Mário J. Franca

The change is here, faites vos jeux!

Hydraulic engineering in times of adaption

inaugural address

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Hydraulic engineering in times of adaption

Inaugural address of Mário Jorge Rodrigues Pereira da Franca

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A river flows near Catandica, Mozambique, by MJ Franca.

Analysis does not save us from mediocrity,
however it saves us from humiliation.

Lídia Jorge in *Os Memoráveis,* 2014

May what I do flow from me like a river,
no forcing and no holding back,
the way it is with children.

Rainer Maria Rilke in
All that has never yet been spoken, 1899

to my parents, *in memoriam*

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A PERSONAL PREAMBLE

When the croupier throws the ball into the roulette, the gamblers hear him saying *Faites vos jeux, rien ne va plus!* It is an irreversible moment, a tipping point [1] with unpredicted consequences. The possibility that human activities may change dramatically the climate was mentioned by H.G. Wells one hundred years ago [2]. In the early 70s, the Club of Rome warned us about the planet unsustainability if the economic and population growth rates were to be kept [3]. Yet, we toyed with the global environment for more than a century changing the planet (*the ground's not cold* [4]), and even today we do not recognize the importance of human interaction or climate change in our symbolic depictions of the water cycle [5]. The fact is that known theoretical frameworks for the bio-geophysical systems and their interaction with humans do not hold anymore, i.e. *rien ne va plus*.

This address

This address contains personal reflections on the three pillars of IHE Delft activities, implementing and producing knowledge, educating professionals in science and engineering, and advising to strengthen institutions. These are (have to be) provided in a context of adaptation to climate change. In the end I reflect upon societal responsibility, including intergenerational accountability.

An act of desertion

I never had a particular passion for water in my youth, except perhaps a teenager-voyeur interest on the inundations provoked by the river in my home town *(Figure 1)*. I started being interested in hydraulics and fluid mechanics while a student of civil engineering as an act of desertion from the subjects of construction, steel and concrete. This detached beginning did not hinder a later passion by the science of water [6], which includes the physical properties of flowing water (mass, momentum and energy) and its interaction with sediments, dissolved matter, gases, living organisms and people. This is my main interest, the mechanics of flowing water and its relationship with other elements.

Figure 1. Inundation in Bombarral, my home town, in December 1989 (photo by Luís Matos Duarte).

THE PRODUCTION OF KNOWLEDGE

Academics are responsible to produce knowledge. They are also the ones who codify the scientific advances into a language which can be appropriated and further implemented by professionals, and they have the responsibility to advice implementation by using the latest available knowledge. In the following pages I articulate about the need to define research lines leading to societal change and impact and I present topics related to the research which I want to lead in the coming years in the River Basin Development Chair Group (RBD).

The impact

The assessment of scientific output is mostly dominated by counting citations in scientific journals, which does not necessarily capture the main functions of science. As a consequence, to promote their careers, scientists tend to choose research lines which provide them more favourable metrics rather than topics for interest and importance [7].

However, worldwide, organizations supporting research, such as the Dutch Research Council or the European Commission, are including in their mission the support to research capable of promoting societal breakthroughs [8]. This implies the construction of problem-centred scientific teams and projects, which automatically include diverse specialized knowledge experts.

In the recent report on the global status on SDG 6 and other water-related targets [9][1], UN-Water highlights the need for capacity development in engineering, scientific and technical disciplines. This report also refers the need for further investment in water infrastructures to cope with the levels of water stress in some regions of the world. Further than SDG 6, other SDGs are intrinsically linked to water and to the disciplines of hydraulic engineering and fluid mechanics such as SDG 7 (*Affordable and Clean Energy*), SDG 11 (*Sustainable Cities and Communities*) and SDG 15 (*Life on Land*).

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1. The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. The SDGs came into effect in January 2016, and they guide United Nations Development Programme policy and funding until 2030.

In the report on world risks issued by the World Economic Forum in 2018 [10], in their map of the global risk landscapes, the following risk causes are among the top ten in terms of likelihood and impact: *Extreme weather events, Failure of climate-change mitigation and adaptation, Natural disasters, Water crisis, Man-made environmental disasters* and *Biodiversity and ecosystems collapse.* These are all water-related risks and within the scope of hydraulic engineering.

Finally, in the last assessment report of the IPCC [11], references are made to the multidimensionality nature of the adaptation to climate change (different frameworks: natural hazards, climate impacts, geophysical, biological, sociological, economic, etc), and to the risk of cascading processes given different socioeconomic and environmental vulnerabilities and resiliencies.

The research led by the RBD responds to the societal challenges expressed in these development frameworks, by investigating processes in the natural and built environment which are determinant for the design and planning of sustainable water infrastructures prepared for global change.

Lost in translation

River basin professionals are invited to cope with multi-dimensionality, hence the activity of hydraulic engineering cannot be monotonically focused on water. This multi-dimensionality is contained in a river basin where water, sediments, minerals, chemical substances, biological species, heat and pollution, are conveyed from the hillslopes to the low hills and downstream lakes, seas and oceans [12]. The connections between this complexity and human behaviour are manifold, and touch upon many scientific fields.

The assumption that each of these disciplines provides partial and biased understanding lead many scholars to defend the need for interdisciplinary research. Interdisciplinarity is often frowned upon, for instance by modernist thinkers, however there is virtue on the complementarity and enhancement of understanding through integration of disciplines [13].

