**International Association for Hydraulic Research**
**Association Internationale de Recherches Hydrauliques**

**IAHR Research Agenda and Future Topics of Concern**

**1999**

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Foreword

Since publication of the first edition of the Research Agenda in 1993, IAHR has been through a process of re-examination of its basic aims and objectives. Scientific and technological developments in the last decades have led to increasing specialisation which has separated researchers and professionals. IAHR considers to be of fundamental importance its role of providing a bridge across which the results of research and innovation are taken up in professional practice. The global nature of the Association provides us with the opportunity to achieve worldwide transfer of knowledge to the direct benefit of researchers, engineers, planners and regulators everywhere.

This report summarises the current state of research across the whole hydraulics spectrum, and where future research investigation is envisaged - from the perspective of the research community. The report consequently represents one side of “the bridge”, and is to be seen as an important contribution which will provoke a wider dialogue involving the whole hydraulic enginnering community.

Dr Christopher George
Executive Director
IAHR

**Introduction**

In 1993 the International Association for Hydraulic Research published for the first time a *Research Agenda* under the title “IAHR looking into Sustainable Development”. The Dublin Conference on Water and Environment and the 1992 Rio Conference on Environment and Development focused world attention on the use of natural resources under the constraint of sustainable development.

The 1993 *IAHR Research Agenda* was the response of the IAHR-community to the challenges that sustainable development impose on future development and use of water resources. The aim of the report was an outline of the State-of-the-Art and a Research Agenda for sustainable development for hydraulic research and hydraulic engineering. It is evident that such an exposition needs regular and timely revisions.

This second edition was initiated by the IAHR Council, and is again a joint effort of the chairmen of the IAHR Technical Divisions and Sections. It attempts also to respond to ideas formulated in the position paper *IAHR Profile 95*. IAHR recognised that *Bridging the gap between Research and Application* will be the major new challenge to IAHR at the turn of the century.

This report is published by the IAHR Secretariat and distributed as a basis for, and encouragement to discussion among the members of IAHR.

Zurich, 1999

Andreas Müller, Editor

**1. The Role of Hydraulic Research and Hydraulic Engineering in the Management of Water and the Environment**

Working hydraulic systems depend on favourable conditions of the natural environment, a sound economic base and the collective political effort of the community. Yet, the successful construction, operation and maintenance of these hydraulic systems rely on the ability of just one group of people, the engineers. Examples of this expertise and experience includes large-scale irrigation systems for agriculture, water supply and sewer systems in our cities, hydraulic power production and navigation, and coastal protection. Hydraulic engineering and hydraulic research are two of the pillars which bear our hope to meet the water problems of our common future.

Hydraulic Engineering includes the planning and the design of engineered solutions to water-related problems which arise both in the natural environment and in the social environment. Inherent in these problems are both the hazards posed by water as well as the need to protect it. Planning and design often lead to the construction of hydraulic structures or to improvements of the operation of a system. All efforts are based on methods, theories and results developed by hydraulic research.

Hydraulic Research is the development of basic knowledge and its transfer to engineering methods, for the purposes of designing socially acceptable solutions to water related problems. It includes both the human environment and the protection of the natural environment.

Hydraulic engineers have to plan and design their structures and interventions in a complex environment. Hydrological data is often scarce or deficient. Flows are three-dimensional and time-dependent. Chemical and biological reactions are uncontrolled. Boundary conditions are ill-defined and are strongly influenced or determined by geological conditions and human behaviour. Clearly defined issues are required to make adequate system description.

Simplifications are necessary but need sound engineering judgements to include the relevant parameters and not to overlook important factors.

The methods provided by hydraulic research all have their inherent limitations. Systems with complex boundary conditions require simplified flow models, systems with complex flow can be calculated only with simple flow geometries.

The tasks of hydraulic research are manifold. New methods beyond present limitations and existing knowledge have to be found. New scientific ideas and knowledge of many related disciplines, and new and better engineering solutions have to be integrated. This includes the documentation of research and efficient transfer of knowledge to the engineering community.

The roots of hydraulic research are in both the natural and social sciences. Within the engineering sciences it has developed into many specialities. Table 1 highlights the most important hydraulic sciences and specialities.

Table 1: Overview of basic sciences and specialities of hydraulic research

| **Basic Sciences** | **Domains** | **Specialities of Hydraulic Research** |
|---|---|---|
| Physics | Fluid Mechanics, Thermodynamics | Motion and Forces in fluids, Viscous Flows, Non-Newtonian Flows, Boundary Layer, Turbulence, Porous Media, Multiphase Flows, Transport Processes, etc. |
| Mathematics | Calculus, Numerical Analysis, Logic, Statistics, etc. | Analytical Methods, Computational Hydraulics, New Algorithm (genetic algorithm, neural networks, etc. ), Risk Analysis of hydraulic and hydrological phenomena, Probability of Occurrence |
| Information Theory | Informatics, Data | Hydroinformatics, Representation of measured and modelled Results, |

| | | |
|---|---|---|
| | Processing | Data Mining, Data Standardisation |
| Chemistry and Biology | Water Quality | Transport, diffusion and dispersion of species and matter, degradation, adsorption, resorption |
| Geology | Sedimentology Geotechnics | Sediment Yield, Dam Sites, Foundation of Hydraulic Structures, Effect of Earth Quakes on Hydraulic Structures |
| Climatology | Meteorology | Hydrological Cycle, Water/Air Interface, |
| Social Sciences | Communication, Management of Resources, Psychology, Local Government | Risk Management of hydraulic and hydrological phenomena, Allocation of Water Resources, Integration of Water and other Resources |

| **Engineering and Technology** | **Specialities of Hydraulic Research** |
|---|---|
| Hydraulic Structures | Design, construction, foundation, operation, maintenance |
| Hydraulic Machinery | Design, Systems, hydraulic transients |
| Fluvial Hydraulics | Fluvial, sediment transport, river morphology, channel stability, flood protection |
| Maritime Hydraulics | Coastline protection, harbours, waves, offshore structures |
| Groundwater Hydraulics | pollution control, management of aquifer |
| Ice Engineering | Ice hydraulics, thermal regime, ice forces on structures, testing methods and ice modelling, |
| Hydraulic Modelling | Physical models, Numerical models |
| Urban Water Resources | Water supply, sewer, sewage treatment, pollution control |
| Industrial Hydraulics | Energy production, two-phase flow, metering |
| Management of Water Resources | Development of water resources (sources, supply, demands), Operation and maintenance |

## 2. The Contributions of IAHR

### 2.1 Background to IAHR

Under the name International Association of Hydraulic Structures Research, IAHR was founded in 1935 by engineers and scientists under the guidance of directors of hydraulic research laboratories. It was their intention to stimulate and promote basic and applied research in hydraulics and hydraulic engineering, and to provide a forum for the international community of hydraulic engineers. It was an association of individual members and was not based on national groups like other organisations of the time.

Today it is an association of over 2000 individual members of all continents. Additionally, 187 private, governmental and university laboratories involved in hydraulic research are corporate members. Members of IAHR are involved in teaching and research at universities, in consulting, design and construction and in governmental services. They are interested in an international exchange of ideas and in international co-operation. A matrix of categories of membership and their activity is given in Table 2.

*Scientific exchange* is the main activity of IAHR. The biennial congresses and many speciality conferences provide a forum for formal and informal communication. Conference Proceedings, the Journal of Hydraulic Research published since 1962 and an impressive list of books, monographs and manuals assure written records of our experience.

*Technology transfer* is developed in several ways. Education is the classical method of transferring knowledge to the next generation. Besides this classical method there is a need, during the whole professional life of engineers and researchers, to exchange new findings in science and technologies between individuals, national group of individuals and regional group of individuals. Workshops and the publication of books and manuals are adequate tools for parts of this transfer. Yet, their production requires sufficient resources. A Third World membership fund provides the services to IAHR-members in the countries where membership fees might be difficult to be paid by individuals. This fund is paid for by IAHR members.

*Research Management* is a topic which stimulated increased exchange among the directors of hydraulic research laboratories. These laboratories had been founding members of the IAHR and their role as corporate members is essential for the Association. They are and should be an engine for these activities, but one must keep in mind that there are nowadays other research organisations who should be linked into the IAHR activities (e.g. in France CEMAGREF, IFREMER, CNRS). On the other hand, although some of the Laboratories are less involved in research, most of them are involved in consulting and engineering. The activity called “Research Management” covers more than research, actually it is nearer to the subject of “transfer of new R & D results into engineering practice”. Hence, besides the Research Institutes mentioned above, a number of leading consulting and engineering organisations should be involved in these activities of IAHR.

Organisation

A council of 12 members elected by the General Members Assembly defines the general policy. An Executive Director together with the Secretariat are responsible for the day-to-day operation of the organisation. Scientific activities in basic research, in applied research and in engineering are promoted by 14 sections which are grouped in three Technical Divisions. A section on Continuous Education and Professional Development is forming a new effort. Three Regional Divisions, the Latin American Division, established 1963, the Asian and Pacific Division, established 1975, and the African Division, established 1991, organise regional meetings.

Table 3: Organisation of IAHR

Council:

Task Groups:
Future Directions and Initiatives
Management of Hydraulic Research

Sections

Technical Divisions:
Division I: Methods in Hydraulics (Basic Research)

1. Fluid Mechanics
2. Hydroinformatics
3. Experimental Methods and Physical Modelling
4. Probabilistic Methods
5. Hydraulics Instrumentation
6. Education and Professional Development

Division II: Applied Hydraulics (Applied Research, Engineering)

1. Hydraulic Machinery and Systems
2. Urban Water Management
3. Fluid Phenomena in Energy Production
4. Water Resources Management
5. Industrial Two-phase Flow
6. Hydraulic Structures

Division III: Geophysical Hydraulics (Basic Research, Applied Research, Engineering)

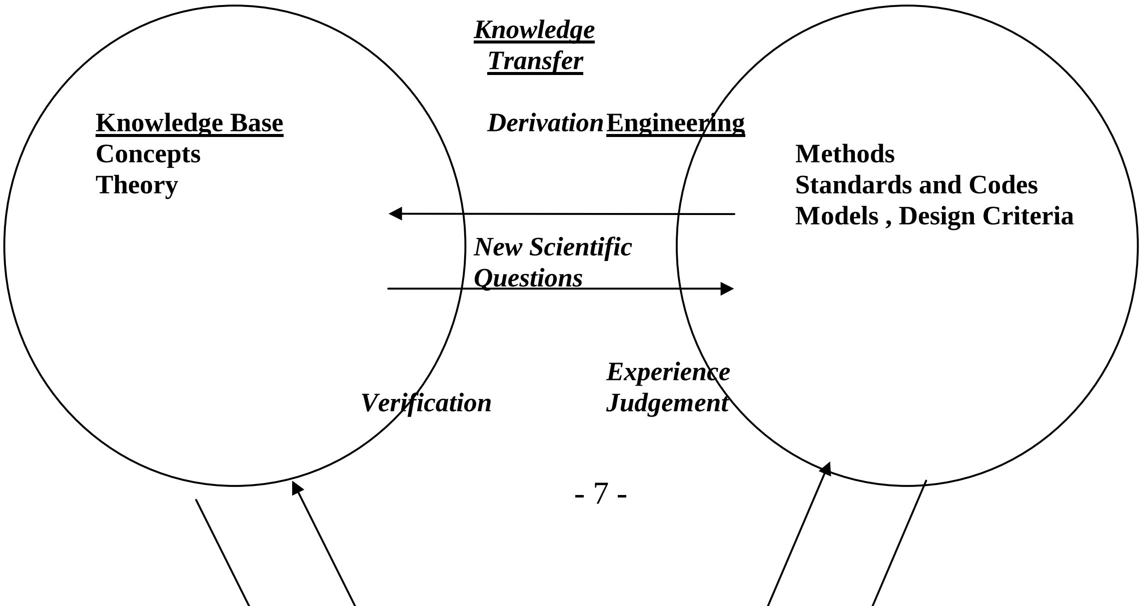
1. Fluvial Hydraulics
2. Maritime Hydraulics
3. Porous Media Hydraulic
4. Ice Research and Engineering
5. Eco-Hydraulics

Regional Divisions:
Latin American Division
Asia and Pacific Division
African Division

**2.2 Definitions of Research and Application**

A simple distinction between research and application is not sufficient to describe the activities of scientists and engineers in our field and to clarify their interrelations. The following attempt may bring some clarification and stimulate discussions.

