to consider adding a levee design committee similar to that of the USSD to help dealing with flooding as we proceed into the 21st century.

As noted, ICOLD and its members recognize that dams benefit flood management. To help ensure this benefit, the safety of dams during floods must be carefully considered. Increased magnitudes of precipitation and the resulting run-off could likely mean that spillways at existing dams may have insufficient hydraulic capacity to safely pass increased magnitude floods that result from climate change. In fact, dam failures result more from overtopping due to insufficient spillway capacity than from any other cause.[16]

Both the standing committees on Hydraulics for Dams and Dam Safety should include this activity as part of their terms of reference; if not already done.

[16] Association of Dam Safety Officials. Retrieved from www.damsafety.org.

3.6. IMPACT ON ENERGY PRODUCTION

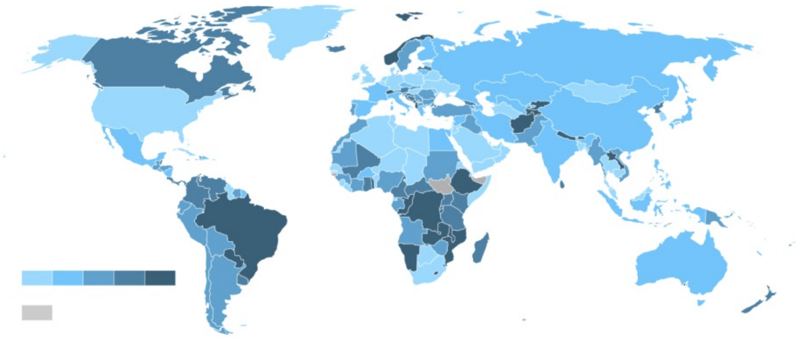

Fig. 3.8
Areas of the globe dependent on hydropower

The Middlebury College Senior Seminar entitled "Hydro-Power Vulnerability and Climate Change"[17] notes that "Each region of the globe will face unique challenges as climate changes." Severe storms such as hurricanes caused by warming ocean temperatures can and have wreaked havoc on infrastructure, including power supply. Hydropower is not the only form of energy production that could be disrupted or damaged. Renewables such as tidal power and wind power are equally susceptible to disruption.

Hydropower is considered to be a renewable resource and has a "low carbon footprint" when compared to fossil fuels but has its own environmental impacts that likely will be affected by climate changes and the associated increased variability of precipitation run-off. Figure 3.4 (from Middlebury)[18] shows the areas of the globe dependent on hydropower.

For purposes of this presentation, there are three types of hydroelectric projects: Reservoirs coupled with a hydro station, run-of-river where the hydro station is on the river, and pumped storage hydro (PSH) where water is pumped to an upper reservoir (usually during periods of low energy demands). While all three types can

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[17] Middlebury College Environmental Studies. (2011, Fall). Senior Seminar, Hydropower Vulnerability and Climate Change 2011.
[18] Ibid.

be impacted by climate change, the reservoir-type and run-of-river-type schemes will likely be the most vulnerable.

This can be seen in the Fig. below.

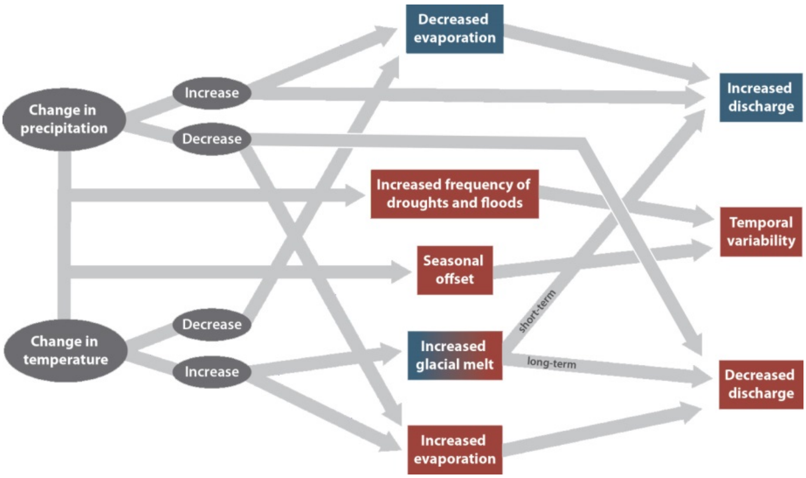

Fig. 3.9

Effects pertinent to hydropower (Red indicates effects that are typically detrimental to hydroelectric production; Blue indicates effects that typically improve hydroelectric production potential)

Climate changes will affect hydropower production in varying degrees based on the location or the type of hydropower scheme.

To present the effects based on the location and type of hydropower scheme, the Middlebury College team created the matrix shown in Figure 3.6 below. Climate change effects are located along the x-axis and the type and characteristics of the hydropower schemes along the y-axis

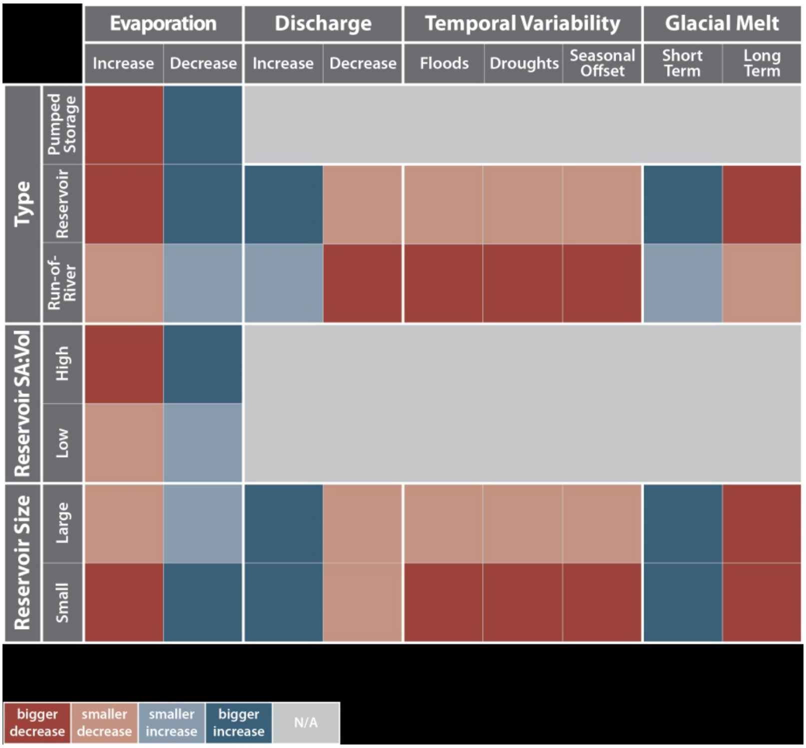

Fig. 3.10

Effects based on location and type of hydropower scheme

In summary the COEC&S concludes that energy production will be impacted by climate change. Impacts could result from more frequent extreme weather events, such as flooding or from the documented results of climate change including temperature change, glacial melt, and run-off. Pumped storage hydro (PSH), which is an essential partner of renewable energy will likely be the least affected by climate change, and consequently should be integrated into many regional energy schemes.

A specific region where such impact might be greater than elsewhere is the Himalayas, where glacier melt could lead to strong changes in the flow regime, affecting very large regions of the Asian continent.

3.7. GHG EMISSIONS FROM MAN-MADE RESERVOIRS

As stated by a recent technical note by the World Bank[19], "much research has been conducted and published during the last decade, and scientific papers from 2017 indicate that the science and methodologies to estimate GHG emissions from reservoirs are converging. As a result, predictive tools are now available for practitioners involved in dam development. One such tool is the GHG Reservoir Tool (G-res tool), developed and launched in May 2017."

One result of the most recent studies is that the global emissions by man-made reservoirs are lower than previously estimated.

The most complete reference for a detailed assessment of GHG emissions by reservoirs was recently published by the IEA[20]. A thorough review of the issue is presented. In the review, mitigation measures are presented for reservoirs causing excessive emissions; they were summarized in ref[19] as follows:

- "Measures to increase oxygen concentrations upstream of intakes in Nam Theun 2 have been shown to decrease emissions of CH4 degassing (Deshmukh et al. 2016) downstream of the outlet.
- Keeping intakes above the level of the hypolimnion is another mitigation measure that may have large potential to decrease methane emissions.
- During operation, one possible mitigation measure is to avoid a rapid drawdown, as this favours CH4 bubbling.
- Further, although not considered part of the net emissions, UAS (Unrelated Anthropogenic Sources) can contribute to a high volume of reservoir GHGs but this is to a large extent manageable. Organic material and nutrient effluents from the upstream catchment can also be managed and covered in the catchment treatment

[19] Greenhouse Gases from Reservoirs Caused by Biogeochemical Processes, World Bank Group, Dec. 2017

[20] HYDROPOWER AND THE ENVIRONMENT: Managing the Carbon Balance in Freshwater Reservoirs – Guidelines for Quantitative Analysis of Net GHG Emissions from Reservoirs, 3 volumes

plans included in the ESMPs. Management of UAS reduces gross GHG emissions and improves the water quality of the reservoirs, an aspect that has both recreational and O&M benefits."

4. POPULATION GROWTH AND EXPANSION

4.1. BACKGROUND

The world population passed 6 billion at the end of the 20th century and was approximately 7 billion in 2012.[21] It is currently increasing at 1.1% annually.[22] The population of the world is expected to increase during the next 35 years, from 7 billion today to 9.1 billion in 2050.[23] The populations of many countries, particularly those in Africa and Asia, are expected to increase greatly in the coming decades. During the same period, some developed countries are expected to experience a significant population decline. Overall, the population of the more developed regions, estimated at slightly more than 1.2 billion persons, is expected to change little during the coming decades.[24] Rapid growth is expected in the group of 50 countries classified as the least developed. By the mid-century, for example, the population of the least developed countries could more than double in size.[25] An important point is that in 2008, for the first time in the history of human civilization, more than half of the world's population was living in cities.

4.2. THE NEED FOR WATER

The key development goal for the international community is to achieve sustainable development as a means to ensure human well-being, equitably shared by all people today and in the future.[26] As noted above, the population is expected to increase substantially, especially in developing countries.[27] Therefore, the need for water and energy will increase consistent with the

[21] United Nations Department of Economic and Social Affairs. (2005). *Population Challanges and Development Goals.* New York, USA.
[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Ibid.
[27] Ibid.

population growth. In many countries, slower population growth has bought more time to adjust to future population increases, to improve the ability of those countries to combat poverty, protect and repair the environment, and to set the conditions for sustainable development.[28]

Water is essential for human life, development and environment, but it is a finite and vulnerable resource which has quantitative limitations and qualitative vulnerability.[29] Water shortage is becoming a global issue owing to the increasing population, economic growth and climate change.[30] Population growth, along with rising incomes, changing dietary patterns, and urbanization and industrial development, will increase demand for a fixed supply of water.[31] There were five major drivers demanding a major expansion of water resources in the 20th century, namely population growth, industrial development, expansion of irrigated agriculture, massive urbanization, and rising standards of living.[32] The traditional approach was to construct wells, dams, reservoirs, canals, and pumping plants over the years to collect, control, and contain excess flows and to distribute water on demand during different periods.[33] This approach has helped to change the world's varying water resources into reliable and controlled supplies.[34] As a result, most water users take for granted that unrestricted quantities of freshwater are instantaneously available to them on demand.[35] Development of new sources of water beside its efficient use, together with conservation measures, should be an important component of any country's national water plan.[36]

Agriculture is an essential use of water to sustain life. Data from researchers within the World Bank indicate that globally, 70% of freshwater is used for agriculture. In most regions of the world, over

[28] Ibid.
[29] Lalzad. (2007). An Overview of the Global Water Problems and Solutions. London.
[30] Ibid.
[31] Mogelgaard, K. (2011). *Why Population Matters to Water Resources*. Washington, DC, USA: Population Action International.
[32] Gleick, P. (2004). The World's Water 2004 – 2005. The Biennial Report of Freshwater. Island Press.
[33] Lalzad. (2007). An Overview of the Global Water Problems and Solutions. London.
[34] Ibid.
[35] Ibid.
[36] Ibid.

70% of freshwater is used for agriculture. By 2050, feeding a planet of 9 billion people will require an estimated 50% increase in agricultural production.

Table 4.1
Share of freshwater withdrawals by sector (%) in 2014

	Agriculture	Industry	Domestic
Asia	91.2	6.9	2.0
Middle East and North Africa	85.3	9.0	5.7
Sub-Saharan Africa	80.7	14.7	4.6
Latin America and Caribbean	72.1	16.9	11.0
East Asia and Pacific	71.8	11.7	16.3
Europe and Central Asia	35.7	30.7	33.5

Source: World Development Indicators

There is a growing and conflicting demand for water for domestic, agricultural, and industrial purposes in the face of water scarcity, inadequate infrastructure, limited access to water, and habitat destruction and pollution, all of which affect water quality and quantity.[37] The availability of and access to water have become one of the most important challenges that countries face today, and water resource management has become a major priority in most countries where water supply shortage is threatening their development.[38] According to the Water Project, Inc., 783 million people do not have access to clean and safe water.[39] Based on the forecasted population growth, this number will increase. Also, according to the U.N., November 2014, this number includes 75 million to 250 million people in Africa alone.

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[37] Ibid.

[38] PEMSEA. (2015). *Water Use and Supply Management.* Retrieved February 10, 2015, from Partnerships in Environmental Management for the Seas of East Asia.: www.pemsea.org.

[39] The Water Project, Inc. (2016, August 31). Retrieved from https://thewaterproject.org/water-scarcity/water_stats.

The case of India

Water storage in India today is highly inadequate, especially the fact that climate change will aggravate drought and floods. There is a need for storage for flood protection, irrigation and water supply. Once a reservoir is built for storage to combat the flood and drought, hydropower generation is a by-product of the same facility. Excess and controlled water release from a reservoir during flood and drought will pass through the turbine to generate electricity. The water resources of India, assessed by National Institute of Hydrology are enumerated below:

- Geographical area 329 million Ha
- Flood-prone area 40 million Ha
- Ultimate irrigation potential 140 million Ha
- Total cultivable land area 184 million Ha
- Net irrigated area 50 million Ha
- Natural run-off (surface and ground) 1 869 km^3
- Estimated utilizable surface water potential (*) 690 km^3
- Groundwater resources 361 km^3
- Net utilizable groundwater resources for irrigation 325 km^3

(*) The assessment is based on projects where a preliminary feasibility report is prepared and feasibility is established. Further feasibility studies in other project locations are continuing.

In India per capita water storage in cubic meter as on 2015 is as follows:

- Total effective storage 175 km^3
- Population 1 282 Million
- Per capita effective storage 136 m^3
- Mini. sustainable water storage per capita (*) 300 m^3
- Projected population by 2030 in India 1 528 Million
- To ensure per capita 300 Cum, storage needed 458 km^3 (< 690 km^3)

(*) The present effective storage capacity of India is 175 km^3. This is highly inadequate and the minimum storage per capita of 300 cum is a rough estimate as indicated by various publications and papers.

It is an admitted fact that the net irrigated area in India is only 50 million Ha as against the total irrigable potential of 140 Million Ha. Which indicates that only 36% of agricultural land is covered by irrigation and rest 64% depends on the highly unreliable monsoon. The adverse effect of climate change on the increased rate of the population is visible and will aggravate the situation on floods and drought.

4.3. THE NEED FOR ENERGY

The growing energy demand is driven by the population growth, industrial growth, changing demographics and a shift from fossil fuels towards electrical power (e.g. electric cars). This demand calls for an increase in the supply capacity. As we move into the 21st century, global economic prosperity is driving the consumption of energy to record levels, with electricity consumption anticipated to increase at rates faster than the overall energy supply (See Section 5, Trends in Energy Production). As of 2016, about 80% of energy is provided from thermal sources, i.e. coal, gas and oil, but there are growing global concerns regarding the lack of sustainability of these forms of energy that bring into question their use in a long-term energy strategy. The energy consumption per inhabitant per year is generally in correlation with the standard of living of the population, which is a characteristic of welfare from an economic, social and cultural point of view.

It is clear that world energy consumption, and especially electricity consumption, will increase considerably during this century, not only because of the demographic pressure, but also because of the development in living standards in the less developed countries. The base case scenario considers a more than doubled electricity production from today to 2050 (section 2.1).

