PROJECT FINAL REPORT

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Project acronym: HYDRALAB IV

Project title: "HYDRALAB IV More than water; dealing with the complex interaction of water with environmental elements, sediment, structures and ice"

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1. Executive summary

The issues society is dealing with at the moment, such as development of adaptive strategies to climate change and increasing environmental pressures as well as developing sustainable protective measures against various natural hazards (floods, tsunamis, hurricanes, etc.), require a profound knowledge of the behaviour of water and its interaction with the environment. In HYDRALAB we bring together the most important experimental infrastructures in the European hydraulic research area. Experiments in our unique research infrastructures deal with complex questions regarding this interaction of water with environmental elements, sediment, structures and ice and goes beyond just hydraulic research: hence we have adopted the theme 'More than water'.

The coordinated and integrated approach of HYDRALAB aims at structuring the access to unique and costly hydraulic and ice engineering research infrastructures in the European Research Area. The HYDRALAB network is unique in the hydraulic research community and has extensive experience in co-operating since its inception in 1997. It began by informing and coordinating the activities of partners in HYDRALAB I and II, and via enhanced collaboration in HYDRALAB III we have further integrated of our research services throughout Europe in HYDRALAB IV. Over this period our network has grown from 8 participants in 1997 to a total of 30 participants from 15 countries today.

A fully integrated and balanced ensemble of Networking Activities (5), Joint Research Activities (4) and Transnational Access Activities (10) supports the integrated provision of infrastructure related services to the hydraulic research community at a European level, and harmonizes and optimizes the coherent use and development of the best infrastructures in our field of work. This allows the European scientific community to remain at the core of the knowledge triangle of research, education and innovation, both in Europe and abroad.

HYDRALAB coordinates access to a unique portfolio of research infrastructures through our common User Selection Procedure in such a way that access is optimized at the European level. Access is open to users from different geographical origins and at different stages in their career and our user groups are enabled to conduct high quality research using unique facilities and world-class scientific expertise. Furthermore, access to our unique research infrastructures has been simplified by the development of tools for dissemination of important background information on both infrastructures and instruments and experimental results.

Within the HYDRALAB community there is a clear necessity to implement a balanced methodological approach when using the various research tools available to hydraulic researchers, i.e. physical-modelling, theoretical analysis, numerical modelling and field tests. This balance is essential to optimize the use and application of unique and costly experimental research infrastructures. It is an important objective within HYDRALAB to determine how this methodology can be implemented for all the elements of the project.

Finally, it is essential that valuable knowledge and experience in experimental hydraulic research is transferred to the next generation. HYDRALAB has been bringing well-educated and skilled early career researchers from across Europe to the top level of research found at our participating institutions by sharing years of hydraulic experimental experience with the next generation of researchers.

2. Project context and main objectives

2.1. Project context

The coordinated and integrated approach of HYDRALAB aims to structure the access to unique and costly hydraulic and ice engineering research infrastructures in the European Research Area. Research in our infrastructures deals with complex questions regarding the interaction of water with environmental elements, sediment, structures and ice and goes beyond just hydraulic research: hence we have adopted the theme **More than water**. Questions that we need to answer deal with e.g. the development of adaptive strategies to climate change and sustainable measures against natural hazards, like floods. In HYDRALAB IV we have focussed on promoting the coordinated provision of services and developments related to our infrastructures with regard to the following elements:

- Water & Environmental Elements (with focus on ecology and biology)
- Water & Sediment
- Water & Structures
- Water & Ice (with focus on interaction with structures).

Adapting to a changing climate

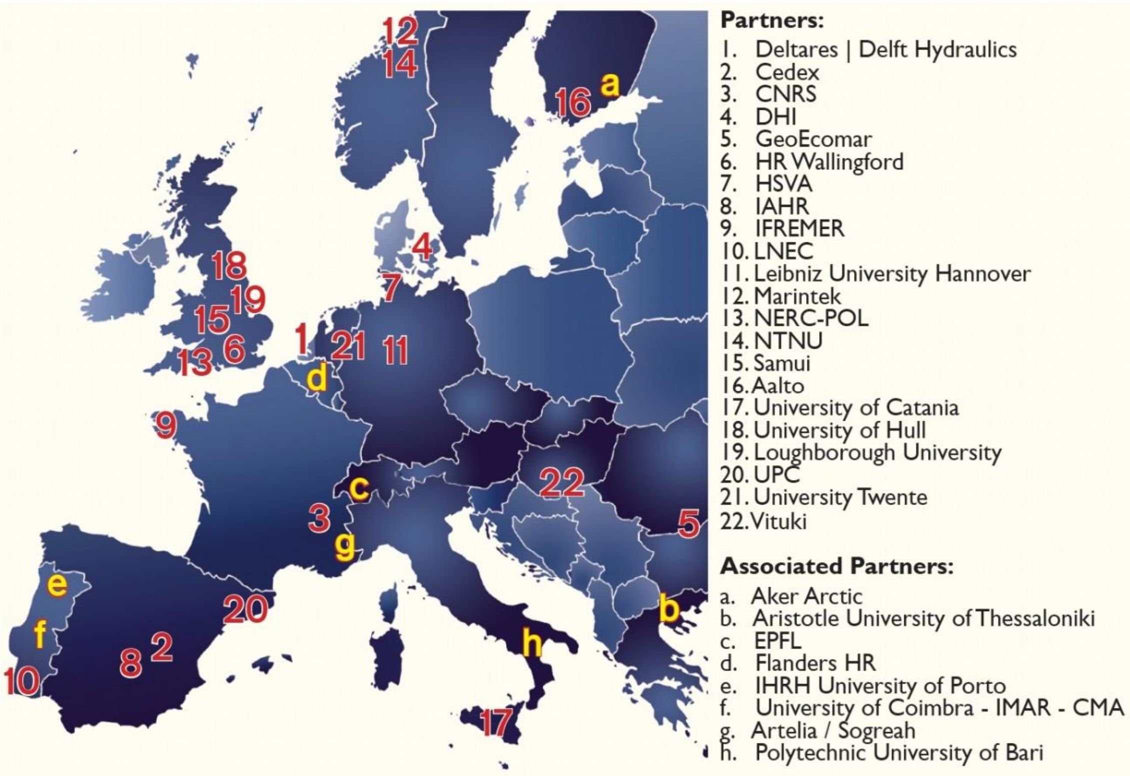
Sea level rise and increasing storminess are likely to result in the intensification of coastal zone erosion, which will, in turn, affect the safety against floods and produce changes in coastal ecology. Furthermore, increases in summer rainfall intensities over northern Europe will also increase the likelihood of pluvial flooding and result in changes to river and estuarine ecology, influencing food security and sustainable agriculture. The observed changes in sea ice on the Arctic Ocean and in the mass of the Greenland Ice Sheet, Arctic ice caps and glaciers over the past ten years are dramatic. The impact of renewable energy devices on our environment can also not be ignored and needs investigation, since society needs these innovative devices for clean and effective energy when adapting to climate change.


Coastal damage during a flood, courtesy Angela Scott, Environment Agency

It is evident that an informed management and use of our water resources and environment is essential to human well-being, and a pre-requisite to the development of advanced innovative technologies. To find solutions for these problems research in our hydraulic research infrastructures needs to go beyond just hydraulics and needs to focus more and more on complex questions regarding the interaction of water with other elements. These topics require more than just numerical modelling and really need research with a special purpose that requires the use of unique and costly experimental research infrastructures. The coordinated use of research infrastructures and the development of instrumentation and tools within the field of environmental hydraulics are an essential part of the tools available to study these issues. This is where HYDRALAB plays a vital role in the European research community for experimental hydraulics.

HYDRALAB, structuring the European hydraulic research community

HYDRALAB has been advancing the integration of infrastructure-related services for the European hydraulic research community since 1997. From an initial endeavour launched by 8 organisations, we quickly grew into a large-scale network spanning 15 countries and involving 22 full participants and 8 associated members. In the figure below our partners are presented.



HYDRALAB partners across Europe

Our activities are carried out in the framework of the Integrating Activities funding scheme of the European Commission. HYDRALAB IV ran from 2010 until 2014 and integrated a balanced ensemble of Networking Activities (NA), Joint Research Activities (JRA) and Transnational Access Activities (TA) to enhance the operation of our infrastructures and their instrumentation beyond the present state-of-the-art and identifies potential future developments. This ensures that Europe keeps its position at the forefront of experimental hydraulic research and has a strong focus on combining the knowledge of experienced researchers with new ideas from the next generation of researchers and innovative market players all around the world.

Advancing experimental hydraulic research

In HYDRALAB we have conducted a broad range of networking activities comprising events, training of next generation researchers, development of guidelines for experimental research and foresight studies. All networking activities were specifically aimed at enhancing the services provided by the research infrastructures and at disseminating the results to the European user community and beyond.

The research facilities available through HYDRALAB include flumes and basins, large-wave channels, environmental hydraulic facilities, a Coriolis platform and sites specifically dedicated to ice and Arctic environments. Applications are channelled through a centralised User Selection Procedure and evaluated by an independent panel of experts.

The ensemble of the Joint Research Activities PISCES, WISE and HyReS focused on the development of instrumentation facilities beyond the present state-of-the-art for areas where the interaction of water with environmental elements, sediment, structures and ice leads to a complex research problem. HYDRALAB IV includes four Joint Research Activities:

The aim of PISCES (**P**rotocols and **I**n**S**trumentation for **C**ombined hydraulic and **E**cological model**S**) was to develop innovative technologies, experimental protocols and improved methodologies for incorporating organisms, both plants and animals, into physical hydraulic models.

The aim of WISE (**W**ater-**I**nterface-**S**ediment **E**xperiments) was to observe with unprecedented accuracy the simultaneous and collocated profiles, of water and sediment flow and the associated bed-dynamics and particle features.

HyReS (**Hy**draulic **Re**sponse of **S**tructures) addressed both structures and ice. The response of coastal and offshore structures to wave loading is a significant issue in their design. At high latitudes, dynamic ice-structure interaction also causes high loads to act on fixed or floating moored offshore structures and harbour facilities.

In RADE (**R**emote **A**ccess to **D**ata and **E**xperiments) we have developed a robust set of information systems to improve access to our experiments and data through the innovative use of modern data management, curation and communication technologies.

2.2. Project objectives for the period

HYDRALAB IV aimed at achieving the following seven objectives within the project, strengthening its coherence and developing its infrastructures. All activities in HYDRALAB IV are tailored to fulfil these objectives towards the end of the project.

1. Update background information on all European hydraulic infrastructures and relevant instrumentation facilities gathered in HYDRALAB III and make these accessible for the hydraulic research community, both European and internationally.
2. Create a quality-controlled database of experiments where HYDRALAB researchers can exchange the results of their experiments and which can be used in the future for other research purposes by the whole hydraulic research community.
3. Introduce remote access functionalities in the hydraulic research area to allow researchers all over the world to exchange experiences and results in a more efficient way.
4. Develop instrumentation facilities beyond the present state-of-the-art for areas where the interaction of water with environmental elements, sediment, structures and ice require new measurement solutions, tools and techniques.
5. Identify gaps and develop roadmaps for experimental research on each of the elements focussed on in HYDRALAB IV.
6. Further integrate EU policies, including the establishment of sustainable funding structures

7. Exchange knowledge and experiences between senior researchers and the next generation through the large HYDRALAB IV events and the organisation of activities specially aimed at early career researchers.

HYDRALAB had the following overall goals:

- To support the integrated provision of infrastructure related services to the hydraulic research community at a European level, and harmonize and optimize the coherent use and development of the best infrastructures in our field of work, contributing to the goal of the FP7 Capacities Work Programme regarding Infrastructures. This allows the European scientific community to remain at the core of the knowledge triangle of research, education and innovation, both in Europe and abroad.
- Coordinate the access to unique research infrastructures through our common User Selection Procedure in such a way that at a European level access is optimized, users are enabled to conduct high quality research and access is open to users from different geographical origins and at different stages in their career.
- Simplify access to our unique research infrastructures by developing tools for dissemination of important background information on both infrastructures and instruments and results of experiments.
- Improve, on a European and worldwide scale, the operation of our research infrastructures and their instrumentation facilities beyond the present state-of-the-art for research areas where the interaction of water with environmental elements, sediment, structures and ice is essential.
- Implement a balanced methodology for using the various research tools available for the hydraulic research world, i.e. experimental physical-model research, theoretical analysis, numerical-model research and field tests. This optimizes the role of unique and costly experimental research infrastructures.
- Bring well-educated and skilled early career researchers from across Europe to the top level of research found at our participants by sharing years of hydraulic experimental experience with the next generation of researchers.
- Contribute to the EU targets to increase the number of women involved in hydraulic experimental research.

3. Science and technology results for HYDRALAB IV

3.1. Introduction

Throughout HYDRALAB IV we provided guidance and support to the European Research Area to map out the desired direction of development at a European level and jointly develop a vision for the next five to ten years. Part of this vision is that we expect that laboratory experiments in this field are likely to be as essential in 20 years' time as they are today but that we need to expand beyond our traditional research topics like waves and sediment, with research on environmental elements and ice.

Laboratory experiments need to supply the new process information that feeds into numerical models, and educate engineers and researchers in the processes controlling the behaviour of the hydraulic elements identified above. Within HYDRALAB IV we have, therefore, focussed on improving instrumentation, processing methods and procedures to deal with research on this complex interaction with water.

High-quality research infrastructures, methodological diversity and effective synergy between available tools are necessary to realize scientific progress beyond the present state-of-the art. This is essential if we are to achieve real improvements in the reliability of predictions and further development of research methodologies and experimental protocols. The extent of the research challenges for the coming decades necessitates further co-operation both at national and international levels. This was also concluded at special sessions organized in the framework of HYDRALAB at the IAHR (International Association for Hydro-Environment Engineering and Research) Congresses in Vancouver in August 2009 and Chengdu in September 2013.

HYDRALAB IV integrated a balanced ensemble of Networking Activities (NA), Joint Research Activities (JRA) and Transnational Access Activities (TA) and enhanced the operation of our infrastructures and their instrumentation facilities beyond the present state-of-the-art and identified potential future developments. As a result Europe is able to keep its position at the forefront of experimental hydraulic research and has a strong focus on combining the knowledge of experienced researchers with new ideas from the next generation of researchers and innovative market players all around the world.