In Figure 1 we postulate that the ***knowledge base*** and ***engineering*** exist in the same context as ***reality***.



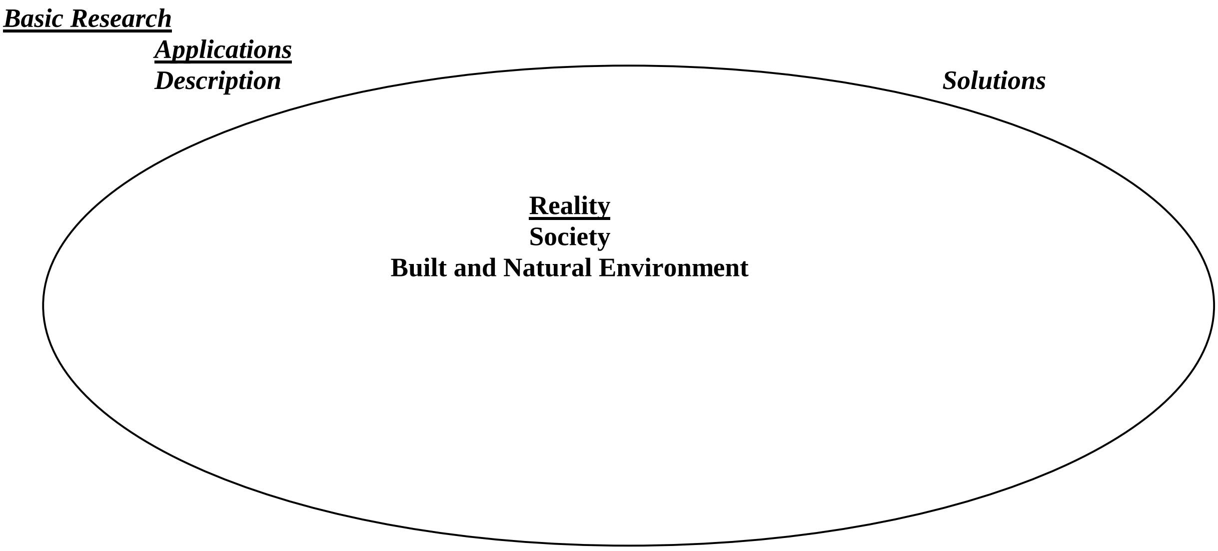



Figure 1: Schematic of the Interrelations of Research and Application

The knowledge base which is available to scientists and professionals is a description or a “model” of reality (but not reality itself). It includes scientific theories that can be verified through experiments.

Engineering proposes and executes solutions which are safe, economic and comply with ecological and social constraints. Engineering involves the development of standards and legislation, and application of models, methods, guidelines and design criteria.

Reality denotes “the real world”: society and the built and natural environments.

The activities of IAHR members appear as relations (arrows) between these entities and are grouped in (1) basic research, (2) knowledge transfer, and (3) applications.

Basic research is the activity of building up, improving and refining the description of reality. The first step is always to formulate a conceptual model based on the fundamentals of basic sciences. Research includes the verification of ideas and hypotheses, and the comparison of concepts. Successful descriptions become part of the knowledge base.

Applications are studies or works carried out for the solution of a specific problem in the “reality”. Engineers combine their theoretical background with experience and judgement which is developed in their individual professional activities. Engineering is supplemented by applied research in which specific answers to specific engineering problems are developed.

Transfer is the link between engineering and scientific knowledge. Engineering methods are derived from scientific knowledge by developing physical and numerical modelling methods. The needs, limitations and failures of engineering methods lead to new scientific questions and thus to new basic research.

Hydraulic research, as encouraged by IAHR, always has practical engineering applications in mind. This means that the effort to understand physical phenomena is not undertaken just for intellectual pleasure, but because such understanding can help to implement more socially acceptable solutions both in terms of the human environment and protection of the natural environment. Hydraulic research focuses on the “Knowledge Transfer” domain, i.e. the derivation of engineering methods based on knowledge of basic sciences. But our IAHR-community must also be able to formulate new scientific questions, whose answers demand further developments of the knowledge base through basic research.

Table 2: Matrix of the area of activities against categories of IAHR-membership

| Areas of<br>activity | Basic<br>Resea<br>rch<br>and | Kn<br>owl<br>edg<br>e | Ap<br>plic<br>atio<br>n |
|---|---|---|---|

| | Education | Transfer | |
|---|---|---|---|
| Actors: | | | |
| University Staff | O | O | |
| Research Institute Staff | O | O | O |
| Consulting Engineers | | O | O |
| Governmental Agencies | | O | O |
| International Organisations | | O | O |

**2.3 Bridging the Gap between Research and Application**

A study was performed in 1995 of the nature of IAHR (IAHR Profile 1995). The third chapter of the report discusses the *Gap between Research and Application*. A research agenda has to face the questions and problems that are raised there, and has to take into account its conclusions:

*The IAHR profile involves research and the implementation of research results into practice in order to serve the different needs of society. This implies development of more professionally related activities, notwithstanding the fact that dealing with professional issues and applications may have commercial implications for the entities involved. It is the aim of IAHR to bring the researcher and the end-user (contractor, consultant, client) together: this means that the transfer of research results into engineering practice and the needs and experiences of practice must obtain proper attention. This used to be inherent in early IAHR times.*

*Until the late sixties, the results of hydraulic research have been quasi-immediately applied by practitioners who themselves have often been involved in research and development. The Association was thriving because the corporate and individual members were applying the research findings in professional activities bringing them considerable earnings and savings. Nowadays, the correlation is not so direct and visible any more. Some aspects of classical hydraulics are no longer of prime public interest, and instead, there is a strong shift in emphasis towards modern hydraulics and its applications. Highly specialised research and development benefits do usually not result in immediate supplementary earnings and savings for the engineering profession. Most professionals in hydraulic engineering are no longer involved in research themselves, but they do value benefits which they can get through professional associations.*

*Scientific and technological developments in the last decades led to an increasing specialisation which has separated research and application as well as researchers and professionals including engineers (industry), planners and regulators (government). While previously many of the leading figures of IAHR were active in both fields, IAHR is now an Association which includes researchers on the one hand and engineers and planners on the other. These two communities strive for different goals:*

- *understand, explain, find new things, teach/publish high level scientific papers, be recognised by the peers in the research world;*
- *be efficient, manage well, construct safely, get satisfaction from using latest research and technological findings, be sure that young professionals are well trained, remain economically viable, be recognised by the community, the customers and their peers.*

*Both objectives must be recognised within IAHR. This is possible because knowledge in the field of hydraulics is their common interest. The researcher tries to increase this knowledge, the professional applies it.*

*This implies that IAHR has to establish a clear identity in the two domains and be supportive of both interests. The Association must be open for mutual benefit of both research and engineering. Besides being a forum for exchanging research results, IAHR must also be a market place for products of development and for the results of research to be used in applications. Aspects of commercialisation will necessarily be involved, but this seems perfectly acceptable as long as IAHR remains always technically objective and is not reduced to being just a mouthpiece of some commercial ventures. IAHR should seek* *industrial participation and involvement of practising engineers, and the development of the market is one of the prime reasons for which the practising engineers come to the Association. In the effort to bridge the gap between research and application, IAHR should stimulate relevant research which is of interest to the practitioner, and it has to make sure that the practitioner can understand the consequences and limitations of research for this task.*

*IAHR strives to provide a forum and a platform for researchers, research and teaching institutions and individual professionals and companies, corporations and institutions which employ them (consultants, contractors, managers of water resources, utilities, public institutes and government agencies). One of the main goals of IAHR is to provide a bridge across which the results of research and innovation go towards the professional application world and the experience and demands of the latter go towards the research and teaching world. These interactions require education and training activities and involve various aspects of knowledge management, such as:*

- *generation of knowledge (research and teaching)*
- *formalization, storing and conservation of knowledge (monographs, modelling systems, data basis, guidelines and standards etc.)*
- *transfer of knowledge (publications, conferences, continuing education, etc.)*
- *application of knowledge (engineering)*

**2.4 Contribution of hydraulic research and hydraulic engineering to sustainable development**

Hydraulic research and hydraulic engineering contribute to sustainable development in two ways:
(1) They are instrumental in the design of new developments and optimisation of existing systems. They evaluate benefits and reduce drawbacks.
(2) Research and engineering offer alternatives to non- sustainable practices and development practices.

Sustainable management and development has to take a holistic view of the environment to reach the proper trade-offs. Water is just one element to be taken into account, along with air and the land, and Hydraulics is just one tool among many that society has at its disposal. In this perspective Hydraulic research and engineering should offer creative answers, new solutions, and ideas in their field of expertise, in order to help society to strive for its goals.

Speaking of sustainable use of water resources only makes sense in reference to large systems (great city or a large basin) that are integrated into an optimised multi-objective strategy. Working hydraulic sub-systems are essential for sustainable management. They are straightforward technical components of a global context that includes social and political elements that are sometimes less rational. A working hydraulic system depends on favourable natural conditions, a sound economic base and a political consensus that considers local users. But the successful construction, operation and maintenance of these hydraulic systems, in terms of technical operational capacity, in terms of the costs acceptable to the community and in terms of sustainability of the resource, rely on the ability of hydraulic engineers and on the results of research, development and innovation in the field. Any system of water supply and use, including water-related risk management, will fail if these demands, technical and non technical, are not fully satisfied.

**2.4.1 Design of new developments and optimisation of existing systems:**

If water is available, there are technical solutions for practically all water-related problems. The description of the "state of the art" in section 3 gives a detailed outline of the scope of hydraulic research and its limitations. Solutions to difficult problems are expensive. More often it is a question of the available resources, social conditions and other non-technical hurdles which preclude development of large-scale hydraulic systems.

The natural environment always functions in concert with human activities. The awareness and concern for the fragility of natural ecosystems has increased. The measures necessary for environmental protection result in additional costs. Prevention of pollution is better than the costly clean up of environmental disasters. This principle requires that the effects on the environment of any proposed development should be taken into account at the earliest possible stage of planning and decision making.

Another important contribution to sustainable development is the efficient maintenance of hydraulic systems. Canals, reservoirs, navigation channels and harbours have to be freed from siltation. Water supply systems need to be isolated from waste water systems.

**2.4.2 Avoiding non-sustainable development:**

Every threat by water and threat to water necessitates hydraulic engineering and may trigger new hydraulic research and new hydraulic engineering solutions. It is IAHR's role to encourage the search for new solutions.

Natural and man-made disasters require different measures than the long-term evolution of nature and the long-term effects of human activities.

Floods and droughts are common disasters. There are widely accepted measures available to prevent and restrict damage. However, they require the concerted effort of society, an allocation of adequate resources and a change of perspective from fatalism to an awareness of the opportunities for damage mitigation. Retention basins and storage of water in flood- plains reduce the peak of a flood wave. Dams and dikes can confine river flow and prevent storm surges of the sea from inundating low-lands. Water storage basins for regional and seasonal exchange can supply water during drought.

Mountainous regions may comprise highly fragile ecosystems which frequently are subject to disasters due to avalanches, landslides, and flash floods with debris flow in torrents. Landslides are often a consequence of an excess of water. Water can saturate and load the soil, and provide a lubricating layer.

Hydraulic Research is involved in risk assessment. This includes the establishment of hydrological records and the analysis of the frequency and severity of storms and dry periods, which lead to disasters. Such records are and always have been the domain of hydrology, not hydraulics. In view of risk management and sustainable environmental policies it is impossible, however, to wait scores of years in order to collect statistically significant record samples. The classical hydrological approach fails here, while the hydraulic approach based on modelling and scenarios can in most cases close the gap. In this sense the methodology of statistical approach is also a task for hydraulic research. Additionally there is the planning, the design, and construction of embankments. Groundwater hydrology and hydrogeology are concerned with the stability of slopes.