Two language barriers, hindering interdisciplinary, may be recognized in the scope of river basin development. One is thematic or disciplinary which results from differences in the scope, methods, scales and dimensions. The second is related to the level of usage of knowledge, being the extremes the scientific usage level and the applied usage level. As examples of studies which crossed the boundary between the disciplines of fluid mechanics and biology/ecology (first barrier) I refer to my own experience and specifically to three research works: on the improvement of riverine habitats in sediment depleted river reaches downstream of dams [14], [15]; on the resilience of phototrophic biofilms in gravel bed streams [16]; and on the impact of sediment transport in the oxygen distribution in open channel flows [17].

Recently I participated in an integrative and interactive research programme promoted by the Swiss Federal Office for Environment called *Sediment and Habitat Dynamics*. Factsheets to inform stakeholders (applied usage level) about the current status of research (scientific usage level) were produced [18], resulting in a successful example of how to cancel the second type of language barrier.

Scales and cascades

Processes in river basins are characterized by a wide range of scales, which may vary from seconds to decades, in terms of time, and from mm to km in terms of space [19]. Each process has a memory scale which is related to its range of influence; these determine river basin and landscape connectivity and the possible extension of cascading effects which can happen from the river reach scale to regional dimensions [20].

Figure 2 represents an interpretation of how the hydrological power (a proxy for the work which hydrology forcing can perform in a river basin) is distributed through temporal and spatial scales present in fluvial systems. At the turbulent scales, of seconds and millimetres (and below), one observes processes of transport of sediments (essential to rivers shaping), oxygen, contaminants, organic waste and carbon. River basin (or even regional) scales (on the order of km and more) regulate the amount of water, sediments and organic elements arriving at a given river section.

For their processes of interest, engineers typically work at the so-called mean scales (*Figure 2*). Small scale processes are lumped in models whereas large scales are accounted as boundary conditions. This simple construction of the reality assumes separation, or at least a weak correlation, between the small (modelled) and large scale (boundary conditions) phenomena.

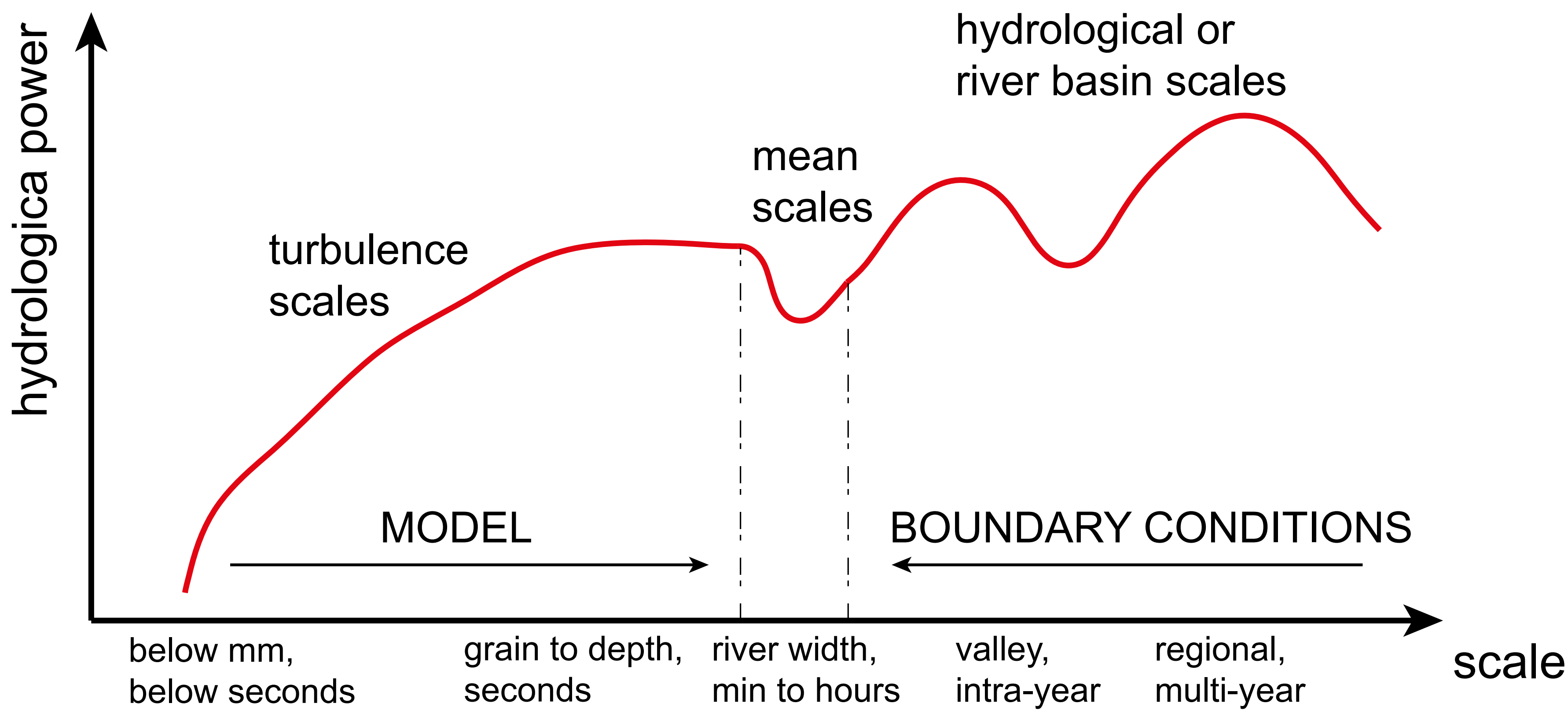

Figure 2. Space and time scales in river systems

Climate change has a first order influence on the boundary conditions. However, climate change may produce indirect but not necessarily less important effects at the smaller scales, which in turn conditions the processes of interest. These indirect cascading effects may feedback and ultimately contribute to further enhance climate change, the so-called positive feedbacks-loops. By undermining the principle of scale separation (or weak correlation) previously stated, cascading processes break the simple construction in *Figure 2*.