<u>The case of India</u>

As on October 2017 the source of power generation in India is as given below:

- Thermal (fossil fuel) 219,415 MW 66.26%
- Nuclear 6,780 MW 2.05%
- Hydro (above 25MW) 44,765 MW 13.57%
- Other renewable (small hydro, wind, biomass, waste to power, solar) 60,158 MW 18.18%

The hydro assessed potential is 148,700 MW and the developed hydropower is 44,765 MW. Hence the potential utilized is 30% which compares favourably with the global average. However, considering the emerging challenge on climate change, the creation of more water storage by dams to mitigate the droughts and floods is an imperative necessity. Hydro power could be a benefit to be attained from the release for irrigation and flood moderation. Air pollution by carbon emission is another challenge in India and the accelerated trend of energy generation by fossil fuel is aggravating the situation. With only 13.57% of hydropower and the continuous diminishing trend of hydropower since 1980, the grid instability is another emerging challenge with needs for additional water storage capacity for hydro and pumped storage projects.

4.4. FLOOD MANAGEMENT

As populations increase, more people will live in urbanized areas close to rivers that are subject to flooding. As the result of populations migrating to flood zones and as the result of climate change (including sea level rise) we can expect more flood disasters that affect people.

Floods are the leading cause of natural disaster deaths worldwide and were responsible for 6.8 million deaths in the 20th century.[40] We note that this trend will likely increase (See Section 3 Climate Change). Asia is the most flood-affected region, accounting for nearly 50% of flood-related fatalities in the last quarter of the 20th century. The events and factors that precipitate flood events are

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[40] Jonkman, S. N., & Kelman, I. (2005). An Analysis of the Causes and Circumstances of Flood Disaster Deaths. *Disasters. 29(1)*, 75-97.

diverse, multifaceted, and interrelated.[41] Weather factors include heavy or sustained precipitation, snowmelts, or storm surges from cyclones.[42] Geographic regions such as coastal areas, river basins and lakeshores are particularly at risk from storms or cyclones that generate high winds and storm surges.[43] Environmental and physical land features including soil type, the presence of vegetation, and other drainage basin characteristics also influence flood outcomes.[44] Floods occur on varying timelines, ranging from flash floods with little warning to those that evolve over days or weeks (riverines).[45] Flash floods, characterized by high-velocity flows and short warning times have the highest average mortality rates per event and are responsible for the majority of flood deaths in developed countries.[46] In contrast, riverine floods which are caused by gradual accumulation of heavy rainfall are less likely to cause mortalities because of sufficient time for warning and evacuation.[47] They may, however, cause very large economic losses.

The most effective flood mitigation is accomplished by integrated and multifaceted management including regulating the storage and discharges of dams located in a river basin[48], assessing the conditions of flood routing in streams and floodplains, reducing the vulnerability of affected areas, and improving the resilience of affected areas. Flood mitigation is a significant purpose for many of

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[41] Jonkman, S. N. (2005). Global Perspectives on Loss of Human Life Caused by Floods. *Natural Hazards 34(2)*, 151-175.

[42] Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The Human Impact of Floods: a Historical Review of Events 1980–2009 and Systematic Literature Review. *PLoS Currents*.

[43] Hunt, J. (2005). Inland and Coastal Flooding: Developments in Prediction and Prevention. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences. 363(1831)*, 1475–1491.

[44] Tobin, G., & Montz, B. (1997). *Natural Hazards: Explanations and integration.* New York: Guilford Press.

[45] Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The Human Impact of Floods: a Historical Review of Events 1980-2009 and Systematic Literature Review. *PLoS Currents*.

[46] Jonkman, S. N. (2005). Global Perspectives on Loss of Human Life Caused by Floods. *Natural Hazards 34(2)*, 151–175.

[47] Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The Human Impact of Floods: a Historical Review of Events 1980–2009 and Systematic Literature Review. *PLoS Currents*.

[48] ICOLD. (2015). *Role of Dams*. Retrieved February 7, 2015, from International Commission on Large Dams. Retrieved from http://cigb.org/GB/Dams/role_of_dams.asp.

the existing dams, and continues as a main purpose for some of the major dams of the world currently under construction.[49]

Urbanization invariably increases the risk of flood damage as a result of heightened vulnerability, stemming from population, wealth, and infrastructure being concentrated in smaller areas.[50] Flood mitigation reservoirs might be very cost-efficient for such cases.

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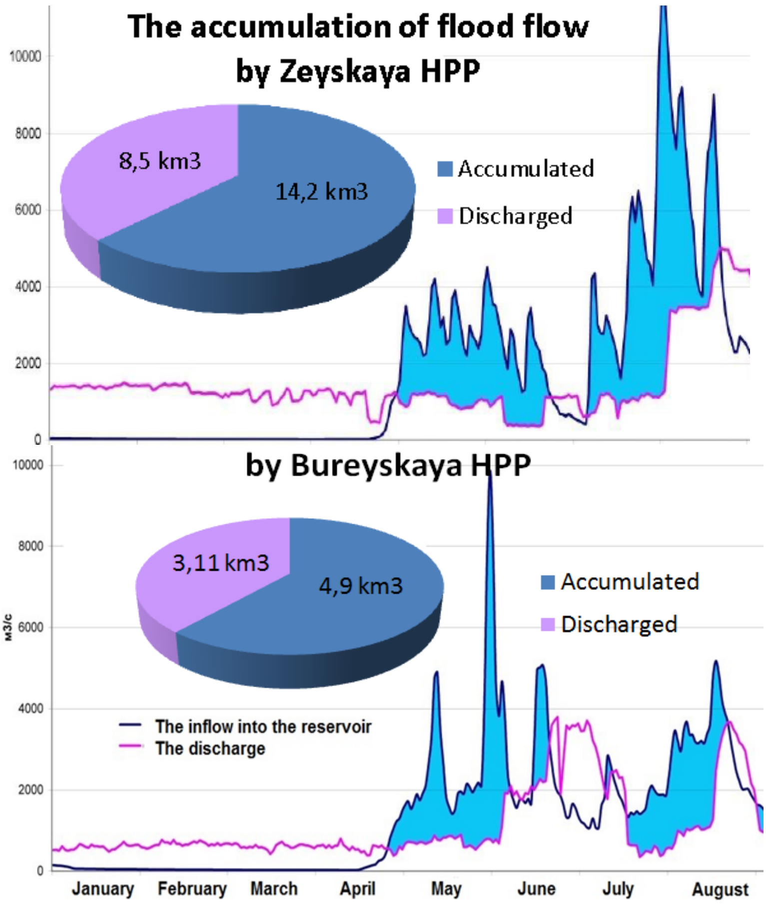
[49] Ibid.
[50] Ibid.

An example from Russia: The role of Bureyskaya and Zeyskaya HPPs in Preventing the Catastrophic Consequences of Abnormal Floods in 2013.

Bureyskaya and Zeyskaya are large hydro plants in the eastern regions of Russia. The installed capacity of Bureyskaya HPP makes 2 010 MW and its average annual turbine output makes 7.1 billion kWh. Its economic importance is vital for the regional economy. In August 2013, the flood in the Amur basin became the strongest flood in the region over the entire observation period. According to RosHydroMet, the observed water levels exceeded the historical peaks by 1.5–2 m. The width of overflowing was 15–30 km in some places. Upstream of the reservoirs, the number of people caught in the disaster area exceeded 360,000 in China and 40,000 in Russia; more than 80 died in China, upstream.



Both of these hydroelectric power plants seriously reduced the large-scale flooding in the Amur Region. They saved lives.

4.5. NAVIGATION AND TRANSPORTATION

Where a body of water is navigable, water transport has the potential to contribute as the best solution for the transportation of large volume goods. Inland water transport (IWT), which is a low-cost, energy-efficient, and environmentally friendly mode of transport, represents an ideal infrastructure for sustainable development.[51] As the populations of developing countries increase (see Section 4.1) and demographics change, IWT will be invaluable in many countries to move both agricultural and manufactured goods to markets. Also, IWT is closely associated with tourism, recreation, and community development.[52] IWT can also be used to assist relief and rehabilitation efforts after natural disasters.[53] Since it ensures a high degree of safety, it is a suitable mode for transporting dangerous goods.[54]

Infrastructure such as dams or barrages enhance the availability of water needed for IWT.[55]

Common understanding, complemented with scientific analysis, support the fact that water-based transport is largely fuel-efficient and more environmentally responsive when compared with transport by road, rail, or air.[56] The navigation sector can be of significant relevance for dealing with climate change mitigation processes.[57]

Considering several levels of possible private sector integration with inland water transmission development plans, joint ventures such

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[51] Ishiwatari, M. (2011). Redevelopment of Inland Water Transport for Post-Conflict Reconstruction in Southern Sudan. In C. Bruch, M. Nakayama, & I. Coyle, Harnessing Natural Resources for Peacebuilding: Lessons from US and Japanese Assistance. Washington: Environmental Law Institute.

[52] Ibid.

[53] Ibid.

[54] Nagabhatla, N., & Jain, P. (2013). Assessing the Potential Role of Inland Water Navigation for Green Economy. Journal of Environmental Professionals Sri Lanka. Vol. 2 – No. 1., 25–37.

[55] Ibid.

[56] Eastman, S. E. (1980). Fuel Efficiency in Freight Transportation. Arlington, VA.: The American Waterway Operators, Inc.

[57] Ibid.

as the build-operate-transfer (BOT) scheme, can be negotiated under a public-private participation framework.[58]

Current cost estimates show that developing and building an inland waterway costs about 5–10% of the costs for a four-lane highway/railway, making it a lucrative transportation option with low capital investment.[59]

Only 10% of the capacity of large rivers in Europe, such as the Danube, the Seine, or the Rhône, has been developed.[60]

Where waterways are available, IWT represents a significant share of the overall transportation of goods in Europe: 42% in the Netherlands, 12% in Belgium, and 14% in Germany. IWT is the largest carrier of building materials in Europe, accounting for 39% of building materials transported, and it is an important carrier of cereals, agricultural products, solid fuels, and ores. Roughly 80% of all transported hazardous goods such as solid fuels, petroleum products, and basic chemicals are shipped by IWT.[61]

The European Commission aims to promote and strengthen the competitive position of IWT in the total transport system in Europe including land, air, and sea. The commission also seeks to facilitate the integration of IWT into the intermodal logistic chain.[62] IWT will contribute to relieving traffic congestion and to mastering energy use and sustainable distribution solutions by linking navigable waterways to the road, rail, and short-sea networks.[63]

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[58] Nagabhatla, N., & Jain, P. (2013). Assessing the Potential Role of Inland Water Navigation for Green Economy. Journal of Environmental Professionals Sri Lanka. Vol. 2 – No. 1., 25–37.
[59] IWAI. (2008). *Annual Report [2008–2009]* published by Department of Shipping-Ministry of Shipping, Road Transport and Highways. Noida-India: Inland Waterways Authority.
[60] Ishiwatari, M. (2011). Redevelopment of Inland Water Transport for Post-Conflict Reconstruction in Southern Sudan. In C. Bruch, M. Nakayama, & I. Coyle, *Harnessing Natural Resources for Peacebuilding: Lessons from US and Japanese Assistance.* Washington: Environmental Law Institute.
[61] Ibid.
[62] Ibid.
[63] Ibid.

In the United States it reaches up to 12% of overall freight shipments. Long stretches of navigable waters remain undeveloped.[64]

In the USA, the U.S. Army Corps of Engineers operates and maintains nearly 19 000 kilometres of waterways with more than 200 locks and dams. IWT accounts for roughly 15% of the total intercity commerce by volume. More than 50% of U.S. grain exports depend on the river network. Principal commodity groups transported using IWT include coal, petroleum, farm products, chemicals, and crude materials such as aggregates for construction and other minerals.[65]

As in other countries, IWT had been utilized as a major mode of transport throughout the history of Japan. Different forms of energy, such as wind, human, and water were used to navigate IWT.[66]

However, the development of rivers for navigation (by dredging, channelling and straightening) may lead to destruction of river courses and may have negative impacts on people.[67] Vessel operations may create waves that can disturb other water users. In addition, inadvertent species introductions, spills, and ship collisions may pollute and damage aquatic habitats. Accidental pollution involves oil and in some cases hazardous substances.[68]

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[64] Ibid.

[65] Grier, D. (2002). Measuring the Service Levels of inland Waterways: Alternative Approaches for Budget Decision Making. *TR News* 221:10–17.

[66] Ishiwatari, M. (2011). Redevelopment of Inland Water Transport for Post-Conflict Reconstruction in Southern Sudan. In C. Bruch, M. Nakayama, & I. Coyle, *Harnessing Natural Resources for Peacebuilding: Lessons from US and Japanese Assistance*. Washington: Environmental Law Institute.

[67] WWF. (2015, March 3). *River Transportation: Clean Alternative or Destruction for Waterways?* Retrieved from WWF - Infrastructure Problems: River Navigation Schemes: http://wwf.panda.org/about_our_earth/about_freshwater/freshwater_problems/infrastructure/river_navigation/.

[68] Ibid.

5. TRENDS IN ELECTRICITY PRODUCTION AND STORAGE

5.1. CURRENT AND PROJECTED MIX OF ELECTRICITY SOURCES

5.1.1. World trends

The COEC&S examined the breakdown (mix) of electricity generation by source to determine trends on a global basis. Figure 5.1[69] below presents global electricity production by all energy sources in 2012 measured as TWh. In 2012 it can be seen that coal (40%), gas (23%), and hydropower (17%) represent 80% of the global energy production. Renewable energy sources, except hydropower, are presented under others and are estimated at 5%.

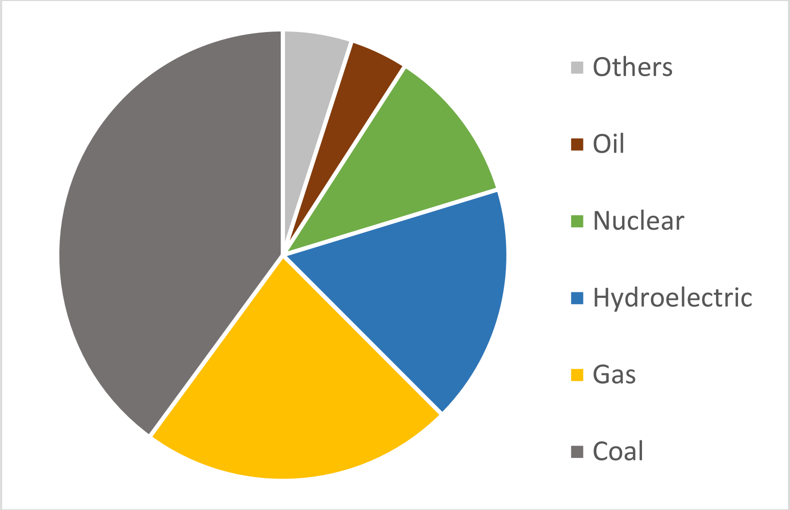

Fig. 5.1
World electricity production from all energy sources in 2012

[69] The Shift Project Data Portal. Retrieved from www.tsp-portal.org.

While it was not practical to examine each source for trends, the COEC&S looked at trends in electricity production that are "emerging" – namely renewable sources including hydropower. Table 5.1[70] shows some interesting trends, especially for the last five years. Solar power, wind power, and biomass are increasing as a percentage of total generation (production) while hydropower is decreasing slightly.

	Hydropower	Solar (PV* and CSP)	Biomass	Wind	Geothermal	All Renewables	Renewable Generation (GWh)
2000	16.8%	0.0%	1.2%	0.3%	0.3%	18.7%	2,727,082
2001	17.3%	0.0%	1.3%	0.4%	0.3%	19.3%	2,872,463
2002	17.1%	0.0%	1.2%	0.5%	0.3%	19.2%	2,953,879
2003	18.0%	0.0%	1.2%	0.7%	0.3%	20.2%	3,211,282
2004	17.3%	0.0%	1.1%	0.8%	0.3%	19.5%	3,247,899
2005	16.9%	0.0%	1.2%	0.9%	0.3%	19.4%	3,358,626
2006	16.7%	0.1%	1.2%	1.1%	0.3%	19.4%	3,488,055
2007	16.4%	0.1%	1.3%	1.3%	0.3%	19.3%	3,644,173
2008	16.6%	0.1%	1.3%	1.7%	0.3%	20.0%	3,822,689
2009	17.2%	0.1%	1.5%	2.2%	0.4%	21.3%	4,064,206
2010	16.6%	0.3%	1.6%	2.6%	0.3%	21.3%	4,319,733
2011	16.4%	0.4%	1.7%	3.0%	0.3%	21.7%	4,582,578
2012	16.3%	0.6%	1.8%	3.4%	0.3%	22.4%	4,891,891
2013	15.9%	0.8%	1.8%	3.7%	0.3%	22.6%	5,095,079

Fig. 5.2

Global renewable electricity generation as a percentage of total generation

The drivers for this slight increase in renewable energy are: (1) the "push" to reduce the carbon footprint of power generation; (2) climate change as it reduces the reliability of some forms of hydropower generation; and (3) the lack of availability of hydropower sites.

However, recently BP (formerly British Petroleum) estimated that renewables will account for only 8% of the energy demand (production) by 2035.[71]

[70] From Pete Danko. (2015, February 5). Retrieved from breakingenergy.com.
[71] From Edward Dodge. (2015, February 18). Retrieved from breakingenergy.com.