There is also a risk of man-made disasters, which have to be assessed by an analysis of possible scenarios. Hydraulic structures can fail and cause severe flooding. Spills of hazardous fluids and sewage discharge can pollute groundwater, rivers, lakes or estuaries.

Long-term effects of human activities can destroy resources needed by future generations. Erosion and salinization can be caused by improper agriculture and deforestation. Excess pumping can cause saltwater intrusion into aquifers. Mining of non-renewable groundwater depletes the reserves.

Ice engineering is an example of extension of the limit, where man still can effectively operate and use resources otherwise accessible only during summer.

## 3. State of the art in Hydraulic Research: Research Agenda

The following description of the state-of-the-art and the research agenda summarises the contributions of the IAHR- sections as listed in Table 3: Organisation of IAHR.

### 3.1. Methods in Hydraulics

#### *3.1.1 Fluid Mechanics*

Fluid mechanics within hydraulic research investigates transport and mixing in turbulent flows. Flow boundaries are often irregular, and shaped by the flow itself. They are characterised by large roughnesses, which lead to flow separation and free shear layers within the flow. The investigations include stratified flows and flows in rotating fluids, where at larger scales the rotation of the earth becomes relevant.

The basic difficulty in fluid mechanics in the context of hydraulic engineering is the transition between the microscopic scale, described by the Navier-Stokes equations, and the large scale of engineering applications. Because of the difficulty in making this transition, fluid mechanics within hydraulic engineering is replete with unsolved problems. Some of the important examples include:

***Research Agenda***

*Turbulence:* The problem of turbulent flows, linking the instantaneous flow characteristics to the flow forcing functions and boundary conditions, is unsolved. Most current treatments are empirical and statistical. The concept of coherent structures is an alternative approach, which limits itself to the description of typical instantaneous motions within the turbulent flow. Stability analysis for low Reynolds number non-turbulent flows need to be conducted to learn more about flow breakdown and turbulence generation. The stability of high Reynolds number flows ought to be analysed to learn more about the formation of coherent structures and secondary flows that significantly affect engineering systems. Turbulence onset, generation, and maintenance in stratified or rotating flow systems is another complex problem area with a surprising variety of flow phenomena. The theories of chaos and fractals, although not a focal point of hydraulic research, may have the implication that flows described by non-linear equations are not entirely predictable.

*Two-Phase Laminar or Turbulent Flows:* The formulation of the dynamic equations for practically all two-phase dispersed systems is empirical. The true dynamics remains a mystery. A key hydraulic engineering problem is sediment transport. The elements of suspended load and bed load transport in turbulent flow need further investigation. Present hydraulic "theories" are at great odds with available data. Even seemingly well behaved laminar flow systems show unexpected behaviour. For example a suspension in a settling tank can exhibit the formation of surprising wave-like fronts. High concentration mixtures that show non-Newtonian fluid behaviour, including slurries, debris flows, mud slides, represent another difficulty. This question is related to rheology. Due to their thermodynamic complexities, gas-water mixture flows, caused by air entrainment at high-velocity in hydraulic structures or by cavitating flows, pose yet further problems. Finally, low Reynolds number porous media flow (Darcy flow) is still waiting for satisfactory predictive explanation of its macroscopic properties, such as hydraulic conductivity.

*Transport Phenomena:* Transport processes for any materials contained in the water flow are incompletely understood as well. At present, the mixing of buoyant mass or momentum injections into a river or coastal current, of great engineering importance, is not well-understood. Concepts such as large-scale eddy diffusivity or hydrodynamic dispersion cannot be rigorously related to the actual flow or solid matrix properties. Empiricism prevails. Advances are urgently needed to provide the tools for the solution of modern hydraulic engineering problems - which are increasingly devoted to the prediction of the transport and deposition of materials in the natural or engineered environment. Double-diffusion is another phenomenon which has not gained needed attention.

*Interface Problems:* The transition from the microscopic to the macroscopic becomes especially severe and intractable at system boundaries, the so-called interfaces. The air-water interface on the surface of a water body remains enigmatic, especially concerning the generation, growth, and instabilities of wind waves. Similarly, the water-sediment interface at a stream bed separating turbulent water flow from the behaviour of granular media has not been successfully described. A systematic approach that reconciles the large-scale macroscopic techniques to describe processes away from the interface with the microscopic processes directly at the interface is needed. Shear waves and internal waves are another interfacial problem which needs attention.

*Interdisciplinary Problems:* Finally, it must be stressed that increasingly many hydraulic problems transcend a purely mechanical approach. This is especially true for transport processes. They involve, for example, the intricate interaction of fluid mechanical transport with physical, chemical, or biological transformations. Entirely new disciplines, such as "physico-chemical hydrodynamics", are being developed and require the close co-operation between the fluid mechanist and other engineering scientists.

### *3.1.2 Hydroinformatics*

Hydroinformatics is not *just* an application of Information and Communications Technologies (ICT) to water resources, hydraulics or hydrology. The best analogy with which to explain the relationship between ICT and Hydroinformatics is probably the relationship between *telecommunication networks* (which can be, and on the trivial level most often are, applied to telephone conversations) and *added value networks,* such as those providing access to WWW servers. The former are only a low cost material support to the latter. Hydroinformatics provides a symbiosis, and even a synergy, between ICT and water science and technologies with the objective of satisfying social requirements.

The “social requirements” are real : the more that society becomes aware that it depends upon water, the more it understands that water is central to sustained development at the level of a country and even a subcontinent. These problems go beyond hydraulics and hydrology. While until recent decades, hydraulics and hydrology were determining these questions; now these problems largely transcend the sphere of influence of hydraulic and hydrology. On the one hand, the concept of “stewardship” exercised by humanity (that is, its responsibility for the conservation or sustainable management of natural resources) has shifted the decision-making power from hydro engineers to politicians, ecologists, NGOs, the public in general, and the media. On the other hand, the technical ways in which investment decisions are transformed into projects and the everyday technical management of water systems are more and more determined by corporations such as water companies, by basin authorities, etc.

Classical hydro engineering (hydraulics, hydrology and related research), seen from a corporate or political point of view, together with meteorology and water quality, deals with “just” one aspect of the total problem. As a consequence, the results of hydraulic research, as well as core modelling software, are ever more rapidly “encapsulated” and in such encapsulated forms integrated in larger systems or “added value networks”. They have to be seen in the context of a more comprehensive exchange of information concerning the real world water-based assets and the interests and intentions of their various stakeholders.

The rationale and purpose of hydroinformatics is to develop a new relationship between the stakeholders and the users and suppliers of the systems: to offer the basis (systems) which supply useable results, the validity of which cannot be put in reasonable doubt by any of the stakeholders involved. We are only in the initial stages of this process. Hydroinformatics changes the way in which hydraulics, hydrology and water resources studies generally are applied in society. In order to achieve this, hydroinformatics places itself deliberately on the market for products and services in this area. Water is a commodity of high market value. So is information and the means to manage information. There are already specific means for the “ICT merchandising of goods” and these are currently oriented towards the management of water and connected resources in a project involving several major European hydraulics institutes. Hydroinformatics deals with these specific goods, this market and, increasingly, this specific way of marketing.

Hydroinformatics is a *technology* built around developments and applications of systems which are, for their users, *objective systems*. A tool is objective if the users *are involved in its definition* , if they can easily understand the results and use them, if they have the possibility to input their own hypotheses into the system and see the consequences - as well as to show these to other stakeholders. Thus, for example, a hydroinformatics system of managing agricultural pollution in a catchment basin demonstrates the consequences of different cultural practices. If the tool is objective, the stakeholders might criticise a hypothesis of cultural practice (hence policies) leading to undesirable results, but not the tool. Thus the tool creates a possibility of negotiation and trade-offs based on *merit* and not on irrational sentiments.

The systems with which we are concerned include not only physical, chemical and biological processes, but also social, including cultural, economic, political, sociological, legal and other such aspects. The hydroinformation correspondingly always works in a team, and may indeed create the sociotechnical means through which the team functions. A hydroinformatics system has to liaise with all these factors through the inclusion of its users. The users become part of the system.

Hydroinformatics is limited to aquatic environments, to water and all with which water interacts. It is a technology, not a science, and we know that technologies often change more rapidly than sciences. Meanwhile it gives to hydraulics and hydrology a chance of synergism with ICT and thus avoids the situation of being simple suppliers of solutions or modelling software to be encapsulated. Socially, such “simple” encapsulations might be disastrous to professionals and institutions in this field because, on the one hand, would not guarantee the scientific quality of the encapsulated material and, on the other hand, it may lead to the death of hydraulic and hydrological research, i.e. to ending all progress in our field. The social roles of hydroinformatics within IAHR might thus be expressed as those of “proper encapsulation” and “creating a synergy between ICT and hydraulics and hydrology”.

***Research agenda***

*The ethics of hydroinformatics*. Hydroinformatics has the responsibility to produce the right environment for a synergy to occur within groupings of stakeholders of different cultures, aims and objectives. This question, as well as how to ensure the fundamental quality and reliability of “encapsulated” results of research as well as of modelling software is today in its infancy and R&D from the philosophical level (which allows for spanning the gap with “different cultures”) to the scientific level are needed.

*Interpretation and availability of knowledge and results for non-specialist stakeholders*. Normally a user of what we produce cannot understand the results. Even if they are shown in beautiful colours, etc. They must be produced in his language. E.g. flood forecasting results supplied to civil protection teams are today either unintelligible or must be reduced so much that only a fraction of potentially available information is delivered – there is a lot of R&D to be done in the field of meta-information presentation from available detailed information, in the field of hardware, software, telematics, integration of multimedia systems.

*Encapsulation of expertise*. So many people today bought modelling hydraulics or/and hydrology software – how many of these users have the experience related to modelling? Is it possible, beyond usual jargon on AI (artificial intelligence) and "expert systems" to encapsulate expertise and make it available? There is a lot of R&D to be done in these field – and it leads to the next point.

*Further encapsulation of hydraulics research results and modelling methods and sub-systems*. This must be done within the wider framework that includes the concept of multi-method, multi-model operational systems; electronic commerce software, models and expertise on the WEB; through the WEB, access to a wide engineering clientele, including SMEs (software manufacturers) and teaching institutions, to these "goods" which became commodities on new market.

*5$^{th}$ generation of modelling systems*. Outside hydroinformatics context, there is no social need felt today for such "intelligent" modelling systems. Hence hydroinformatics R&D should push towards such developments within the framework of electronic commerce and encapsulation of research results.

*Education and communication*. One of most important components of hydroinformatics is communication with other domains and people and systems concerned with the aquatic environment, including hydraulics and hydrology, but also other fields. Hence importance of research aiming at development of methodologies, tools and systems based on ICT and telematics applied to education, for the dissemination of hydroscience results, to conference organisation and publications . On the educational side the range goes from teaching-oriented tools for hydraulics-hydrology students and professionals to "vulgarisation" of water science problems for lawyers, NGOs, elected decision makers, media and the public. As far as conferences and congresses are concerned, their present form based on oral presentation of papers is totally obsolete in face of ICT approaches and means. R&D is needed, as well as experimentation, on new way to organise such events in our field of activity, especially on how to develop the synergies with the hydrosciences .

***Framework for implementation of hydroinformatics R&D***

The implementation of the R&D hydroinformatics agenda should be carried out by the Hydroinformatics Committee and Section of the IAHR through the following main channels and activities:

- Working groups and task groups composed of Hydroinformatics Section and
  - Eco-hydraulics Section and IAWQ
    - Continuous Education Section, TECHWARE, EU/DGXIII and educational institutes (IHE, European Graduate School of Hydraulics),
    - IAHS and WMO (meteorology)
    - Other Sections and the Editor of the Journal of Hydraulic Research in order to improve and/or create the communications and informatics means to assist the elaboration of manuals and monographs

- Working groups specific to the Hydroinformatics Section with various outside co-operations:
    - Conferences and congresses, with the purpose to organise next Hydroinformatics'2000 according to completely novel approach,
    - Electronic commerce in the field of hydroinformatics,
    - Information database and system aiming at aid and assistance to IAHR corporate members in setting up the consortia bidding for international research projects.