An example of cascading processes is in the case of flows in vegetated rivers. We know that riverine vegetation shapes river hydrodynamics as well as the capacity to transport sediments and process pollutants; climate change may affect directly the vegetation by the changes in solar exposure for instance, an effect which will in turn condition small scale processes, feeding back to the level of the mean scales. Another example is modifications in the land use due to migratory fluxes and changes in agriculture practices, both adaptation strategies to climate changes. Different land use may have an influence in the sediment production at the river basin scale, which in turn may have consequences on river morphology, riverine habitats and infrastructures safety and sustainability. In [21] you find a revealing discussion on the convoluted geopolitical cascades which may be triggered by different political options to fight climate change.

[22] showed, for Chilean case studies, that the consideration of cascading processes is needed in river basin risk management, with a holistic analysis considering volcanic eruptions, earthquakes, glacier lake outburst floods, wild fires and mass movements. [23] describes an example of cascading events leading to tragedy; in 2008, caused by above average temperatures in the Indian ocean, exceptionally high precipitation was verified in the so-called short rains period in Kenya. These caused massive inundations and landslides, with the inundation of pit latrines, contaminating fresh water wells and triggering a killer typhoid epidemic.

Topic water: what goes with the flow

Flowing water is the main agent of transport throughout river basins for sediments, minerals, nutrients, chemical substances and biological species, heat and pollution [12]. I am interested on the mechanics of flowing water and its interaction with riverine elements, which include turbulent processes of transport of mass, momentum and energy in river flows.

As an example of previous work, *Figure 3* shows field work performed for the research project *Study of open-channel vegetated flows*, which overall objective was to build a conceptual model for the flow over vegetated boundaries [24].

Figure 3. Field work in river Anços, Portugal, for the project Study of open-channel vegetated flows, funded by the Portuguese Foundation for Science and Technology PTDC/ECM/099752/2008.

In the last decade I have been working in gravity currents [25] which are geophysical flows driven by density differences between two contacting fluids [26]. The either natural or anthropogenic occurrence of gravity currents is of great engineering relevance as it is often related to human and environmental safety. With researchers from EPFL (Switzerland) and the University of Aberdeen (UK), we are working experimentally on the propagation of saline currents over porous media, relevant to such problems as resuspension of contaminated deposits (upstream tailings dams for instance), and carbon degassing from sediment deposits. Together with the same colleagues and the University of Iowa (USA), we are developing theoretically work on the parameterization of shallow water equation [27] and on the erosion capacity of these currents feeding models to be used in practical applications of these [28]. With colleagues from RBD and WSE Chair Groups, we are working on the modelling of outflows from desalinization plants (we observe a massive expansion of these for instance in the MENA region and in Chile, an essential solution to achieve SDG 6.1 target) which cause gravity currents resulting from differences in salinity of the effluent and ambient fluid; problems of accumulation and stratification of these at the mid-distance from the outfalls, with ecological consequences such as dissolved oxygen depletion [29], are observed in many systems and not yet tackled by research. Finally, research on turbidity currents, a type of gravity currents where the extra density is provided by particles in suspension, is being held in collaboration with colleagues from TU Delft, Deltares and Shell. These currents have negative impacts on the sustainability of reservoirs for irrigation, hydropower and water supply, by clogging outlets structures and intakes and reducing storage capacity.

Two prospective projects on environmental fluid mechanics are related to the transport of gases in water. With colleagues from EAWAG (Switzerland) and the Chair Groups HWR and AE, we intend to investigate the strong depletion and slow recovery of dissolved oxygen observed downstream the Itezhi Thezi dam, in the Kafue river, and to propose operational solutions for the dam owners. In RBD, we want to investigate the relationship between bulk river characteristics, which condition the extent of the contact between the water and air (water surface), and the exchange of gases between open waters and the atmosphere. The exchange of gases between the water bodies and the atmosphere is essential for the health of the riverine ecosystems and a main process in the greenhouse gases cycles.

Topic land: sediments and landscape

Bob Dylan's verse *How many years can a mountain exist before it is washed to the sea?* [30], is a poetic and perfect depiction of the sediment cycle in a river basin which comprises three main processes [31]–[33]: production, which includes erosion and overland (unchanneled) conveyance of sediments in the upper regions of the river basins (including actions such as weathering, snow avalanches and glaciers), rill and gully erosion, stream bank failure, landslides and debris flow; transport, along the channels network and inside reservoirs and lakes; and deposition, in the flat lands, lakes and ocean [34] (the conveyor belt metaphor [35]). It is acknowledged that climate change will impact the spatial and temporal distribution of sediments [36], influencing directly their production and transport.