Figure 5.2

This estimate (see adjacent Figure) excludes hydropower as renewable energy and does not consider the drivers for PSH noted above.

It underlines the fact that fossil fuels might still remain the main contributor to the growth in electricity production.

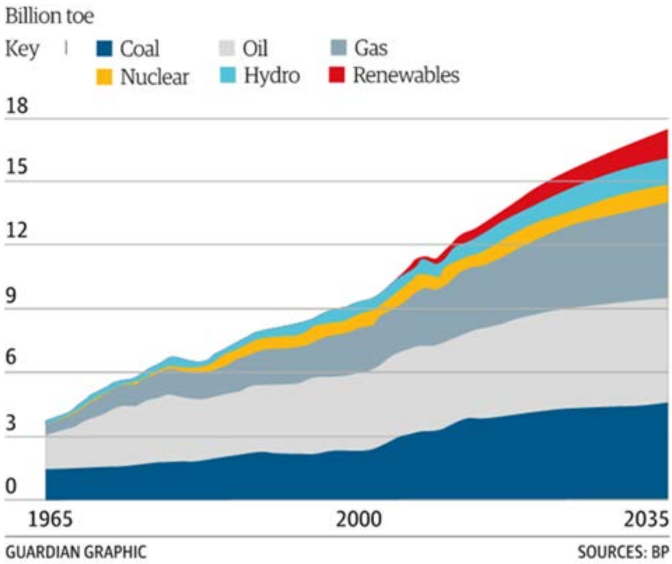

Fig. 5.3
Future share of Renewables, according to BP

5.1.2. A solar (and wind) future?

According to the IEA[72], in 2016, "investment in new renewables-based power capacity […] remained the largest area of electricity spending. Renewables investment was 3% lower than five years ago, but capacity additions were 50% higher and expected output from this capacity about 35% higher, thanks to declines in unit costs and technology improvements in solar PV and wind."

[72] World Energy Investment 2017

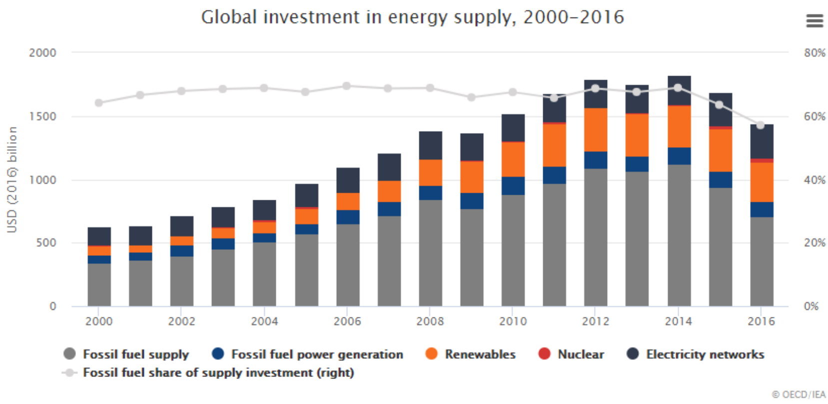

Fig. 5.4

Global investment in energy supply, per year – source: IEA

There is a strong trend toward wind and above all solar renewables, driven by a spectacular drop in PV cell costs.

Data from various sources and published in Wikipedia illustrate this: the record-breaking bid prices dropped from 37.7 US$/MWh in 2015 (USA), to 29.10 US$/MWh and 24.20 US$/MWh in 2016 (Chile, Abu Dhabi), and 17.90 US$/MWh in 2017 (Saudi Arabia). Solar PV is the most competitive electricity source in many countries.

Wind is not far beyond in less sunny countries. On-shore wind can drop under 50 US$/MWh in favourable locations. In 2016, a bid price of less than 60 US$/MWh was offered for a large offshore wind farm in the Baltic Sea.

There is, however still a strong market for fossil fuels, notably coal (and also gas in countries with affordable gas). As recently stated, reports of the terminal decline of coal may be exaggerated[73]. The authors have estimated the cumulative future emissions expected to be released by coal power plants that are currently under construction, announced, or planned. They focused on five countries, and analysed data in terms of CO2 emissions (the purpose of their paper). The Table below, indicates that there could be an increase of 26% in China, and up to 950% in Vietnam. The

[73] Ottmar Edenhofer et al 2018 Environ. Res. Lett. 13 024019

trend is clear – and was referred to as “the renaissance of coal” in several countries.

Table 5.1
Renaissance of coal

Table 1. Percentage change in CO_2 emissions from coal-fired power plants (first column) and all other emission sources (second column) between 2012 and 2030 for China, India, Turkey, Vietnam and Indonesia. Source: [17, 18].

	Change in emissions from coal-fired power plants (2012–2030)	Change in all other emissions (2012–2030)
China	26%	12%
India	84%	23%
Turkey	412%	50%
Vietnam	948%	14%
Indonesia	196%	105%

The future remains uncertain! And, in 2017, CO2 emissions started to rise again[74].

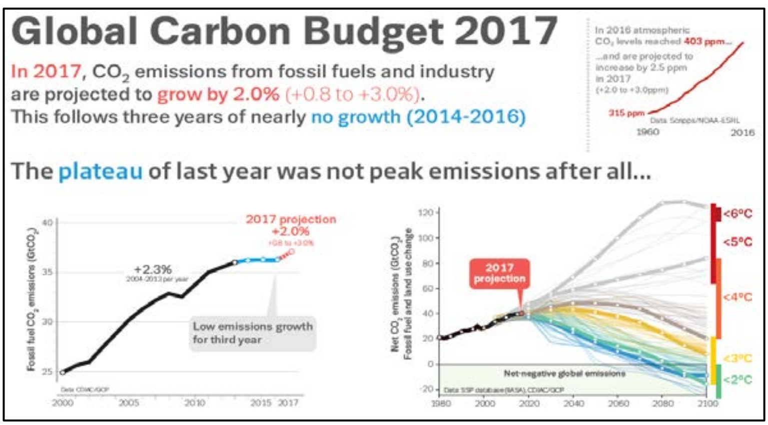

Fig. 5.5
CO2 emissions are still on the rise

[74] http://www.globalcarbonproject.org/carbonbudget/17/infographics.htm

In such a context, hydropower could play a key role.

5.1.3. A possible bright future for Hydropower

Energy use is forecast to increase by one-third by the year 2040 driven primarily by India, China, Africa, the Middle East and Southeast Asia.

Renewable energy technology exists in many forms. Recent thinking often relates renewable energy to electricity from wind energy, solar energy or geothermal energy. Yet the largest source of renewable energy comes from a proven technology, hydropower[75]. Hydropower is renewable because it draws its essential energy from the sun which drives the hydrological cycle which, in turn, provides a continuous renewable supply of water. Hydropower represents more than 70% of all renewable energy generated (see Section 5.1), and continues to stand as one of the most viable sources of new generation into the future. It also provides an option to store energy, and to optimize electricity generation.

The importance of hydropower generation can be summarized as follows:

- Energy plays a key role for the socio-economic development of a country. Hydropower provides a cheap, clean, and renewable source of energy.
- Hydropower is the most advanced, dependable, and economically viable resource of renewable energy.
- There is vast unexploited potential in the regions which are most urgently in need of increased electricity supply.
- Reservoir-based hydroelectric projects provide much needed peaking power to the grid.
- Unlike thermal power stations, hydropower stations have fewer technical constraints and the hydro machines are capable of a quick start and taking instantaneous load variations.

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[75] International Energy Agency. (2014). Energy Technology Perspectives 2014 (ETP 2014).

- While large hydro potentials can be exploited through mega hydroelectric projects for meeting power needs on a regional or national basis, small hydro potentials can be exploited through mini/micro hydro projects for meeting the local power needs of small areas.
- Besides hydropower generation, multipurpose hydroelectric projects have the benefit of meeting irrigation and drinking water requirements for controlling floods, navigation, tourism, recreation, community development, wild life preservation, etc.

More than 70% of the world's renewable electricity comes from dams in the form of hydropower. Hydropower also offers unique possibilities to manage the power network by its ability to quickly respond to peak demands. Pumping-storage plants, using power produced during the night while the demand is low, is used to pump water up to the higher reservoir. That water is then used during the peak demand period to produce electricity. This system today constitutes the only economic mass storage available for electricity (ICOLD, 2015).

The world’s total technically feasible hydro potential is estimated at 15,742.4 TWh/year, of which about 9 575 TWh/year is currently considered economically feasible for development. About 700 GW (or about 2 600 TWh/year) was already in operation, with a further 108 GW under construction by the turn of the century (H&D, 2000). Today about 1 123 GW is in operation (3 901.7 TWh/year) with a further 146 GW under construction (H&D, 2016). In 2013 hydropower supplied about 16% of the world's electricity. Hydro supplies more than 50% of national electricity in about 60 countries, more than 80% in about 20 countries and almost all of the electricity in 14 countries.

The inherent technical, economic and environmental benefits of hydroelectric power make it an important contributor to the future world energy mix, particularly in the developing countries. These countries have a great and ever-intensifying need for power and water supplies and most of them also have the greatest remaining hydro potential. In the future, all available sources of energy will be necessary, but for environmental reasons, the first priority should be the development of all the technically, economically, and environmentally feasible potential from clean, and renewable energy sources, such as hydropower.

We should expect that:

- Hydropower supply could increase from 2 800 TWh/year in 2000 to 5 500/year in 2050 and 7 000 TWh/year in 2100.
- Irrigation storage volume will double during the 21st century, with most of the increase occurring before 2050.
- Other benefits (water supply, drought and flood mitigation) will multiply by three or four times during this century, mostly after 2050.
- While the present reservoir storage is about 6 800 km^3, it will increase by 2 500 km^3, i.e. around 40%, up to 2050. A further increase of 1 000 or 1 500 km^3 after 2050 is not unlikely.

The annual flow volume of all rivers is 40 000 km^3. Globally, the total dam storage is about 6 800 km^3 of water of which more than 2 000 is dead storage. Dams store 4 000 km^3 of water yearly, essentially during the flood and release 3 000 km^3 of water, mainly during the dry season. A total of 1 000 km^3 of water is not released and is mainly used for irrigation.

Increasing needs, cost-efficient potential, and present trends in planning and construction suggest that the number of new dams could double by 2050. A total of 50% of the benefits of present dams and 90% of those of future dams will be in countries which are not yet industrialized. Further investments may be lower after 2050 for hydropower and irrigation, but may be very high for water supply and for mitigating the impacts of droughts and floods and of climate change.

The long operating life of dams and their low cost of operation and maintenance are such that the total annual cost of dams by 2050, including investments and operation will be (at present costs) less than US$ 150 billion for supplying food, electricity, and water to 1.5 billion people, i.e. US$100 per capita, which by that time will represent a very small part of the per capita income.

A doubling of the benefits of dams by 2050 will probably only require an increase in the reservoir storage volume of about 40%. The very useful daily or weekly peaking capacities within a grid only require small storage volumes. Storage for other purposes (irrigation, water supply, and flood mitigation) which will probably double within 50 years, is only 20% of the present overall storage volume.

The increase in reservoir areas will probably be around 30%, because new dams are on average higher than in the past. Increasing lake areas by 3 000 km^2 per year in the future, instead of 10 000 km^2 in the 20th century, together with much better management of resettlement problems will considerably reduce the related impacts.

The overall benefits of dams during the 21st century could be five times what they have been since 1950 – meaning they could benefit five times as many people . Technical, economic and environmental problems should not prevent the implementation of these extremely beneficial structures. About 90% of the water resources development potential is in countries which urgently need safe water and electricity supply for social and economic development. But the major required initial investments and complex procedures may delay them, if there is no adequate public support. The dissemination of fair and balanced information on the benefits of dams and the management of remaining drawbacks are thus essential.

5.2. SMALL HYDROPOWER

5.2.1. Background and Definition

The definition of small hydropower varies from country to country. For this section, the COEI has selected hydropower schemes with less than 30 MW of installed capacity as small hydropower, and schemes with less than 5 MW of installed capacity as mini hydropower.

The *Alternative Energy eMagazine*[76] reports that more than 60 countries use hydropower for meeting half of their electricity needs. Hydropower is popular for reasons that include its ability to respond instantaneously to changing electric power demands as well as coupling hydropower production to water management and flood control. It must be noted that balancing the use of water between water management and power generation is a challenge, but is usually achievable.

5.2.2. Advantages

Small and mini hydropower schemes have numerous advantages over large hydropower schemes. These advantages include:

- Shorter development period, 2–5 years versus 7 years or more
- Smaller footprint
- Generally lower environmental impacts largely owing to lower diversion of water and smaller areas of impact
- Less complex construction, which improves the prospects to use local labour thereby helping the local economy

5.2.3. Drivers for Small Hydro Development

As discussed previously in Section 3.0, climate change is causing changes in surface water run-off both in area (location) and timing. This means that there likely will be periods of run-off when flows increase beyond the amount previously anticipated in project planning, thus justifying the addition of small hydropower to supplement the existing large hydropower installations. Also, in the future, new small hydropower schemes may be sustainable while large installations may not be. The outcome of these effects is that climate change will likely increase the development of small dams.

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[76] Thilak, A.B.G. (2010, June 22). *Global Small Hydro Power Market Analysis to 2020 - Installed Capacity, Generation, Investment Trends.* **Retrieved** from http://www.altenergymag.com/content.php?post_type=1532.

In addition to the above, population growth likely will increase the development of small dams to support M&I demands for water. In the Midwestern region of the USA, extended periods of drought have driven the development of small dams to help meet irrigation needs. These small dams could be sites for small hydropower, especially mini hydropower.

The constant increase in the development of small hydropower seems to be supported by the trends shown in Figure 5.3 below, from the *Alternative Energy eMagazine,* which notes that globally, small hydropower installed capacity is expected to reach about 200 GW in 2020 from its current level of about 140 GW[77].

The constraints to the development of small hydro also vary from country to country. The most frequently cited constraint is inconsistency of regulations covering licensing, permitting, and rights to use the water for hydropower. Also, these inconsistencies affect the ability for developers to attract reasonably affordable financing.

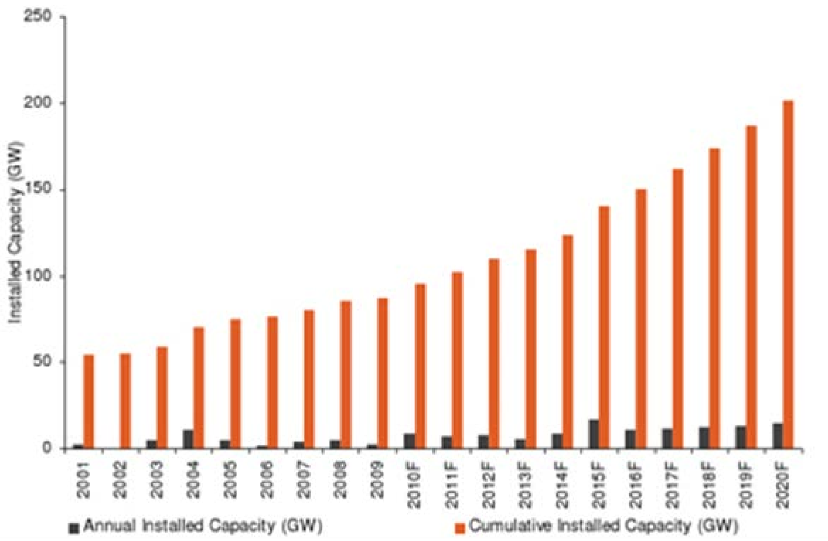


Fig. 5.6

Global small hydropower market, historical and forecast annual and cumulative installed capacity (MW), 2001–2020 (source: GlobalData)

[77] Ibid.

The World Bank's case of a small hydro development in Peru[78] explains typical issues and constraints to the development of small hydro, even though Peru has a renewable energy decree.

5.2.4. Constraints to the Development of Small Hydro

A major constraint to small hydropower development is that, if it is connected to a power grid, it must meet reliability goals, which may vary from country to country, but can be unreasonable. Also, the electricity produced must be sold into the grid, then the "avoided cost principal" takes effect. That is, electricity must be purchased at the kWh rate that the last increment of power sold into the grid was purchased for. In some countries, this rate may be insufficient to finance the project. However, there are inherent benefits of hydropower in managing the power demand, coupled with a low carbon footprint. By ignoring these benefits when establishing the price per kWh, power purchasers are effectively punishing hydropower.