***3.1.3 Experimental Methods and Physical Modelling***

Most flows of practical interest in hydraulics are three-dimensional, turbulent and time-dependent, and cannot be explored by solving the non-linear time-averaged equations. Numerical modelling provides the solution to a simplified set of equations that often ignores or over-simplifies important details of the problem.

The experiment offers a classical way to study real flows. Experiments at the proper scale have the advantage that they do not use simplifying assumptions, and can precisely predict the properties and characteristics of a real flow situation.

With high-level computing power now available, the emphasis on numerical solutions of fluid flow problems is increasing. Nevertheless, experimental hydraulics continues to flourish because it is based on the behaviour of real fluids. The experiment should be seen as a full partner with numerical methods in developing understanding and predictive ability for hydraulic problems.

Experimental fluid mechanics is concerned with prototype flows which can be difficult to measure with instruments. However, new acoustic and optical measurement methods are capable of providing accurate data without adversely affecting the flow field in the experiment. Scaled flows allow the prototype flows to be modelled in the laboratory where they can be easily observed and measured. In addition, laboratory flows in pipes, channels and tanks are studied in order to gain insight into the motions and forces in basic flow situations.

Model flows at small scale have similar properties to those of the prototype, thereby permitting an exploration of natural flows. However, this similarity is never complete and needs to be carefully evaluated by the research engineer. In some situations where scale effects may prevent adequate simulation of prototype behaviour, the necessary understanding may only be obtained by the study of prototype situations.

In parallel with the evolution of high-tech electronics, optics and computer technology the development of experimental methods and instrumentation continues to expand. This leads to the acquisition and analysis of large volumes of digital data, which in turn permits deeper insights into complex motions and forces within the flows.

***Research agenda:***

*Methods and instrumentation:* Further development of experimental methods and instrumentation will yield even more comprehensive knowledge of flow. Studies of the instantaneous flow field in laboratory studies, with particle tracking methods for example, are now feasible for processes such as mixing, drag reduction by polymers, and sediment transport. The experimental methods and instruments used in the field are often very different from those used in the laboratory. They are, however, very important because reliable field data represents the only way to truly verify mathematical and physical models. Prototype experimental methods that require further development include remote sensing to determine such parameters as flow velocities (magnitude and direction), depths, bed load and suspended sediment load concentrations, dissolved matter concentrations, and temperature.

*Scale effects:* Physical models rarely simulate prototype behaviour in every respect. Although much is now known about scale effects, many questions remain. These include the reproduction of non-linear aspects such as boundary layer growth and the reproduction of sediment transport phenomena such as the interaction of suspended load and bed load, and the transport of cohesive sediments. The correct reproduction of transient sediment behaviour in a model is particularly difficult because the relationship between the time scales for fluid motion and sediment motion is not properly simulated in the model, and adjustments must be made to account for incomplete scaling. Furthermore, the effects of contaminants and suspended particles are rarely taken into account in physical model studies.

*Sediment transport phenomena:* Erosion and sedimentation induced by a three dimensional flow pattern (e.g. secondary currents) can result in morphologic changes and bed instability. As a consequence, environmental side-effects may occur (degradation of the river bed, drop of groundwater level).

*Improvements in numerical modelling procedures:* Because numerical models are not able to fully resolve the spatial and temporal characteristics of real flows, much reliance is placed on experiments to provide the quantitative relationships among flow characteristics. Examples are bed shear stress - bed load sediment transport rate, turbulence intensity - suspended load sediment transport rate. Numerical modelling of the development of local scour processes is in its infancy because little is known about the relationship between vortex strength and consequent sediment carrying capacity. The correct numerical prediction of diffusion and transport processes of contaminants in open channels and closed conduits requires fundamental knowledge of mixing processes. Emphasis should be placed on the basic study of the interactive phenomena involved.

*Environmental impact of hydraulic engineering works:* The development of experimental methods and physical modelling procedures for the monitoring and study of long-term environmental impacts is vital. Examples include the management of reservoir sedimentation where siltation, often occurring several times faster than initially predicted, can quickly transform a reservoir from an asset into a liability;

ecological interactions in power plants and water diversions where the passage of all biological species from micro-organism to fish at dam-sites and through power stations is an important environmental concern; thermal pollution from power plants; and river restoration and preservation to benefit and protect endangered riparian habitats.

### *3.1.4 Probabilistic Methods*

In the planning, design and operation of water resource systems, uncertainties arise from various aspects including, but not limited to, hydraulic, hydrologic, structural, environmental, and socio-economical factors. These uncertainties, if possible, should all be explicitly taken into account.

The uncertainties are due to inherent randomness of many processes involved, and our ignorance or inability to understand these processes completely. Consequently, decisions in hydraulic engineering and design are frequently made in uncertainty. The existence of various uncertainties is the main contributor to the potential failure of hydraulic systems.

The presence of uncertainties makes the conventional deterministic design practice inappropriate due to its inability to account for the possible variation of system responses. In fact, the issues involved in the design and analysis of hydrosystems under uncertainty are multi-dimensional. An engineer has to consider various criteria, including, but not limited to, the cost of the system, probability of failure, and consequence of failure, such that a proper design can be made for the system.

Probabilistic approaches provide basic analytical tools to systematically integrate involved uncertainties, to quantify performance reliability of a hydraulic system, and to incorporate uncertainty and reliability information in decision-making for a more comprehensive project design and evaluation. Therefore, the goal of the IAHR Section on Probabilistic Methods is to promote the development and application of probabilistic methods in hydraulics, hydrology and water resources.

***Research agenda:***

*Co-operation:* Applications and development of probabilistic methods in hydrology, hydraulics, and water resources straddle several disciplines. Close cooperation with similar groups in other organisations is essential. The approach taken by the Section is to sponsor or co-sponsor international symposia focusing on applying probabilistic methods to hydraulic problems.

*River Hydraulics:* Cross-section and longitudinal profile of a river vary from one location to another. They interplay with the flow resistance and the velocity profile which may best be described by probabilistic approaches. Examples of some innovative approaches  include using the entropy concept to derive velocity distribution and flow resistance and to use the Kalman filtering model for flow routing.

*Sediment Transport:* Closely related to river hydraulics, modelling and estimating sediment transport in rivers should look beyond the use of empirical equations. Issues involved may include uncertainty and reliability of commonly used sediment transport models, stochastic modelling of sediment particle movement, and implications on the engineering design.

*Ocean Waves:* Waves with their different heights and frequencies in ocean and coastal areas, are inherently random. This results in random wave forces acting on coastal and ocean structures. It is necessary to integrate the random features of waves and their interaction with ocean/coastal structures for safety evaluation.

*Groundwater Flow:* Two main areas of work are in hydraulics and contaminant transport. In the hydraulics arena, efforts should be continued toward better resolution of the spatial variability in hydraulic conductivity and that of desired hydraulic predictions. Challenges of solving inverse problems remain and new developments are needed. On the contaminant transport front further development should be made in the areas of linking probabilistic descriptions of the medium to the statistical moments of transport, alternative ways of looking at transport modelling utilising a transfer-function type approach, and coupling of transport with reactions, both chemical and physical.

*Reliability-Based Design:* A basic methodological framework of reliability-based design of hydraulic systems has been developed. Work needs to be directed toward real-life applications of large-scale complex hydraulic infrastructural systems.

*Water Resources Systems Optimisation:* Parameters in water resources system optimisation models are often subject to uncertainty. In additional to the stochastic dynamic programming or chance-constrained approaches, research is needed to explicitly derive the uncertainty features of optimal solutions in a practical manner.

*non-linear Interactions:* Many interactions in hydraulics and hydrology are non-linear and include lag functions. This implies that the systems are not entirely deterministic and can develop properties which are described by bifurcations, strange attractors and chaotic behaviour. These ideas need further attention, and further applications in hydraulics and hydrology have to be promoted.

### *3.1.5 Hydraulics Instrumentation*

The Hydraulic Instrumentation Section is involved in the design and the use of instruments used in both the laboratory and in the field. Additionally methods for the collection, analysis and presentation of data are developed. Because of the diversity of measured hydraulic parameters and flow situations, a wide variety of methods and instruments have been developed.

The advanced state of instrumentation is followed by increasing expectations for data acquisition, which in turn results in the necessity of increased atomisation of data collection and improvement of handling and processing of large data sets.

In the laboratory, the spectrum of instrumentation extends from traditional tools like gauges, Pitot tubes, weirs and orifice meters to more sophisticated, computer-based systems like laser-Doppler-anemometers, hot-wires, particle tracking methods, and image analysis systems. In the field, most of the instruments are used for discharge measurements (velocity, triangulation), for sediment transport (sediment samplers) or for monitoring water quality.

The investigation of hydrologic and hydraulic phenomena requires reliable instrumentation, which are often designed and developed in the hydraulic laboratories. The generation of new general-purpose instruments requires extensive development and testing of prototype instruments developed in the laboratory. The development, use and maintenance of instrumentation used to evaluate water resources, forces exerted by the water etc. are areas of concern within IAHR. Due to the complexity of many of these instruments successful results of measurements are not always guaranteed - neither in laboratories nor in the field, in developed or developing countries. For example, instruments are needed for the measurement of:

- velocity and discharge in rivers, especially in extreme situations (flash floods, low flows, flows on flood plains)
- shear stress on the bottom of salt-marshes in front of a dike
- discharge in groundwater flows and deduced methods to calculate storage estimates of aquifers.
- rain samplers

***Research agenda:***

*Laboratory systems:* Despite the need for robust and inexpensive hydraulic laboratory equipment, development efforts currently focus on developing tools to analyse fundamental hydraulic behaviour. This leads to the development of more accurate methods and instruments to analyse new properties.

*Systems for field measurements:* Despite the fact that more accurate instruments and methods are also needed in the field to analyse new properties, the main goal is to develop systems that are economical and robust.

*Installation of data-acquisition equipment in the field:* For almost all major river systems in the world, only insufficient data on their water resource and flow-behaviour exists. The missing data may be quite basic in developing countries or very specific in high industrialised nations (pollution, flood insurance problems, etc.). The operation and maintenance of reliable measuring stations need improvement. The cost of continuous data-acquisition needed for this type of data can become prohibitive. Authorities undertake great efforts to automate the measurement, transmission and analysis of water resources data.

The IAHR-section on hydraulic instrumentation could provide an important link between manufacturer and users of these instruments. Particular action is needed in the testing of instruments, a field in which a new system of data-exchange should be set-up in the future. The section of Hydraulic Instrumentation of IAHR offers a platform to distribute ideas for new solutions and knowledge about such instruments and methods. Efforts to establish the position of the IAHR as a contributor to the efforts of international standardisation should be undertaken, based on the world-wide activities of the organisation.

#### *3.1.6 Education and Professional Development*

Major goals of IAHR, founded in 1935, were to stimulate and promote basic and applied research in hydraulics and hydraulic engineering, and to provide a forum for the international community of hydraulic engineers. Today it is an association of over 2,000 individual members of all continents. We need to fill the gap between fluid research and the practice of hydraulic engineering emphasising the importance of application-oriented research and much larger-scale of involvement of practising engineers in the activities of IAHR.

The Section on Education and Professional Development was formed in 1995 based on the work of a Task Group headed by Prof. Helmut Kobus for several years. The activity of the section is aimed at enhancing technology transfer in several aspects. Education is the classical sense of transferring knowledge to the next generation. The dialogue between practising engineers and researchers also needs to be intensified to fill the existing gap. Continuing education for engineers aims at brushing up their professional skills to cope with new developments in technology or professional practices.