3.2. Transnational Access within HYDRALAB IV

HYDRALAB is an Integrated Infrastructure Initiative, financially supported by the EC, to optimise the use of unique facilities for laboratory experiments in the field of Hydraulics, Geophysical Hydrodynamics, Environmental Fluid Dynamics and Ice Engineering. One of the three main activities of HYDRALAB was enabling international groups of researchers to conduct hydraulic research in selected large and unique facilities, which is called 'transnational access'.

Ten partners within HYDRALAB participated in this programme by making their facilities available to external user groups:

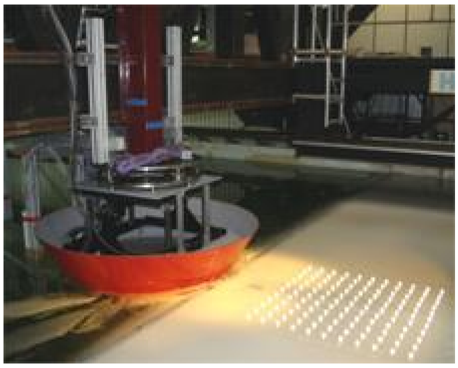
- Deltares, the Netherlands (Delta Flume and Schelde Flume)
- Leibniz Universität Hannover, Germany (Large Wave Flume)
- CNRS, France (Stratified Water Flume and Coriolis table)
- HSVA, Germany (Arctic Environmental Test Basin and Large Ice Model Basin)
- Marintek, Norway (Ocean Basin)
- NTNU, Norway (Sletvik Field Station)
- Aalto University, Finland (Ice Tank)
- Universitat Politècnica de Catalunya, Spain (CIEM)
- DHI, Denmark (Offshore Wave Basin and Shallow Water Basin)
- University of Hull, England (Total Environment Simulator)

The objective of this programme was to stimulate co-operation between European researchers by providing the opportunity to undertake novel research in unique hydraulic experimental facilities which they do not normally have access to. One focus of HYDRALAB IV was to demonstrate that laboratory experiments in hydraulics go beyond understanding simply the flow or movement of water. To address this idea of 'More than water', research groups were invited through open calls to submit proposals that addressed one of these four themes:

- Water and environmental elements (focusing on ecology and biology)
- Water and sediment
- Water and structures
- Water and ice

An international group of independent experts reviewed all the proposals and selected the best which were then granted access to the facilities.





Leibniz Universität Hannover *NTNU, Trondheim* *HSVA, Hamburg*

The programme provided groups of researchers with access, free of charge, to the facilities for the duration of their research project and also covered their travel and subsistence costs. The programme was intended for short access periods, not exceeding 3 months. State-of-the-art measuring instruments, data-acquisition and processing systems were at their disposal, as well as a supportive research environment, from access to facilities through to assistance and guidance from experts at the host institute. Previous background in laboratory methods and techniques was not a prerequisite with all the necessary technical support and training being provided by the host institute.

Marintek, Trondheim

CNRS, Grenoble

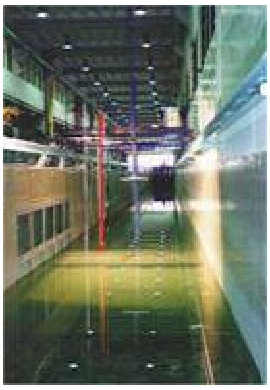
Deltares, Netherlands

Project selection procedure

A common user selection procedure (USP) was followed throughout HYDRALAB IV to select the best projects to be granted access to the facilities. The proposals for access projects were firstly reviewed by the facility provider to check their feasibility. The facility provider then supported the proposers (User Groups) while they improved their draft proposals to compensate their lack of experiences with the facilities. This was of particular benefit to first-time users.

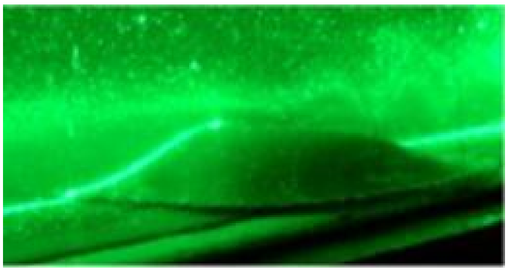
The Access proposals for the various Infrastructures in the same field (e.g. Hydraulics, Geophysical Fluid Dynamics or Ice Engineering) were selected in 3 common sessions of a joint USP-meeting, thus achieving an optimal and coordinated access for the various Infrastructures and User Groups. Each User Selection Panel consisted of 4 to 8 independent members from the experimental hydraulic research community, and a minority of dependent members coming from one of the HYDRALAB Participants. Representatives of the facility providers were present at each User Selection Panel meeting with an advisory role only.

For the acceptance of a proposal, a majority agreement of the USP-members was required in addition to the confirmation of the relevant facility manager that the research was feasible in their specific installation. Sometimes the possibility of moving a project to another facility within HYDRALAB was discussed by the User Selection Panel, where this may have enabled better utilisation of resources.



UPC, Barcelona

Aalto University, Helsinki



CNRS, Toulouse

In total we provided access to 33 research groups. A complete overview of the projects and their titles is given in the table below. For further details on these projects we refer to our website. There we present a project summary report, including a description of the facilty, a data management report and the proceedings from our Closing Event, for each of the projects. Please, go to http://www.hydralab.eu/hydralab_research.asp. An overview of the projects and a reference to the proceedings paper is given in the table below. A complete overview of publications following from the projects is provided in the EC portal.

Acronym	Paper Title	Authors
HyIV-Aalto-01	ICE MODEL TEST OF AN ICEBREAKING TANKER WITH FIXED DRIFT ANGLES IN LEVEL ICE	Zhou Z.L.; Riska R.K.; von Bock und Polach V.B.U.P.R.; Moan M.T.; Su S.B.;
HyIV-Aalto-02	FINDINGS AND LESSONS LEARNED FROM IMPLEMENTING ICE-STRUCTURE IMPACT TESTS IN WATER AND IN AIR	Kim E.; Storheim M.; Amdahl J.; Løset S.
HyIV-CIEM-01	MEASUREMENTS OF SAND TRANSPORT AND ITS UNDERLYING PROCESSES UNDER LARGE-SCALE BREAKING WAVES (SANDT-PRO)	Ribberink J.S.; Van der A D.; Van der Zanden J.; O'Donoghue T.; Hurther D.; Cáceres I.; Thorne P.D.
HyIV-CIEM-02	SEDIMENT TRANSPORT AND BEACH PROFILE EVOLUTION INDUCED BY BICHROMATIC WAVES WITH DIFFERENT GROUPING PERIODS	Alsina J.M.; van der Zanden J.; Ribberink J.S.; Buijsrogge R.H.; Baldock T.E.; Brocchini M.; Peña E.; Sanchez-Tembleque F.; Caceres I.
HyIV-CIEM-03	FORCES ON (FLOOD) WALLS AND BUILDINGS BY WAVE OVERTOPPING	Bellotti, G.
HyIV-CIEM-05	SUBMERGED FLEXIBLE CIRCULAR POROUS STRUCTURES IN CURRENT AND WAVES	Klebert, P.
HyIV-CNRS-Carr	EXPERIMENTAL STUDY OF INTERNAL MIXING AND NEAR-BED DYNAMICS INDUCED BY RESTRICTED STRATIFIED EXCHANGE FLOWS	Laanearu J.; Carr M.; Cuthbertson A.; Sommeria J.; Berntsen J.; Lilover M.J.; Thiem Ø..; Viboud S.
HyIV-CNRS-Nycander	INVESTIGATION OF INTERNAL TIDES EXCITED BY MULTIPLE RIDGES	Nycander J.; Falahat S.; Paci A.; Bordois L.; Auclair F.
HyIV-CNRS-Steeneveld	EXPLORING THE ROLE OF WAVE DRAG IN THE STABLE STRATIFIED OCEANIC AND ATMOSPHERIC BOTTOM BOUNDARY LAYER IN THE CNRS-TOULOUSE (CNRM-GAME) LARGE STRATIFIED WATER FLUME	Steeneveld G.J.; Kleczek M.A.; Paci A.; Calmer R.; Belleudy A.; Canonici J.C.; Murguet F.; Valette V.
HyIV-CNRS-Stiperski	INFLUENCE OF SECONDARY OROGRAPHY ON BOUNDARY LAYER SEPARATION AND ROTORS	Stiperski I.; Goger B.; Serafin S.; Grubišić V.
HyIV-Deltares-08	LARGE-SCALE BARRIER DYNAMICS EXPERIMENT II (BARDEX II) – EXPERIMENTAL DESIGN AND SOME PRELIMINARY RESULTS	Masselink G.; Castelle B.; Conley D.; Matias A.; Puleo J.; Ruessink G.; Ruju A.; Turner
HyIV-Deltares-09	GLOBEX: WAVE DYNAMICS ON A SHALLOW SLOPING BEACH	Michallet H.; Ruessink B.G.; Rocha M.V.L.; de Bakker A.; van der A D.; Ruju A.; Silva P.A.; Sénéchal N.; Marieu V.; Tissier M.; Almar R.; Abreu T.; Birrien F. ; Vignal L.; E.; Mouazé D.
HyIV-DHI-01	PHYSICAL MODEL EXPERIMENTS ON FLOATING OFF-SHORE WIND TURBINES	Tomasicchio G.R.; D'Alessandro F.; Musci E. ; Fonseca N.; Mavrakos S.A.; Kirkegaard J.; Katsaounis G.M.; Penchev V.; Schüttrumpf H.; Wolbring J.; Armenio E.
HyIV-DHI-04	EXPERIMENTAL STUDY OF FORCES ON A SUBMARINE OUTFALL: INFLUENCE OF INCIDENT WAVE DIRECTION OF STABILIZING CONCRETE WEIGHTS AND PIPE DISTANCE FROM THE BOTTOM	Neves M.G.; Mendonça A.; Didier E.; Reis M.T.; Inverno J.; Figueira P.; Afonso M.C.; Vílchez M.; Clavero M.; Ortega-Sánchez M.; Losada M.
HyIV-DHI-05	WAVE RUN-UP AND WAVE OVERTOPPING UNDER VERY OBLIQUE WAVE ATTACK (CORNERDIKE-PROJECT)	Bornschein A.; Pohl R.; Wolf V.; Schüttrumpf H.; Scheres B.; Troch P.; Riha J.; van der Meer J.; Spano M.
HyIV-DHI-08	PHYSICAL MODELLING OF WAVE ENERGY CONVERTER ARRAYS IN A LARGE-SCALE WAVE BASIN: THE WECwakes PROJECT	Stratigaki V.S.; Troch P.T.

Acronym	Paper Title	Authors
HyIV-HSVA-01	USING THE ARCTIC ENVIRONMENT TEST BASIN TO STUDY THE DYNAMICS OF DISSOLVED ORGANIC MATTER IN SEA ICE	Thomas D.N.; Zhou J.; H.; Tison J.-L.; DeLille B.; Jørgensen L.; Luhtanen A.-M.; Kattner G.; Stedmon C.A.; Autio R.; Kuosa H.; Dieckmann G.S.; Kennedy H.; Evers K.-U.
HyIV-HSVA-02	DECIPHERING ICE INDUCED VIBRATIONS – DIIV	Määttänen M.P.; Nord T.S.; Hendrikse H.
HyIV-HSVA-03	RUBBLE ICE TRANSPORT ON ARCTIC OFFSHORE STRUCTURES (RITAS), SCALE MODEL INVESTIGATION OF LEVEL ICE ACTION	Serre N.S.; Høyland K.H.; Lu W.L.; Bonnemaire B.B.; Evers K-U.E.
HyIV-HSVA-03	ICE LOAD MEASUREMENT BY TACTILE SENSOR IN MODEL SCALE TEST IN RELATION TO RUBBLE ICE TRANSPORT ON ARCTIC OFFSHORE STRUCTURES (RITAS)	Lu W.; Hoyland K.V.; Serre N.; Evers K-U.E.
HyIV-HSVA-04	EXPERIMENTAL PROGRAM FOR ICE LOADS ON AN ARCTIC JACK-UP STRUCTURE	Cammaert A.B.; Hoving J.S.; Vermeulen R.
HyIV-HSVA-06	EXPERIMENTS ON THE DETECTION AND MOVEMENT OF OIL SPILLED UNDER SEA ICE	Wilkinson J.; Maksym T.; Bassett C.; Lavery A.; Singh H.; Chayes D.; Elosegui P.; Wadhams P.; Evers K-U.E.; Jochmann P.
HyIV-Hull-01	THE MORPHODYNAMIC IMPACTS OF VEGETATION AND LARGE WOOD IN FLUVIAL SYSTEMS	Mao, L
HyIV-Hull-06	WAVE RIPPLES IN MIXTURES OF COHESIVE CLAY AND COHESIONLESS SAND: PRELIMINARY RESULTS	Baas J.H.; Westlake A.; Eggenhuisen J.; Amoudry L.; Cartigny M.; Coultish N.; McLelland S.; Mouazé D.; Murphy B.; Parsons D.; Rosewell K.; Ruessink G.; Schrijvershof R.; Wu X.; Ye L.
HyIV-Hull-09	EXPLORING THE RECIPROCAL ROLE OF HYDRODYNAMIC FORCING AND MICROBIAL COLONIZATION TO INDUCE BED SEDIMENT PATCHINESS IN BIOSTABILIZATION	Gerbersdorf S.; Cuthbertson A.; Righetti M.; Haynes H.; Parsons D.; McLelland S.; Schmidt H.; Thom M.; Ibikunle O.
HyIV-Marintek-01	MODULATIONAL INSTABILITY AND EXTREME WAVES IN WATER OF FINITE DEPTH	Toffoli A.T.; Fernandez L.F.; Monbaliu J.M.; Benoit M.B.; Gagnaire-Renou E.G.R.; Cavaleri L.C.; Proment D.P.; Pakozdi C.P.; Stansberg C.T.S; Waseda T.W.; Onorato M.O.
HyIV-Marintek-02	EXPERIMENTAL INVESTIGATION OF NONLINEAR WAVE INTERACTIONS, WAVE TURBULENCE AND ROGUE WAVES	Luxmoore J.F.; Ilic S.; McClintock P.V.E.; Efimov V.; Stefanovska A.; Fortes J.; Santos J.; Capitao R.; Kolmakov G.; Pakozdi C.; Stansberg C.T.; Nygaard I.; Mori N.
HyIV-Marintek-05	LARGE SCALE EXPERIMENTS ON THE INTERACTION OF A CAISSON BREAKWATER WITH BREAKING WAVES	Stagonas D.
HyIV-NTNU-01	CORRELATION BETWEEN SILICATE UPTAKE AND SINKING FLUXES OF BIOGENIC SILICA AND PARTICULATE ORGANIC CARBON IN A NON-TURBULENT OUTDOOR MESOCOSM EXPERIMENT	De La Rocha C.L.; Gallinari M.; Moriceau B.; Boutorh J.; Coffineau N.; Donval A.; Evertsen A.-J. O.; Giering S.L.C.; Iversen M.H.; Jacob J.; Koski M.; Lampitt R.; LeGoff M.; Masson A.
TA FZK-02	LARGE SCALE TESTS ON A GENERALISED OSCILLATING WATER COLUMN WAVE ENERGY CONVERTER	Allsop W.; Bruce T.; Alderson J.; Ferrante V.; Russo V.; Vicinanza D.
TA FZK-03	LONG WAVES CLIMBING THE SLOPES OF DIFFERENT ROUGHNESS: RUN-UP HEIGHT AND THE LOAD ON INDIVIDUAL ROUGHNESS ELEMENTS	Denissenko P.; Pearson J.; Rodin A.; Didenkulova I.