River basin management must include both water and sediments. Sediments transport is the major factor governing river morphology and landscape evolution [37] and it has a significant role on flood risk, stability of riverbanks, dykes and in-stream structures, and on the sustainability of water storage infrastructures such as reservoirs. Sediments are determinant to ecology (with a crucial role on the stability of riverine biodiversity), food production (source of nutrients), safety, economic and societal functions of rivers and assure a coherent continuum along valleys in terms of mineral, chemical and biological components [38]. In rivers systems, they have a beneficial role as a sink in the carbon cycle and the stability and preservation of buried organic carbon is affected by geomorphological processes in rivers [39]. In the far reach, sediment delivery to coastal areas is determinant to the stability of dune systems. Therefore, considering sediment in catchment management is essential to contribute to socially and environmentally sustainable water, food, and energy security, contributing directly to UN Agenda 2030.

Recently we investigated how the distance to sediment deposits conditions the measurement of concentration of suspended sediments in rivers, first by studying fifty years of data measured in the upper Yangtze [40], and subsequently through laboratory experiments [41]. We also have investigated how bedload transport is modulated in river basin headwaters [42], a modulation which will later condition the sediment availability downstream; and we developed a novel concept for permeable sediment traps which keep their safety functions, but allows sediments fluxes to happen which are essential to ecology and morphology of downstream reaches [43]. These studies contribute to understand, predict and manage sediment fluxes in river basins.

At RBD, with the HWR Chair Group and colleagues from the University of Lyon (France), we are developing a basin scale sediment management model where adequate empirically- and physically-based conceptual principles take into account the relevant key environments and their interrelationships [44]: sources, pathways, plugs and storage zones. Data used to validate and calibrate the model include detailed field surveys *(Figure 4)* and basin-scale monitoring of morphology and sediment characteristics by using unmanned aerial vehicles. This model will allow us conclude how perturbations such as anthropogenic interference, natural paroxysms or climate change, may affect in the long term the sediment fluxes through a valley, and consequently its ecology and safety. It is also an instrument to investigate mitigation and adaptation measures for landscape preservation and recovery such as dam reoperation or removal, land rewilding and reforestation.

Figure 4. Alessandro Cattapan sampling sediments in the Alps in the framework of his PhD research on Dynamic sediment connectivity in Alpine catchments as a tool for sediment management at the river basin scale.

We have been investigating with colleagues from the Instituto Pirenaico de Ecologia – CSIC (Spain), Polytechnic University of Cartagena (Spain), EPFL, The University of Iowa and University of Lisbon (Portugal), sediment transport and geomorphology mechanisms on strongly three-dimensional flows with complex geometry, experimentally [45], [46] and numerically [47]. These include river confluences and lateral river cavities which are ecology hotspots within the fluvial network [48] and control river basin distribution of the water and sediments fluxes [49]. Furthermore, river confluences play a socioeconomic role given their importance in transportation river networks. The convergence of many bio-geophysical processes and socioeconomic roles at these locations, makes them vulnerable to cascading and interacting effects caused by climate change.

Topic energy: tapped and untapped

The world's energy consumption will increase by 28 % between 2015 and 2040 due mainly to the increase of economic activities, access to energy and growth of the population [50]. According to [51], 15.9% of the global electricity was produced by hydropower in 2019; like it or not, hydropower is a key element in the renewable energy mix, thus an inevitable resource to be considered when equating the reduction of carbon emissions from electricity production and for the substantial increase of renewable energy necessary to meet the SDG 7 [52].

In regions like Asia and Africa, hydropower is greatly untapped and there is a new rush for the planning and implementation of hydropower projects [53]. It is essential to develop adequate basin scale optimization tools to choose the best configuration of new hydropower investments which takes into account geophysical (topographic, geological, hydrological and morphological), ecological and environmental (local and global impacts), and societal (additional purposes, impacts and needs of local communities, transboundary implications, available financial means) criteria. Furthermore, these models must allow a better insight on the effects of climate change in production estimates and can also be used to study adaptation in existing schemes leading to eventual redefinition and reoperation. MSc students from RBD have been working on these tools using advanced geographical and hydrological models, [54] among others.

The ongoing project S-MultiStor [2] was designed to support the effective engagement of IHE Delft and partner universities in ongoing international initiatives related to sustainable hydropower and multipurpose storage. The project focuses on the Irrawaddy Basin of Myanmar, Zambezi Basin of Southern Africa, and Magdalena Basin of Colombia. In Myanmar, two research efforts carried out in collaboration with the Yangon Technical University, Myanmar Maritime University, the Ministry of Agriculture, Livestock and Irrigation, and Charles Stuart University (Australia), include the support to the implementation of national frameworks for environmental flows and fish migration

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2. Sustainable Hydropower and Multipurpose Storage to meet Water, Food, and Energy Development Goals: A Program for Collaborative Research and Innovation, supported by the Programmatic Cooperation between the Directorate-General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs and IHE Delft in the period 2016 - 2020, also called DUPC2. http://smultistor.nl/

across dams and wetland infrastructure. In Magdalena basin, the Chair Group HI with Escuela Colombiana de Ingeniería (Colombia) are developing decision making hydroinformatic tools for integrated and sustainable management of water storage and for estimation of environmental flows together with local stakeholders and NGOs [55].