***Activity agenda***

The goal of the Section on Education and Professional Development is to provide educational guidelines for future hydraulic engineers and to promote involvement of IAHR in continuing education for professionals. The activities of the Section are classified into three major areas:

(1) To establish educational guidelines at the undergraduate level for future hydraulic engineers, paying attention to problem-oriented curricula. For this purpose we need to increase dialogues between practising engineers and educators to bridge the existing gap in the coming new century. Emphasis is laid on newly emerging and interdisciplinary subjects. Before the Graz Congress in 1999 it is planned to summarise how to educate students in the area of eco-hydraulics.

(2) Continuing education for engineers is highly appreciated for brushing up their professional skills to cope with new developments of technology and professional practices. The IAHR European Graduate School of Hydraulics composed of a series of short courses took a real form in 1997. This EGH will provide a better chance not only to postgraduate students for schooling toward higher degrees, but also to practising engineers for refreshing or acquiring new knowledge and skills. IAHR supports integration of informatics and mathematical simulation in continuing education programs. Fundamental research in IAHR should continue in dialogue with practising engineers. This will also feed back to a wider audience through continuing professional development.

(3) Dissemination of knowledge is planned on an international scale through the co-operation of the regional divisions of IAHR. In the first step it is intended to strengthen ties with the African Regional Division. Links with other organisation like UNESCO remain close in the area of education and training of water resources management and international co-operation.

### 3.2. Applied Hydraulics (Applied Research Engineering)

#### *3.2.1 Hydraulic Machinery and Systems*

The IAHR-Section on Hydraulic Machinery and Systems deals with the advancement of technology associated with the understanding of steady and unsteady flow characteristics in hydraulic machinery and conduit systems connected to the machinery. The technology elements include the fluid behaviour within machine components, hydro-elastic behaviour of machine components, cavitation, and two phase flow in turbines and pumps, hydraulic machine and plant control systems, the use of hydraulic machines to improve water quality, and even considerations to improve fish survival in their passage through hydro plants. Included in two phase pumping are gas oil pumps and sand laden water. Because model tests and laboratory tests carried out in laboratories must be scaled down from the prototypes, studies of size and pressure scale effects are also a central research field. The research work in the section forms the basic study for the IEC standards code dealing with hydraulic machinery for hydroelectric power plants.

The main emphases of the IAHR Section on Hydraulic Machinery and Systems are to stimulate research and understanding of the technologies associated with hydraulic machinery and to promote interaction between the machine designers, machine users, the academic community, and the community at large.

Hydraulic machinery is both cost effective and environmentally responsible. The increasing atmospheric content of carbon dioxide related to pollution from thermal power plants, is one of the most significant threats to our global ecology. The problem is exacerbated by the need for increased energy production in third world countries. This results in rising global temperatures and dramatic changes in climate which may also result in flooding in parts of our globe. Energy conservation together with replacement of coal and oil-fired power plants are, therefore, needed. The development and installation of more efficient hydroelectric power plants which work hand in hand with water storage and flood protection is part of this strategy. Waterpower is the most significant “renewable resource”. The goals of this IAHR section are to improve the value of hydraulic machinery to the end user and to society and to improve society’s understanding and appreciation of that value.

To meet its objectives, the section focuses on the best possible exchange of technical knowledge through collegial contacts by arranging Section Symposia every second year, between the IAHR Congresses. The Symposia are designed to attract scientists and engineers from industry, universities, consultants and users of hydraulic machinery. In addition, specialised symposia are organised focusing on the subjects of its 4 working groups: WG1 – “Behaviour of Hydraulic Machinery Under Steady Oscillatory Conditions”; WG2 – “Similitude for Cavitation Model Testing of Hydraulic Machinery”; WG3 – “The Scale Effect on Performance and Efficiency of Hydraulic Turbines and Pumps”; WG4 – “Use of Numerical Flow Simulation for the Prediction of Losses in, and Therefore the Performance of, Hydraulic Machines”.

The Section on Hydraulic Machinery and Systems will stimulate the following activities through its symposia and working groups:

1. The production of “environmentally friendly” turbines with higher efficiencies, wider operating ranges, smoother operating characteristics, and increased life-spans for new hydropower installations.

2. The upgrading, uprating, and life extension of existing hydropower facilities.

3. The production of inexpensive small hydro.

4. The production of large pumping systems for transport of water for drinking and irrigation, for cooling in thermal power plants and for pumped-storage applications.

5. The production of improved digital systems for cost effective and environmentally effective plant operation, maintenance, and energy recovery.

***Research Agenda:***

The continuous development seen in the standard topics like performance, cavitation, scale-up and unsteady phenomena should progress to a more advanced level, especially through improved computational methods and measuring techniques. Because hydropower is often exposed to public scrutiny it is also necessary to reduce any adverse effects from hydraulic energy generation and also to explain the benefits to experts in other fields and to the general public. Therefore, research and development in the future shall also consider biological aspects and generally take into account the interaction between hydraulic machines, their surrounding structures, and the environment. Key elements of the research agenda are:

*Flow analysis within machines:* The viscous 3-D numerical simulation of steady-state flows in turbines and pumps and the resultant refined knowledge of internal flow physics have led to a significant improvement in the performance characteristics of hydraulic machines. Further improvements in the operating qualities and performance of hydraulic machines can be made using advances in computational modelling. Faster computers, improved computational methods, advances in turbulence modelling, and the inclusion of unsteady multi-phase flow physics in the “Numerical Laboratory,” combined and correlated with laser doppler and dynamic pressure measurements of rotating and stationary parts in turbines in the “physical Model Laboratory” will provide the basis for these improvements. Analyses accounting for unsteady 3-D viscous flows including the interaction between stationary and rotating components will be a central research theme in the future. The activities of WG 4 will use advanced flow analysis technologies to advance the state of the art in understanding scale effects.

*Machinery and systems under steady oscillatory flow:* The increased size and head of machines with higher rotational speed can lead to problems of a dynamic character. Dynamic analyses in frequency and time domain for control and behaviour of machines as well as hydro-elastic analyses of pipes and turbine structural components are main activities currently being studied. The most important parts of these analyses may be the study of unsteady behaviour of diffuser flow in turbines and pumps and high frequency interference in the rotating and stationary cascades. The activities of WG 1 stimulate research and an interchange of ideas on these subjects.

*Water column separation and transient flow:* The work in this field will continue, including further research on two-phase flow operation of pumps and turbines and taking into account the dynamic behaviour of conduit systems.

*Scale effect:* The efficiency of pumps and turbines is normally measured on scale models, and is assumed to be valid for the prototype, after adjustment for scale by the effect formula. In this field, the need for research is great because of the need for an improved scale effect formula in the IEC TC4 code dealing with standards for efficiency measurement of water turbines. Basic research work is also underway for specific scaling relationships for the various losses in a turbine. The activities of WG 3 and WG 4 stimulate research and an interchange of ideas on this subject.

*Cavitation and erosion and corrosion:* The influence of water quality and sediment on cavitation, erosion, and corrosion and their effects on machine performance and materials remain the subject of great interest to designers and users of hydro machinery. This section includes research related to the above in its activities. The activities of WG 2 stimulate research and an interchange of ideas on these subjects.

*Other activities:* Future activities will include research on pumps dealing with two-phase flow and non-linear problems solved by new techniques such as chaos theory. Draft tube flow appears to be one of the subjects suitable to be studied by such methods. As a consequence of the wishes of hydro plant owners for improved reliability and reduced downtime, considerations for the future will also include the development of new materials and manufacturing methods for hydraulic machines, as well as the analytic tools for design and evaluation of machine components. Research to improve the environmental friendliness of hydraulic machines will become a significant theme, including methodologies for increasing fish passage survival and for reducing water borne pollution. Methodologies for sensing and diagnosing impending plant problems and for making recommendations for mitigation are also subjects of growing interest.

### *3.2.2 Urban Water Management*

Urban drainage systems are designed to convey stormwater runoff and sewage flows of magnitudes varying from low dry-weather flows to floods, control fluxes of pollutants resulting from human activities, and contribute to the general well-being of the urban population. Furthermore, such goals should be accomplished within the framework of integrated management of urban waters, with minimal impacts on receiving waters, in a cost-effective way, and under conditions of steadily increasing populations of large cities. In view of these high demands, urban drainage is becoming a key issue in the management of urban water resources.

The main objective of the Joint IAHR/IAWQ (International Association for Water Quality) Committee on Urban Storm Drainage is to promote an ecosystem approach to the planning, design and operation of urban storm drainage. This objective supports sustainable development of urban areas, protects their natural environment, and requires that hydrologic, hydraulic, water quality and ecological issues of drainage design are properly considered in a cost-effective integrated way. Computer modelling, operational research techniques and expert systems are standard tools for the optimisation of drainage design, operation and their associated costs.

Every urban area has its special characteristics depending on climate, topography, development, engineering practices, institutional and political framework, population and economy. Thus, there are no universal solutions which could be recommended under all circumstances and the state-of-the-art solutions have to be examined and promoted with respect to the specific local conditions and drainage problems. For example, drainage problems in developing countries as well as in the newly established democracies in Eastern Europe need special considerations. These countries are facing great difficulties in dealing with environmental issues under adverse economic conditions, strong competition among various sectors for limited available funds, and the lack of effective institutional arrangements that can resolve these problems.

The Joint Committee organises the triennial International Conferences on Urban Storm Drainage, related workshops and training courses, supports regional or specialty conferences, publishes technical reports and a comprehensive annual newsletter, and initiates research on important issues.

***Research agenda:***

*Rainfall/Runoff Processes and Modelling:* The theoretical development of rainfall/runoff models has reached maturity and further progress will be incremental . Current research issues include adaptation of models for use in the realm of hydroinformatics (i.e., in conjunction with special databases), use of radar-measured rainfall data including moving rainstorms, efficient routing of pressurised flow in a computing environment with full graphical support, refinement of flow quality modelling, consideration of management options (storage and treatment facilities), interactive, dynamic control required in real-time control studies, and realistic modelling of sediment transport and flow quality.

*Assessment of Stormwater and CSO Quality and Its Impacts:* The traditional approach to stormwater and CSO (Combined Sewer Overflow) quality focused on chemical characterisation with successive emphasis on solids, biodegradable matter, nutrients, heavy metals, hydrocarbons, and trace organic contaminants. These chemical protocols often fail to distinguish between toxic and non-toxic contaminants, their bioavailability or the synergistic effects of chemical cocktails. Hence, current research focuses on the assessment of stormwater and CSO quality by ecotoxicity measurements. Further development of methods for the assessment of stormwater and CSO impacts is needed, using such concepts as biotesting, biomonitoring and biological community assessment. Some of these methods can be also used for monitoring impacts of thermal enhancement of urban runoff. The methodology to be developed needs to recognise the time-dependent nature of CSO and stormwater impacts, and the associated acute and cumulative effects.

*Role of Sewer Sediment:* Sewer sediments cause numerous problems in drainage operation, including loss of hydraulic capacity, concentration and transport of pollutants, septicity accompanied by gas and corrosive acidity production, and a risk of washout into the receiving waters or overloading at the wastewater treatment plant. Furthermore, many treatment or control options applied to CSOs and stormwater result in sediment settling and accumulation (e.g. in stormwater ponds, CSO tanks), and the settled sediment causes problems similar to those caused by sewer sediment, including impacts on water quality in the overlaying water column. Progress has been made in mathematical description of transport of sewer sediment, either as a suspended load, or bedload. Options for sediment control have been developed, and generally include combinations of management practices in urban catchments, including source controls and improved maintenance of streets and catch basins, and in-system improvements. New research should focus on the behaviour of cohesive sediments, and the water quality impact of contaminated sediments.