Acronym	Paper Title	Authors
TA FZK-05	WAVE SLAMMING FORCES ON TRUSS STRUCTURES IN SHALLOW WATER	Arntsen Ø.A.; Gudmestad O.T.;
TA FZK-06	LARGE SCALE MEASUREMENTS OF WAVE LOADS AND MAPPING OF IMPACT PRESSURE DISTRIBUTION AT THE UNDERSIDE OF WAVE RECURVES	Stagonas D.;
TA FZK-07	WAVE DISSIPATION AND TRANSFORMATION OVER COASTAL VEGETATION UNDER EXTREME HYDRODYNAMIC LOADING	Moeller I.; Rupprecht F.; M.; Spencer T.; Paul M.; van Wesenbeeck B.K.; Wolters G.; Jensen K.; Bouma T.J.; Miranda-Lange M.; Schimmels S.

3.3. Joint Research Activities within HYDRALAB IV

3.3.1. Protocols and Instrumentation for Combined hydraulic and Ecological modelS (PISCES)

The aim of PISCES is to develop innovative new technologies, experimental protocols and improved methodologies for incorporating organisms, both plants and animals, into physical hydraulic models. This will enable hydraulic research infrastructures to be used to predict the response of benthic aquatic and marine organisms to changing flows and the influence of organisms on flow and sediment erosion, both of which are poorly understood. PISCES brings together an interdisciplinary team of ecologists, sedimentologists and engineers to bridge the gap between field observations and physical models of plants and animals. Ecohydraulics experts are drawn from the large laboratories offering access in this integrated infrastructure project and other partners with important ecological experience.

Improving Ecohydraulic Modelling and Experimentation

Ecohydraulic modelling and experimentation are essential if we are to improve our understanding and management of the environment since organisms can modify their environment and they and their behaviour can be modified by the environment around them. The PISCES project in HYDRALAB IV aims to improve the physical modelling of plants and animals through the development and improvement of measurement technologies and experimental methodologies and protocols. There is considerable potential for physical models of ecohydraulics to bridge the gaps between field observations and theoretical, stochastic and numerical modelling of aquatic ecology. This integrated approach to understanding ecohydraulics has the potential to improve our ability to predict changes to aquatic ecology resulting from present and future climate change. However, for such research to be meaningful and produce the greatest impact, care has to be taken to ensure that both the ecology and hydraulics are properly represented. The complex interactions between aquatic organisms and physico-chemical processes within ecohydraulics requires an interdisciplinary approach to research; therefore the PISCES research team included ecologists, geomorphologists, sedimentologists and hydraulic engineers to bring together knowledge and expertise from different disciplines.

Although it is challenging to incorporate plants and animals into physical models, it is an essential requirement to improve our representation of natural systems in experiments and to understand how those organisms can modify, or can be modified by, sediment transport dynamics and/or flow patterns and structures. The challenges include maintaining organism health and ensuring realistic behaviour of organisms during experiments as well as working with the complexity of the interactions among organisms, sediments and flow. To help the researchers meet these challenges, the PISCES team has produced an IAHR Design Manual entitled ‘Users Guide to Ecohydraulic Modelling and Experimentation’ to disseminate good practice. The guide includes practical information on experimental methods and procedures, including animal and plant husbandry, the design and use of surrogates and flow measurements around organisms. It also covers specific experimentation with different types of organisms including biofilms, plants and macrozoobenthos. The design manual concludes with a decision-making framework to assist researchers in their experimental design.

The PISCES project has also undertaken research to evaluate the limitations of using physical models to represent organisms in hydraulic experiments. Two of the key objectives from this research were to understand: (i) the complexity required to adequately reproduce the hydrodynamics of the natural system; and (ii) which aspects of living organisms must be replicated in surrogates to reproduce the hydrodynamics of the natural system.

These questions were investigated in a series of experiments that were conducted in both the field and the laboratory. Field experiments were undertaken at the Hopavågen tidal inlet, NTNU, (Fig. 3.1). Observations included bathymetry, bed sediment size distribution, macroalgal species distribution, macroalgal geometric properties (e.g. stipe length and diameter, blade length, width and depth, numbers of blades, and blade projected area), and mechanical properties of macroalgae (e.g. Young's bending modulus, flexural rigidity, buoyancy). Laboratory experiments were undertaken at the Total Environment Simulator at the University of Hull (Fig. 3.2), with replication of the physical conditions found at the field site including mean flow depth, flow rate, bed sediment characteristics, and macroalgal size and position. For both the field and flume cases, measurements of the flow field were taken for four different cases:

A. Full complexity of macroalgae as found in the 'undisturbed' natural environment;
B. Reduced complexity of macroalgae in which the macroalgae community was simplified to a single species (*Laminaria digitata*);
C. Reduction of the number of macroalgae from 19 individuals to a single macroalga; and
D. "Cleared" condition with no macroalgae.

Case A was repeated in a second series of flume experiments and five additional tests were also undertaken in the flume experiments to investigate the effect of macroalgal arrangements with experiment B being repeated using the same density of colonization, but with different geometric arrangements of macroalgae.

E. Full complexity of macroalgae in which the algal community surveyed in May 2012 was replicated, but with surrogate *L. digitata*;
F. Reduced complexity of macroalgae in which the algal community was simplified to 19 surrogate *L. digitata* thalli;
G. Rearrangement of the 19 surrogate *L. digitata* from their natural distribution into an inline array;
H. Rearrangement of the 19 surrogate *L. digitata* from their natural distribution into a staggered array; and
I. Reduction of the number of surrogates from 19 individuals to two closely-spaced *L. digitata* surrogates.

Figure 3.1. *The Hopavågen tidal inlet, NTNU.*

Figure 3.2 *(a) Experimental set-up in the Total Environment Simulator, University of Hull with flags showing the locations of macroalgae to replicate field distribution. (b) View looking downstream in flume during experiments.*

In all cases, flow measurements in the field and laboratory were repeated with an identical methodology. Detailed, three-dimensional flow measurements were made using the Nortek Vectrino Profiler ADV sampling for 240 s at 100 Hz and with a 0.25 m lateral and longitudinal spacing within a 2 × 2 m grid. New techniques were developed to process ADV data to reduce spikes and noise in these measurements as part of the data analysis programme. This velocity post-processing was implemented within MATLAB, and included included 2-D phase unwrapping or dealiasing, phase space threshold filtering and correlation threshold filtering. All steps were implemented within fully vectorized MATLAB code. Figure 3.3 shows an example of the flow measurements.

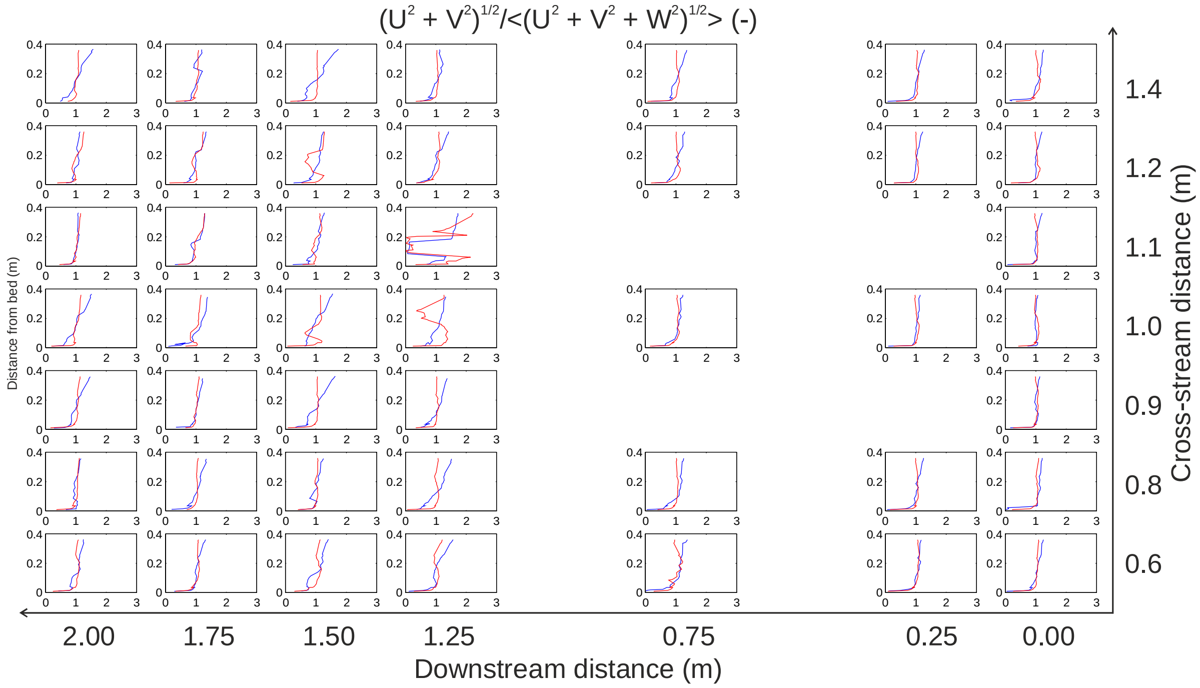


Figure 3.3. *Comparison of velocity magnitude for flume (red lines) and field (blue lines). At 0.9 and 1.1m cross-stream, locations without profiles are directly above the macroalgae being studied.*

As expected, in all the tested cases the flow field was dominated by the along-stream component. Mean flow patterns and Reynolds stresses suggest intermediate relative submergence flows with isolated roughness for all the vegetated cases. Results showed that the agreement between the different mean velocity and stress profiles is in general relatively good away from algae but there are significant differences closer to the algae. Turbulence intensities and shear stresses were found to be of the same order of magnitude and the vertical distribution of these quantities is, for the most part, similar. Low turbulent kinetic energy levels (TKE) were observed at the bed, indicating the absence of sediment transport under the observed conditions. The computed spatially-averaged velocities and form-induced stresses identify clear differences between undisturbed, surrogate and cleared cases and the comparison of flow fields around real and surrogate algae suggests that results are sensitive to heterogeneities of algal properties, orientation and position. The surrogate plants behaved more like the live alga in the field than in the flume. Despite variations in the turbulent properties, the flume reproduced most of the mean flow characteristics observed in the field. However, live plants in the flume behaved differently to those in the field and streamlined to such an extent that they added no or little roughness.

Detailed experiments were also undertaken to improve our understanding of how to use surrogates in experiments and how closely their behaviour replicates natural organisms. During the project, the morphological and biomechanical properties were measured for two different populations of Laminaria digitata, growing in flow- and wave-dominated environments. Measured macroalgal properties derived from the population sampled at the flow-dominated field site in Sletvik were used to develop three possible surrogates. We then compared hydrodynamic behaviour (i.e., mean and turbulent flow fields, together with applied drag forces and observations of reconfiguration behaviour) in a flume study and also investigated the effect of surrogate shape. An image analysis method was developed to enable the development of a representative plant shape based on the scaling of natural specimens. The hydrodynamic behaviour (i.e., mean and turbulent flow fields, together with applied drag forces and observations of reconfiguration behaviour) of these test surrogates were compared to real macroalgae during experimental tests at FZK, Hannover (Fig. 3.4). From these experiments, an “optimum” surrogate was selected for further testing in field and flume experiments where 19 live *Laminaria digitata* thalli (Case B, above) were replaced with 19 of the optimised surrogates. The developed surrogates were also used in a laboratory study to investigate the effect of the spatial arrangement on hydrodynamics at both small and medium scales (cases F, G, H and I).

(a) (b)

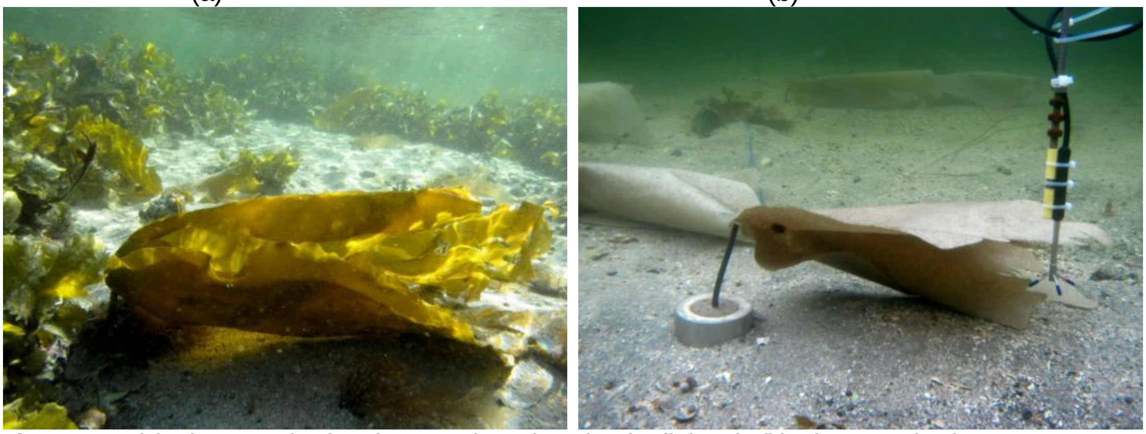


Figure 3.4. *(a) Photograph of real macroalgae (Laminaria digitata). (b) Photograph of surrogate macroalgae at the field site (Vectrino profiler measuring flow velocities shown to right of image).*

The results from all the experiments demonstrated that surrogate development is crucial for the accurate description of the hydrodynamic processes involved in the natural conditions as these processes are highly sensitive on a wider scale to the (mechanical) vegetation-flow interactions. Because the mechanical properties of living organisms are variable and highly dependent upon environmental factors during their different growing phases, artificial surrogates (rather than "living surrogates") appear to be more appropriate to reproduce the hydrodynamics of a natural vegetated flow in the flume, avoiding phenotypic plasticity.