In the search for low-carbon and low-cost solutions to produce electricity, the improvement of the energy efficiency in existing water infrastructures and the development of renewable energy technologies are priorities and important axes of research and investment. The use of existing infrastructures to produce energy has the advantage of reducing installation costs and environmental impact, and pilot studies show the feasibility of installing electrical converters in such infrastructures as water supply systems and networks, irrigation infrastructures and drainage systems [56]–[58]. The use of these decentralized renewable source has low cost and low maintenance and it is ideally to be used in remote places and in regions where no structured electrical grids exist. We have been developing a line of research on circularization of energy, or energy sourcing, in the existing hydraulic infrastructure (hidden hydropower) which was discussed in the World Water Week in Stockholm in 2018. This can be done in rural [58] and urban environment [56] (rural or urban mining of energy).

Furthermore, we are interested on the development of low-impact small-scale decentralized renewable sources based on hydropower. With the Instituto Pirenaico de Ecologia – CSIC, University of Cardiff (UK) and University of Zaragoza (Spain), we are developing high fidelity mathematical models and numerical techniques to simulate naturally oscillating flows, which can be used to evaluate the potential for energy production of these [59].

Finally, together with colleagues from the WG Chair Group, we are establishing an IHE-internal working group on Sustainable Hydropower combining IHE's knowledge in engineering, natural sciences (including hydrology, ecology, etc.) and social sciences (including law, diplomacy, sociology, etc.). This platform aims at promoting regular exchange among platform members in order to ensure a more coherent and integrated approach to sustainable hydropower within IHE and to cross-support between different projects to produce added value for each project. We intend to participate in research, advisory and capacity building projects, to develop educational opportunities and promote communication, discussion and publication on the subject.

Topic sustainability: water storage and supply

Dams to provide reservoir water storage from rivers have been one of the main infrastructures responsible to reliably supply fresh water, which is essential for the health and welfare of civilizations, and it is previewed that climate change increases the search for reservoir storage as a solution to cope with the increase of flow variability in rivers [60]. On the other hand, the substantial ecological and socio-economic negative effects of the impoundment of valleys by dams are well known, representing a conundrum which involves the conflict between the objectives of ensuring food, water and energy security (SDGs 2, 6 and 7) and the objectives of protecting and promoting a sustainable use of terrestrial ecosystems (SDG 15).

This is the complicated nexus of the sustainable production as referred in [52].

From the point of view of hydraulic engineering, one of the main challenges to guarantee the sustainability of the water storage is reservoir sedimentation [61], [62]. All reservoirs are subject to sedimentation, which reduces their storage volume. The current global net decline in storage due to sedimentation threatens domestic water supply, food and power production, and the ability to mitigate floods. Although efficiency is far from optimal, scientific advances in terms of prevention and mitigation measures against sedimentation in reservoirs exist and are manifold. However only few examples of best practices of modelling and management of sediments exist. There is hence an implementation impasse. The introduction of the economy concept of exhaustible resources in reservoir management is essential to promote the implementation and development of solutions to prevent the loss of water storage in reservoirs to sedimentation [60]. By not applying any measure to prevent sedimentation, reservoirs are being treated as exhaustible natural resources. The preservation of this natural resource has high costs but the price associated to scarcity and loss of natural resources is not often considered. Considering scarcity rents for natural resources, which will be regionally dependent, completely changes the paradigm of the economic analysis of preservation measures and may well justify the application of these, transforming these resources from exhaustible into renewable ([60], [63], [64]). However this is not yet a common practice on the planning and design of infrastructures and an implementation framework which includes the financial and engineering dimensions is yet to be developed.

Still in the framework of the above mentioned S-MultiStor project, and in contrast with large-scale/large-impact water storage structures, we analysed local solutions for storage and seasonal regulation of water supply for local populations in the region of Tete, in the Northwest region of Mozambique [65]. Typically two solutions are being implemented in the region, concrete small weirs which form a small reservoir *(Figure 5)* and sand dams, and both aim at water abstraction for human consumption, animal consumption and irrigation of small farms. The adequacy and sustainability of both types of storage structures was investigated in an integrative and interdisciplinary research by the Chair Groups RBD, AE, HWR and FRG, and the University of Eduardo Mondlane (Mozambique). Three master students from IHE and one from the University of Eduardo Mondlane participated in this research which implied intensive field and desk work to know local consumption needs and to evaluate hydrometeorology, soil characteristics, sediment fluxes, water quality and stream connectivity. Based on a simplified model using simple conservation principles, the resilience of these solutions to climate change was analysed. A comparative and critical discussion between the two types of storage structures is ongoing aiming at proposing improvements measures.

Figure 5. View from downstream of the small dam in Changara, region of Tete, Mozambique, surveyed in the framework of a subtask from S-MultiStor project on "Sustainable small-scale water storage in remote sub-Saharan regions".

LEARNING IN SCIENCE

Given the variety and complexity of problems with which the students from IHE Delft will later face, where lack of data and resources are common, we are required to educate creative engineers for the non-trivial in contexts of diversity. The versatility of a professional engineer is proportional to his/her theoretical background, hence engineering studies must provide a solid theoretical background and at same time practical tools for quantitative answers to practical problems. However, problem-centred-implementing professionals require a learning process which forces students to search and verify (in a parallelism with the notion of emancipated spectator as defined in [66] for different contexts), rather than merely a logically orderly learning process, based on the knowledge inequality between the lecturer and the student.

Learning for relevant implementation

In the next decades, global change will produce unforeseen feedback and cascading effects at multiple scales with entangled consequences to the life on the planet. An uncertain future, fast-adapting contexts (technological driven), chaotic and gigantic data sources and the need for societal relevance, impose novel competences for the professionals of the next decades. Continuously adapting learning languages, with technological-driven changes happening on a sub-decade scale, and the requirement to fast-track the translation of scientific findings into adaptation programs and policies, make contemporary education a complex matter. Global and continuous change requires a new generation of water professionals (*There's gonna have to be a different man* [67]).