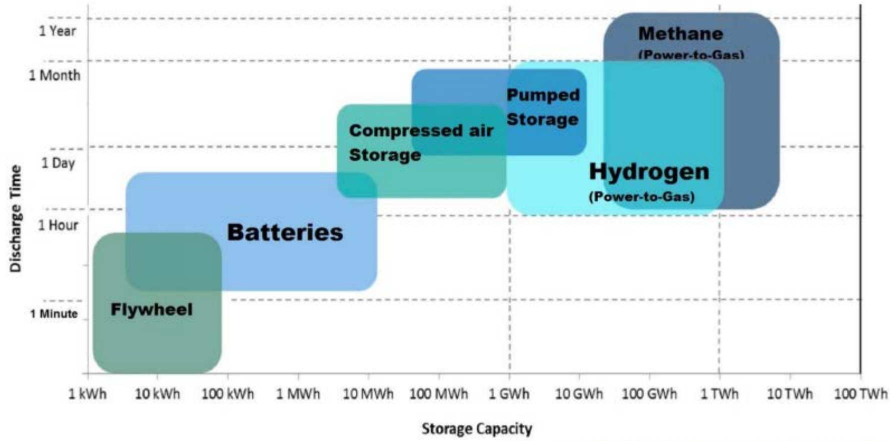
Besides, there may be environmental issues related to the cumulative impact of multiple small hydro schemes, versus the impact of one larger project. This important question certainly has to be considered at a river-basin scale. Of course, the developer of one single small hydro project cannot take charge of a complete river-basin scale strategic impact assessment. Such a necessary preliminary environmental study shall be performed by the relevant state authority.

5.3. THE OPTIONS FOR ELECTRICITY STORAGE

Electricity storage is an emerging market of great importance. The market is driven by the development of intermittent renewables, the increased use of electricity (especially for cars) and by the more and more stringent requirements of grids in terms of availability and frequency regulation.

[78] Energy Sector Management Assistance (ESMAP). (2011, March). Formal Report 340/11 – Peru Opportunities and Challenges of Small Hydropower Development.

As underlined by the figures below[79][80], pumped-storage is the leading mature technology for mass storage, and today counts for more than 95% of the world electricity storage capacity.



Source: School of Engineering, RMIT University (2015)

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[79] EUROPEAN COMMISSIONC - Energy storage – The role of electricity, 2017

[80] Electricity Storage Technologies, impacts, and prospects ; September 2015 ; Deloitte Center for Energy Solutions

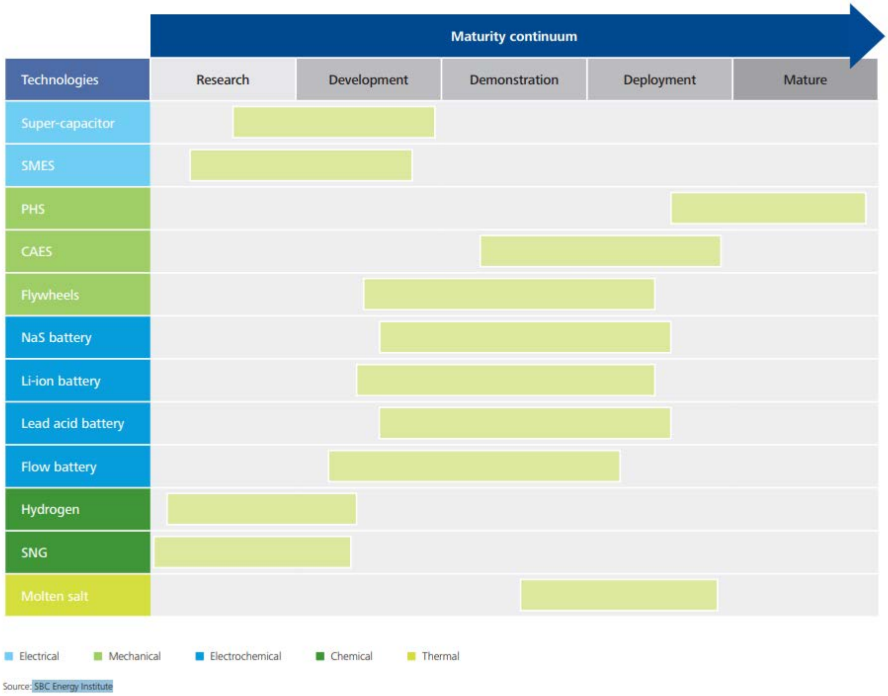

Fig. 5.7
Electricity storage technical options

However, there is a lot of research into new forms of electricity storage (e.g. hydrogen), and the cost of batteries is dropping. PSP could meet competitors in a few years.

In the next years and decades, the greater need for pumped storage will probably be driven by new solar power plants, the need for regulation (need to offset the “cloud effect”) and time shift they generate. Rapid regulation capabilities will be sought; combining variable turbines with variable pumps and new generators reacting in seconds could open new markets for PSP.

This is the key of the development proposed in the next section.

5.4. NEW IDEAS? SOLAR-HYDRO

The solar-hydro concept aims at generating hydropower or enhancing hydropower production on existing reservoirs. The concept combines floating solar cells on the existing reservoir and a pumped-storage power plant at the same location. With such a scheme, almost any reservoir, whatever its main purpose, can produce energy.

The solar-hydro energy is renewable and predictable, and it can be stored. It offers all the services associated with hydropower: flexibility, quick-start capability, regulation and frequency response, voltage support, black-start capability.

The solar-hydro energy does not consume water, and therefore does not compete with other water uses.

The solar-hydro concept bears four key developments that constitute its novelty.

1/ Floating solar panels

Floating panels are not essential to the development of solar hydro. But they have various advantages that make them a key component. Floating panels spare available land, facilitate permitting, reduce evaporation, and may enhance water quality.

2/ Hydropower without consumption of water

Traditional hydropower does not actually “consume” water, but it consumes water head, and it has to release water when there is a need to produce energy, sometimes regardless of the schedule of downstream needs. Water might be lost for other purposes. This is why hydropower cannot develop in countries where water is scarce.

Solar hydro actually produces energy from water head, like traditional hydro; but does not have to release water downstream. There is no competition with other purposes.

3/ A fully predictable and flexible renewable energy

Solar panels, pumps, turbines and water storage, once smartly combined, offer an entirely renewable energy, as predictable as fossil fuel plants and as flexible as reservoir hydropower.

- It is better than intermittent energies like wind or sun, because of its predictability.
- It is better than fossil fuels, because it is renewable.
- It is better than run-of-river hydro, because of the flexibility.
- It is as good as reservoir hydropower, with a lesser footprint and less sensitivity to climate change.

4/ High quality of electricity

Because of the association at a single location of the solar panels and the pumped storage power plant, and thanks to a tailored design of the electromechanical and electrical components, solar hydro can meet stringent grid requirements, in terms of voltage support and frequency regulation. The storage offers spinning or non-spinning reserve capabilities.

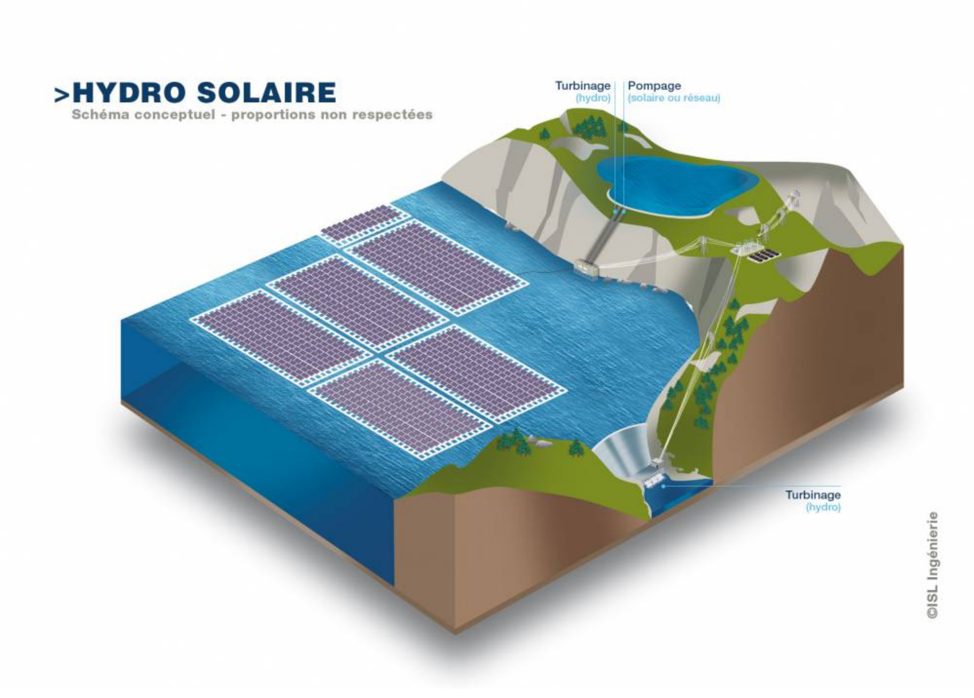

Fig. 5.8
The solar hydro concept, with association of floating panels and a dedicated pumped storage power plant

Opportunity studies have been performed in various countries, and lead to the following conclusions.

5/ From small hydro to very large hydro

Under reasonable sun conditions, 1 ha of reservoir can typically host 1 MW of solar power and 0.2 to 0.5 MW of solar-hydropower that produces more than 1.5 GWh/year of on-demand electricity at less than 100 €/MWh.

- Projects have been considered in some French islands with installed capacity less than 10 MW. They are devised to produce renewable electricity in almost off-grid conditions. They compete here with diesel units or with solar farms with battery storage, they offer better costs, better services than battery storage and a 100% renewable solution.
- Projects have been considered in various mainland countries, in Africa and Asia, with capacities of several hundreds of MW. These preliminary studies proved that it is possible to produce 100% renewable and 100% predictable electricity at a reasonable cost that can compete with fossil fuel alternatives.

5.5. NEW IDEAS? HYDROPOWER AT SEA

Many studies, tests and implementations of energy generation at sea have been undertaken in the last few decades. The theoretical potential of waves, wind and tides is extremely high and there are many possible solutions which may or may not use dams. Before studying the possible utilization of dams some data are first given for solutions without dams.

5.5.1. Energy at sea without dams

The key problem is the extra cost linked with the sea conditions which may prevent cost-effective solutions.

Waves energy

Many waves energy solutions have been proposed for using the huge waves energy potential and some have been tested at full scale. The results are generally disappointing because a significant generation requires places with exceptionally high waves and the cost for withstanding the impact of such waves is usually much too high. There is now much less efforts for the technology than 10 years ago.

Tidal energy in open sea

In-stream turbines use the same principle as wind energy; their shape is often similar as well as their unit capacity. Technical problems may be solved but their development is limited for two reasons:

- There are many places with water velocity in the range of 1 m/s but only few places where it reaches 3 m/s, a range of value necessary for cost-effective utilization.
- Places with rather high water velocities are generally exposed to high waves and construction is costly. The cost effective world potential of in-stream turbines in open sea seems thus limited to about 100 TWh/year.

Wind energy

The offshore potential is extremely high and has two advantages as compared to onshore wind energy:

- The wind availability is at least 50% more.
- Transporting very large and heavy elements is easier at sea than by road.

These two advantages may balance the extra costs from sea conditions. Large unit capacities up to 10 MW are likely as well for fixed units or floating ones. Cost will probably be mid-century close to 5 cents of $ per kWh.

Offshore wind farms will probably be a large part of electric supply by mid-century possibly in the same range as hydropower; they may be associated to large scale energy storage devices, possibly at sea.

5.5.2. Dams at sea

Dams could be used at sea for coastal protection, tidal energy and energy storage. These purposes may be associated.

- The need for coastal protection will increase with the sea level rise. The cost of a 10 or 20 m high dyke at sea may be dozens of millions US$ per km but this may be cost-effective for very populated areas. The Netherlands or St Petersburg are good examples. In areas with significant tides, such dykes may be paid to a large extent by tidal power.
- Tidal energy may be mainly used through storing water in large basins along shore. Operating them both ways may keep or improve environmental conditions and the coast is protected from exceptional high water levels and from high waves.

This utilization requires three conditions:

- A limited depth of sea within some km from the coast such as 20 m under low tides.
- A reduced length of dykes per GWh, i.e. a favourable topology or a very large scheme such as 50 to 500 km^2. Supplied energy, in GWh/year, is in the range of 0.5 to 1 $S H^2$, H (m) being the average tidal range and S the basin area in km^2.
- A minimal tidal range. Most past studies were devoted to the utilization of bulb units under a water head over 5 m, requiring a high tidal range and a specific management; this requires a rather high tidal range such as 6 m. There are worldwide about 10 relevant sites of which half have difficult weather conditions or are very far from utilization such as: north-east Siberia, Alaska, north-west Australia. The best areas are in Canada (Fundy), U.K. (Severn) and northern France but their overall potential is limited to some 100 TWh/year.

Twenty countries have sites with a tidal range of 3 to 6 m for which 3 solutions may be foreseen:

- Adaptation of bulb units operating both ways under 4 m head; it may be cost-effective for a tidal range over 5 m.
- Orthogonal Russian turbines operating under 2.5 m head, possibly cost-effective also for a tidal range over 5 m.
- Tidal garden solutions which link the basin to sea by channels in which are placed in-stream turbines operating in optimal conditions. This promising solution seems to be cost-effective for a tidal range over 3 m.

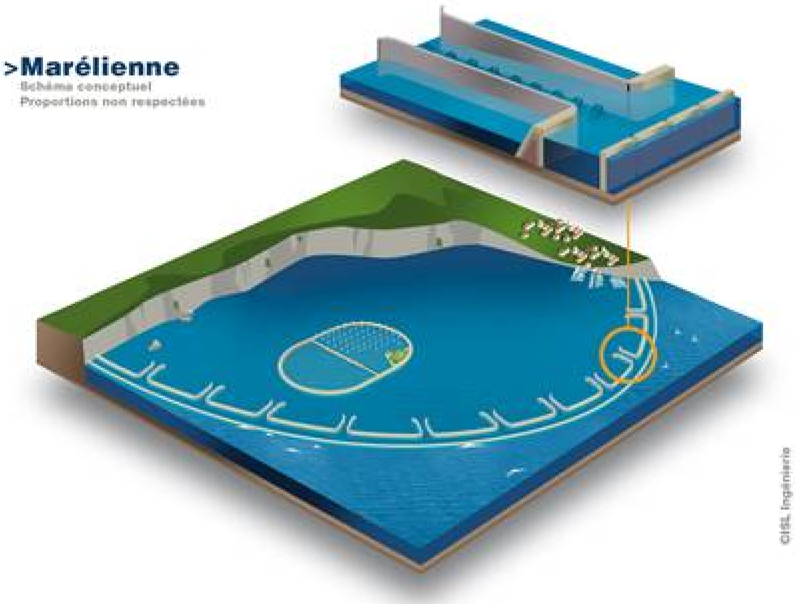

Fig. 5.9
The tidal garden option

It seems thus possible mid-century to supply about 1000 TWh of tidal energy by 300 GW of plants, a total of 5 000 km² of basins and 5 000 km of dykes 20 to 30 m high. Main relevant countries may be China, Russia, India, France, The UK, Canada, South Korea, Argentina, Brazil, and Australia but there are also some possibilities in the US, the Netherlands, Germany, Vietnam, Pakistan, and Myanmar.

Some 5 000 km of populated coast may thus avoid very high sea levels and huge waves.

Energy storage with sea-water PSP (Pumping Storage Plants)

The needs may be very important, up to 1 000 GW storing 10 or 20 hours and used 200 times per year. The favourable sites are rocky places and especially cliffs.

The upper basin of a PSP may be upon a cliff but it also may be off-shore along a cliff. The level of this basin may be 20 m or 200 m above the sea.

Such PSP may be associated with basins of tidal energy production and various PSP within tidal basins are possible.

6. EMERGING PUBLIC AWARENESS OF ENVIRONMENTAL CONCERNS

6.1. ENVIRONMENTAL CONCERNS: BIODIVERSITY

Biodiversity is an aspect of our environment, which, if ignored, may threaten the future of humanity and should be considered very carefully. The current rate of biodiversity erosion or loss suggests that half of the species could disappear by the end of the 21st century (Wilson, 2002) (Gerardo Ceballos, 2015) (J.H.Lawton & R.M.May, 1995). This event is usually referred to as the Holocene extinction or the Sixth extinction – the greatest loss of biodiversity since the Cretaceous-Palaeogene fifth extinction that was probably caused by the Chicxulub meteorite and that is notorious for having killed dinosaurs.

E.O. Wilson suggests that the main threats to biodiversity may be designated by the acronym HIPPO: habitat destruction, invasive species, pollution, population (human overpopulation), and over-harvesting. Habitat destruction is likely a key factor. Also, according to various authors, the most threatened ecosystems are found in tropical forests and in freshwater (UNEP, 2005).