*Stormwater Management:* Best management practices (BMPs) mitigate the impacts caused by progressive urbanisation, including increased discharges and volumes of runoff, and export of pollutants or heat from urban catchments. Although individual BMPs vary due to differences in climate, stormwater characteristics, local conditions, design procedures, and modes of operation and maintenance, international experience with BMPs can be summarised in the following four points: (1) No single BMP offers a universal solution to stormwater pollution; (2) BMPs should be considered as part of the treatment train, which starts in the catchment, continues in the collection system and a series of complementary BMPs, and ends with in-stream measures; (3) The sustainability of BMPs has to be ensured through proper operation, design modifications (where required to meet the original objectives) and maintenance; and, (4) Even though well-designed BMPs provide stormwater quantity and quality control, visual amenities, and wildlife habitat, they must be recognised as wastewater treatment facilities that may impact on wildlife and cause contaminant entry into the food chain. Further research is required on new BMPs (e.g. biotreatment systems), advanced knowledge of BMP performance in a treatment train and under special conditions (sensitive receiving waters, urban redevelopment, cold climate, tropical climate), their sustainability by proper maintenance, and their role in sustainable urban development.

*CSO Control:* Perhaps the greatest innovation in CSO control is the introduction of the integrated management approach to CSOs, considering the catchment drainage (including the collection system), wastewater treatment plant (WTP) and the receiving waters. In fact, only this integrated approach to pollution control offers a true assessment of the effectiveness of individual system components and a basis for their optimal design. In the analysis of CSO control, several components are considered - source controls, storage (in-line and off-line), treatment (both central and satellite), and in-stream measures. Source controls address both reduced influx of stormwater (e.g. by such BMPs as infiltration) and controls of dry weather flow or solids deposits (storage prior-to storms, reduced pollutant fluxes through regular maintenance etc.). Temporary in-system storage can be created by oversized storage pipes, or off-line by special storage facilities. Recognising that the methodology for CSO control by storage is well developed, the current research focuses on treatment processes for CSOs, including lamellar settling, degritting with a chemical stage for pre-treatment and flotation reactor, chemically aided settling with microsand, and UV disinfection for protection of recreational uses of the receiving waters.

The complexity of sewer systems, and the dynamics of flow, storage, loads and treatment processes, make it particularly desirable to control the sewerage/treatment/receiving water systems in real time. Real time control (RTC) was found particularly useful in systems with operation problems varying in type, space and time, and with some idle capacity. Further research continues on RTC of quality of wastewater and receiving waters, and reliable hardware.

*Hydroinformatics:* Functional, spatial and temporal integration required in comprehensive drainage studies necessitates the use of computer models. The international modelling practice continues to be dominated by a limited number of well-supported and continuously updated modelling packages incorporating some aspects of hydroinformatics and merging environmental modelling with information technology. A wide range of options available in some of these tools allows to address comprehensive drainage/environmental systems, including the collection system, management and control schemes, WTPs and receiving waters. Expert system supports and RTC simulation modules are also available. Further refinement of such tools through new research is desirable.

*Regulatory Programs:* A successful implementation of stormwater management and CSO control requires, as a prerequisite, supporting environmental programs, regulations and laws. Surveys of regulatory tools from several countries indicate great variations in regulatory stance among the leading countries in this field, implying that regulatory aspects of stormwater management and CSO control are rather uncertain, and in some cases, may even impede effective environmental practices. Further research is needed into pros and cons of such current regulatory trends as attempts to regulate according to a comprehensive assessment including impacts, according to discharge without regard to site specific impacts, according to the available technology without regard to its specific effectiveness, and with or without consideration of economic means to implement these regulations.

### *3.2.3 Fluid Phenomena in Energy Exchanges*

Knowledge of fluid behaviour and thermal transfer is critical to ensure economical and safe power generation. The most striking and immediate example is the need for safe operation of nuclear reactors, especially in regard to an adequate supply of core coolant. From computational fluid dynamics, to cooling-towers engineering or to advanced nuclear reactors thermohydraulics, the effort of this section is to provide a forum for exchange of information among the researchers and professionals, including engineers from industry, who have as a common interest the study of flow phenomena encountered in the production and use of energy.

*Intersociety Co-operation*: It is the aim of the section to foster co-operation with other groups and organisations striving for similar goals. A recently established, very active association of researchers and professionals from industry engaged in Computational and Experimental Fluid Dynamics is ERCOFTAC (European Research Community on Flow Turbulence and Combustion). The section has established a working association with ERCOFTAC, with joint workshops and mutually sponsored symposia.

***Research agenda:***

*Numerical Flow Modelling*: The explosion in computational capabilities and the availability of computational fluid dynamics software is rapidly changing the approach to hydraulic modelling. Advances in numerical techniques must be accompanied by further insight into physical behaviour and by experimental investigation. A special interest for the section is the refined modelling of turbulent flows. In this field a section is organising, on an annual basis, workshops (in association with ERCOFTAC) with benchmark exercises on well documented test cases.

*Cooling Towers*: Research subjects for the section working group on cooling towers include thermohydraulic performance, environmental impact, civil engineering of cooling towers, the performance of spray cooling ponds and water conservation. The section organises biennial symposia.

*Advanced Nuclear Reactors*: A third working group focuses its research exchanges on the thermohydraulics of advanced nuclear reactors. Of particular interest are investigations of passive safety systems, where continued cooling of critical reactor components such as core and containment under accident conditions is assured through passive devices. These systems do not require operator action, but rather rely on physical principles, such as gravity, natural coolant circulation and enhanced heat transfer. The working group regularly organises workshops and benchmark exercises focusing on flows with heat transfer.

*Wind engineering*: This recently established working group focuses on turbulent flows around structures. The purpose of the working group is, first, to be able to compare various turbulence approaches for this difficult problem, ranging from one-point closure models (using Boussinesq assumption as the k-epsilon one or full Reynolds stress modelling) to Large Eddy Simulation. Then, the definition of wind loads on structure and problem of fluid-structure interaction will be addressed. A direct industrial application is the fluid-structure interaction between wind flow and cooling towers, but wind action can also be seen as a source of energy.

***3.2.4 Water Resources Management***

Integrated water resources management is embedded in political, legal and institutional contexts and these complexities are reflected by multiple and sometimes conflicting objectives, purposes, actors and groups which have to be integrated into the decision-making process. Water resources management is understood to be a set of actions taken to use and control natural resource inputs in relation to water, to obtain outputs and natural systems conditions useful to individual users and to society. To be effective, the management approach has to accommodate fundamental physical, economic, social and environmental linkages and interactions. Water management systems have a long physical lifetime and a broad impact area. The consequences of any management decision have to be evaluated in a multi-objective context for both short and long-term consequences. Additional uncertainties arise due to the long-term variability of available water resources and of the unpredictable changes in demand over long time periods. The evaluation process itself is subject to the changing values of society. For instance, the objective of environmental preservation has become a high priority in the last two decade, whereas previously it was generally ignored in the decision-making process.

The objective of the water resources management section of IAHR is to improve understanding about the linkages between water-related decision-making, society and the environment. These scientifically based results have to be transferred to the water management institutions and companies, which requires an intensive co-operation between scientists and managers to ensure sustainable water use. The concept of sustainability which is widely used in international declarations and documents is highly appealing, but it needs further analysis to develop an operational concept appropriate for daily water management. The Section for Water Resources Management has therefore adopted, as a primary long-range goal, to promote the use of advanced technologies to address problems of environmentally sound water resources management, and has committed itself to encourage interdisciplinary approaches in hydraulic engineering with special regard to ecological concerns. Moreover, the section wants to promote the adoption of appropriate methodologies for developing countries by education and by training.

***Research agenda:***

Although not explicitly mentioned in the topics listed below, it is worth noting that regional and climatic characteristics have to be considered as well as the social structures and the economic circumstances under which water management is carried out.

*Interdisciplinary research*: Improved collaboration among hydraulic engineers, hydraulicians, regional planners, economists and ecologists is essential. It will also assist in improved communication among these disciplines which have their own jargon and methodological approaches. It is essential to ensure the transfer of data and results required by other disciplines for further analysis. Another important aspect is to demonstrate how hydrologic uncertainties are transformed into uncertainties in the impacts. This will contribute to better assessment of the vulnerability of the social and environmental systems affected by water management.

*Water resources management under increasing uncertainty*: The ongoing debate about climate change has raised questions about possible effects of such a change on the hydrological environment in different regions. Research must address the uncertainty about future hydrological conditions under which a water resource project will have to operate.

But water resources are also affected by several other anthropogenic impacts. One of the most important and direct impacts is from modified land use which in turn is often dependent and stimulated by the availability of water and its management. These feedback mechanisms, not sufficiently monitored and understood, contribute substantially to an increase in uncertainty about the availability and quality of water supplies.
Research will be initiated to improve the scientific knowledge about the linkages between climate, land use and the hydrological system under different climatic settings. This in turn will assist in the

reassessment of operation principles currently being applied. Sustainability, resilience and adaptability supersede optimality, defined in the traditional economic sense, as the decision criteria.

*Conflict resolution in water management*: Water, as an increasingly scarce resource, is already and will become more frequently the subject of conflicts. Different types of conflicts are observed which refer either to conflicts among interest groups like water resources developers and ecologists, or to unbalanced utilisation of water among upstream and downstream users or even transboundary conflicts among users sharing the same resource are occurring.

In general, the objective is to develop methodologies for emergency management and conflict resolution strategies. The methodology of multi-objective evaluation and decision-making is quite well developed but the application in real life problems is lacking. Such techniques could at least contribute to defining the scope of the problem and the set of alternatives in a rational framework and could therefore assist to compromise decision-making. For larger conflicts, methodologies are being developed which will contribute to improved understanding of problems and the consequences of any decision and will therefore support rational conflict resolution. The transfer of these techniques from the academic world to applied water management has to be encouraged and carefully reviewed. Decision-makers also need to be able to identify the possibilities of non-structural measures for the remediation of problems, including emergency management and conflicts among different water uses and users.

Methods for supporting negotiations for water allocation should be developed and tested for international, national and regional application. A methodological framework for comprehensive environmental risk and impact assessment must be developed to quantify the vulnerability and resilience of the environment.

*Non-structural water management:* The investment costs for flood protection are often correlated with costs from flood damage because land use in the protected areas is intensified and new housing areas are developed. Proper flood protection not only requires the correct design of levees, but also land development plans and restrictions imposed on the utilisation of the former flood plain. Guidelines have to be developed otherwise catastrophic events like the recent ones in the Odra and Rhine basin will become more frequent.

Non-structural flood control measures such as real time forecasting and flood warning systems, flood plain zoning, subsidised insurance and relocation are alternatives to structural measures that should be investigated. The analysis would have to asses advanced communication in flood warning systems for the fast and effective dissemination of information, flood emergency plans including evacuation of people exposed to major risks, the potential of temporary flood protection measures and finally, the willingness of the population to accept such an approach.

*Urban water management*: Separately from the activities of the IAHR Section of Urban Water Management, the goals listed below refer to general aspects of urban water management with the emphasis on large agglomerations, which often develop in an uncontrolled way. Urban drainage, water supply, solid waste and sewage treatment and disposal are components of urban water management that must be adequately integrated in order to cope with the increasing demands for municipal and industrial water uses.
Most urban centres in the developing world still lack adequate facilities for the proper collection and disposal of domestic and industrial wastes. Only about half of the urban population in developing countries has access to sewage disposal systems. Most of the existing collecting systems discharge directly into receiving waters without any treatment. Due to budgetary constraints as well as inefficient institutional and administrative settings millions of people in developing countries have taken direct responsibility for their water supply and try to do so with extremely limited resources. A typical example is in the uncontrolled development in large agglomerations where people individually exploit the limited water resources to cover their basic needs and at the same time endanger the resource itself by untreated waste water. The development of basic low-cost technical tools for water supply and treatment combined with the training of local self-organised groups could substantially reduce harmful impacts on the water resource.

In the industrialised countries, the large agglomerations have to cover their water requirements by exploiting neighbouring regions to such an extent that the water balance of large aquifers and karstic systems is endangered. At the same time the pollution of the groundwater bodies within the cities is often poorly monitored because of the limited use of this resource in urban areas.

Taking into account that the trend of urban population concentration increase will continue in the future and mainly in less developed countries, a programme for encompassing all hydrologic, ecological and water-related socio-economic aspects of urban planning and management should be developed.