Professionals of hydraulic engineering require in-depth disciplinary knowledge in relativistic mechanics applied to fluids. However, all in-depth disciplinary knowledge typically provides partial and biased understanding which led many scholars to defend the need for interdisciplinary approaches. Interdisciplinary thinking, supported by solid in-depth disciplinary knowledge, has an important role in an academy which is problem-centred and aiming at the making of professionals prepared for relevant implementation. Furthermore, new forms of learning are necessary aiming at the intellectual emancipation of students, making them playing the role of active interpreters developing their own translation of the disciplines, and able to constantly adapt to new unforeseen complex problems which are expected to happen in the next decades.

The education for which RBD is responsible has strong ties with the SDGs 6 (enough water), 7 (energy), 11 (safe water) and 15 (river morphology). Furthermore, the content of all the modules provided by RBD are now required to approach implementation strategies for adaptation to climate change. At RBD, we are involved in the preparation of a programme of graduate diplomas together with the University of California in Davis (USA), aiming at long life learning education of professional related to global problems.

Codification

Mature knowledge has a stable degree of codification and it is typically widely accepted by the technical community. An example close to hydraulic engineering is the equation of conservation of momentum, the Navier-Stokes equation (see [68], among many others). Their derivation was initiated two hundred years ago and the final configuration is more than one hundred years old. They are the base to many applications from the realm of hydraulic engineering.

Given its longevity and maturity, publications proposing updates or changes in the Navier-Stokes equations in the context of hydraulic engineering practically do not exist anymore. However, to fully model the Navier-Stokes equations and the development of a theoretical model capable of solving such a variety of scales is nearly impossible except for very short domains or very special simple situations. Restrictions, whereby a selective scaling that is limited to the necessary and sufficient detail of the problem under study, must be imposed [19].

An application of the “restricted scale treatment” is the double-averaging methodology conceptual framework, applied to river hydraulics, whereby up-scaling is performed in the spatial and temporal sense [69], [70].

Although it is based on earlier theoretical developments, the double-averaging methodology started being applied to open channel flows in the beginning of the century. Since this is a recent development, a boom of publications in observed since then corresponding to a period of intense scientific production for development and consolidation of this theoretical framework. In this period of intense scientific production *(Figure 6)*, the main language used is scientific and the knowledge is immature. This period will eventually be followed by a refinement period, corresponding to a reduction in the number of publications and to the moment when the application of the theoretical framework to real cases starts, together with the codification of the knowledge. The application to cases studies brings validation of the models which provide trust to practitioners. Finally, a period of residual scientific production should be observed corresponding to a period of full codification of the knowledge and assimilation by the praxis.