When considering the global environment, a relative consensus was reached based on the work and recommendations of the World Commission on Dams: Dams play a significant role in human development, but a series of conditions must be met to avoid social impacts or an excessive environmental impact.

Within the more limited scope of biodiversity, the public perception of dams is largely negative. Simply put, many critics of dams think that dams are a necessary evil that can cause negative environmental impacts that we should seek to avoid whenever possible. If dam developers cannot reduce or eliminate the negative impact, they must at least compensate for their impacts. This opinion is supported by the fact that freshwater biodiversity, which is of such importance at a global scale, is undoubtedly affected by dams.

6.2. IMPACT OF DAMS ON BIODIVERSITY

The impact of dams and reservoirs on biodiversity is not easy to quantify; the impact may be globally positive, for at least three main reasons:

- Dams can contribute to fighting poverty by providing initial employment during construction, followed by longer-term socio-economic development, and also by adding water supply to support industry and agriculture. According to several publications, poverty added to population growth is perhaps the greatest threat to biodiversity.
- Dams can contribute to mitigating climate change. Climate change is one of the main threats to biodiversity and especially to freshwater biodiversity (Biofresh, 2014).
- Some dam reservoirs have become reservoirs of biodiversity and thus could be supported for their overall positive ecological impact. The Ramsar convention lists wetlands of international importance; on February 1, 2015, the database contained 1 767 inland wetlands, 717 man-made wetlands including 216 reservoirs. Man-made reservoirs can thus provide, in some cases, a variety of valuable ecological habitats.

However, it is undeniable that many dams have had, and still have, an overall negative impact on biodiversity. Better designed and better operated projects may alleviate this trend. Considering this assessment, the next question is: how to make dams biodiversity-"friendly"?

This is not easy because the quantitative assessment of the impact of reservoirs on biodiversity remains an open scientific issue.

The impact of reservoirs on biodiversity can be, to some extent, placed into specific themes [15, 16] as shown below:

Table 6.1
Key drivers of biodiversity (from Q96 General Report)

Water quality impacts	Chemical and physical water quality: quality deterioration in reservoirs (stratification, eutrophication, temperature); dilution of downstream pollution
Flow regime impacts	Downstream flow regime: low flows, surges due to hydro-peaking, variety of flood regimes - in connection with the cycles of downstream ecosystems
Impacts on sedimentation and debris	Sedimentary (and floating objects) transit, including the issue of estuaries
Impacts on migratory fish	Free circulation of migratory fish
Impacts on terrestrial wildlife	Free circulation of terrestrial wildlife, "biological corridors", including riparian wildlife
Submergence of land impacts	Loss of biodiversity in submerged lands: forests, grasslands, wetlands.
Freshwater lakes	Dams create freshwater bodies that may foster valuable ecosystems
Invasive species	The proliferation of invasive species that impact appurtenances

6.3. ACTIONS TO MITIGATE IMPACTS

For many of these themes, mitigation measures can be implemented, particularly at the design stage or during operation. Examples of actions are listed here but they are not exhaustive.

The *water quality* theme is central. ICOLD Bulletin 128 is dedicated, in part, to this theme and lists a series of techniques that have been used to improve the oxygen content of the releases downstream of dams. But the report was written in 2004, and the techniques have progressed in the past 12 years.

There is a direct connection with the issue of the *downstream flow regime*. Sometimes inexpensive modifications to the operation rules may have a very positive impact on downstream ecosystems. In some cases, a well-thought-out flow downstream of the dam can actually improve upon the benefits that result from the natural flow. These improvements can have a positive effect on biodiversity. The pulse flow experiment on the Colorado River is an emblematic and successful example of such procedures. Weirs and dams have been installed on some rivers to increase the benefits from inundation on streambeds or riverbed areas. This has been done recently on the iconic drought-affected Murray Darling basin in Australia.

A series of indicators have been developed to cover these issues and to try to monitor water quality and biodiversity of aquatic ecosystems. These indicators are sometimes very simple (temperature, dissolved oxygen), and sometimes more elaborate (such as eutrophication forecast from Q92R18, microhabitat method developed in France). First, the definition of and second, the monitoring of these indicators are very useful sources of feedback and in some cases provide invaluable assistance to the reservoir operation.

Ecological continuity for *migratory fish* and *sediment transit*, is also essential. For large reservoirs, complete solutions are not available yet. For smaller reservoirs, there are very positive experiences including improved fish passages and adaptation of passages to the target species, improvement of devices and operation rules for the management of sediment transit, and the installation of monitoring devices to assess the performances. Also, it is sometimes possible to consider alternative solutions, such as creating reservoirs off river that would be fed by diversion or pumping.

The themes *Terrestrial Wildlife* and *Submergence* focus on biodiversity loss associated with reservoir impounding, which often submerges habitats and forms barriers to the movement of wildlife. Data are lacking to be able to make preliminary assessments related to these themes. But, some important projects have prompted scientific monitoring, with large-scale measurements of the impact of reservoir impounding on biodiversity. For example, this is the case for the Petit-Saut reservoir in French Guyana. Each case is of course specific, but the feedback gained from these projects, in diverse geographical contexts, can provide lessons for future projects. A recurrent issue is whether we should concentrate dams on one river or construct dams on other rivers to spread the impacts. The answer is probably case-specific: Reference [15] stresses the incidence of cumulative effects in the case of dam cascades. For example, it may be preferable to keep some rivers free of barriers. The diversity of environments is very important; in a given geographical context, the creation of new reservoirs can increase or decrease the diversity of environments. The biodiversity analysis – like geology – should not be restricted to a narrow area.

The impact of *invasive species* is an issue to be dealt with on a case-by-case basis, again by accumulating feedback on regional freshwater lakes or reservoirs. Reported invasive species in dam reservoirs most often relate to fish species that were introduced for aquaculture and then preyed on other fish (e.g. craystone fish in Africa, bass in North America). However, dams often block the migration of these species. More generally, reservoirs may host non-native species (e.g. snails, algae, water hyacinth, mussels) that affect the ecosystems.

6.4. BENEFITS TO BIODIVERSITY

Dam reservoirs affect the ecosystems. There are losses, but there are also gains.

Creating *freshwater lakes,* especially in regions where there are few, might be an ecological gain which can be provided by dams. The value of the ecosystems that emerge depends on many factors, some of which result from the design and operation of dams. Reservoirs could be specifically tailored to foster biodiversity, such as artificial islands, freshwater reefs, branches of the reservoir with constant water elevation, and the creation of humid air.. There is a lack of data to assess in advance how a new reservoir will promote biodiversity and to assess accurately what would be the favourable design options. Compilation of feedback from existing reservoirs is useful in this respect. The COEC&S suggests that the Committee on the Environment add these data collection needs to its TOR or list of recommendations.

Creating reservoirs also play a role in the purification of polluted water.

6.5. SMALL DAMS VS LARGE DAMS

Small dams often may be a key aspect of dealing with the need for more water storage as small dams can often be built on more difficult sites, have fewer environmental constraints, and are often easier to finance.

Selecting a small dam or dams is often not the best option. When considering environmental impacts, developers and regulators must carefully consider all issues associated with more small dams instead of fewer large dams. Many countries require an assessment of the cumulative impacts resulting from all dams and reservoirs in a drainage basin or on a river system. However, by opting for small dams, it is often easier to deal with the core value of accountability – that is keeping promises made during project development.

There is no definitive answer to this question of small vs large.

6.6. SUMMARY

Eventually, ICOLD and its Committee on the Environment (COE) may consider that:

- Following ICOLD commitment and as circumstances require, ICOLD should consider biodiversity as a major component of our projects.
- The scientific understanding and progress in design responses both remain incomplete; there would be a great value in sharing the experience from reservoirs where a detailed ecological survey has been performed after the reservoirs' impoundment.
- It is very useful to define and monitor a series of indicators dealing with water quality and the ecological wealth of aquatic ecosystems. Much research has been done on the subject; it could be further shared, discussed, and disseminated.
- Even with incomplete knowledge, adapted projects and operational decisions can have very positive impacts. Some are inexpensive; costly solutions could be economically justified by the inclusion of the economic value of the services provided by ecosystems.

7. CONSTRAINTS TO SOLVING CHALLENGES

7.1. BACKGROUND

The COGD in 2007 determined that to ensure sustainability of dam-related projects, the owners or developers must focus on several interrelated issues, including socio-environmental aspects; public opinion and political will; financing; technical; perceived risk related to dams; and other perceived problems.

In this section the COECS will focus on all of the above with the exception of technical issues, as these are best handled by the appropriate ICOLD standing committees. The COECS understands that each country or region has unique regulations that contribute to solving the constraints or making them more difficult. Therefore, the COECS will give examples based on specific constraints created by each country. However, many of the identified constraints are common to many countries.

Most of the constraints to development are often most effectively dealt with at the project planning stage (Section 7.5) followed by a commitment to deal with them throughout all phases of development. The COGD in its paper entitled “Guidelines for Decision Makers”, (H. Blohm, 2007) noted that core values are essential to dealing with constraints during planning and ultimately during development. The core values are equity, efficiency, participatory decision-making, sustainability, and accountability. These core values are often dealt with during the project planning process described in Section 7.5.

7.1.1. Socio-Environmental Constraints

Most states ***in the USA*** have environmental regulations that are consistent with those of the Federal Government. In California, for example, there is the California Environmental Quality Act (CEQA) that requires developers or owners to prepare an Environmental Impact Report (EIR) and that it be certified before a project can be constructed. This process requires about two to three years in

California. If the Federal Government is involved, a similar report called an Environmental Impact Statement (EIS) must also be prepared. The EIS can be prepared concurrently with an EIR but can require more time.

There is another federal act entitled the Endangered Species Act that influences the cost and schedule of project development. If there is a threatened or endangered species present at a project site, development can be delayed for several years and the cost of mitigation can be enormous. Consequently, large dam projects in California are virtually non-existent with most project developers or owners choosing small dam options or off-stream storage. By opting for small dams, it is often easier to deal with the core value of accountability. That is, keeping promises made during project development.

In Brazil, project developers are required to prepare a very detailed Environmental Impact Report to be submitted to a state authority or, in rivers that are borders of states, a federal authority. If the proposed reservoir is to affect a national park, this park must be officially reduced; if the proposed reservoir will occupy part of an indigenous population reservation area, the project must be approved by the Congress. This helps to ensure that the project provides an equitable solution and is sustainable. Also, the developers must provide a summary of the Environmental Impact Report edited in a simple way, to be easy for everyone to understand. This short report is distributed to the city halls of the area of the project, so that everyone is able to read it before the public hearing. In order to receive the permit to start construction, the developers must submit an Environmental Basic Report in which all the mitigation projects are detailed. After the dam has been built, the reservoir can only be created after all the proposed actions of the environmental basic report have been implemented. Each of the three steps above usually takes at least three years.

Turkey has some regulations to minimize environmental impact of HPP. Turkey has had an Environmental Impact Assessment Regulation since 1993. The Environmental Impact Assessment (EIA) process is a most significant legal tool to tackle the adverse environmental impacts of HPP projects. A regulation on Strategic Environmental Assessment harmonized with the EU SEA Directive has been prepared and published in the Official Gazette in 2017. Strategic Environmental Assessment aims to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and approval of plans and programs with a view to promoting sustainable development, at basin scale. Strategic environmental assessments are defined as impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project. This includes cumulative effects. There exist, also, several special laws and regulations aiming to protect flora and fauna. If there is a wildlife area or wildlife development area present at a project site, development can be delayed for several years and the cost of mitigation can be enormous.

However, it seems people are not satisfied with the current situation and believe that HPPs can cause serious harm to the nature. In the legal context, it is important to determine whether the EIA regulation is sufficient or not for the environmental protection against the adverse impacts of HPPs.

Social effects of development projects, in Turkey, aimed to manage by two laws and their implementation regulations: Settlement Law: 5543 and Expropriation Law: 2942. Settlement law (5543) also mentions the Resettlement Action Plan and Income Restoration Plan. According to the Expropriation Law (2942), the administrations shall primarily apply the purchasing procedure (including barter). On the condition that expropriation is not performed by means of purchasing, the administration shall apply to the court of first instance authorized at the location of the immovable property. The administration establishes value appraisal commissions in order to determine market value of property. The Settlement law (5543) defines three resettlement options: (a) agricultural settlement, (b) non-agricultural settlement, and (c) physical settlement. According to the Settlement Law (5543) all impact categories of project affected people including vulnerable groups and landless have resettlement rights.

In India there is a well-established process of Environment Impact Assessment (EIA), which is handled by the Central Government or the State government. The Central Government would handle projects of more than 50 MW and projects of more than 25 MW if located fully or partially within 10 km from the protected area/critically polluted area/eco-sensitive area (including reserved forest area). For projects less than 25 MW an entity of Small Hydro Project does the environment assessment and clearance process. The impact assessment and evaluation process consists of impact on terrestrial ecosystem, change in land use and habitat destruction, impact on wild life, species population loss, impact on aquatic ecosystem, deterioration of water quality, fisheries, impact on air environment, noise pollution, sedimentation, and downstream impacts. EIA is a three-stage process starting with assessment followed by mitigation plan of short and long term, and finally by the examination and clearance process by the authority with and without conditions of change in project features or revising/improving the mitigation plan.

<u>In China</u>, the government pays more attention to the negative influence of water conservancy projects construction to the environment and strongly advocates river ecological protection, including ecological environment recovery of the dam area, establishment of the ecological demonstration base, soil and water conservation, the environmental monitoring, and the rare animals and plants protection. Project developers have to prepare a detailed environmental impact assessment before project approval. Technical guidelines for environmental impact assessment of construction project are formulated and issued by the national environment authority. The assessment report includes a project environment survey, effectors identification, prediction, countermeasure, monitoring, management, and investment and economic profit and loss analysis. The report also includes aspirations of the affected publics and associated social organizations.

<u>In France</u> – and in many places in Europe –, development of new dams and reservoirs is becoming more and more difficult. This situation results from two main reasons: (1) regulations related to environmental protection are more and more stringent, and (2) new dams rarely succeed in gaining public support.

Among the European Union (EU) regulations that hinder the development of new dams, two are especially difficult to deal with:

- The regulations protecting natural species place a very high value on endangered species or habitats. The regulators naturally regard every new dam project as a threat because the dam and the reservoir would affect wetlands, river streams, riverine zones, and forests, which almost always contain valuable ecosystems in the present context, thus contributing to the rapid loss of biodiversity and endangered species.

- Based on regulations created in 2015 to protect water quality, dams are considered systematic threats because they modify the natural river morphology, block sediments, and alter the water quality within the reservoirs.

These two regulations emanate from the EU and are applicable (with minor modifications) in every country member of the EU. Some dam projects are less affected by these regulations and include flood control reservoirs that do not store any water even in the case of small floods, and off-stream reservoirs that only divert a fraction of the high flows.

Some traditional projects continue to be developed, but in very small numbers. They succeed in gaining approval when the Environmental Impact Assessment (EIA) proves that the reservoir is an essential project and that there are no alternatives to receiving a permit. It must also be proven that all measures to reduce its footprint will be included, and that all residual impacts will be properly compensated.

In the EU, it is believed that climate change will place more stress on water as a resource, thus leading to a real need for new reservoirs. Nevertheless, the water industry will have to be creative in developing better engineering of the ecological features of the reservoirs to help ensure environmental sustainability.

Burkina Faso is one of the less developed countries located in the semi-arid area of West Africa with scarce groundwater resources. Water storage is not an alternative but rather it is the means to ensure water availability for all purposes. Water stored in reservoirs is the principal source of water for the nine-month-long dry season each year. Dam construction is underway throughout the country. Dams are classified as a priority infrastructure feature by both the people of Burkina Faso and the Government, which has led to the title “fétichisme des barrages”. Since the 1990s, a set of regulations has been drawn up regarding environmental and social impact assessment and management and plans for the resettlement of affected populations and infrastructure. Environmental and forestry protection regulation codes (laws) have been issued by the Government, along with their implementation decrees. A code for public health protection also has been issued. A water law has also been enacted with some articles dealing with dam design and construction, as these activities affect water management.

According to the environmental code (law), dam projects are classified into three categories (A B and C) depending on the potential environmental and social impacts and are subjected to in-depth environmental and social impacts assessments along with social impact management and resettlement plans.

The studies must be agreed upon by the Department of Environment before projects move to the construction phase.

These rules and regulations are applied with some difficulty owing to the lack of appropriate funding for these activities. The absence of funding and lack of adequate preparation often lead to conflicts during project implementation.

The progress achieved during recent decades to include public consultation regarding project benefits and risk sharing during project development has been significant. This approach is supported by regional institutions like the Economic Community of West African States (ECOWAS), which led to this programme for dialogue and consultation for development of large dams in the ECOWAS Countries.

In Vietnam regulations for the protection of the environment (particularly flora and fauna) exist, but they are not always applied by the independent power producers owing to financial issues. For public organizations and for large projects with international financing, these regulations are more consistently applied.