In addition, we developed and tested new PIV measurement techniques that could be used for large-scale applications in both the field and laboratory so that such measurements can be compared between different environments. PIV techniques have many advantages over other flow measurement techniques, in particular their capacity for capturing spatially-distributed measurements over a relatively large area. However, the application of PIV to measure near-bed velocities in large-scale facilities and the field is often problematic and uncommon - unlike acoustic techniques which are often the standard measurement technique. The problems arise from the combined effect of large measurement volumes and unavoidable turbidity which pose critical limitations on optical access. These problems can be more easily circumvented in small-scale laboratory studies where PIV is commonly used, but further developments in the technique are required before they can be applied to large-scale facilities and the field. Several new methods and prototypes were developed and explored.

First, to circumvent absorption due to turbidity over long distances, a steeply inclined stereoscopic system was proposed which can be used resolve the three velocity components and allows measurement of the in-plane vectors from non-orthogonal camera views (i.e., one steeply inclined camera cannot measure the standard in-plane components). The steep inclination not only reduces the optical path, but also requires less laser power and anisotropic scattering improves the image quality. However, other factors may reduce the benefits of this configuration, so a systematic study was undertaken to evaluate the optimum angle of the cameras and to help give guidance in the design of such systems. Prototype tests were conducted in the laboratory at CNRS/IMFT to evaluate the combined effect of turbidity and stereoscopic viewing angles and a model has been developed to predict the damping of light intensity along its path from the source to the camera sensor. When applied to the measurements in the laboratory, the expected anisotropic scattering by turbidity and PIV particles was evident. The results suggest an optimum camera inclination angle of about 25° and enable measurement near a vegetation canopy in highly turbid conditions.

In parallel to the stereoscopic system described above, a simplified, portable and submersible planar (2D-2C) PIV system was developed, built and deployed in the second field study of the PISCES project at Sletvik in 2013. Those tests demonstrated that the system was capable of measuring in-situ and provided valuable design information. Also, specific processing algorithms were developed to account for the non-stationary and less than optimal measurement conditions. An improved version of the submersible 2D-2C PIV system was developed and deployed in the second laboratory study in Hull in 2014 to complement the Nortek Vectrino Profiler profiling ADV turbulence measurements. Optical conditions were similar to the field conditions in Sletvik, with levels of turbidity even exceeding normal in-situ levels and the system was capable of measuring under those unfavourable conditions.

Following two highly successful workshops, attended by research from within Europe and beyond, the PISCES team have also considered the future needs of experimental ecohydraulics research. Together we identified five key themes that should be addressed if we are to improve and progress our understanding of ecohydraulic interactions:

1. Abiotic Factors: the detection of, reaction to, and modification of a number of environmental factors that may be dependent on or independent of the flow field by subaqueous plants and animals;
2. Adaptation: the adjustments made to or by organisms at multiple spatio-temporal scales in response to hydrodynamic forcing, abiotic stimuli or both;
3. Complexity and Feedback: complex interactions between organisms and the hydrodynamic environment and the role of feedback, whether positive or negative, in amplifying or moderating organism or environmental response, respectively;
4. Variation: differences between (parts of) individual organisms, or groups of organisms of any species caused either by genetic differences or by the influence of environmental factors; and
5. Scale and Scaling: is it possible to scale down biological (and biomechanical) processes operating at the large scale, are the variables measured at the large scale pertinent at the small scale and does technology permit us to measure the same variable across scales?

The PISCES project has brought together researchers from a wide range of disciplines to improve experimental research in ecohydraulics through better sharing of existing knowledge and also by developing improved experimental protocols. Results from an extensive series of experiments comparing flow fields around real and surrogate plants in the field and in the laboratory has shown the importance of heterogeneities in plant properties, orientation and position. This will help improve future experimental design so that results can be more widely applicable. The project has also developed robust methodologies for surrogate design and for flow measurements around organisms. Continued interdisciplinary discussion and collaboration are essential if hydraulic experiments are to make a significant contribution to future ecohydraulic research and environmental management under a changing climate.

Below is a list of some key publications from the PISCES research:

- Thomas, R.E., McLelland, S.J. and Frostick, L.E., 2013. The impact of macroalgae on mean and turbulent flow fields. *In:* Proceedings of 35th IAHR World Congress, Chengdu, 8-13 September, 2013. Tsinghua University Press: Beijing, China.
- Frostick, L.E., Thomas, R.E., Johnson, M.F., Rice, S.P. and McLelland, S.J. (eds.), 2014. *Users Guide to Ecohydraulic Experimentation*. CRC Press/Balkema: Leiden.
- Thomas, R.E., Johnson, M.F., Frostick, L.E., Dijkstra, J.T., McLelland, S.J., Paul, M., Penning, W.E., Rice, S.P., et al., 2014. Physical modelling of water, fauna and flora:

Knowledge gaps, avenues for future research and infrastructural needs. *Journal of Hydraulic Research* 52(3), 311-325.

- Paul, M. and Henry, P.-Y.T., 2014. Evaluation of the use of surrogate Laminaria digitata in eco-hydraulic laboratory experiments. *Journal of Hydrodynamics, Ser. B* 26(3), 374–383.
- Henry, P.-Y.T., 2014. Bending properties of a macroalga: Adaptation of Peirce's cantilever test for in situ measurements of Laminaria digitata (Laminariaceae). *American Journal of Botany* 101(6), 1050-1055.
- Paul, M., Henry, P.-Y.T. and Thomas, R.E., 2014. Geometrical and mechanical properties of four species of northern European brown macroalgae. *Coastal Engineering* 84, 73-80. doi: 10.1016/j.coastaleng.2013.11.007.
- Thomas, R.E. and McLelland, S.J., In revision. The impact of macroalgae on mean and turbulent flow fields. *Journal of Hydrodynamics, Ser. B*.

3.3.2. Water-Interface-Sediment Experiments (WISE)

The aim of WISE was to observe with unprecedented accuracy the simultaneous and collocated profiles, of water and sediment flow and the associated bed-dynamics and particle features. The potential to have a detailed picture of the flow field both in the horizontal and in the vertical direction is crucial for the correct understanding / quantification of fluid-sediment interactions, (e.g. generation and shedding of vortices). This JRA has, thus, taken to a new level the capabilities of sedimentary bed hydraulic facilities by bringing the measurements of water velocity, sediment velocity and concentration, shear stresses (at the boundary), bed-forms and erosion/accretion rates to a new quantitative level. The aim, based on the advances achieved under HYDRALAB III, was to (i); take the significant step of moving from classical one-dimensional vertical profiles, 1DV, to quasi-3D resolution, (ii) extend opto-acoustic measurement capabilities currently limited to suspended sediments (developed under HYDRALAB III), to the highly concentrated nearbed layer usually identified as the bedload or sheet flow layer of primary importance for morphodynamics.

Introduction

Sediment transport at land-water boundaries, such as the sea bed or the swash zone, has not yet been adequately solved. This applies to numerical models and to field or lab observations. And yet these boundary fluxes contribute a non negligible percentage of the total sediment transport and cannot be neglected whenever accurate and robust predictions are required. One of the main reasons for this limitation in knowledge is the lack of high resolution observations, particularly under sharp gradients such as those found in boundary areas.

Within the WISE-HYDRALAB (Water Interface Sediment Experiment) project we have obtained simultaneous and collocated profiles of water and sediment fluxes and the resulting bed dynamics with an unprecedented accuracy. The characterization of the flow field in the horizontal and vertical dimensions has allowed a quantitative understanding and even quantification of sediment transport and entrainment, including vortex shedding and the bed boundary level. This leads to quantitative estimates of bed and suspended load, even in the near bed or sheet flow layer.

To perform such an analysis we have carried out a series of identical large scale tests in the wave flumes of Hannover and Barcelona, using a number of vertical profiles over a horizontal transect. This has provided quasi 3D resolution under controlled laboratory conditions, comparable to the level of information usually provided by numerical models, leading to an upgrade of mobile bed research facilities with information on water-sediment processes above, within and across the flow-bed interface.

Development

Most available instrumentation does not allow recovering the sharp variation of sediment fluxes near the bed boundary nor the pulsing transport in the alternatively wet and dry swash zone. The novel instruments developed and tested in WISE (figure 3.5a & b) as part of the HYDRALAB research effort have allowed, for the first time, a resolution comparable to that of advanced numerical formulations, whose development had slowed in the last years due to the limitations of observational equipment.

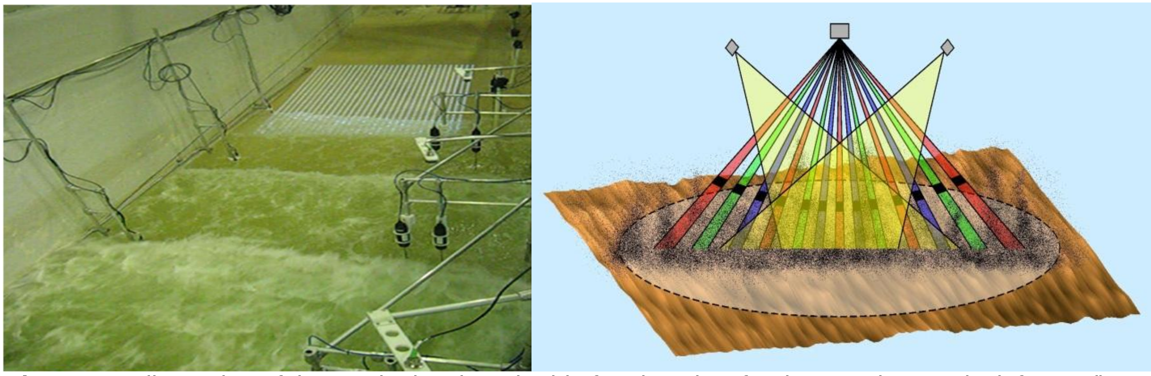


Figure 3.5*: Illustration of the newly developed grid of optic points for the swash zone (a, left panel) and the bed form and suspended load acoustic imager for the nearshore zone (b, right panel)*

The novel optic and acoustic instrumentation, plus the experimental protocols to recover reliable and high resolution data, have provided a breakthrough (figure 3.6) that allows measuring directly sheet flow and suspended loads, sediment properties and even the elusive bed level. This has resulted in a unique data set at two complementary large scales supplemented by numerical modelling results.

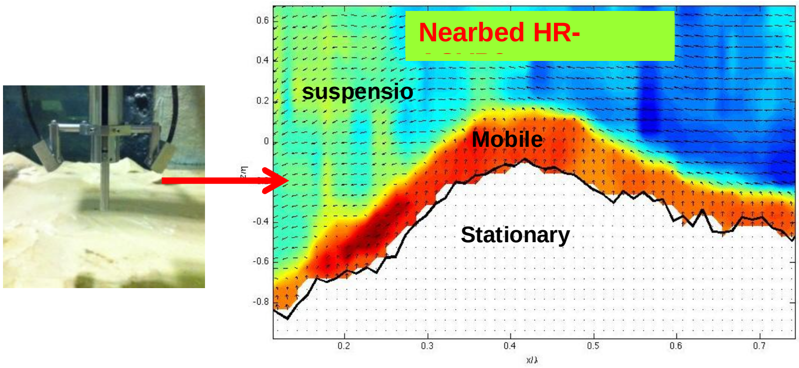


Figure 3.6*: Sample image of the near bed sheet flow layer and the suspended sediment patterns recovered with 1.5mm vertical resolution and sampling at 50Hz.*

Such a combination of hydraulic and numerical modelling has enabled experiments to be optimized prior to their execution with guidance and support for the equipment deployment. The combination of opto-acoustic techniques includes an enhanced stereoscopic technique for beach topography, including water front tracking in the swash zone. It also features a suspended sediment imager combined with high resolution acoustic concentration and velocity profilers that allow recovering the dynamics of bed levels and forms, as well as some of the sediment characteristics. The resulting data set provides information on bed plus suspended loads, together with bed forms and their evolution. The experimental work has also dealt with novel techniques such as the sensing of ferrofluid deformation, with an inductive read out strategy to recover near bed velocities and bed shear stresses.

Results

The WISE results include a benchmark data set with high resolution hydro/morphodynamic observations for erosive and accretive wave conditions. The experiments from the Hannover and Barcelona wave flumes have been designed to reproduce as closely as possible both drivers and responses, allowing an assessment of the limits for facility and instrument performance, as well as providing valuable insight into the controlling processes as a function of scale and energy levels (figure 3.7).