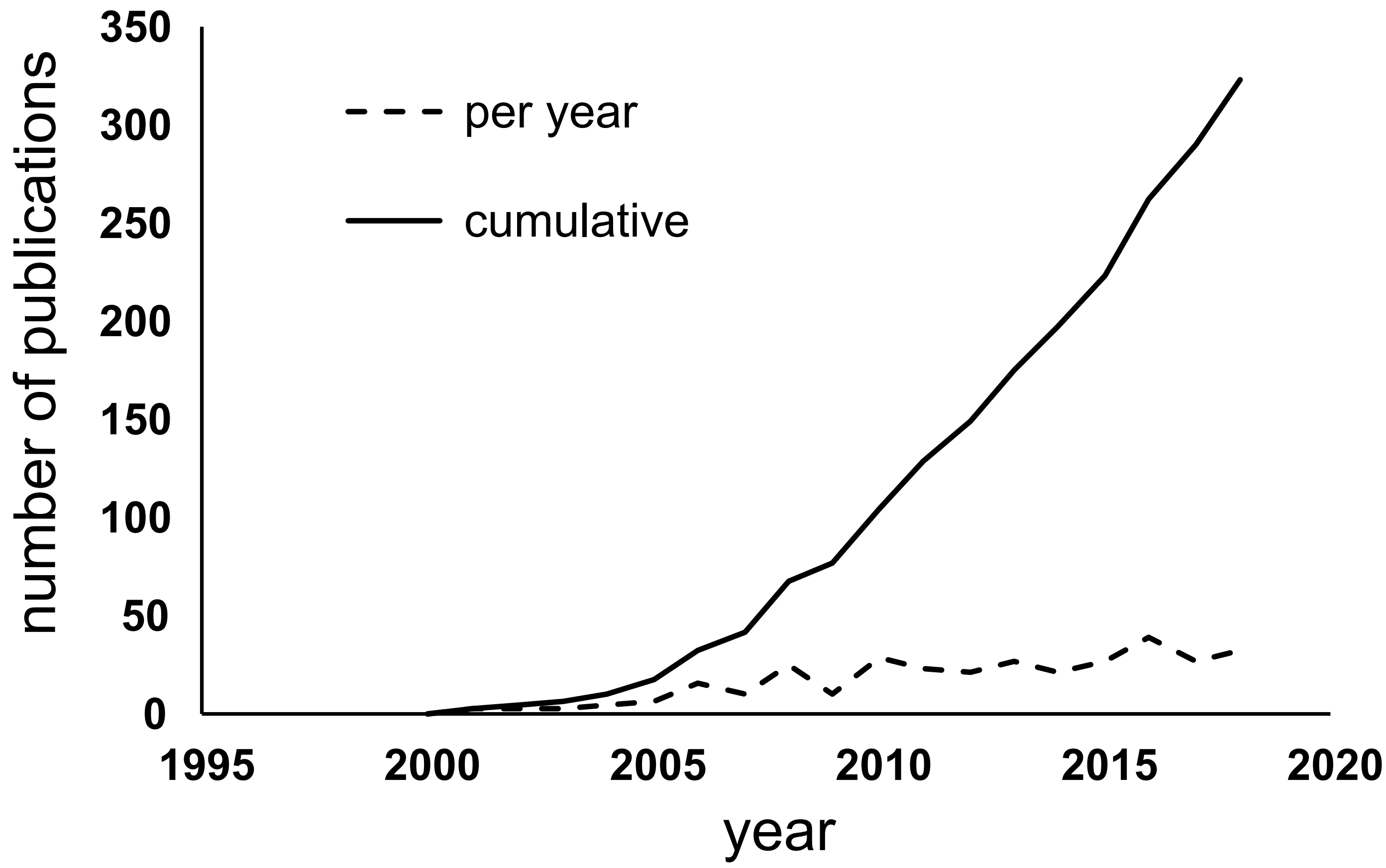

Figure 6. Number of publications with the words "double", "averaged", "Navier" and "Stokes" in the title or main body, search made with GoogleScholar engine.

Appropriation

Never before was the scientific production as high as it is today. A quick search in Scopus database shows, for the first semester of 2019, an impressive and steadily growing rate of 129 publications per day with "water" in the title. However, the translation of the scientific language to a skill-oriented language (codification) takes time and the speed of knowledge production is larger than the capacity of academic staff to make this codification.

A short cut to this process is necessary and the education of professionals today has to provide them the capacity to interpret the scientific language and methods so that they are able to appropriate and transform immature knowledge (scientific usage level) into praxis (applied usage level). Furthermore, given the fast pace of global change causing unforeseen problems, professionals need more often to be able to produce and to implement scientific knowledge in a constantly changing environment. This may be seen as the intellectual emancipation of the students, transforming them from 2d spectators to 3d actors of the learning process. Rather than studying science, students need to make science.

In our modules, RBD has been introducing techniques of active learning. One of them is the flipped classes, where the students are in charge of learning given contents and interactively share them with the colleagues. Another method is in the form of paper club, where scientific papers about novel engineering methods are given to the students who have to interpret and discuss them in practical terms and explain to their colleagues how to apply the paper findings. Finally, project based modules allow the students to investigate themselves the best methods to solve practical real (or realistic) situations, using the most recent methods and making use of traditional compendiums, together with recent scientific papers and other supports of knowledge (digital).

Finally, students performing their MSc research with RBD are encouraged to participate in the national scientific NCR [3] days, a Dutch annual conference, generally populated by young researchers from the Netherlands and direct neighbours.

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3. The Netherlands Centre for River studies (NCR) is the leading cooperative alliance between all major Dutch institutes for river studies (https://ncr-web.org/).

Their participation is a great moment for the students to share their work with peers, to learn from colleagues as well as from senior scientists, and to make the students as actors of the interpretation and transformation of the scientific knowledge into praxis.

All these methods prove to promote active learning, allowing the apprehension and identification of the students with the production of knowledge and the acquisition of competences to long term learning.

STRENGHTENING INSTITUTIONS WITH SCIENCE

A very important pillar of IHE Delft is the mission to strengthen institutions, especially in developing economies. Institutions equipped with critical thinking, and learning and adapting capacity, are essential in times of change. As said in [11], in a context of global change, risk management is easier for nations, companies, and even individuals when the likelihood and consequences of possible events are readily understood.

Identification

Institutional strengthening is often made under the umbrella of funding agencies and aligned with cooperation politics, at a national or international level. This includes the definition of the targets or funding but also the definition of themes of cooperation.

Successful institutional strengthening activities imply that the target institutions identify themselves with the problems to be addressed and not that these are externally imposed. We are often asked not to describe how well our models serve others needs but rather to show what we know and together figure out how that can help. Problem-centred discussions, based on scientific and technological knowledge, and on cultural and ancestor practises, leads to complementary, interactive and collaborative contributions more prone to be successfully implemented.

In the above referred research programme *Sediment and Habitat Dynamics*, the scientific objectives and the research questions were jointly formulated by the research institutions involved (EPFL, ETHZ, EAWAG and WSL, all Swiss institutions), and stakeholders which included, among others, public administration, NGOs, energy producers and fishermen associations. Recently, in the investigation of sustainable small-scale water storage in remote sub-Saharan regions as part of S-MultiStor project, we constructed our research objectives with local authorities and NGOs (Administração Regional de Águas do Zambeze and Concelho Cristão, Mozambique), with whom we collaborated during the field work and whom hopefully will benefit from our critical analyses of the types of storage structures used locally.

I believe that the question of identification is essential to make a true societal impact in developing societies, integrating our complementary scientific knowledge with local scientific and technological knowledge, and socioeconomic and cultural realities.

Independence

Strengthening an institution is more than solving a specific problem, it needs to provide long term capacity to adapt and produce knowledge, which assures sustainability of the knowledge.