Resettlement of displaced populations, particularly in areas with ethnic minorities, coupled with low compensation for the displaced populations, creates anti-dam sentiment. Opposition by the public and local news media exists, but a substantial amount of the opposition originates from overseas NGOs.

Also in Vietnam, issues related to how water is shared among beneficiaries can be significant and can affect both the project cost and schedule. It should be noted that this is a problem in most counties, and can be negotiated if the process outlined in Section 7.5 is followed.

7.1.2. Public Opinion and Lack of Political Will

<u>In the USA</u>, news media and environmental groups generally oppose dams, except after a large flood or during a drought. Even during a drought, environmental groups are very vocal in speaking out against new storage projects. They aggressively promote more conservation. Groundwater storage is often promoted as an alternative. However, groundwater storage is often far less efficient than surface storage, as it is usually expensive to extract the stored water by pumping. Furthermore, water in the ground often migrates away from the planned storage aquifer, thus creating arguments over ownership and water rights.

As of 2016, the entire western USA has been experiencing a severe drought. California is in the fourth year of drought. Some experts believe that California is in year 15 of a 20-year drought based on examination of hundreds of years of data using tree-ring data. To help deal with drought, voters in California recently approved a US$7.5 billion water development bond. The projects covered by the financing-type bonds are being challenged by environmentalists who state, once again, that we only need more conservation. Many politicians agree with the environmental groups in order to get re-elected, even though California's economy is being devastated by the drought.

<u>In Brazil</u>, environmental groups and the general public are mostly against the construction of new large dams for power production, navigation, irrigation, and even for water supply or flood control. In the recent past, the power production from hydropower stations represented 95% of the total power produced. Currently, power that is generated in hydroelectric plants is less than 80% of the total and will be closer to 65% by 2020. Although the feasible sites for new power plants are numerous in the country, the constraints are severe. This leads to the installation of a large number of thermal plants with a much larger environmental impact and a much higher energy cost. This has also led in the last two decades to the construction of hydro stations with run-of-river plants. At present, the country is losing the major benefit of regulating stream flows that it once had in the recent past because run-of-river hydro provides little or no river regulation. Stream flow regulation often provides for flood management, ecosystem protection, and more water available for other beneficial uses.

In Turkey, there are formally defined public disclosure meetings that are conducted both within the scope of EIA and expropriation process in accordance with the related regulation. In addition to the local people affected from the project, NGOs and various local groups (farmers and businessmen) can attend the meetings. However the critical point is that stakeholder engagement is a tool for managing two-way communication between the project sponsor and the public. In practice the meetings are recognized by related authorities as just informing people. Therefore stakeholders are not actively involved to the project. While some local people are not opposing large HPPs owing to the expropriation incomes, there may be still some resistance against the construction of large HPPs.

<u>In India</u> **the** opposition to major dam construction is strong from the public, NGOs and occasionally from local political organizations. The reasons for oppositions also vary widely like land loss and resettlement issues, downstream adverse effects, and apprehension about safety and stability on dams. Even though all these factors are rigorously studied during the Detailed Project Report preparation and evaluation by various expert groups and organizations, the public opinion often prevails over the project evaluation. To deal with this issue the "National Green Tribunal" (NGT) was created where any individual or organization can voice their grievances and the NGT has the power to keep the construction of the project on hold until the hearing and judgment is delivered. As most of the hydropower dams are located in forests, the department of forest and environment is always against the construction of dams and project even when the cost of reforestation and catchment area development including improvement cost is included in the project. In absence of any guidelines for the comparative study on relative assessment of environment damage by hydro project and thermal projects, the latter always get priority causing much more destruction to the environment. There is an urgent need for a more transparent system of communication to educate the public on benefits of the project and scientific assessment of comparative environmental damage between hydro and thermal projects to mitigate the impasse.

<u>In China</u>, the construction of new water conservancy and hydropower projects is generally acknowledged through project contribution dissemination, public participation, and decisions by the public and social organizations. There are about 200 water projects, such as water resource projects, water diversion projects, agriculture water-saving projects, river-lake-control key projects, flood prevention and flood water utilization and water supply projects. The major challenge for new water projects is resettlement of inhabitants in reservoir regions. Since 1949, there are about 18 million migrants owing to reservoir construction. More than 1.2 million migrants have been released and 5 billion USD have been used for migrant compensation because of the Three-Gorge Project construction. The migrant cost increase is becoming more arduous. Now the Central Government has established and revised reservoir immigration laws and regulations for benefit distribution, preferential policies, compensation scheme, and supportive measures.

In France, and in most European countries, public opinion is probably not directed as much against dams as it used to be, but it is certainly more than ever "anti-change". The construction of a new large reservoir would certainly not be supported, but the destruction of an existing large reservoir would also be strongly opposed. Also, every new dam project attracts opposition from environmental groups (that are mostly against dams) and activist groups. These groups use the communication media with great ability and usually do not seek open discussions.

In Vietnam there is opposition to dams largely because of population resettlement issues, but the source of the opposition is largely from overseas NGOs.

In Burkina Faso, in contrast to many other countries, the opposition to dams is much less significant, as most of the population support new dams and reservoirs because the local climate is arid, with the dry season lasting nine months of each year. Without water storage, the population would feel the effect of the lack of water.

Experience shows that the only way to deal with anti-dam groups is through education of the more neutral or open-minded electorate, so that they understand the value and importance of dam and storage solutions.

One way to improve the public image of dams is to continue improving the designs of new projects and the operation of existing ones. Also, there is a need to enhance communication, including the use of social media – but there is no pro-dam lobby to take on this role. Some improvements in general acceptance have come from discussions with non-governmental organizations (NGOs) or environmentalists, who agreed to discuss the issues of dams and hydropower.

7.1.3. The opinion of third parties

Opinions come from two different groups, namely the dam-opposition and the pro-dam groups. The stakeholders group could represent the indigenous people originally from the project area or outsiders with special interests on the existence of a dam project. Each of them may have their own perception about the advantages and disadvantages of dams for the community as well as the environment.

According to the dam-opposition groups:

- Dams create huge problems that affect people owing to relocation issues
- The changes to the environment after reservoir impounding have a negative impact on the ecosystem, particularly to the farmland and fisheries

According to the pro-dam groups:

- Dams become the solution for the people who have a high demand of water for irrigation of their crops, drinking water supply, prevention of floods or those who seek a better livelihood
- The environment becomes even better after water is available in the reservoir especially in the arid and semi-arid areas

7.1.3.1. The case of Indonesia

To turn the dam-opposition group into a pro-dam group, Indonesia is currently encouraging dam owners to support community-based initiatives in their effort to convince dam-affected people about the long-term benefits and sustainability of dam projects. This sort of bottom-up approach is more likely acceptable rather than a top-down approach when people are forced to follow the government programmes regardless of the relevancy to their needs. Informal community leaders with positive perceptions of dams should be equipped with the means on how to prepare their own short-, midand long-term plans in managing the dam-affected area. These plans become the input for the overall dam project planning and are beneficial for all parties. There are success stories using this approach in various spots in the archipelago. For example, there has been public acceptance in the Sulawesi Island even during the site investigation stage before any dam construction activity because of correct approach by the private sector dam owners to the community. In another project in Lombok Island where the dam has already been in operation for about 35 years with people entering the area near the reservoir, the locals recently took their own initiative to relocate themselves from the green belt after realizing the importance of a sustainable dam operation for irrigation and drinking water supply.

7.1.3.2. Non-Governmental organizations

NGOs have made decisive contributions to the environment and they play a decisive role in influencing public opinion. Their influence notably comes from the fact that they are supposed to be neutral, whereas the other stakeholders may be excessively driven by their own economic interests. Of course, the neutrality of NGOs is often overrated – as other organizations, they, also, have to defend their own durability and purpose.

NGOs might focus on a specific topic, or deal with a broad agenda, covering both biodiversity and poverty issues. An organization like *International Rivers* would for instance mainly focus on river wilderness and biodiversity, whereas others like *Greenpeace* and *WWF* would develop a wider approach.

Their point of view shall be listened to and considered, especially when they do not put nature (conserving biodiversity) above people (fighting poverty by providing access to water and electricity). Some NGOs have indeed developed valuable expertise in our fields. By challenging our methods, they may help us develop better projects.

Among them, the WWF (whose purpose is to "stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature") has published its general opinion about dams[81]. Of course, its appreciation differs from our experience and we would certainly not always agree with the

[81] http://wwf.panda.org/our_work/water/water/dams_initiative/dams/ Retrieved in May 2018

positions it holds on various specific projects. But its general opinion on dams and hydropower is fairly balanced –see box below.

NGOs that are purely focused on nature conservancy may on the contrary develop biased approaches.

WWF Opinion

From the WWF website

Dams can play an important role in supporting the economic development of a country and its people. The key to their environmental and social sustainability is to explore all possible options and consider the entire basin.

Once an urgent need for more electricity, irrigation water, or other service has been demonstrated, an options assessment can show whether a large dam is the best alternative. If it is the best alternative, the assessment will outline how to move forward in a way that is economically, socially, and environmentally acceptable.

People look to dams for a variety of reasons, such as public water supply, energy, irrigation, and flood control. But there are many ways to ease the pressures for a dam by examining our current behaviours.

Changing agricultural practices can have a significant impact on water consumption. Generating energy through alternative sources or by upgrading existing hydropower facilities may provide more overall benefits. Nature can turn out to be better at flood management than any dam could be.

Increasingly, there are attempts by dam builders and investors to ensure that dams are built in a more sustainable way. The WWF is partnering with banks, industry, and other NGOs to develop and promote environmental standards and best practices for dams.

From a brochure “WWF and the Dams of Southeast Europe”

1. Proposals for new hydropower plants must meet the World Commission on Dams guidelines. New hydropower plants should only be considered when they are truly the best option, judged by criteria that include energy efficiency and the best available energy-demand management.
2. Governments should ban hydropower schemes, large or small, on some of the remaining unregulated rivers (or their tributaries) in areas of high conservation value, thereby creating “no-go areas”.
3. Decisions on where to situate hydropower plants should minimize environmental impacts on the whole river basin. Efficient hydropower sites that minimize the area flooded per unit of energy produced should be preferred (but taking into account point 2 above).
4. Mitigation (environmental flow regimes, habitat restoration and protection, fish ladders) can significantly reduce the impact of hydropower projects and should always be included.
5. The capacity of existing hydropower plants should be increased to minimize the need for new ones.
6. Small hydropower plants, which can supply rural areas in developing countries with renewable energy, must include mitigation measures and their cumulative impact must be considered.
7. Developers must ensure fair resettlement, in accordance with WCD principles, by involving all stakeholders in decision-making, including displaced residents.

7.1.3.3. International funding agencies

Funding agencies play a key role in dam and hydropower developments in developing countries (see §7.1.4). Their opinion on dams and hydropower is crucial in the development of new projects (and the refurbishment and upgrading of existing infrastructures).

Most of the international funding agencies are currently willing to contribute to such developments. Depending on their internal policy, they put more or less stress on environmental and social issues. Among them is the World Bank which has stated the following: "*The World Bank is committed to continued support for its borrowers in developing and managing priority hydraulic infrastructure in an environmentally and socially sustainable manner, and views the WCD Report as a significant point of reference in this process."*

7.1.4. Financial Constraints

7.1.4.1. Increasing costs

The cost of dam and storage projects is increasing for several reasons. First, dams are more expensive than in the past because of environmental constraints and requirements as noted in Section 7.1. Second, the quality of dam sites is decreasing as the ideal sites were developed first with the less-than-ideal ones remaining to be developed last, i.e. with difficult geological conditions, long energy tunnels, etc.

Accounting for environmental issues certainly increases the project costs. In the case of France, it is difficult to determine the "cost of environment"; it is probably low-to-moderate in most cases (where only small adaptation and compensatory measures are considered), and very high in other circumstances (where environmental issues induce radical changes in the project purposes or components). There was a case in 2010 where a water supply dam project was abandoned for an alternative river-pumping option that was three times more expensive.

The "cost of environment" is, however, not necessarily the greatest challenge. The main difficulty is that the environmental and social issues have to be dealt with entirely before the permit is delivered. That means very long procedures and large upfront costs, before the project can be approved.

7.1.4.2. Lack of public funding

The negative image of dams promoted by environmental groups contributes to the lack of public funds available for financing. For example, in California, USA, environmental groups and politicians are fighting the use of approved bond financing for legitimate dam projects even in the face of a severe drought. While this fight will likely only delay the projects, the economy and the citizens will bear the long-term impact of the delays.

Yet public financing is often necessary for dam project development. A substantial part of the opposition against dam projects comes from overseas NGOs. On the other hand, financing has been granted to all dam projects by the National Development Bank.

7.1.4.3. Lack of private funding

Private funds are currently widely abundant and may offer reasonable priced financing. But they are most often not directed towards dam-hydro projects.

Of course, this is also related to environmental delays, as lenders do not want their money tied up for years owing to delays with no project benefits being delivered.

But above that, private financing is inhibited by two factors: long-term timing and risks.

- Dam projects bear risks, among them geological hazards (implying cost overruns and delays) and hydrological uncertainties. Private funds are adverse to such risks.
- Dam development projects need time for engineering and construction; they need time for benefits to reimburse capital expenditures and reward investors. Yet time is another factor of risks: political and

economic risks that may endanger the the window of opportunity and bankability of the project.

As noted in previous sections, the COEC&S strongly urges ICOLD to re-establish a committee on dam financing to assist countries, particularly developing countries, to explore creative ways to find or obtain reasonable financing.

Following the planning processes outlined below in Section 8.5 often helps to alleviate constraints to new dam development.

7.2. SAFETY AWARENESS AS A CONSTRAINT TO DEVELOPMENT

7.2.1. Perception of Risk

Society's perception of risk is changing. Perception of risk as a negative influencer can and often is a constraint to development and must be considered in the project planning process. The following paragraphs indicate where more attention by ICOLD would be helpful to improve dam safety and public awareness, thus helping to deal with risks often perceived by society as unacceptable. It is beyond the scope of this bulletin to develop solutions to deal with all risks but rather the COEC&S will note areas that will likely require the attention of standing committees, including the Committees on Dam Safety and Public Awareness.

According to (H.J. Pasman, 2003), "On the one hand, the structures become larger and contain larger quantities of toxic substances, energy, or both, and on the other hand the number of people at risk increases continuously. Moreover, the acceptability of being victim of an involuntarily taken risk decreases." While dams and reservoirs are not "toxic substances" but only "energy", the principle proposed by Pasman likely remains applicable.

Also, according to H.J. Pasman, the changes in acceptability are triggered by the improved information-type networks that offer large and sometimes dramatic coverage of natural and industrial accidents and in many parts of the world by the improvement of the living standards that make people more sensitive to natural and industrial risks.

H.J. Pasman suggests that these changes result in:

- A growing perception that risks imposed on people should be justified, which is especially true for risks that could have catastrophic consequences.
- An increasing reliance by the public on regulators that they trust, because the individuals are aware that there are risks that cannot be avoided, and also that they are not in a position to assess the risks for themselves.
- Calls for greater openness and involvement in the decision-making process. (Refer to Section 7.6)

There is a trend towards more understanding of risks by affected populations and towards a decreasing tolerability by the public at large, regulators, and other stakeholders.

This improved understanding, on several occasions, has been inserted into the corpus of laws: the “precautionary principle” as a legal concept has been created; risk assessment procedures and critical reviews of industrial hazards in many countries have been expanded.

7.2.2. Understanding Risk as a Safety Issue and an Impact ON Human Populations

According to (ICOLD, 1997):

- the probability of failure for large dams built after 1950 is 0.5% per dam, which is roughly 10-4/year; it was 2% per dam for dams built before 1950
- 20 recorded accidents caused more than 100 fatalities each
- 8 recorded accidents caused more than 1 000 fatalities each

A recent inventory of failures was handed to the authors by the ICOLD Committee on Dam Safety, and completed by them (see Appendix A). The inventory excludes tailings dam failures. Thus it is not necessarily complete. The inventory records 27 “validated” large dam (> 15 m in height) failures with complete loss of the reservoir. They resulted in more than 530 fatalities. Considering that there are more than 50 000 large dams in the world, this is a rate of failure of the magnitude of 2.10^{-5} per year. This is five times better than the previous probability noted above compiled by ICOLD in 1997; the safety performance of dams keeps improving.

7.2.3. Future of Dams

As noted by ICOLD, in the past 25 years, the safety of large dams has been continuing to improve, but must be further improved by following state-the-art planning, design, construction, and operational techniques. The listing below indicates areas where most of the dam safety awareness and failure mitigation techniques should be focused under the direction of the Committee on Safety of Dams and the Committee on Public Awareness

7.2.3.1. Resistance to floods

Most of the recent accidents at large dams were caused by floods. There is still a need for a better assessment of floods and for improved designs that can handle large and extreme floods. Various recent technical and scientific findings in this field clearly show that some substantial improvement is at hand.