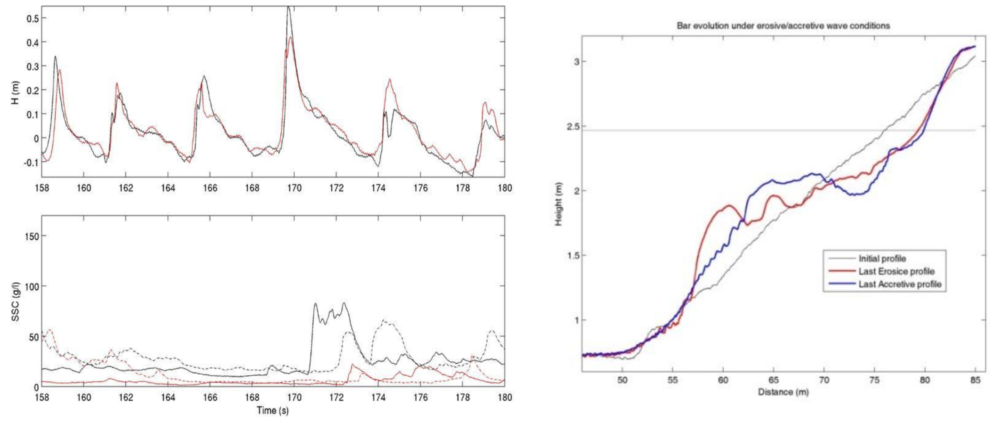


Figure 3.7: Sample result of the intra-wave suspended sediment concentration peaks (left panel, below) as a function of the wave height (left panel above). The aggregated result in terms of profile evolution for accretive wave sequences appears in the right hand panel, showing the limited shoreline recovery.

The numerical modelling has dealt with detailed sediment transport formulations to calculate sediment fluxes as a function of boundary layer streaming and sediment properties. It has also included more integrated hydro-morphodynamic models to predict beach evolution for the simulated hydrodynamics. The results have allowed validating 3D models (including advanced aspects such as sediment entrainment and wave current interaction effects) and improving the efficiency of hydraulic models.

Conclusions

The experimental work performed is expected to contribute to an improved performance of hydraulic facilities, particularly for mobile bed experiments in areas that had not been considered before. This includes the swash zone and the near bed sheet flow. The obtained benchmark set of data will be also useful for process research and numerical modellers, covering aspects such as front tracking techniques, alternatively wet and dry zones and the effects of scaling as a function of dominant processes. More information can be found in a Coastal Engineering collection of papers presenting the advances available at the time of writing (2011, Coastal Engineering Vol. 16, 7).

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- Revil-Baudard T., Chauchat J., Hurther D. and Barthelemy E. (2014a). Experimental study of sheet flow regime of sediment transport in a laboratory flume. Proceedings of River Flows conference, Lausanne, Switzerland.
- Revil-Baudard T., Chauchat J., Hurther D. and Barraud P.A. (2014b). Investigation of sheet-flow processes based on acoustic high-resolution velocity and concentration measurements. Under review at Journal of Fluid Mechanics.
- Ribberink, J.S., van der A, D., van der Zanden, J., O'Donoghue, T, Hurther, D., Cáceres, I., Thorne, P.D. (2014) SandT-Pro: Sediment Transport Measurements under Irregular and Breaking Waves. Proceedings of Intern. Conference on Coastal Engineering.

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- Veen, R. (2013). The implementation and testing of the SANTOSS sand transport model in Delft3D. MSc thesis (Report 1204017 -OOO-ZKS-OOO), Deltares & University of Twente, The Netherlands.
- Vousdoukas, M.I., de la Torre, M., Schimmels, S., Fernandez, H., Kirupakaramoorthy, T. (2014). Controls, characteristics and parameterization of equilibrium profiles based on large-scale physical experiments. Submitted
- Kranenburg, W.M., Tian-Jian Hsu and J.S. Ribberink (2014). Two-phase modeling of sheet-flow beneath waves and its dependence on grain size and streaming, Advances in Water Resources 72, 57 -70, doi.org/10.1016/j.advwatres.2014.05.008
- Kranenburg, W.M., Ribberink, J.S., Schretlen, J.L.M. & Uittenbogaard, R.E. (2013). Sand transport beneath waves: the role of progressive wave streaming and other free surface effects. Journal of geophysical research. Earth surface, 118(1), 1-18.

3.3.3. Hydraulic Response of Structures (HyReS)

HyReS addressed both structures and ice. The response of coastal and offshore structures to wave loading is a significant issue in their design. At high latitudes, dynamic ice-structure interaction also causes high loads to act on fixed or floating moored offshore structures and harbour facilities. This JRA brought together leading experts in Europe to improve the quality of the service provided by hydraulic infrastructures for the testing of structures by improving techniques on wave generation and measurements on the interaction of water and structures or floating ice.

Laboratory measurements of wave and / or ice loads on coastal and maritime structures can play an important role in their final design. The number and range of man-made structures that are subject to these loads is increasing – from offshore oil and gas facilities, through ships and renewable energy devices, to breakwaters, quay walls, bridges and tunnels. However, the capabilities of numerical models are increasing and they have displaced physical models in certain areas, so physical modelling cannot afford to stand still. In order for hydraulic laboratories to remain competitive, we must develop our equipment and techniques to improve the services we offer.

A Foresight study conducted as part of HYDRALAB-IV (Sutherland and Evers, 2013) reviewed techniques for making physical model measurements of wave and ice loads on marine structures, summarised their weaknesses and outlined the advances in modelling techniques that the authors expect to see. Meanwhile, the members of the joint research activity *Hydraulic Response of Structures* (HyReS) have been developing techniques in three main areas:

1. Wave generation – so that a selected time series of waves can be generated;
2. Optimizing the wave sequences at the structure being tested; and
3. Improving techniques for modelling, measuring and interpreting the responses of structures to waves and to ice.

Some of the main developments made by HyReS partners between 2010 and 2014 are summarised below.

Wave generation

Wave generation using a phase-resolving numerical model

If we can generate nonlinear waves in shallow water, we can conduct tests at larger scales, minimising scale effects and improving accuracy, or we can run the same scale of test in a smaller facility. However, as waves enter shallow water, their shapes evolve from near sinusoidal into skewed (sharp wave crests separated by broad, flat troughs) then into asymmetrical forms (pitched-forward, sawtooth shapes with steep front faces). Hansen et al (2014) have been developing techniques to drive wave paddles using input from a phase-resolving Boussinesq numerical wave model, so that the waves are generated in shallow water with the required skewness and asymmetry.

The Boussinesq model reproduces wave shoaling and outputs wave flux and surface elevation at a point in shallow water where the wave paddle will be situated in the physical model. Horizontal velocity is determined from flux and the displacement of the water is determined from velocity. The paddle position time series is created by applying a paddle transfer function and is then used to drive the wave paddles in the physical model.

The theory was tested using 2D flume and 3D basin tests, where surface elevations from numerical and physical models were compared a few metres from the wave paddle position (Figure 3.8). The coupling method was shown to be a robust and reliable wave generation method, capable of reproducing advanced 3D effects over a wide range of wave parameters.

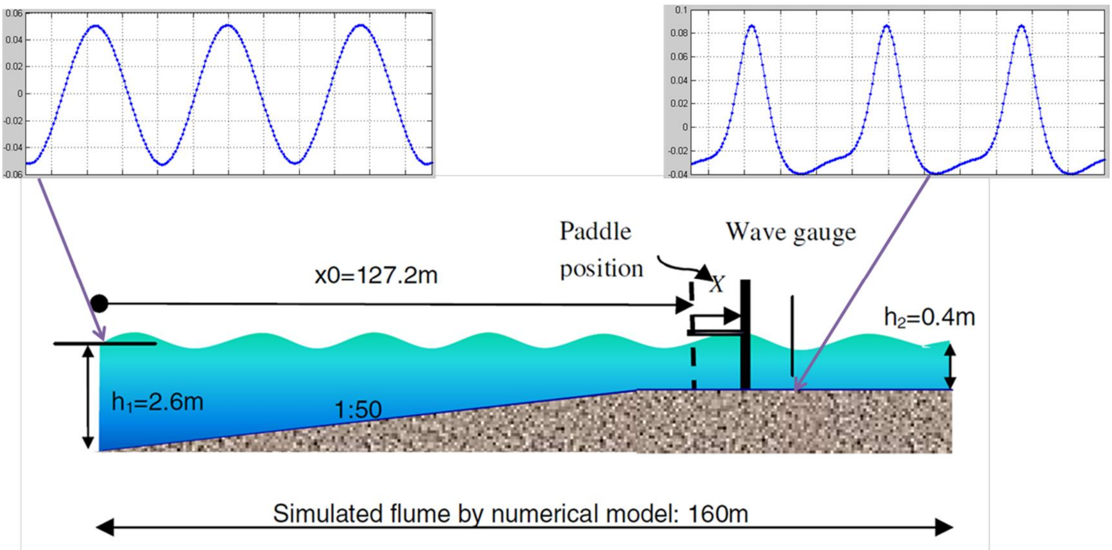

***Figure 3.8**. Numerical wave flume showing waves generated in deep water, passing information to a wave paddle and providing a shallow water time series to compare to the physical model (courtesy of DHI)*

Tsunami wave generation

Tsunami waves have caused significant destruction to coastlines during the last decade. The generation of tsunamis in the laboratory is particularly difficult as they have a very long period and require a very large stroke (peak to peak displacement of the wave paddle). In practice, most ‘tsunami’ waves generated in laboratories have actually been solitons: a representation of a single wave crest only. HR Wallingford has worked on improving a pneumatic tsunami generator using a OpenFoam CFD model of the test setup (Allsop et al, 2014). The new design includes a taller and shorter cross-section to reduce sloshing and help in the reproduction of steep leading edge waves. It also features a smoother inlet profile to reduce head losses. A revised tsunami generator was built and tested in a wave flume, where it reproduced N-waves and measured tsunami traces.

Propagation and optimisation of wave time series

Sampling schemes
In order to determine extreme loads, long physical model test series are often run to produce many independent extreme events, to which a statistical distribution can be fitted. Hofland et al (2014) has been investigating how to decrease the duration of repeated physical model tests, while still reproducing the same distribution of extreme values. In cases where it is the highest waves that cause the extreme response (for example when only those waves will hit a structure well above water level) it is easy to isolate these events. However, in cases such as wave overtopping of a structure in shallow water, many effects (such as shoaling, breaking and partial reflection) affect the results, so it is not easy to identify which waves will cause the greatest response.

Hofland et al (2014) have adopted a practical approach to these, more complex, test cases. They have developed a procedure for running a single, long duration, test, and using this test to identify the most extreme events. Shortened time series which include the wave groups with the largest events are then run for repeated tests, or those with small changes to the structure. The results are sensitive to the length of time signal around an extreme event that is used to construct the short time series and this varies with the travel time of short waves from the paddle to the structure and the degree of reflection from the structure. Some test with a deterministic *New Wave* extreme wave group led to overtopping volumes of the same order of magnitude as the long time series.

Focussed wave groups in shallow water
Extreme waves, such as the deterministic *New Wave* extreme wave group, have been generated in deep water wave flumes and basins for several years using different means of focussing wave groups. Where these techniques generally do not work well is in the presence of a varying bathymetry or a reflective structure.

Fernández et al (2014) have developed the Self Correcting Method (SCM) for the generation of focused waves or other deterministic wave sequences by means of a few iteration steps. The method has been developed, tested in a Numerical Wave Tank (NWT) and eventually validated in the Large Wave Flume or Großer Wellenkanal (GWK). In the SCM phase and amplitude correction steps are used to correct a second order wave profile, so that a focussed wave group can be reproduced at the desired location. The method was developed for flat seabeds then was extended to cases with variable water depths, wave reflection and the combination of both with very good results. The validity of the SCM to produce both non breaking and breaking focused waves over constant depth, variable water depth and with a reflecting structure was demonstrated in experiments in the GWK (Figure 3.9).

Figure 3.9 *Focussed wave generated using self-correcting method in shallow water in front of a truss structure (courtesy of LUH)*

Assessment of structural response

Active transducers

Physical models of moored floating structures are used extensively when looking at complex wave-structure interactions such as vessel downtime & mooring analysis. In order to correctly represent the motion of a vessel at berth, the nonlinear characteristics of mooring lines and fenders need to be correctly re-created at scale. It is common practice to represent the mooring lines or fenders using either cantilevers or coil springs with integrated strain gauges. However, when faced with modelling a highly nonlinear mooring line or fender response the use of multiple coil springs and cantilevers becomes increasingly impractical. In response to these limitations Sutherland et al (2014) have created a novel active mooring line transducer (AMLT) that uses servomotors to replicate the stiffness characteristics of the mooring line.

The heart of the AMLT system is a servomotor and a programmable logic controller, with a 1ms time base and low latency. A stable torque, which varies with the position of the servomotor, is generated, so the AMLT can be programmed to produce a non-linear force – displacement curve. This reproduces the non-linear characteristic of a vessel's mooring lines. The same technology could be applied to reproduce the nonlinear characteristics of render recover winches, constant tension winches, fenders, or dynamic loading.

Quadratic transfer functions

The second order interaction between waves leads to oscillating terms at double, sum and difference frequencies. In the presence of a moored floating body, the second order forces and moments may excite low frequency resonant motions when the difference frequencies become small and they can generate relatively high mooring line forces. The magnitude of the low frequency force generated by two component waves is related to those waves by a Quadratic Transfer Function (QTF). A QTF matrix, covering plausible ranges of incident wave frequencies can be built up from measurements of a large number of bi-chromatic sea states, although this is time consuming. Within HyReS MARINTEK, DHI & IFREMER have been developing numerical algorithms to extract the low frequency Quadratic Transfer Functions from random sea tests in wave tanks (Figure 3.10). 'Time-domain', 'cross-bi-spectral' and 'Direct Fourier Transform with Fourier Fit' analysis methods have been developed.