### *3.2.5 Industrial Two-phase Flows*

Activities in the IAHR-section Industrial Two-Phase Flows include theoretical, experimental and numerical studies on two-phase flows in the chemical industry, two-phase transportation and phase separation techniques in the oil industry, droplet or particle-laden flows in air tied to combustor aerodynamics and boiling flows in pipes, boilers and reactors. The objectives of the section are the improvement of the physical understanding of two-phase flows by detailed experimental and theoretical studies. The experimental studies involve modern measuring techniques like Laser- and phase-Doppler anemometry. Based on the experimental and theoretical results, numerical prediction procedures will be improved by refined flow modelling. This implies that the experimental results are stored in a database accessible to all interested researchers. Furthermore, activities like working groups and workshops will be organised by the section.

***Research agenda:***

*Two-phase flow predictions*: Collaborative testing of numerical modelling has to be applied to particle-laden turbulent jets, particle-laden swirling combustion chambers and further bubbly flows. The series of workshops on two-phase flow predictions, cosponsored by IAHR and ERCOFTAC (European Research Community on Flow Turbulence and Combustion) promotes the comparisons of Eulerian and Langrangian methods and different models for turbulent dispersion on well-instrumented experimental test cases.

## 3.3. Geophysical Hydraulics

### *3.3.1 Fluvial Hydraulics*

This branch of geophysical hydraulics consists of the observation, analysis and control of fluvial processes. Any engineering intervention of a river (control) requires a preliminary assessment of the mechanisms involved (observation) and the prediction of their effects (analysis).

Physical processes in rivers are determined by the interaction of water and sediments. Waterflow and sediment transport are, therefore, traditional topics of study of this branch. Chemical and biological processes are also becoming more important, especially as their relationships to river morphology are recognised.

River engineers work in close contact with the natural environment. Their measures often interfere with natural processes. Environmental consideration and careful handling of fragile ecosystems are gaining increasing attention.

The morphology of a river is highly variable along its course, from the steepest branches of the upland regions down to the flat reaches of the estuary where rivers meet the sea. The behaviour of rivers in their middle course, where sediment transport is constituted by the relatively uniform material of the bed, has been investigated rather comprehensively by hydraulic engineers. Less attention has been paid to the upper and lower parts of the river. In the upper reaches sediment transport is directly controlled by the input from mass movement and surface erosion. In the lower estuary region, sediment motion is affected by salt, and tidal influences.

Consequently, the fluvial hydraulics section is now interested in research that involves components from other disciplines like biology, geomorphology, soil mechanics and oceanography.

Fluvial hydraulics needs contact with practice. The researchers depend on the engineers involved in practical river management, including construction. Their models and scientific approaches require data and experience from the field. On the other hand, the engineers doing practical work can benefit from research results and innovations by applying them in practice.

***Research agenda:***

*River processes*: Experimental and theoretical investigations are being carried out to describe, in a more accurate and detailed way, various aspects of fluvial dynamics. These investigations include secondary flow and secondary sediment transport in geometrically complex configurations. Horizontal distribution in the bottom of non-uniform grainsize material, and dynamics of hyperconcentrated flows, like mud and debris flows. Overall models of the entire fluvial system, which would take into account the above-mentioned components, are also required for various engineering purposes.

*Risk analysis and mitigation in fluvial systems*: Besides the traditional one-dimensional analysis of the propagation of flood waters along a fixed-bed river, many other aspects of risk analysis and mitigation should be considered for general hazard assessment.
In the past years, attention has been focused on the two-dimensional spread of a steep wave in a valley produced by a ruptured dam. However, catastrophic inundations may also be related to large earth movements like the falling of a large mass into a reservoir, the sudden washing-away of a natural dam formed by landslides, or the rapid overaggradation of a mountain river, by mud and debris flow. Mitigation of these effects, including reliable warning systems and structural and non-structural measures are currently under investigation.

*Re-naturalisation of river environment*: Due to increased environmental awareness by hydraulic engineers and the mounting pressure exerted by conservationist groups, the design of structural interventions in rivers must now consider environmental problems. In some cases, existing works decades and centuries old are under scrutiny for a possible "re-naturalisation".
As a "natural" configuration will generally correspond to more severe hydraulic conditions, research is needed to improve the compatibility between biological and engineering requirements, as well as to define new standards for the design of trained rivers.

*Long-term evolution*: While in some places (e.g. in Europe), future interventions in rivers will likely be limited to relatively small training and re-naturalisation works of secondary streams, new projects in other countries will probably involve important constructions on the largest rivers of the world.
In general, the necessity of environmentally acceptable and economically feasible sediment management which is oriented towards sustainable development must be given careful consideration
Improved methods for predicting the effects of new projects have to be developed, especially with regard to the hydrological and sedimentary regimes of the system. Because the reaction-time of the system depends upon its size, the evolution of very large rivers following these constructions may go on for centuries.
Special long term models that can simulate this time-scale should be prepared and tested against historical records. The history of river-water utilisation is full of examples of the unpredictable changes to river morphology and water quality as a result of river constructions.

#### *3.3.2 Maritime Hydraulics*

Maritime Hydraulics covers all aspects of maritime, coastal and estuarine problems including coastal morphology, waves, tides, currents, sedimentation and pollution. The activity of the IAHR Maritime Section is focused on six topics:

- Study of environmental parameters such as waves, tides and currents through: Field data collection, analytical methods and numerical and physical modelling techniques. Special emphasis is given to achieve a better understanding of non-conventional parameters such as wave groups, bounded short and long waves, wave asymmetries, directional waves, etc. and their relevance to structural response.
- Design of ports & harbours and their optimisation through physical and numerical modelling including design of fixed and floating structures.
- Analysis of bed load and suspended load, cross-shore and longshore currents involved in sedimentation and bed evolution, erosion and deposition problems related to structures, and dredging.
- Study of pollution problems including convection of pollutants by currents, residual drift, dispersion and diffusion.
- Coastal and ecosystem management including the interaction of the coastal environment with coastal developments.
- Study of consequences of sea level trends and impacts on coastal engineering.

Contacts with other organisations, such as the Coastal Engineering Research Council (CERC) of the American Society of Civil Engineers, the Permanent International Association of Navigation Congresses (PIANC), the International Towing Tank Conference (ITTC), are well established.

The present effort is mainly focused on improving numerical and mathematical models of coastal processes through a better understanding of the associated complex physics. As well, there is the need for certain field data to validate these numerical models.

Many laboratories are now equipped with segmented wave generators that can simulate the multidirectional characteristics of natural sea states. Although the use of multidirectional waves provides a more accurate representation of wave interactions with structures, often resulting in more cost-effective and safer designs, there are limitations again in the lack of sufficient field data.

One of the priorities of the IAHR Maritime Hydraulics Section is to form international Working Groups for standardising and validating analysis algorithms that can be used both in field and laboratory situations.

***Research agenda***

*Remote sensing and exchange of field data*: Future fields of investigation will revolve around remote sensing, including the launching of a new generation satellites. The exchange of data and the access to data banks have to be improved.

*Interdisciplinary approach of ecology*: Especially in the field of numerical tools, there is a need for closer ties between specialists in hydraulics and specialists in ecology; for example between physicists, biologists, chemists and ecologists.

*Sea level rise*: The expected rise in sea level and associated climate changes will most probably have severe consequences for coastal and estuarine management.

### *3.3.3 Groundwater Hydraulics*

Groundwater hydraulics covers the flow of water in aquifers and involves, more generally, the flow and transport processes in porous media. Water management and the environment are main topics of concern. Groundwater is part of the hydrological cycle and represents a complex ecosystem which needs a multidisciplinary understanding. Groundwater constitutes the most available freshwater resource of the earth, as much as two orders of magnitude larger than the total water volume of rivers and lakes. Because it is less prone to pollution than surface waters, it is most important as a drinking water resource.

Groundwater systems vary greatly, depending on the geological formation of the aquifer (sand and gravel aquifers, fissured rock aquifers, karstic aquifers). Their hydraulics are characterised by large water bodies, very small flow velocities and hence extremely long exchange times. Transport at the regional scales is affected by local heterogeneities of the geological formations, and is governed by advection and molecular diffusion at pore/grain size scale. Chemical reactions of pollutants and bacterial life take place at the pore/grain size scale. Groundwater is recharged by rainfall, when it percolates through the unsaturated zone to the aquifers, and by infiltration of surface water. Across its open boundaries, groundwater can be polluted by local sources of accidentally released contaminants or by pollutants released from diffusely distributed sources like agricultural activities.

Groundwater contamination has developed into one of the key environmental issues in most industrialised countries. Industrial contamination sources include waste sites, leakage, accidental spills and leaking septic tanks. Liquid contaminants (e.g., oil products or halegonated hydrocarbons), which are not miscible with the water can exist underground (in the unsaturated and in the saturated zones) as non-aqueous phase as well as dissolved in the water, adsorbed at the solid phase, and mixed in the soil-air. In such cases the subsoil is a multi-phase system. Agricultural contamination sources are fertilisers and the use of herbicides and pesticides. Air pollution contributes by depositing contaminants that make their way into the groundwater.

***Research Agenda***

*Groundwater management*: Acute problems for groundwater management are overexploitation, lowering of groundwater tables, water deficits , and water pollution. The evaluation and development of sustainable water resources systems remain important topics in groundwater management. Improved land use management, needed to increase recharge by reducing runoff and evaporation, is currently being studied especially in arid climates. Further problems result from land subsidence caused by overexploitation of groundwater resources. In coastal areas, problems of salt water intrusion are important. Furthermore, groundwater can be used to store and retrieve heat for cooling and heating. However any groundwater management activity has to be based on an adequate description and thorough prospecting. Improved methods have to be developed.

*Groundwater monitoring*: Monitoring groundwater quantity and quality: Careful monitoring of aquifers, including estimates of discharges in groundwater flows and storage, can allow early recognition of chemical spills and biological activities and enhance timely countermeasures. Remote sensing methods, using new sensors like radar, are being developed for estimates of the soil water balance.

*Groundwater remediation*: A re-establishment of groundwater quality of polluted aquifers requires the clean-up of contamination in the saturated and the unsaturated zones. The mechanisms of multiphase flow, and the transport, mixing and mass transfer in the multiphase system ”subsurface” are not sufficiently understood and the efficiency of different clean-up techniques is difficult to assess. Therefore, there is a need for basic work concerning the understanding and the mathematical description of the processes, as well as applied research concerning the developed and improvement of remediation techniques and the construction of effective hydraulic barriers for polluted sites.

*Political decisions on land use*: Groundwater is often considered as a secondary issue in decisions regarding land use in highly populated and industrialised countries. However, the issue of groundwater protection has to establish its value among the conflicting interests of infrastructure, industry and agriculture.

*Risk and uncertainty analysis in the decision-making process for sustainable development*: The risk of groundwater pollution is ubiquitous, and it is often characterised by extremely long remediation and recovery times. Improved assessment of the vulnerability of groundwater resources is critically important.

*Underground space use*: Caused by an increased demand for the use of underground space for construction, the development of suitable geotechnical techniques that ensure both quantity and quality of the adjacent groundwater is needed.

*Unsaturated Zone*: The zone of groundwater table fluctuations is characterised by frequent changes between saturated and unsaturated conditions. Of particular significance are areas such as flood plains or wetlands. Within the unsaturated zone, air is present as a third phase, leading to aerobic processes. It can form an important barrier that prevents pollutants from entering the groundwater. Although models of transport and reaction in the upper soil layer have been developed, they are not sophisticated enough to be able to predict with confidence the impact of new agricultural practices on the watershed. Improper irrigation can cause salination problems. Direct effects of changes in groundwater tables upon vegetation and the terrestrial ecosystem can be observed and should be better understood.

*Exchange with surface water*: Groundwater is related to the surface terrestrial and aquatic ecosystems in many ways. The directions of the fluxes of water and pollutants vary with the levels of surface water and groundwater, depending on hydrological conditions. These fluxes are controlled by the state of the river bed or lake bottom, which can be clogged by filtering, biological growth or previous chemical reactions. Alternatively these areas can be cleared by a flood with the consequence that pollutants stored in the sediment are released. This interface is a crucial zone where processes like absorption and decay of pollutants need further study.