The possible increase in extreme rainfalls that could result from climate change (See Section 4) calls for the immediate implementation of these findings with inputs from the Committees on Dam Safety and Hydraulics of Dams.

The issue of spillway gates and other large discharge gates also requires specific improvements:

- Spillway gates have to meet two opposite objectives: dam safety during floods (priority to opening) and d/s users’ safety during normal operation (priority to non-opening).
- The design methods and criteria for spillway gates operation are far less mature than the design methods and criteria for other flood safety issues (hydrology, hydraulics).
- Spillway gates might be sensitive to cyberthreats when their operation relies on remote control.

7.2.3.2. Large dams (or large reservoirs) safety

Apart from the Gouhou dam in China, there has not been any large dam failure causing more than 100 fatalities in the past 25 years; and the last accident with more than 1 000 fatalities dates back to 1979, almost 40 years ago. However, one single accident with several thousands of fatalities in the next 50 years would drastically change the perception regarding dam safety.

Avoiding this means ensuring a level of safety equivalent to a probability of failure as low as 5.10^{-7} $year^{-1}$ for the dams that could cause such a large number of fatalities. This is indeed a very stringent criterion, especially when resistance to floods is considered.

As stated by some authors, the threat might not specifically come from a very high dam, but rather from large and very large reservoirs with populated cities downstream: the worst dam accidents were provoked by fairly low dams (Banqiao and Shimantan, 25 m each, and Machu, 26 m), and levee failures can cause a very large number of fatalities despite their low height.

Specific attention should be paid to these dams that are, from a safety point of view, of international importance.

7.2.3.3. Tailing dams

Tailing dams were not included within this analysis. In general, the safety record of tailing dams is much poorer than the safety record of classical dams.

This poor record impacts the image of the entire dam industry.

7.2.3.4. Small dams and levees

Small dams and levees were not included within this analysis. A specific review of small dam accidents is currently being carried out by COES&S.

7.3. PROJECT PLANNING BEFORE DEVELOPMENT TO MITIGATE CONSTRAINTS

The diagram of the project development task flow, Figure 7.1, presents the tasks required in many countries to develop a project. Many of these tasks (highlighted in grey with a bold outline) represent activities that are often the areas described above where constraints to development surface and stop, or significantly delay a project. Also, this activity is where core values including equity, efficiency, participatory decision-making, sustainability, and accountability can and should be dealt with by owners and developers. Not all of these tasks will be presented in the following sub-sections because they are beyond the scope of this bulletin.

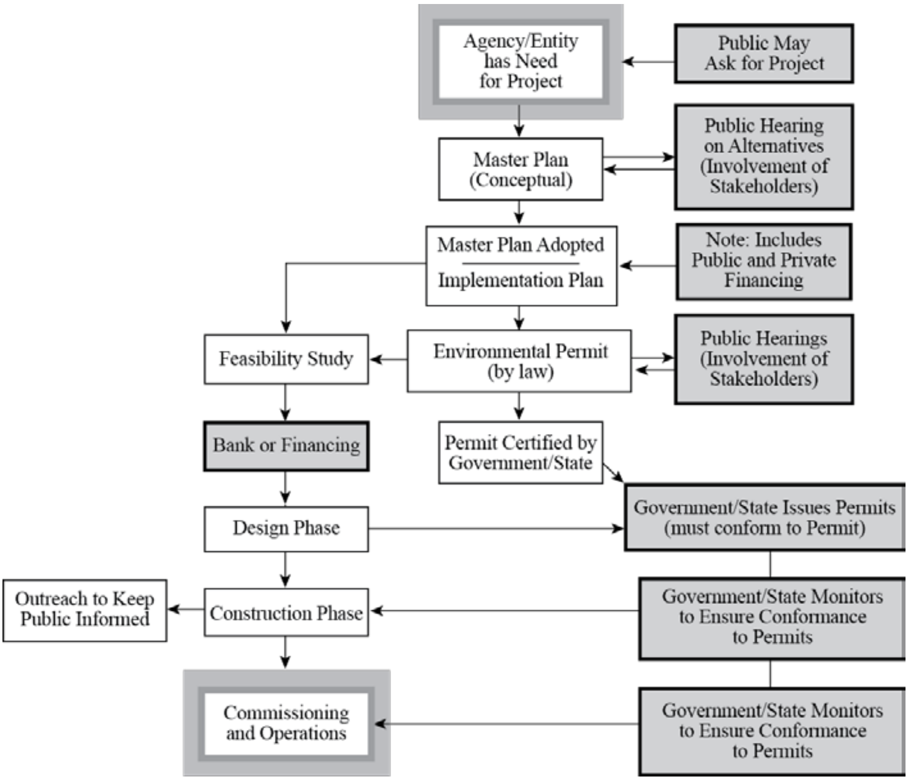

Fig. 7.1
Project development task flow

7.3.2. Public Involvement

Public involvement must be implemented within the context of the organization and policies of the country in which the project is located. A proposed dam and reservoir project has a wide range of stakeholders, which include, in addition to the project sponsor or owner, policymakers, regulators, investors, special interest groups, and the public. A project that can be implemented must involve all of these stakeholders, to varying degrees, to ensure their needs, concerns, and issues are met or dealt with. Traditionally, dam and reservoir projects have involved policymakers, regulators, and the investment community (the latter because bond issuance or special grants or loans are often required) but not until recently, the public. Owing to the lack of early public involvement, special interest groups have often become involved towards the end of a process, especially in cases where they objected to some aspect of the project, and stopped or delayed it.

The values of equity, efficiency, participatory decision-making, sustainability, and accountability are fundamental components of the public process. These values enable true public involvement. In the American Water Works Research Foundation's *Public Involvement, Making it Work*, public involvement is described as "a process that draws stakeholders and interested members of the public into the decision-making process or as an issue evolves in order to develop a shared solution." When practiced honestly, consistently, and in a timely manner, public involvement helps ensure project acceptance and implementation, thus minimizing delays.

Effective communication programmes include several phases that correspond to and support the technical phases of a project. During the assessment phase, for example, the communication task might be to raise awareness through public information programmes. It is during this initial phase that stakeholders will be identified. As the project progresses, it is desirable to obtain input and advice from stakeholders. Communication during this phase is two-way. Finally, stakeholders may be asked to provide specific advice or participate more directly in the project development.

7.3.3. Stakeholder Participation

The stakeholders of a potential dam and reservoir project include:

- Project sponsor or owner: The project sponsor or owner is defined as the entity empowered with the authority to decide to build the project and capable of implementing that decision. The sponsor may be either a private or public entity (government or state agency).
- Secondary decision makers: "Secondary" decision makers are entities capable of denying permission or capability of the project sponsor to implement a project. Examples include environmental, regulatory and permitting agencies; state offices of safety of dams; a judge in a court of law; entities that arrange for the marketing of bonds or financing of a project; and voters in a general election.
- Involved public: The involved public is defined as including special interest groups whose property, livelihood or personal values would be affected by the significant benefits and important investments of public resources caused by a dam and reservoir project.
- General public: This category of stakeholders includes the balance of the population in the project region potentially affected by the proposed project or its various alternatives.

As shown in Figure 7.1, the public should be involved in the early decisions regarding project needs all the way through decisions regarding environmental factors and permitting, most likely by government agencies. Factors such as impacts on local populations (resettlement is often a major issue), flora, fauna, and land impacts must be considered in an open forum so that the public generally will understand and be likely to support the project.

Financial issues must be dealt with as well, to help ensure the feasibility of the project. Commitments made to obtain permits and to deal with public concerns are often costly and must be included in operation plans. The operation plans must honour promises/commitments made to financial institutions, the public, and governmental permitting agencies. Not honouring these promises or commitments can stop a project.

8. POTENTIAL SOLUTIONS AND RECOMMENDED ICOLD ACTIONS

8.1. DEVELOP PROJECTS THAT ARE EXEMPLARY

8.1.1. Background

Dam projects require qualified owners and developers, and supportive regulators, who will be able to handle the various issues and long-run planning of such project development, from the very beginning to the long-term operation. (§7.3)

This requires, as a minimum, the following:

- Performing a better appraisal of future needs of both water and electricity, at a regional scale and with full consideration of climate change. Planners should be fully aware that water supply and hydropower development go hand in hand and are complementary purposes that can enhance project development. The COEC&S urges ICOLD to assist its members and other agencies, such as the UN, the World Water Forum, the World Energy Council, and the IEA, to accomplish this task.
- Maintaining our commitment to the core values of equity, efficiency, participatory decision-making, sustainability, and accountability. Public involvement and stakeholders participation are crucial for every project. Please see Section 7.
- Engaging in discussions with NGOs to improve mutual understanding. This is dealt with specifically in Section 7 with suggested actions for project developers.

Dam development is certainly a difficult task that requires qualified owners, developers and regulators. Many projects have been delayed or abandoned because of inappropriate handling of the initial steps of dam development; and some projects underperform because of inappropriate handling of the long-term issues such as operation, maintenance, and sedimentation.

Besides, there is a trend toward more multipurpose dams and toward more “basin-scale” approaches. This trend increases the complexity associated with dam development and operation. We believe that ICOLD could produce a short useful bulletin that contains basic guidelines for a dam developer or dam owner.

8.1.2. Dam safety and the cost of dam safety

Dams are safer today than they were a few decades ago. But we need to keep improving the figures. This requires continuing efforts to guarantee dam safety of large dams (§7.2).

We would recommend three specific actions for large dams:

- Several future safety improvements will derive from non-structural measures: reviews of new projects by independent panels; periodic reviews of dam safety, surveillance of the first impoundment, written and tested flood instructions for every dam, and warning systems. An update of the bulletin E02 published in 2001 is deemed necessary to reflect the important recent progresses in this field.
- Many fatalities today come from faulty operation of gated spillways. Researches and a bulletin on this issue would be useful. There is indeed no published standard or guidelines regarding the safe operation of gates – and there is no criteria on how to assess whether a specific discharge or discharge gradient would be dangerous or not.
- Surface erosion of rock downstream concrete dams or of earthfill dams covers is an important issue that has not been thoroughly dealt with so far. This is a very important issue in terms of dam safety and in terms of the costs of construction and maintenance. The subject probably deserves a specific committee or a sub-committee of the committee on hydraulics.

In addition, we still have to find a correct approach regarding the safety and sustainability of small dams (bulletin under preparation by COECS). This approach requires distinguishing the LHSD for which different conception rules can optimize the economy of the project.

- We need a simple tool to quickly assess whether a small dam is a high hazard or a low hazard.
- We probably need a different set of design standards for the smaller dams. This set could be specific to different regions with adaptation to local hydrology, geology, and topography.
- We need innovative solutions for these LHSD, to lower their costs and/or delay of construction while keeping or improving their safety and durability.
- We need improving the governance of LHSD, particularly in some developing countries, with a better implication of the owner, the designer, the operator and other stakeholders.

8.1.3. Multipurpose reservoirs

This Bulletin explores the 'Challenges and Needs for Dams in the 21st century'. ICOLD published Bulletin 171 'Multipurpose Water Storage – Essential Elements and Emerging Trends' that explored similar topics as this Bulletin. Reference should be made by the reader to the findings contained in Bulletin 171 as the two Bulletins explore the needs, challenges, and the future of dams and the retained reservoirs in the global context.

Bulletin 171 presented what the authors regarded as 'Essential Elements' and 'Emerging Trends' for planning and managing multipurpose water storage projects. The focus of the Bulletin was not on what should be done, but on what is being done, and how and by whom. The findings and reflections stemming from a review of the case studies are not presented as guidelines, but as recommended 'essential elements' and 'emerging Trends'.

The key findings from Bulletin 171 were:

- Globally there is a strong trend from single-purpose, mainly for electricity generation, to multipurpose reservoirs.
- Flood protection has become a dominant purpose owing to the high population density in major river basins.

- Environmental and social aspects are underpinning drivers for enhancement to schemes, to make them multipurpose, and for new developments.

Bulletin 171 presented its finding as ‘Essential Elements’ and ‘Emerging Trends’. Many of the ‘Challenges’ and ‘Needs’ explored in this Bulletin follow a similar theme. The Bulletin 171 ‘Essential Elements’ were summarized as:

- Adaptive management
- Asset conservation
- Conflict management
- Economic value
- Engineering
- Environmental management
- Financial viability
- Governance
- Global warming
- Long-term planning
- Social development

Bulletin 171 ‘Emerging Trends’ were identified as:

- Long-term planning
- Water supply reliability
- New storage in developed countries
- Transformational projects in developing countries
- Adaptive resource management
- Predictive uncertainty
- River ecology
- Asset conservation
- Synergy among renewables

While it is the dam that retains the reservoirs, Bulletin 171 identified that the future of the reservoirs is changing also, primarily from a single use to a multipurpose use. The ‘dam’ is the critical component of the reservoir system, and sections 1 through 7 of this Bulletin identify that the future needs and challenges for the dam structures are changing as well. Section 1 presented the needs and challenges for ‘dams’, section 7 presented the ‘Constraints’ and this section 8 the ‘Solutions’ to these needs and challenges, all of which are intertwined with the ‘Essential Elements’ and ‘Emerging Trends’ that are presented to multipurpose reservoirs in the 21st century.

8.2. PROVIDE SOLID FOUNDATIONS FOR PROJECTS

8.2.1. Better data for better projects

Dams and reservoirs projects strongly interact with their environment (topography, hydrology, geology, biodiversity). An in-depth knowledge of the local environment helps to develop good projects. But this remains a challenge.

In many regions, hydrological data are scarce and not sufficient to properly design the reservoirs. Hydrology – and especially run-off – is often poorly assessed because of a lack of adequate measurement equipment. Installing, operating and maintaining a reliable hydrological observation network are difficult and rewarding at medium term only. Measures in this direction, as well as regional-scale hydrological syntheses would help in obtaining more robust economic models.

Small- and medium-size projects usually do not have enough resources to properly perform complete environmental impact assessments. A classical means to solve this consist of preparing "Strategic Impact Assessment" on a broad scale (usually a river basin or a sub-basin), which help devising where and how dam reservoirs could be considered, and with environmental and social specifications.

The financing of such hydrological networks and regional-scale studies of general interest is certainly the responsibility of states – with, if necessary, the assistance of international funding agencies.

8.2.2. Financing is the key

In a workshop conducted by the COEC&S in 2014 in Bali, the panellists all agreed that financing is and will be the major constraint to project implementation, particularly in developing countries. The COEC&S is aware that ICOLD formed a committee on project finance and that this committee did not produce either bulletins or recommendations. Nevertheless, the COEC&S recommends that a committee on project financing be re-established but with a TOR that is narrower than that of the previous committee. The TOR should start by developing a list of constraints to financing, methods to deal with these constraints and a list of projects that have successfully applied these methods. See Appendix B.

General suggestions are given below.

Hydropower often requires preliminary technical and environmental assessments that are long and expensive compared to thermal (gas and coal) or solar. Investors often struggle to finance these studies, which too often result in cancelling or postponing projects or, sometimes, in achieving incomplete studies. This difference in preliminary assessment requirements is often an unfair advantage in the competition between energy production methods and it should be corrected. The COEC&S recommends that funding of preliminary assessments (technical and environmental) be facilitated by agencies and governments. Such assessment should include regional hydropower assessments, preliminary designs, and strategic environmental assessments.

Benefits from dams and reservoirs are for some of them non-monetary – though sometimes essential or even vital. Besides, dams have a long lifespan. These parameters are not considered in economical comparisons among alternatives. These facts imply that the projects should not be paid only by future revenues, they also deserve public financing – or at least a fairer comparison. The best tool to perform an unbiased comparison of alternatives require a complete “life cycle assessment”, so as to value non-market costs and services. In that view, progress is possible in the development of shared methods to assess total costs. This should enhance the attractiveness of well-designed hydroelectric projects. ICOLD may try to develop such a tool – which is not an easy task.

Hydropower competes with thermal plants and intermittent power plants. It would be fair to define appropriate and supporting feed-in tariffs that value the fact that reservoirs provide guaranteed power and grid regulation tools (frequency, voltage). It is certainly inappropriate to utilize similar kWh prices for predictable and stable HPP reservoirs electricity and for intermittent solar or wind production. This is a difficult issue that ICOLD can hardly cover. One possible action would, however, be to gather best practice standards of various countries and disseminate them.

8.2.3. Improving projects through Financing and contractual instruments

Dams are very specific structures and require specific contractual and financing terms. Among various particularities, COECS pointed out three specific issues that would help improving the projects governance.