The effort of capacity building has to promote active learning and knowledge appropriation of those involved. Strengthening institutions is not done by encouraging the consumption of closed models, but by joint development of models or providing the basic knowledge for own development of models. By developing their own knowledge, institutions will integrate local culture and know how, which is essential for independent implementation.

In Myanmar, and under the umbrella of the project S-MultiStor, we are contributing to establish a framework for the implementation of national frameworks for environmental flows. A first stage workshop was held in August 2018, organized jointly with Yangon Technological University, Charles Sturt University, IFC and WWF, to build awareness of the need for environmental flows within water management, and gain a baseline understanding of the policy/legislation, research and data, and capacity of institutions to start to work towards a national framework on environmental flows. Hopefully, a consolidated plan to establish an environmental flows legal framework will result from a joint effort with local researchers and administration and based on joint field work, hence adapted to the local bio-geophysical reality, local culture and tradition.

RESPONSIBILITY

Engineering endeavours, especially of large scale and with large impact, are often politically motivated and emotionally driven. Shortcuts are common on essential analyses during the stages of planning and feasibility studies, where thorough global and local impact assessments should be made including ecology and environment, socioeconomic organization, heritage, local cultures, health, among others.

In dreams begin responsibilities [4]

When the site for a new dam is spoken and politically marketed it means that sooner or later it will be constructed. It is true that often many public and political pressure imposes changes in the configuration, in the location or date of construction (spatial or temporal deferment), but rarely a construction is withdrawn after it is referred (an exception is the example of Foz Tua dam in Portugal [71]). These decisions are an example of subjectivity and bias in scientific and engineering practises. These may happen at the very early stages of the decision process as referred by [72], namely at the stages of framing the problem, data collection and preparation.

The economic development process, which is technical and political at the same time, should be made at a larger scale and considering the multidimensional and multisector realities, and expected benefits and harms of alternative solutions. If the aim is to produce energy for instance, promotors should exhaust a multi-dimensional analysis of possible clean sources and the benefits/harm of each one of these, before choosing the modality of production.

[4] In [80] Delmore Schwartz writes about the disappointment resulting from unrealistic dreams in a dramatic short story which is a metaphor on how responsibility begins at the moment when intentions are formulated.

Intergenerational equity

Thomas Jefferson in 1789, in his letter to James Madison while ambassador in Paris, questioned *whether one generation of men has a right to bind another* [73]. This is one of the first explicit references to intergenerational equity, recognized two centuries before the introduction of the term sustainable development [74]. Although these clear references to the consideration of the temporal dimension in our sustainability analysis, rarely is this considered in practical terms.

The benefit/harm analysis is manifold but typically only considering the spatial dimensions of the problem; this is typical in the analysis of transboundary rivers where only neighbouring and upstream/downstream relations are observed. However, the implications of the temporal changes which may be felt in time scales of years and decades are never analysed (civil constructions typically have life spans of decades and some dams were commissioned more than a century ago). It is a case to evoke words by William Bell, *You don't miss your water (Till your well runs dry)* [75].

The controversial case of reservoirs, a civil engineering infrastructure with undoubtable socio-economic benefits but large notorious negative socioeconomic and environmental impacts, is an example of the challenge imposed by sustainability and intergenerational equity. Accumulation of pollutants and gases (such as methane) upstream in reservoirs; sediments depletion downstream which are essential for habitats and biodiversity maintenance, nutrient supply (food production) and coastal dunes; interruption of seeds migration with implications in forest renovation; are all problems which can be manifested with an intergenerational delay and are not commonly tackled in the planning phase of investments.

Besides guaranteeing future-proof concept of the service of infrastructures, environmental and socio-economic protection have to be considered, bringing many times an ambiguity to the question of sustainability [60]. We still have a lot to learn in terms of time propagation of perturbations in our geophysical systems. To master these and include them in our planning and governance of infrastructures is undoubtedly essential to avoid intergenerational harm.

A PERSONAL FINAL NOTE

We observe fast global change in the Earth systems prompted by climate change, we face an unprecedented increase of the loss rate of biodiversity, and at the same time we are close to eight billion inhabitants on Earth. We also observe a (technologically-driven) fast change in the way we perceive and connect with the world and we see fast evolving scientific and engineering efforts to tackle global change. However, and mainly due to economical inequalities, the effects and response to the climate change crisis are not uniform throughout the planet and the risk of climate apartheid is real [76], [77]. Fortunately, an increase of global conscience and acts of disobedience à la Thoreau [78], led by citizens and young generations like the school strike for climate movement, are occurring, and climate change and environment became a crucial topic to be debated by eligible politicians.

In this context of providing conflicting resources (the water-food-energy nexus) and preserving our planet (the water-food-energy-ecosystems nexus), makes the profession of water professionals and hydraulic engineers extremely complex. However, when we studied the mechanics of turbulent flows, we know that exciting and productive things happen when higher rate of change and strain exist. These are therefore stimulating times to contribute to *save the planet for another day* [79].

With my professor position, I hope to produce knowledge to quantify the human interference in natural aquatic systems (on the topics of water, land, energy and sustainability), and to contribute towards sustainable options for the human interaction with the natural resources. I want to contribute to increase substantially the levels of independency and emancipation of the water professionals and hydraulic engineers from developing economies who come to learn with us at IHE Delft. And I have the ambition to help transforming IHE Delft in an international centre for water professionals, from both consolidated and developing economies, who meet here to learn and develop joint knowledge and solutions for our global water challenges.

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