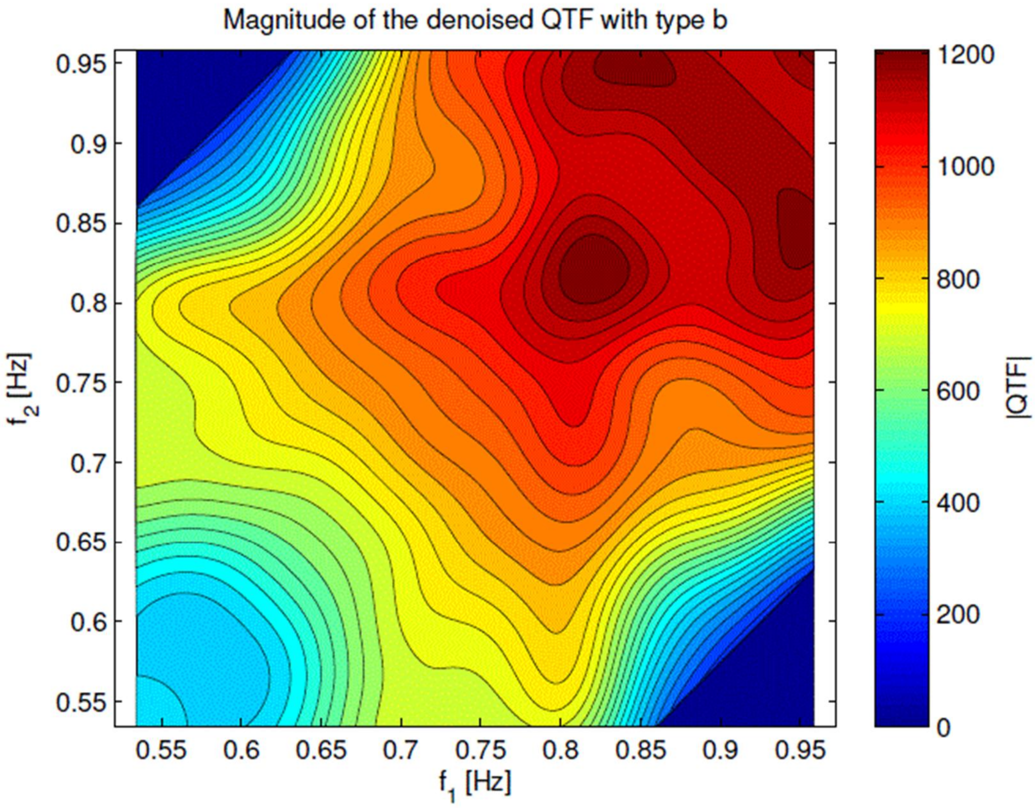

Figure 3.10 *Quadratic Transfer Function matrix (courtesy of MARINTEK)*

Tactile Sensors

Pressure distributions on structures during wave impacts are often measured using an array of pressure transducers. However the number of sensors is often limited. Within HyReS a number of institutions have been applying tactile (flexible, electronic, grid-based) sensors to a range of scenarios as an alternative to pressure gauges (Ramachandran et al, 2013, Marzeddu et al, 2014, Evers and Lu, 2014).

Tactile sensors are made from two flexible polyester sheets (about 0.1 mm thick) with silver conductive electrodes printed in columns on one sheet and in rows on the other. The intersection between a row and a column creates a sensor or 'sensel'. These matrix based sensors are able to record real-time static and dynamic loads with very high spatial resolution at a reasonable sampling rate. However, each application requires an optimal match between the measurement area, spatial resolution and the pressure range provided by the manufacturer. This optimisation is required as the resolution is low (8-bit) and the total number of samples per second (given by the number of sensels times the sampling frequency) has an upper limit, so high frequencies (in the kilohertz ranges used for wave impacts) can only be obtained by reducing the number of sensels.

Ramachandran et al (2013) explored the application of a tactile sensor to measure wave impact pressures with high spatial and temporal resolution in large scale model tests. They also developed and analysed a dynamic calibration technique. This was tested on the surface of a sloping revetment in the GWK (Figure 3.11). The sensors were again successfully applied in a HYDRALAB Transnational Access project to measure the wave impact pressures on parapets mounted on a vertical wall.

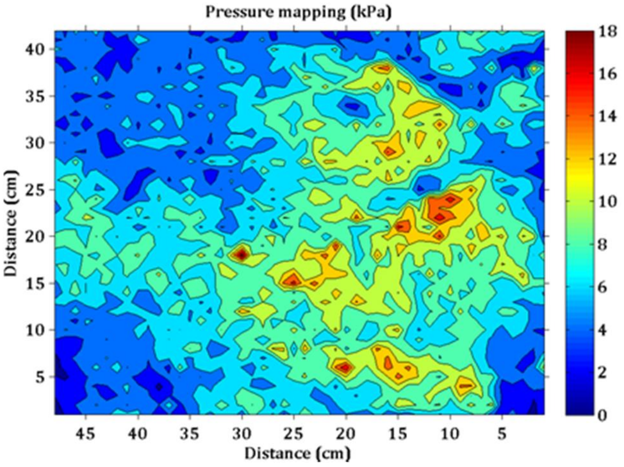

Figure 3.11 *Spatial distribution of pressure on surface of sloping revetment caused by a breaking wave (courtesy of LUH)*

Marzeddu et al (2014) tested a scaled model of a vertical breakwater in a small flume. The vertical wall of the breakwater was equipped with six pressure sensors, two load cells and a tactile sensor, in order to record the pressure and the total force at the same time. About 290 tests were conducted. Various tests were made under the same wave conditions recording at different sample frequencies (from 50 Hz to 19200 Hz). The total force on the vertical wall was computed for each test using the load cells and the pressure sensors (using interpolation and extrapolation techniques) while the tactile sensor was used to give information on the coherence of impact pressures.

It is common practise in ice model testing to measure the global ice load acting on the entire structure, while in practice most of the load is transmitted through local high pressure zones. The application of tactile sensors to ice loading (Evers and Lu, 2014) is therefore an interesting development as it provides the spatial resolution hitherto unattained in physical models.

Conclusions

The work conducted in the Joint Research Activity 'Hydraulic Response of Structures' as part of HYDRALAB-IV has made noticeable advances in developing techniques for conducting hydraulic model experiments, which have included:

- improved methods for generating water waves,
- improved efficiency of tests for measuring the structural response to waves,
- development of a technique for focussing wave signals in shallow water or with a structure,
- development of an active mooring line transducer,
- development of code for calculating QTFs from random wave series, and
- investigated how tactile sensors compare to the use of pressure sensors and load cell.

These advances are in the spirit of HYDRALAB as they seek to keep physical modelling as an indispensable tool in hydraulic modelling.

The results are summarised in the key papers below and the deliverables:

- Kirkegaard (Ed), Wave Generation, Description and validation of improved techniques. HYDRALAB IV Deliverable D9.1, http://www.hydralab.eu
- Hofland and Sutherland (Eds), Hydraulic Response of Structures, Propagation and optimisation of wave time series. HYDRALAB IV Deliverable D9.2, http://www.hydralab.eu

- Sutherland (Ed), New techniques to assess the response of structures to waves and ice, Hydraulic response of structures, Task 9.3. HYDRALAB IV Deliverable D9.3, http://www.hydralab.eu

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- Hofland, B., Wenneker, I. and van Steeg, P. (2014). Short test durations for wave overtopping experiments. Proceedings of Coastlab'14, Varna, Bulgaria.
- Ramachandran, K., Schimmels, S., Stagonas, D., Müller, G. (2013). Measuring Wave Impact on Coastal Structures with High Spatial and Temporal Resolution – Tactile Pressure Sensors a Novel Approach. Proceedings of 34th IAHR World Congress, Chengdu, China.
- Marzeddu, A., Stagonas, D., Gironella i Cobos , X., Sánchez-Arcilla y Conejo, A. (2014). Effect of measurement systems on impact loads on rigid structures. Proceedings of Coastlab'14, Varna, Bulgaria.
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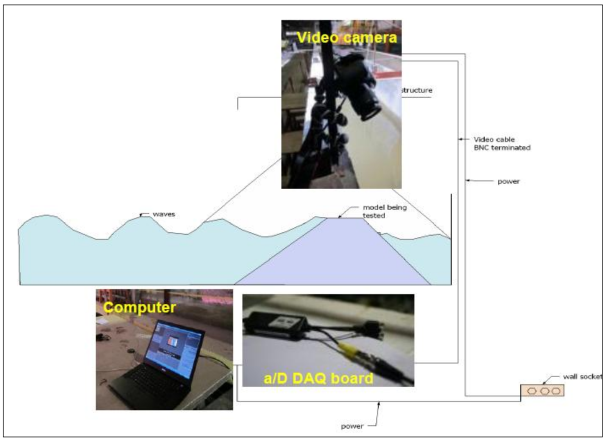
3.3.4. Remote Access to Data and Experiments (RADE)

In RADE we have developed a robust set of information systems to improve access to our experiments and data through the innovative use of modern data management, curation and communication technologies. Traditionally, the hydraulic research community is accustomed to exchange the results of their experiments through papers and conferences. The direct exchange of data is limited to the authors and only after the experiment has finished. The objectives of RADE are to allow much larger groups of researchers' access and input to laboratory experiments remotely, thereby saving on costs and the environmental impacts of long distance travel, and to make the results of our experiments more easily accessible for researchers beyond the HYDRALAB community within a shorter time. This further improves the synergy between different partners in Europe and worldwide and the impact of an experiment, thus creating a climate for further innovations.

The systems show data on the screen at your remote desk and give a visual impression of a detail in the experiment that is conducted in the laboratory. The most elaborate information system we have developed also distributes the data in real-time to all that have been invited to witness the experiment remotely. Deltares developed a methodology using a client-server facility to share live measurements data as well as live images from experiments to outside participants. The robustness of the system has been demonstrated by testing involving other HYDRALAB partners. The principles applied have been published and can be implemented at other research facilities to the benefit of their partners and clients.

LNEC has developed methods to provide online visual access to experiments and at the same time providing online meeting and presentation capabilities including visualization of data. The system was extensively tested with HYDRALAB partners as well as partner institutions in South America and Africa. Other commercial tools for on- and offline communication in connection with meetings and experiments have been tested for robustness by HYDRALAB partners Samui, UHull and DHI.



LNEC remote access setup

As part of RADE we also developed the basic data structure and procedures for sharing of information between research installations and research groups through a database of experiments. This has led to the development of a web interface and search engine to explore meta-data obtained from experiments at hydraulic infrastructures. This was a large step forward to facilitate scientific interchange between European researchers and it is a pre-requisite for subsequent access to remote experiments at the installations of research partners.

More details on RADE can be found in the following international publications:

- IAHR's newsletter HydroLink, number 2/2014, Lemos et al. (2014d). The news article describes the elements of the LNEC and Deltares systems;
- IAHR Hydrolink number 3/2014 also gives reference to RADE technologies as part of a comprehensive description of all activities in HYDRALAB IV;
- Coastlab2014 conference proceedings – Lemos et al. 2014a;
- 12th Water congress/16.º ENASB/XVI SILUBESA conference proceedings – Lemos et al. 2014c.

3.4. Networking activities in HYDRALAB IV

The specific aims of the networking activities were to enhance the services provided by the research infrastructures and disseminating the results to a broader user community in Europa and beyond. The networking activities expand the results and experience gained in HYDRALAB IV as described below. The activities were formulated in five work packages under the following headings:

1. Foresight studies
2. Databases and website
3. Dissemination events
4. Outreach to new users of Transnational access
5. Further Integration of EU policies including establishment of sustainable funding structures

3.4.1. Foresight studies

The focus of HYDRALAB IV is formulated by the theme 'More than water'. The underlying objective is to consider the interaction between the water (hydraulics) and environmental elements, sediment, structures and ice. It is through these interactions that water impacts on society and human beings. The objective of the foresight studies is then to review present state-of-the art and on basis of the recognition of gaps in knowledge and technology to formulate future needs for scientific and technological development.

It was natural to divide the foresight studies in three parts:

- Water & Environmental elements (with focus on ecology and biology)
- Water & Sediments
- Water & Structures and ice.

Each of the foresight studies describes the limitations in existing practices and experimental facilities and suggestions for future improvements have been made. These improvements include clever combinations of physical and numerical modelling for use in the design and testing of complex structures subject to extreme conditions.

In adition to the deliverables of the task three papers related to the three foresight studies were presented at the IAHR congress in Chengdu in September 2013:

- Agustín Sánchez Arcilla, et al.: The evolution of Mobile Bed Tests. A Step towards the Future of Coastal Engineering
- Rob Thomas, et al.: Physical Modeling of Water, Fauna and Flora: A Foresight Study for Ecohydraulics.
- James Sutherland, et al.: Foresight Study on the Physical Modelling of Wave and Ice Loads on Marine Structures.

3.4.2. Databases and website

The HYDRALAB website, which was launched during HYDRALAB III, has been upgraded with regards to content and functionality. The ambition of HYDRALAB IV was to develop the website as a primary tool for participants to cooperate and for disseminating results of the HYDRALAB activities.

The new structure developed at the start of HYDRALAB IV provides easy access to different parts of the website such as a very flexible document exchange area and registration procedures for meetings and events. These facilities have been used and proven robust during the project.

The second important development was the project registration site - the database of experiments - used to give an overview of participants and results from the transnational access projects. This section of the website is partly open to the public so that information on projects and test facilities can be freely disseminated. Other parts are accessible only to project participants. The project database has been extended to cover experiments conducted during HYDRALAB IV.

The existing database on European experimental facilities has been upgraded There are in fact only few changes to the number of facilities but it became clear that the database requires significant input to ensure that it is updated to reflect actual contact points and technological upgrades. The facility database is now linked to the database of experiments to ensure that relevant facility data shall be maintained in only one location. Similarly the database of instruments has been upgraded.

An important aspect of the databases is how to keep them operational in the future. Links have therefore been prepared for future mapping the HYDRALAB databases into UKEOF (UK Environmental Observation Framework). This aspect has been one of the important parts of Work Package 10, Remote Access to Data and Experiments (RADE).

3.4.3. Dissemination events

Dissemination events have been held as planned six times during the project period. Each event gathered participants for participant meetings (PM and PGA), workshops on research actions and networking activities, Early career researchers training workshops, meetings of the User selection panel for Transnational Access and for TA-providers and meetings with the International advisors (IAB). These events provided opportunities for the participant organisations to interact and exchange experience on all subjects covered by HYDRALAB IV.

The participants meetings included updates to present the status for the different Joint Research activities and Networking activities. Furthermore examples of Transnational Access projects were presented. The General Assembly meetings discussed necessary modifications to the contractual basis for the project coordinated the reporting.

A number of external experts have been invited to participate in the events in order to enhance communication beyond the group of participants and outside Europe.

The concept of organising large events with many different meeting opportunities during a short intense period has appeared to be an excellent and valuable way to coordinate among the European specialists in experimental hydraulics.

HYDRALAB IV also saw the beginning of Social Media Usage for dissemination purposes, through Twitter and LinkedIn and the publication of news sent to registered users by email. This has proven to be an effective way to share our results with larger groups at the same time and increase our impact. In addition all our presentations during the Closing Event in Lisbon were streamed live and are now available through our YouTube account.

Two of our users (Bardex II and WECwakes project) have made professional videos for their projects that allow easy dissemination of their project.