Risk allocation and construction cost containment

Contractual terms could improve the IPP projects in hydropower by securing both parties (owners, contractors) and limiting the risks of costs overruns. Contracts are often based on FIDIC rules, which provide a sound basis, but which could be further tailored to HPP projects (handling and sharing of hydrological and geological risks). It would be certainly useful to prepare specific “HPP additions” in addition to FIDIC red, yellow and silver books, including specific issues regarding the sharing of risks (with focus on what is dam-specific or HPP-specific: hydrology of floods and resources, borrowed materials, large tunnels, etc.) and including standard guidelines to elaborate a fair and unbiased remuneration of the private investor.

Financing OPEX

Funding that covers the 10 first years of operation is crucial to dam safety and also to reservoir operation. In the case of public funding, the allocation should always cover 10-year assistance to the owner, to ensure:

- verification of the adequacy and optimization of the operation procedures,
- surveillance of the dam during the first filling and first years of operation, and
- assistance to and training of maintenance teams.

Assessing and valuing the non-market services

This topic is essential for two reasons:

- At development stage: it might be the key to finance some hydropower projects that would not be bankable if they have to support the entire CAPEX.

- During operation: if non-market services are valued, a larger share of the water resources might be devoted to them.

The key issue here is obtaining proxies to get an economical value of these services that could be included in the analyses.

8.3. MITIGATE AND ADAPT TO CLIMATE CHANGE

In Section 3 of this bulletin, the COEC&S notes that the Intergovernmental Panel on Climate Change Working Group III in its report entitled *Summary for Policy Makers – Climate Change 2014: Impacts, Adaption and Vulnerability*[82] offered the following observations:

- "In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans."
- "In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (medium confidence)."
- "Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes with varying degrees of success.
- "Adaptation to climate change is becoming embedded in some planning process, with more limited implementation of responses (high confidence)"

Climate change is – and will remain – a major driver for our profession. We can still make progress, at least in three directions:

- Objectively demonstrate the role of reservoirs in adaptation to climate change. The key, in that regard, is to promote regional hydrological models including climate change trends, to assess the resources and needs at various time horizons. The models should

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[82] Intergovernmental Panel on Climate Change Working Group III. (2014). *Summary for Policy Makers – Climate Change 2014: Impacts, Adaption and Vulnerability***.** Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf.

include the possible increase of drought frequency and seriousness.

- A typical example of such approach is the “Garonne 2050” report that was prepared to understand the incidence of global changes at the Garonne basin scale (65 000 km²) in France and get prepared. Based on detailed hydrological simulations, the report concluded with several possible scenarios, all of them requiring the construction of new reservoirs. In a country like France, such a study helps changing public opinion.
- Our profession shall keep working on the issue of GHG emission (TC “Environment” or “Climate Change”), with possibly two goals: integrating the recent results from academic researchers for the assessment (§3.7) and securing best practices for future projects (§3.7).
- Increased magnitudes of precipitation and the resulting run-off could likely mean that spillways at existing dams may have insufficient hydraulic capacity to safely pass increased magnitude floods that result from climate change. In fact, dam failures result more from overtopping due to insufficient spillway capacity than from any other cause.83 This issue is linked with the need for innovation – and past innovation dissemination – in the field of spillway and of resistance of dams to extreme floods.

8.4. PROMOTE INNOVATION AND SUPPORT NEW IDEAS

Innovation has become essential in the dam engineering profession, for various reasons. Three reasons stand out particularly.

- In many countries, particularly OECD nations, dams and reservoirs have lost a lot of ground. It seems that dams and reservoirs have not (yet) adapted to the new social and environmental background, although the needs exist in many places, driven by climate change.
- Hydroelectric dams suffer from competition imposed by other forms of electricity generation. Hydro’s share in the global mix is tending to decrease, for various

[83] Association of Dam Safety Officials. Retrieved from www.damsafety.org.

reasons (good or bad). Electricity storage, which will be a considerable market in the decades to come, could also escape our profession. Imagination is required to keep improving projects and prevent an energy market dominated by coal-fired power plants and batteries.

- Small dams designed and built in developing countries for water supply are too expensive. This is a problem because it reduces the contribution of our profession in doing useful work for the hundreds of millions of people who need seasonal water storage to meet their needs.
- ICOLD has led progress since its inception, and is increasingly focusing on innovation. Several national committees also foster innovative projects and products. There is clearly an appetite for innovation throughout the dam profession.

The fields open for innovation are numerous, and wide[84].

It is necessary to keep working on the sedimentation issue (Technical Committee "Sedimentation"), and keep disseminating the results that are achieved in various countries, in terms of:

- Soil and water conservation in catchments, which might be an option in some specific circumstances,
- Hydraulic modelling of sediment transport,
- Technologies: flushing, dredging, sluicing, bypassing,
- Management of the release of sediment downstream of reservoirs. The question would be on how to appraise the amount and quality of sediments that can be released to a specific river, with respect to the hydrology and species habitats.

In several circumstances, the classical dam option might not be the best solution to create a reservoir. Alternatives might sometimes be considered, among them:

- Off-stream storage, with the reservoir filled by gravity or pumping,
- Empty reservoirs for flood protection – or reservoirs that would be filled only during short periods,

[84] Dams and the need for more innovation, F. Lempérière, A. Nombre, L. Deroo, Hydropower&Dams, Issue 3, 2018

- Underground dams, even if this solution is only viable in very specific circumstances.

New solutions have been devised that could result in new markets of hundreds of GW each.

- Reservoirs using sea water, either seawater PSP or tidal basins for energy and coastal protection.
- Solar-hydro or wind-hydro solutions that could turn out any reservoir into a power plant, producing renewable and predictable electricity at a reasonable cost.

Many other issues deserve innovation to increase the services delivered by reservoirs. The list below is certainly not exhaustive:

- Innovative solutions to raise reservoir operation levels (spillways, dam strengthening, safety of dams at very high water elevation)
- Innovative solutions to reduce evaporation
- Innovative solutions to remove sediments
- Innovative approaches in hydrological models, hydrometry, economical assessment, and governance of reservoirs [see Bulletin 171]
- A better understanding of external erosion, first factor of dam failures
- A refined understanding and engineering of spillway gates operation
- Cyberthreats

One very important field for future expertise and innovation is biodiversity. Our profession succeeded, during the 20th century, in setting the methods, standards and criteria for dam design and construction with respect to dam performance and safety. We may succeed, during the 21st century, in setting the basis for reservoir design and operation, with respect to water quality and biodiversity. Such research would focus on the various topics listed in §6.3, with two main goals:

- Improve our (scientific and technical) knowledge regarding reservoir physical, chemical and biological cycles (including impact on human health), and disseminate it so that practical ideas of improvement may be sought.

- Devise ideas to foster biodiversity of reservoirs, around reservoirs and downstream of reservoirs. How to get the most out of existing reservoirs in terms of biodiversity. This includes fish migration, birds, and mammals (§ 6.4) with the focus on endangered species.

8.5. MEET THE EXPECTATIONS: THE NEED FOR MORE WATER STORAGE WORLDWIDE

The sections in this bulletin identify the need for more water storage throughout several regions of the world. While the precise quantities are speculative and subject to judgement based on population growth, industrialization and climate change, the need for more storage is clear. The major drivers are: (1) the need for water supply including municipal, industrial and irrigation; and (2) climate change which can cause severe droughts and long-term regional shortages. See Sections 2, 3, and 4 of this bulletin.

Perhaps the most significant driver is that, according to The Water Project, Inc., “783 million do not have access to clean and safe water”[85] and with forecasted population growth this number will increase. The World Bank also reports that: “Much of the developing world will have to cope with droughts and/or the growing risk of flooding. Currently, 1.6 billion people live in countries and regions with absolute water scarcity and the number is expected increase to 2.8 billion people in 2025.”[86]

This formidable challenge requires both small and large dams.

ICOLD has spearheaded the dam development throughout the 20th century.

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[85] The Water Project, Inc. (2016, August 31). Retrieved from https://thewaterproject.org/water-scarcity/water_stats.

[86] The World Bank Group. (2015). *Water and Climate Change.*

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10. APPENDIX A: LIST OF RECENT LARGE DAM FAILURES

The Table below does not include:

- Tailing dam failures.
- Levee and small dam failures.
- Fatalities caused by dam operations.
- Fatalities caused by accidents of penstocks or power plants.

Table A.1
List of recent large dam failures

Dam Name	Country	Year of_accident	Year_of _completion	Type_of _dam	Height_ of_dam	Fatalities	Main cause
Belci	Romania	1991	1963	TE	18	17 - 25	Flood ; spillway gates were not opened
Gouhou	China	1993	1989	CFRD	71	288	internal erosion + parapet & d/s instability ; first filling
Zoeknog	South Africa	1993	1992	TE	38	0	internal erosion (first filling)
Kruin	South Africa	1994	1982	TE	22	0	internal erosion
Opuha (partially completed)	New Zealand	1997	1999	ER	29	0	Failure during construction
Shih Kang	Taiwan	1999		PG	25	0	Earthquake
El Guapo	Venezuela	1999	1978	TE	60	???	Flood (10'000s of death in venezuela)
Koos de Beer (Welgevonden N°1)	South Africa	2000	1967	TE	15	0 ?	Overtopping (Cyclone Leon-Eline)
Fry Dam	South Africa	2000	1967	TE	15	0 ?	Overtopping (Cyclone Leon-Eline)
Mambedi Lower	South Africa	2000	1985	TE	22	0 ?	Erosion of spillway (Cyclone Leon-Eline)
Lebea	South Africa	2000	1963	TE/VA	18	0 ?	Overtopping (Cyclone Leon-Eline)
Zeizoun	Syria	2002	1999	ER	32	22	Internal erosion and overtopping (spillway obstructed)
Bellair	South Africa	2003	1920	TE	20	0	Overtopping during a flood
Camara	Brazil	2004	2002	PG	50	3	First filling ; inadequate geology
Shakidor	Pakistan	2005	2003	ER		70 – 135	Flood
Taum Sauk	USA	2005	1960	TE/ER	25	0	Overtopping with no flood
Chaq-chaq	Iraq	2006	2005	TE	15	0	Overtopping during a flood
Algodoes	Brazil	2009		TE	21.6	9	Flood – Erosion along spillway (dam did not overtop)
Situ Gintung	Indonesia	2009	1932	TE/ER	16	98	Overtopping during a major flood
Delhi	USA	2010	1922	TE/PG	18	0	overtopping + internal erosion
Witka-Niedow	Poland	2010	1962 or 1968	PG/TE	16.7 or 18	1	Summer 2010 floods in central Europa
Gararda	India	2010	2010		32	0	Internal erosion (rock - earthfill interface) during first filling – with very low water height in the reservoir
Açude dans Naçoes**(Bom Conselho)	Brazil	2010			15	0?	flood + overtopping**31 fatalities during the event ; probably 0 from the dam breach
Fujinuma-Ike	Japan	2011	1949	TE	18	8	quake
Eleyele	Nigeria	2011	1942	TE	14.6	120	

Dam Name	Country	Year of_accident	Year_of_completion	Type_of_dam	Height_of_dam	Fatalities	Main cause
Ivanovo	Bulgaria	2012	1962	TE	19	10	flood
Oaky	Australia	2013	1956	ER/PG	18	0	flood : overtopping or erosion ?
Krel2	Vietnam	2014	2013	TE	27	0	2 failures in 2 years (2013, 2014) ; internal erosion ?
Ha Dong	Vietnam	2014	2011	TE	27.5	0	Overtopping during a flood

Dam Name	Data sources for Height & Reservoir	Data sources for accident cause & fatalities
Belci	ICOLD Register	C23-Q91-R12 - BRASILIA - 2009**http://www.usbr.gov/assetmanagement/WaterBulletins/202dec2002.pdf
Gouhou	ICOLD Register (V=1.6)	https://de.wikipedia.org/wiki/Gouhou**https://www.soilvision.com/downloads/docs/pdf/research/3DDam.pdf
Zoeknog	ICOLD Register : year of completion only	ICOLD, Q68, Discussion pp205-210**Photos : **http://www.sancold.org.za/images/Practical_aspects_of_dam_break_analysis.pdf
Kruin	ICOLD Register	C24-Q93-R31 - KYOTO - 2012**https://commondatastorage.googleapis.com/comsa/bpg_a4pollutioncontroldamsaug07.pdf
Opuha (partially completed)	ICOLD Register	http://www.ipenz.org.nz/nzsold/2003Symposium/LargeDams2003pages84-104.pdf
Shih Kang	Not recorded in ICOLD Register	http://shake.iis.u-tokyo.ac.jp/home-new/projects/Seismic%20Fault%20WS-1/14.pdf
El Guapo	ICOLD Register	
Koos de Beer (Welgevonden N°1)	List of Registered Dams - DWA (Not recorded in ICOLD Register)	Data forwarded by SANCOLD to Committee on Dam Safety**C24-Q93-R31 - KYOTO - 2012**
Fry Dam	List of Registered Dams - DWA (Not recorded in ICOLD Register)	Data forwarded by SANCOLD to Committee on Dam Safety**C24-Q93-R31 - KYOTO - 2012**
Mambedi Lower	List of Registered Dams - DWA (Not recorded in ICOLD Register)	Data forwarded by SANCOLD to Committee on Dam Safety**C24-Q93-R31 - KYOTO - 2012**
Lebea	ICOLD Register	Data forwarded by SANCOLD to Committee on Dam Safety**C24-Q93-R31 - KYOTO - 2012**
Zeizoun	ICOLD Register : H	The non-finished, non-well compacted soil of the crest of Zayzoun dam, the technical and administrative errors, and the correct ways of its reinforcement and renovation ; Youssef Hamze, Anna Stanivska - Lebanese University, Faculty of Engineering, Lebanon; Physics Procedia 55 (2014) 271 – 278****https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290812/scho0811buba-e-e.pdf
Bellair	ICOLD Register	
Camara	Not recorded in ICOLD Register	https://www.highbeam.com/doc/1P1-95643419.html
Shakidor	Not recorded in ICOLD Register	
Taum Sauk	Previous dam - Not recorded in ICOLD Register	http://www.usbr.gov/ssle/damsafety/documents/RCEM-CaseHistories20140731.pdf
Chaq-chaq	Not recorded in ICOLD Register	http://www.ijera.com/papers/Vol4_issue5/Version%201/T4501109116.pdf
Algodoes	Not recorded in ICOLD Register	Newspapers (O Globo – 29 de maio 2009)****Dam failures of embankments dams caused by overtopping or accidental leakage (Vogel, Courivaud, Jarecka) - Proceedings of the 1st international seminar ; madrid, spain, 24-26 november 2014.

Dam Name	Data sources for Height & Reservoir	Data sources for accident cause & fatalities
Situ Gintung	Not recorded in ICOLD Register**RCEM Case histories	http://www.usbr.gov/ssle/damsafety/documents/RCEM-CaseHistories20140731.pdf**
Delhi	Not recorded in ICOLD Register	https://en.wikipedia.org/wiki/Delhi_Dam**
Witka-Niedow	ICOLD Register (1968 / 18m)	Dam failures of embankments dams caused by overtopping or accidental leakage (Vogel, Courivaud, Jarecka) - Proceedings of the 1st international seminar ; madrid, spain, 24-26 november 2014.
Gararda	ICOLD Register (H only)	Dam failures of embankments dams caused by overtopping or accidental leakage (Vogel, Courivaud, Jarecka) - Proceedings of the 1st international seminar ; madrid, spain, 24-26 november 2014. (*)
Açude dans Naçoes**(Bom Conselho)	Not recorded in ICOLD Register	http://www.ctec.ufal.br/professor/vap/Cheia2010.pdf**http://zonaderisco.blogspot.fr/2010/07/inundacao-mega-desastre-em-alagoas.html**
Fujinuma-Ike	ICOLD Register	
Eleyele	Not recorded in ICOLD Register	http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/08/16/000425962_20120816140425/Rendered/PDF/706080ESW0P1250lood0in0Ibadan00Dams.pdf****http://www.bbc.com/news/world-africa-14774793**
Campos de Goytacazes	Not recorded in ICOLD Register	http://planetsave.com/2012/01/06/13000-homeless-9-dead-from-dam-break-in-brazil/
Ivanovo	Not recorded in ICOLD Register	http://www.novinite.com/articles/136567/Bulgaria+Has+600+Unsafe+Dams+-+Economy+Minister
Oaky	ICOLD Register	http://www.damsafety.nsw.gov.au/DSC/Download/Oaky/Oaky%20River%20Dam%20Failure_%20DSC%20Statement_Draft.pdf
Krel2	Not recorded in ICOLD Register	http://tuoitrenews.vn/society/21416/dam-at-hydropower-plant-in-central-vietnam-breaks-again
Ha Dong	Not recorded in ICOLD Register	http://www.vietnambreakingnews.com/tag/dam-ha-dong-reservoir/