*Coupled flow, transport and bio-geo-chemical processes*: In order to model non-conservative contaminant transport, it is essential to couple chemical and biochemical phenomena with flow and transport models. The approach taken by chemists and biologists is to understand the microscopic reactions (redox reaction, sorption, precipitation, biodegradation). The kinetics of the reactions can be controlled either by the actual thermodynamic reaction or by the transport mechanism in the porous media which bring the reactants into contact with one another. It is therefore essential to understand the exact coupling of flow and transport and of bio-geo-chemistry. Aquifers as bacterial ecosystems are poorly described. More effort is needed to understand the dependence of the nature and abundance of bacteria upon factors like temperature, water movement, distribution of organic matter, chemical composition and physical properties of the aquifer. The interaction of these micro-organisms with the chemistry of the groundwater has to be further studied.

*Upscaling*: The rules and laws that can be used to upscale flow and pollutant transport still need to be further developed, both in terms of the constituent equations and the relevant parameters which have to be measured in the field. Spatial variability of flow and transport parameters and bio-geochemical properties in natural media can be very large. Major multidisciplinary field experiments have to be carried out to study this upscaling.

*Mathematical modelling*: The purpose of mathematical models is not only to provide instruments to forecast or estimate processes in a real system, but also to relate sub-processes and concepts, e.g., found in laboratory, and to transfer concepts from one system to another. Stochastic approaches are needed to describe the heterogeneity of the aquifers and to develop parameter estimation methods which allow the models to be calibrated against field observations. These issues are addressed by estimating the variance of the predictions or by conditioning based on measured values. Therefore, adequate models should be formulated.

### *3.3.4 Ice Research and Engineering*

In cold regions, the effects of ice on human activities can be either harmful or beneficial. Some of the problems caused by ice are floods induced by ice jams, clogging of water intakes and trash racks by frazil ice, severe impediment to winter navigation, and damage to coastal and offshore structures by moving ice. On the positive side, stable ice covers have extensively been used for transportation, recreational activities, landing of aircraft and working platforms, and also ice is a source of clear drinking water. At times, however, mishaps during these activities have resulted in loss of life. So, a major goal of ice engineering is to protect life and property against the harmful effects of ice by understanding ice phenomena and processes. Ice engineering deals with ice formation, ice movement, the thermal regimes of rivers, lakes and seas, and the development of methods to alleviate the harmful effects of ice.

About 77% of the fresh water of the world is stored in glaciers and massive ice sheets, mostly in Antarctica and Greenland. Possible global warming will affect these massive ice sheets, resulting in a global change of the sea level. Regionally, a cold climate and the formation of ice on water bodies strongly affect human activities in countries located at the higher latitudes of both hemispheres. In countries having a moderately cold climate, the existence of ice is limited to short periods of a few weeks per year, but unexpected winter conditions can cause severe ice-related problems, such as interruption of navigation, ice-jam induced floods, ice damage to bridges, coastal structures, hydropower plants and other hydraulic structures, ice blockage of water intakes, etc.

Research and engineering efforts are mainly directed toward a better understanding of ice and how best to manage it. Research topics include: (1) the formation and evolution of various types of ice; (2) the movement and accumulation of ice in surface waters and around structures; (3) the interaction between flow and ice cover; (4) the effects of ice on the environment and ecology; (5) methods of ice control and use; (6) the mechanical physical properties of ice; and (7) mathematical and physical modelling of ice engineering problems. The research should aid in the solution of ice related problems affecting strong economic and environmental interests, such as hydropower production, navigation in ice-infested waters, water transfer in cold regions, mitigation of ice-jam floods, effects of ice on hydraulic structures, and exploitation of petroleum and other natural resources in polar regions. Active co-operation exists between the research community and industry in ice hydraulic engineering. This kind of co-operation should be maintained and promoted, and the importance of basic research should be recognised.

#### *Research Agenda*

*River, lake and reservoir ice hydraulics:* Important topics to be investigated include the freeze-up process, especially the development of different types of ice runs and covers starting from frazil ice formation; the hydraulic and ecological effects of frazil and anchor ice; river ice break-up, with emphases on the dynamics of ice cover interaction with river flow and the effects of basin runoff; the dynamics of surface and undercover ice runs and jam formation; the blockage of water intakes and fish hatcheries, which impedes the continuous flow of water; the impacts of ice on sediment transport, water quality, and river and lake morphology; and methods of ice control and mitigation.

*Thermal regime:* The great variety of complex phenomena that depend on thermodynamic processes need to be understood, because the thermal regimes of rivers, lakes and seas control the growth of ice and its properties.

*Ice forces on structures:* These forces depend on the mechanical strength of ice and the processes leading to its failure. There is a need to investigate the ice failure process in bending, crushing, fracture and buckling. Non-simultaneous crushing of ice at high indentation rates is caused by a combination of ductile and brittle failure, and the understanding of this process is far from complete. Study of structure's interaction with a pressure ridge should also receive emphasis.

*Ice modelling:* Ice modelling is used for testing the performance of icebreakers, determining the forces on an offshore structure, studying the effectiveness of hydraulic structures, etc. Although modelling techniques have improved considerably, there are still limitations on model tests because of facility size and the requirements for model ice to have low strength and brittle properties. The modelling techniques need to be improved by comparing the results from model tests with data obtained from full-scale structures. To clarify scale effects should be a main focus.

*Environmental and ecological effects of ice:* Important topics to be investigated include: climate changes; the effects of global climate change need to be assessed with respect to the ice regimes of rivers, lakes and seas; diffusion and dispersion of pollutants. These differ in partly and completely ice-covered waters versus ice-free waters. Oil spills, the effects of spills in ice-infested waters also need to be understood. The effects of ice on stream ecology and the presence of an ice cover influences the level of dissolved oxygen (DO) in streams, and ice control techniques may also affect the stream habitat. These are all emerging areas of research.

*Instrumentation:* There is a need to develop instruments suitable for cold environments, for use in both the laboratory and the field.

*Numerical modelling:* Numerical modelling is an essential part of ice engineering research. With the lack of understanding of many of the complex ice phenomena, theoretical formulations are usually not available. Mathematical modelling should be used in conjunction with field observations and laboratory experiments as a tool for developing solutions to ice engineering problems with known analytical formulations. Because of the intricate flow, thermal and mechanical processes in many ice phenomena, traditional numerical methods are usually not adequate. Innovative mathematical and numerical techniques should be developed. The transfer of new models from researchers to practising engineers should be promoted and supported.

*Navigation in ice covered waters:* To provide safe and economical vessels is an essential goal for investigators. Exploitation of petroleum and other natural resources in polar regions requires ice navigating vessels to transport massive amounts of product. Ship operators strongly request vessels that can safely and effectively navigate in ice-covered waters. The presence of an ice cover is not only a severe impediment to winter navigation in inland waters, but also affects ships and barges passing through locks and dams. Coastal regions and harbours have to be protected from ice movements and the combined actions of ice and waves. Methods to mitigate these problems need to be investigated.

### *3.3.5 Eco-Hydraulics*

The environment, especially in terms of water quality, pollution and protection of ecosystems, is one of major concerns of modern civilisation. Although research in this field has very much increased in the past years, a lot of work still has to be done in order to improve our knowledge and capacity to understand phenomena, predict the effect of human works on natural ecosystems, and find solutions for maintaining acceptable water quality and biodiversity in our marine and continental environment.

In fact knowledge does not progress as quickly as one could hope. One of the reasons is that co-operation and exchange between scientists involved in these problems are not sufficient. Ecology is a very multidisciplinary domain where ecologists, physicists, hydraulicians, hydrologists, climatologists, chemists, biologists, toxicologists, statisticians clearly need to work together, which is rather rarely the case at present.

Another reason is that nature is very complex and the study of aquatic ecosystems requires a lot of data and field measurements in order to understand and simulate natural phenomena. Numerical models have become more and more precise and sophisticated, but they are very often not worthwhile using because of the lack of data to feed and calibrate them.

All these reasons have recently led IAHR to create a new Section on “Eco-Hydraulics” in order to encourage collaboration between hydraulicians, biologists and chemists. This is all the more justified as hydraulics are the basis for any study of water quality and aquatic environment, and that IAHR still has within its sections and members many specialists whose concern for ecosystems is well known and whose expertise needed to be gathered in a specific section.

***Research Agenda:***

As the Section has been set up very recently, its work are not yet completely finalised, but the main orientations will consist in close collaborations with other international associations working in the field of aquatic ecosystems, in setting up speciality working groups on specific themes, and in working on state-of-the-art papers, monographs, guidelines for “end users”. A first working group, focused on hydraulic modelling of aquatic ecosystems, has been launched in collaboration with IAMG (International Aquatic

Modelling Group). Another one has also just began its works on Fish Passes, and a third one is under discussion on eutrophication in lakes and reservoirs. Their general aims are to bring specialists together in order to discuss, compare and evaluate methods in these fields, and to propose with recommendations for the end-users.

## 4. Visions on the Implementation of indicated Steps

### 4.1 Preservation and education of engineering expertise and experience

It cannot be taken for granted that the expertise and experience in hydraulic engineering and hydraulic research will be preserved. Preservation and education of engineering abilities need the continuous effort of universities, engineering schools, research laboratories, professional societies, and industry to pass this knowledge with high standards to future generations of engineers. Resources needed for this basic task cannot be underestimated.

The growth of knowledge and the introduction of new tools like numerical methods results in specialisation of the profession which then implies the loss of a broad general view of hydraulic problems. One consequence of specialisation is the widening gap between fluids research and the practice of hydraulic engineering. Closure of this discontinuity will require the efforts of both camps in a variety of ways. Research-oriented professionals should devote more time to writing books that sort, collate, evaluate and translate into usable terms the relevant research results. Practising engineers should share their real-world experiences including technical failures with universities. This exchange has to become part of continuous education.

There is a need for monographs and manuals. It is not a problem of education; it is a problem of good practice and of the transfer of technology within the profession. Monographs and manuals should be written with participation of professionals, and should not be dominated by researchers. They must be reviewed by practising professionals. The corporate members of IAHR, in particular those who are engaged in consulting, design and engineering should accept the responsibility for reviewing manuals and granting (or do not granting) their approval. They should support the commitment of their engineering personnel to use IAHR manuals in everyday design work and to comment on them in order to improve new releases.

The addition of the environmental aspects to hydraulic problems not only requires traditional hydraulicians formed in civil engineering schools but hydraulicians with backgrounds in physics, chemistry and biology. The foundation for this interdisciplinary co-operation can be laid in complementary graduate studies and training courses, where engineers learn the basics of the natural sciences and the scientists are introduced and trained in the methods of hydraulic engineering.

### 4.2 Maintenance and development of research capabilities

In addition to the quality of researchers, the development of hydraulic research depends on sufficient research funds. Although experiments are expensive to conduct, there is a need for a balance between experimental and numerical research. Only a balanced understanding, formed by experience and practised perception, can develop the judgement needed to identify promising new ideas and new directions for research. When research funds dry up these abilities disappear.

To pursue the research agenda is an assignment of the hydraulic research community. It comprises research in basic fluid mechanic, including non-Newtonian fluids, turbulence, two-phase flow transport phenomena and interfacial problems. This research requires improved methods of risk evaluation, optimisation of construction and operation of hydraulic systems. There is also a continuous need for better software tools for numerical modelling of flows, for computer-aided design and systems engineering for policymakers. The research agenda asks for extension of the database for the evaluation of water resources and of sea states, and an international communication system for the exchange of this data. Finally, it includes the interdisciplinary effort which is needed to handle ecological problems.

Hydraulic research has to monitor new developments in other sciences like fluid mechanics, supercomputing, electronics, computer hardware, optics and materials for possible applications to hydraulic engineering.

### 4.3 Encouraging co-operation

The benefits of complex hydraulic systems can only be sustained where a tradition of high standards of engineering assures the proper operation and maintenance of those systems. The broad support of education and application of hydraulic engineering needs to be intensified.

The international exchange of knowledge, software and data needs our continuous attention and encouragement.

References:

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