3.4.4. Outreach of new users and review procedure Transnational Access

The selection of the most relevant and ambitious projects to be supported by the Transnational Access programme is an important task of HYDRALAB IV. Three calls for proposals were launched during the course of HYDRALAB IV. There were no stated preferences to specific topics and the selection of projects was thus adapted to the types of facility available.

The principles of selection as developed during HYDRALAB II and III were adapted to the new programme. The experiences from earlier programmes have been used to specify the contents of the Database of Experiments described in Section 3.4.2 above. The new requirements related to the database were included in the agreements with the selected users.

The independent user selection panel (USP) held three meetings. In some cases the USP was able to shift project proposals to an alternative infrastructure and thereby secure access for quality proposals when the first choice facility was not available. Almost all capacity was fully booked after the first call for proposal which is an advantage for both users and infrastructures to ensure that projects can be succesfully completed during the project period. However this also illustrates that the demand for access exceeds the financial resources of HYDRALAB.

3.4.5. Future integration of EU-policies including establishment of sustainable funding structures

The aim of the Integrating Activity HYDRALAB IV was to bring together and integrate, on a European scale, key research infrastructures in the field of experimental hydraulics. With HYDRALAB IV we built on experience of years of collaboration (since the start of HYDRALAB in 1997) between a large number of European partners in hydraulic research. In these years we have been able to optimise the access to our infrastructures and realize a sustainable operation of the infrastructures. In HYDRALAB IV we have explored the possibilities to further integrate our activities and intensify this collaboration.

The need to adapt to the effects of climate change and increasing environmental pressures as well as the need to develop sustainable protective measures against various natural hazards has led to a great number of national and international policies. The stakes are high and the issues transcend national boundaries and concerted action at the level of the EU is necessary to ensure an effective protection against i.e. flooding. This has implications for the co-ordination of the use of our research infrastructures.

Therefore, a mapping of European policies was carried out as a basis for discussing sustainable funding for European cooperation and integration of activities. EU policies recognize that environmental issues and future adaptation to climate changes cannot be solved at national levels. European cooperation is important to seek solutions and hence a strong European scientific community will benefit our society.

As part of HYDRALAB IV we have also updated our inventory of scientific infrastructures in European countries and it is obvious from this mapping that the many existing facilities have been established to support local preferences and needs. There is presently no general financing mechanism in any of the participating nations.

In some countries a similar programme has been launched, to cover the national dimension of the unique facilities for hydraulic research. This national service, added to the international accesses within HYDRALAB will foster more local problem solving applications, since it is at these local (harbour, beach or river) scales that the problems must be solved and analysed. In spite of these efforts the present economic situation has precluded these initiatives to receive any sustainable funding.

The combination of EU plus national support together with the expected activation of the engineering activity will provide the means to start looking for such a sustainable funding. It is clear that we need to strengthen our connections at all national levels across Europe, but the HYDRALAB community is well positioned for this purpose. Especially since the recently addressed aggregated modelling of water, sediment, structures and ecosystems must be at the core of sustainable engineering interventions to deal with present and future coastal and river margin problems, representing one of the most heavily populated types of region on earth.

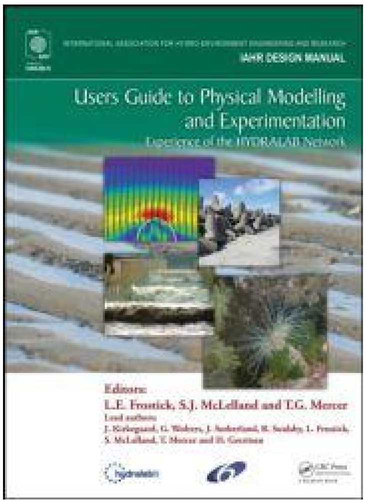
Based on our inventories we have concluded that further integration and coordinated actions add value, but that there is no strong need to move to a single legal entity.

4. Potential impact of HYDRALAB IV

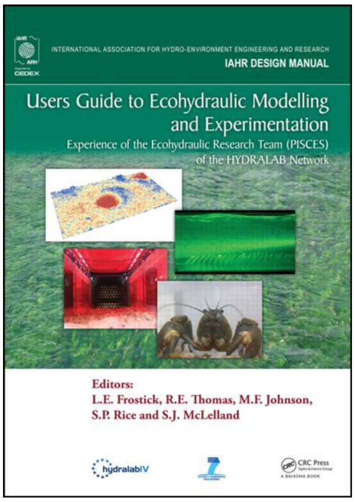
4.1. Introduction

Reflecting international developments, progressively the research in our experimental research infrastructures goes beyond just hydraulics and focuses on questions regarding the interaction of water with its environment, thus enlarging the complexity. By adopting the theme 'More than water' we aimed to emphasize our belief that the solution to many pressing environmental problems associated with the interaction of water (in ocean, coastal, estuarine, and river systems) with environmental elements, sediment structures and ice requires an integrated approach.

Integrated investigations require very advanced and specific research tools and, therefore, unique research infrastructures are desperately needed. The impact of HYDRALAB IV is the improvement of the performance of experiments to yield more powerful results and the coordination between experimental infrastructures to increase the efficiency of research activities. HYDRALAB IV has set the agenda for experimental hydraulics through the development of guidelines and best practices on specific experimental research topics. Two key examples that were published as part of our project are the following Users Guides:



Users Guide to Physical Modelling and Experimentation



Users Guide to Ecohydraulic Experimentation

Furthermore, the project generated more than 200 scientific publications in peer-reviewed journals and conference proceedings. More information on the dissemination of our results is given in paragraph 4.5.

The potential impact of HYDRALAB IV is derived from:

- ***Effective structuring of the European Research Area*** by streamlining the access to key experimental facilities and giving first time users the opportunity to conduct excellent research in major and unique research facilities (TA).
- ***Optimisation and improvement of hydraulic infrastructures and experimental methodologies and procedures*** through collaborative research projects that focus on key areas of development that meet societal challenges e.g. ecohydraulics, sediment dynamics and the response of hydraulic structures (JRA).
- ***Sharing knowledge and good practice*** from within the HYDRALAB network with users and practitioners outside the network and also educating early career researchers from

across Europe by sharing years of hydraulic experimental experience with the next generation of researchers (NA)

- ***Increase the reach of our research outputs*** by developing tools for dissemination of important background information on both infrastructures and instruments and results of experiments (NA, JRA and specific dissemination activities)

In the following paragraphs we will present our results in more detail to support the potential impact of our outcomes.

4.2. Impact of Transnational Access

Effective structuring of the European Research Area *by streamlining the access to key experimental facilities and giving first time users the opportunity to conduct excellent research in major and unique research facilities*

Through the Transnational Access programme of HYDRALAB IV 17 unique experimental facilities at ten institutes were offered to the European research community. State-of-the-art measuring instruments, data-acquisition and processing systems were at their disposal, as well as modern support facilities, such as library, computers, processing and printing. Furthermore, the visiting researchers were offered a scientific intellectual environment, with assistance and guidance from experts at the host institute.

Three calls for proposals were sent to hundreds of hydraulic scientists. The calls for proposals within HYDRALAB IV led to an overwhelming number of applications, where the number of available access days was always exceeded, an overview is given below.

Institute shortname	Call	Number of proposals	Number of requested access days	available days entire contract	Factor of oversubscription
Deltares	1	13	468	70	6.7
Aalto	1	2	25	7	3.6
CNRS	1	11	313	186	1.7
DHI	1	6	225	98	2.3
LUH - FZK	1	6	185	160	1.2
HSVA	1	8	146	88	1.7
Marintek	1	2	26	30	3.2
Marintek	2	4	71		
NTNU	1	2	56	36	1.6
UHull - TES	1	2	71	99	3.6
UHull - TES	2	7	287		
UPC - CIEM	1	11	360	92	3.9
Total		74	2228	866	2.6

Number of proposals received

A total of 33 Transnational Access projects have been completed covering a vast array of experimental hydraulic research themes that were judged by external assessors to be at the forefront of the discipline. To date these projects have produced over 135 publications to ensure the distribution of outcomes amongst the wider scientific community. In addition HYDRALAB organised a final event in Lisbon with nearly 150 attendees to disseminate the results from all our Access projects.

Some key figures for the provision of Transnational Access in HYDRALAB IV.

- Total number of projects: 33
- Total number of access days provided: 977
- Average number of users per project: 9
- First time users: 76%
- Women in user groups: 27%
- Total number of nationalities: 31
- Average number of nationalities per project: 4

HYDRALAB IV used a common User Selection Procedure to select users for their research infrastructures.

The expected impact beyond the scientific community will vary between all TA projects. Below we give for each HYDRALAB theme an example of a project with the potential for significant impact beyond hydraulic research:

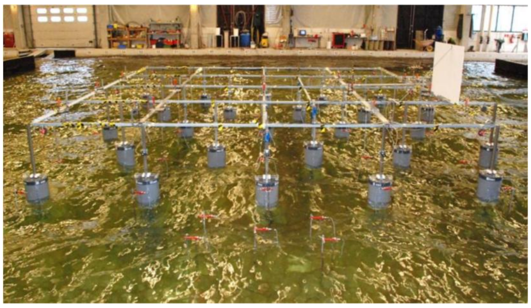
Water and environmental elements
The risk of coastal flooding is increasing worldwide aas a result of rising sea level, increasing storminess, and land subsidence. Awareness of the role that salt marshes play as natural buffer zones providing, amongst other ecosystem services, protection from waves during storms has also increased as a result. In spite of this general recognition, crucial understanding is lacking as to just how effective marshes are when it really matters, under extreme water levels and waves. Experiments undertaken in one of the world's largest wave flumes at FZK in Hannover (TA FZK-07), using a transplanted section of natural salt marsh typical of NW European coasts, provide the first evidence of wave dissipation under storm surge conditions.

The experiments demonstrated that energy reduction is affected by individual dissipation processes, and also identified the wave energy threshold above which salt marsh vegetation ceases to make an effective contribution to salt marsh defence capacity. Below this threshold, the effect of vegetation on wave attenuation was found to be significantly larger than expected, even for high water level conditions. Above this threshold, however, marsh vegetation was significantly damaged. The marsh substrate itself remained remarkably stable and resistant to surface erosion under even the highest wave energy conditions. These findings allow, for the first time, the quantitative assessment of flood risk reduction by salt marshes under extreme conditions and thus provide input into the future engineering of such biophysical buffers in the face of global environmental change.

Water and sediment; COHWAVE
A full understanding of the entrainment, transport and deposition of sediment is needed to provide insights into the morphodynamic evolution of the coastal zone, especially under the impact of climate change. Mathematical and numerical models have been employed to understand and predict the movement of sediment under various forcing mechanisms. A major source for uncertainty in these models is the representation of near-bed hydrodynamics and sediment dynamics in relation to bed roughness, which is closely linked to the shape and size of bedforms. The COHWAVE (HyIV-HULL-06) project demonstrated that the presence of cohesive sediments does not affect equilibrium bedform height which controls bed roughness. This is a significant result for modelling bed roughness in mixed sediments which will impact on the assessment of and response to future climate change.

Water and structures; WECwakes

In our search for more sustainable energy sources we are looking increasingly towards the generation of wave energy. Commercial exploitation of wave energy will require the installation of large numbers of Wave Energy Converters (WECs), arranged in an array (or a farm or park). Power production from an array, may be smaller or larger than the sum of the power by the equivalent number of individual WECs, due to interactions that take place between the WECs within an array (so-called intra-array interactions). In the *WECwakes* (HyIV-DHI-08) project the team has conducted tests on large arrays of point absorber type WECs (up to 25 WEC units) in the Shallow Water Wave basin of DHI.



The data obtained from these tests is crucial to enable optimization of the geometrical layout of WEC arrays for real applications and will therefore enable reduction of the cost of energy from wave energy systems. Most importantly, the *WECwakes* database is extensive, and can be extrapolated to floating structures/platforms or stationary cylinders under wave action as well as other structures. For all arrays of structures this will improve the understanding of wave impact on the array elements and wave field modifications around them.

Water and ice; RITAS

The *RITAS* (HyIV-HSVA-03) project focussed on improving ice load measurement by tactile sensor in model scale test in relation to rubble ice transport on arctic offshore structures. Because of the presence of rich natural resources in the Arctic and also its strategically important location, an increasing interest has long been placed on the study of ice load on various types of Arctic structures (e.g., fixed or floating offshore structures and icebreakers). Ice load varies both spatially and temporally. Ice load measurements can be roughly categorised into two groups, i.e., field measurements and model scale measurements in ice tanks. There are many types of ice load measuring techniques have been developed. However, conventional ice load measurements typically focus on the total ice load history and less attention has been paid to its spatial variation which is equally important. The results from this work will therefore benefit Arctic research by improving the understanding of loading on structures and icebreakers.

4.3. Impact of Joint Research Activities

Optimisation and improvement of hydraulic infrastructures and experimental methodologies and procedures *through collaborative research projects that focus on key areas of development that meet societal challenges e.g. ecohydraulics, sediment dynamics and the response of hydraulic structures*

The ensemble of the Joint Research Activities PISCES, WISE and HyReS focuses on the development of instrumentation facilities beyond the present state-of-the-art for areas where the interaction of water with environmental elements, sediment, structures and ice leads to a complex research problem. This leads to quantitative and qualitative improvements of the services provided at the infrastructures being offered within Transnational Access.

The most significant impact from the **PISCES** project is the development and improvement experimental methodology and protocols. This has been delivered through the dissemination of good practice via the *Users Guide to Ecohydraulic Experimentation* which gives an overview of our current knowledge of organism-environment interactions in marine and freshwater aquatic systems and has been published by the International Association for Hydraulic Research in their Design Manual series. The book has been distributed to the key hydraulic laboratories throughout Europe and will be used by scientists and engineers working in hydraulic experimental facilities to investigate ecohydraulic processes. The outcome will be more effective experimental design and more successful interdisciplinary research in the area of ecohydraulics. In addition, results from the comparisons between laboratory and field experiments have shown the importance of developing effective surrogates for use in physical modelling and has developed new approaches to modelling complexity in experiments. Dissemination of these outcomes will influence experimental design, improving experimental results and delivering experiments that are better value for money with results that are more transferrable.

The most significant impact from **WISE** is the development of an observational capacity comparable to that of numerical simulations. The high resolution in time and space collocated measurements of water/sediment fluxes, concentrations and bed evolution have allowed an unprecedented level of accuracy and resolution above, across and even below the sea bed boundary layer. The observational effort has allowed a significant step ahead in laboratory equipment and facility performance. Such advance has also been tested in the field, since the large scales represented by the participating hydraulic facilities permit a direct extrapolation to field conditions. In addition, this wealth of observations has stimulated the development of novel approaches to intra wave sediment transport and prompted the validation of more integrated modelling tools commonly used in morphodynamics and engineering. Some remarkable points from these developments are the identification of the elusive bed boundary (from a sharp gradient in the recovered signals), the direct measurement of velocities and stresses even within complex beds with sediments (via the magnetic filed and the response of ferrofluid particles), the role played by suspended sediment pulses in boundary regions (bed or swash zones), the combination of opto-acoustic devices to improve the recovery of hydro-morphodynamic signals and the scale and zone dependent scaling as a function of the dominant process.

The most significant impacts from **HyReS** will come from the take-up and further use of techniques and instrumentation developed during the project. Of particular note here are

1. The construction of a new tsunami generator under the ERC-funded UrbanWaves project, which incorporates all the design improvements identified in HYDRALAB IV (some of which could not be implemented by altering the previous design).
2. The Self Correcting Method is the only practical method for generating specific time series in the presence of a varying bathymetry and partially-reflective structures. There is increasing interest in the use of design waves in shallow water (for example in the ENFORCE project in the UK) and the SCM is the best available for achieving this. We expect the SCM to be taken up and used regularly.
3. The development and testing of three sets of code for determining QTFs has lead to an improved service being offered by DHI, IFREMER and MARINTEK. The new codes are expected to be used on subsequent commercial projects.
4. The application of the HyReS procedures for using tactile pressure sensors in Transnational Access projects involving wave and ice impacts on structures. The popularity of tactile pressure sensors for these projects implies that their use in coastal engineering is likely to increase and this experience should help drive improvements in sensor design.

Other work, such as the development of improved sampling schemes, will only be taken up and applied after further research to validate the proof-of-concept work undertaken here.

RADE was formulated with the objective to facilitate sharing of data between researchers and provide wider participation in ongoing research programmes through online access to the active research facility. The impacts will be derived from two tasks.

1. By development of the HYDRALAB project database as part of the HYDRALAB website and subsequently mapping it to the UK-EOF (UK Environmental Observation Framework) and making a bulk transfer of the HYDRALAB data, the project has prepared for increasing use of research output in compliance with EC policy. The UK-EOF has been established on basis of the EC INSPIRE Methodology and through that

implemented data services based on Inspire data standards for Environmental Monitoring Facilities (EMF). The significant impact is that data will now be accessible on a permanent facility independent of HYDRALAB. As an early user of the draft schema, HYDRALAB contributed to the development of the published schema. Further developments will be required to map all contents from the HYDRALAB database but the project has provided examples of how this could be approached.

2. Methodologies for online access to ongoing research in experimental facilities have been developed at different ambition levels. Maximum use of commercial tools and software ensures that the methodologies can be kept alive even as technological developments lead to improvements in this field of communication.

4.4. Impact of Networking Activities

Sharing knowledge and good practice *from within the HYDRALAB network with users and practitioners outside the network and also educating early career researchers from across Europe by sharing years of hydraulic experimental experience with the next generation of researchers*

All Networking Activities were specifically aimed at enhancing the services provided by the research infrastructures and at disseminating the results to the European user community and beyond by mutually coordinating the Access activities and Joint Research Activities. The HYDRALAB consortium consists of 22 participants that have all played an active role in the networking activities. In addition to these consortium partners we have included 8 Associated Partners from across Europe in the project. These Associated Partners participated actively in our meeting and contributed where possible to our research activities.

The foresight studies undertaken as part of the Networking activities have set-out a clear future agenda for the development of key areas in physical modelling. The outcomes from these studies clearly set the agenda for future developments in physical modelling in terms of infrastructure construction and development, experimental design and protocols and research needs and requirements. Notably, the results from the ecohydraulics foresight study have been published in a high impact journal to disseminate these findings to an international audience.

At each HYDRALAB Event, external experts have been invited to attend and participate in our meetings to ensure an exchange of information and dissemination of scientific developments among the wider scientific community. During the project we organised 7 themed workshops where we invited more than 50 researchers outside the HYDRALAB consortium. In addition, two Early Career Researchers workshops have been held during HYDRALAB meetings to ensure the impact of HYDRALAB continues with the development of the knowledge and skills for the next generation of hydraulic researchers and the dissemination of expertise from experienced researchers in the HYDRALAB community. Researchers from the Early Career Researchers workshops were subsequently invited to the HYDRALAB Closing Event, where they obtained an overview of JRA and TA activities and were able to network with the other participants of this event.

The HYDRALAB Closing Event was organised as an experimental hydraulics conference and was attended by 150 participants from Europe and across the world. The event itself was available in web conferencing live using the Adobe Connect web conferencing platform. This was advertised on the HYDRALAB website and on social media accounts and was attended by a number of participants who couldn't make it to Lisbon. All presentations were recorded and are available to view on the HYDRALAB website and on the HYDRALAB Youtube account.

The HYDRALAB community has also worked with other FP7 infrastructure activities by participating in meetings and events including the Marine Renewables Infrastructure Network

(MARINET) and the European Marine Biological resource Centre (EMBRC) both to share good practice and develop collaboration.

Considering the future was an on-going concern for the HYDRALAB network. Within HYDRALAB IV we have made an inventory of funding possibilities to establish sustainable funding structures to guarantee the continuation of our activities. We believe that the long and intense collaboration within our network provides a strong base for future activities, but advancing experimental hydraulic research in a coordinated way requires considerable resources. We are, therefore, continuously exploring existing and future funding possibilities in Europe and at national levels in our participating countries.

The complex and cross-boundary European water-related issues, that will only become more acute with the on-going developments as a result of climate change, have not been solved at present. To address these matters in a sustainable and integrated way requires the influx of new, creative ideas. The HYDRALAB network offers an unprecedented combination of environmental hydraulic facilities (among the best in the European Union), observational equipment (novel opto-acoustic techniques never applied before in this field) and the required human skills-base to interpret the results. The outputs from HYDRALAB will benefit and impact upon both direct users (public sector and private companies) and the many agencies responsible for delivering climate change adaptation.

With this in mind, we trust we will be able to find ways to continue our network in the field of the large hydraulic experimental research facilities in Europe. This will allow us to contribute to research on availability of water, safety against flooding and access to new sources of energy and food in a sustainable way at the onset of the consequences of climate change.

4.5. Dissemination activities and exploitation of results

Increase the reach of our research outputs *by developing tools for dissemination of important background information on both infrastructures and instruments and results of experiments (NA, JRA and specific dissemination activities)*

HYDRALAB aimed at optimizing the use and development of existing research infrastructures in the field of hydraulic research and ice engineering. To that purpose it was essential that we made the results of HYDRALAB IV widely available within the hydraulic and ice engineering research community in Europe and internationally, beyond the specific HYDRALAB research community. To realize this we have made full use of the international network of our participant IAHR (International Association of Hydraulic engineering and Research) and defined a focussed set of dissemination tools.

To be able to effectively disseminate the results of our project we distinguished different target groups: The dissemination and exploitation of HYDRALAB IV results targeted the following communities:

- A The Consortium (i.e. the participants actively participating in the I3 and the European Commission) and the associated participants
- B The European research community (i.e. (potential) users of installations, who can bid for access and/or participate on a voluntary basis in selected activities)
- C The international research community
- D The early career academic user community (an important subset of the third community).

An important feature for an international co-operation network like HYDRALAB is to have a global platform to store, manage and disseminate key information. The HYDRALAB website played an important role in our project in this respect.

We distinguish two roles for HYDRALAB in the research community. We play these roles in each of the above mentioned communities.

- HYDRALAB as a knowledge exchange platform
- HYDRALAB as a disseminator in the research community

4.5.1. HYDRALAB as a knowledge exchange platform

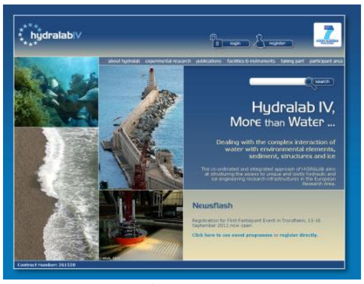
Over the last 10 years HYDRALAB has become well-known as a group of experts within the hydraulic research community. We have been able to bring together knowledge and people from the field of experimental hydraulics, particularly within Europe, but also from other parts of the world. There are now strong connections with research labs in Korea, USA, Canada and Australia.

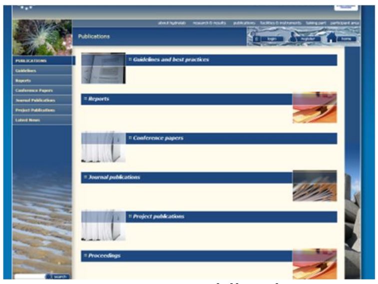
All HYDRALAB participants use the website (http://www.hydralab.eu) to exchange network specific information and ideas through this platform. Currently the website contains details of all HYDRALAB participants, experimental installations available for access and research results, all of which aid communication between participants and third-parties (e.g. Transnational Access user groups) and facilitate data re-use.

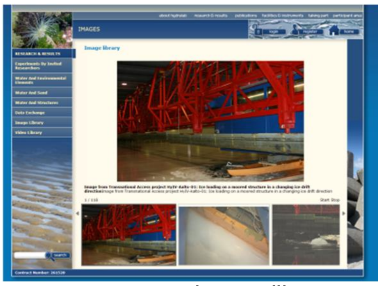
In the different fields of research covered by HYDRALAB, various data handling techniques are in use by the laboratories, with little coordination. This makes data re-use and data exchange difficult. HYDRALAB has improved this situation by sharing the expertise of the HYDRALAB participants for the benefit of the Transnational Access program and the Joint Research Activities.

In HYDRALAB IV we have managed to consolidate the HYDRALAB website as an European knowledge database in the field of experimental hydraulics, hydrodynamics, environmental fluid dynamics and ice engineering. The website now contains the following components focussed on dissemination and targets at all identified communities:

- Public pages promoting the project
- Public pages focussed on dissemination of research results
- Specific websites for all JRA's
- Inventories of research infrastructures, instrumentation facilities and results of experiments


HYDRALAB homepage


HYDRALAB publications


HYDRALAB image library

In the final year of our project we have made a big step towards actually sharing our results and data within the research community. We have developed a new section to the website called: research & results which contains information on each of the TA projects that were carried out under both HYDRALABIII and HYDRALABIV. The two databases have now been consolidated to provide one single search function for both HLIII and HLIV projects. All information has been reformatted to provide consistent information throughout all TA projects. For each of the TA projects carried out in HYDRALAB we now have the following information available.

- General information about the experiment conducted, the group leader, the facility used (with link to the full information page for that facility) etc…

- Access to the Data Management Report access to full datasets for some of the experiments
- The project summary report (also downloadable as a PDF)
- A photo slideshow
- Access to videos (published in Youtube), if available
- Access Lisbon proceedings paper
- Access to publications related to the TA project

We have found that most of our users are very willing to share their data with the research community well before the two year deadline. This functionality allows them to do this in a safe environment. We believe that this approach will impact the scientific community significantly and position HYDRALAB in the centre of experimental hydraulic research.

4.5.2. HYDRALAB dissemination in the research community

Hydraulic research is developing more and more beyond traditional civil engineering to meet increasing demands in environmental studies and assessment of natural hazards like flooding and coastal erosion. The issues society is dealing with at the moment, such as development of adaptation strategies to climate change, environmental issues related to the Water Framework Directive, the Flood Directive and sustainable protective measures against hazards (floods, tsunamis, hurricanes, etc.) require a profound knowledge of the behaviour of water in interaction with the elements around it. Therefore, it is crucial that we share the results of our research with the wider community and the next generation.

One of the objectives of HYDRALAB is to bring well-educated and skilled early career researchers from across Europe to the top level of research. To that purpose we encouraged early career scientists to be part of the user groups that apply for Transnational Access, leading to 76% of first time users. Additionally we organised three workshops that were especially targeted at early career researchers. In total we included 70-80 early career researchers in our network.

The HYDRALAB events once again proofed to be an effective way of organising the project. It created synergies and stimulated the interaction between researchers from different disciplines. We have seen the added value of a good working knowledge exchange platform, but face-to-face meetings are still the best way to really advance science and educate the next generation.

During the project we have attended numerous conferences during which we presented our progress. Typical conferences that were attended by our participants are:

- (to address the coastal and civil engineering community)
- Coastal Sediments (to address the geological community)
- Coastal Dynamics (to address the oceanographic community)
- International Association for Environemental and Hydraulic Research (to address the Hydraulic Community)
- International Conference on Offshore and Polar Engineering (ISOPE) (to address the ice-engineering community)
- River, Coastal, Estuarine Morphodynamics Conference (RCEM), IAHR
- Coastlab (to address the oceanographic community)

During these conferences we focussed on the application of experimental methodologies and demonstrated that HYDRALAB is a well-known and respected research community providing international guidance for hydraulic research.

At the 35th IAHR Congress in Chengdu we organised a special session on the future of experimental hydraulic research. The purpose of the session was to discuss with experimental hydraulic researchers around the world what the key challenges are for the near and far future, following our findings in the foresight studies. The session was well received and allowed us to gather insight from researchers outside Europe. HYDRALAB presented 7 papers in this conference.

Until today we have produced approximately 200 publications of which more than 30 were published in peer reviewed journals. At present more than 25 papers are in preparation. A complete overview of publications is given on our website (www.hydralab.eu/publications.asp) and in the EC portal. In addition we expect that our TA users will keep on publishing their work once they have carried out further analysis of their data. As part of our dissemination plan we have published a special HYDRALAB issue of Hydrolink, the primary magazine of the IAHR community (www.iahr.org).

HYDRALAB IV also saw the beginning of Social Media Usage for dissemination purposes, through Twitter and LinkedIn and the publication of news sent to registered users by email. This has proven to be an effective way to share our results with larger groups at the same time and increase our impact.