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Hydrolink

FIELD-SCALE EXPERIMENTATION IN FLUVIAL HYDRODYNAMICS: EXPERIENCE AND PERSPECTIVES

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Field measurements and observations have been traditionally basic methods in fluvial hydraulics before laboratory studies became successful and widespread. Despite the success of laboratory work, observations and measurement studies in nature have remained a major source of inspiration. Up-scaling the results obtained in the laboratory is often performed against coarse and episodic measurements completed in the field. Recent developments in acoustic velocimetry, computer technologies, laser survey and global positioning systems have greatly expanded the possibilities for carrying out detailed field measurements. Nevertheless, the results of field observations remain snapshots of reality while laboratory experiments give an insight into the dynamics of idealized systems. This paper reports on experience and outlines perspectives in development of an alternative approach which combines field measurement studies with the techniques of control on experimental variables.

During the last century research in fluvial hydraulics has demonstrated several successful attempts to expand the methods of experimentation to a prototype scale – the scale of natural streams. With a few exceptions those research activities were primarily focusing on the propagation of flood waves in rivers and the results of those studies were used to verify and calibrate numerical models. An experimental control of principal variables – a core element of laboratory experimentation – in those studies was achieved through the manipulation of flow rates during the releases of water from reservoirs. These studies allowed rigorous testing of many theoretical approaches, for instance a theory of kinematic wave propagation, and expanded their application for large-scale management and engineering of fluvial systems.

Although the advantages of experimentation on the prototype-scale are quite obvious, implementation of this approach to the study of river hydrodynamics until recently was almost impossible due to the technical limitations. Most of the studies carried out in the field until 1995 can be classified as measurements rather than true “experiments”. The measurements facilitated the assessment of flow resistance and mainly focused on the vertical structure of mean flow and, sometimes, turbulence. However, some of those studies, as for example the systematic studies of river turbulence carried out in the USSR by the late Prof. David I. Grinvald and his colleagues over thirty years period [1] and systematic research on river confluences carried out over the last two decades by Prof. B.L. Rhoads [2] in the USA, have contributed to the development of experimental techniques and established a methodology for interpretation of the results.

In the mid- nineties, with the invention of commercial acoustic doppler velocimeters

Fig. 1
A view of the experimental river reach on the Tagliamento river in Italy.

Fig. 2
Experiments in vegetated groyne fields with rigid emergent vegetation (left), and flexible submerged models of aquatic plants (right).

(ADV), research on river hydrodynamics has gained a new inspiration and valuable prerequisites for the development of experimentation on a prototype scale. Several field measurement studies have proved ADVs as reliable and robust instruments capable of the accurate assessment of turbulent flows [2, 3]. Progress was further strengthened by developments in geodetic instrumentation and acoustical survey technologies which made routine surveys of extended river reaches easy and accurate. Concomitant with these technical advances there appeared an obvious trend for carrying out experimental research on larger scale facilities. Probably the most well-known example today of these facilities is the Outdoor StreamLab built in 2007 at the University of Minnesota in the USA. This paper informs on another initiative in field-scale experimentation which for a while received less attention in the media though it has proven a success through a series of recent research projects.

Environmental Fluid Dynamics Laboratory in the Field

Field studies of turbulent flows have been of a special interest for the scientists of the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB) – the largest research center in Germanyfocused on the ecology of freshwater systems. The necessity to quantify fluxes of momentum, heat, solutes and particulate matter which drive the functionality of aquatic ecosystems in lotic and lentic environments comprises a modern paradigm in ecology. This interest and the financial support provided by the Deutsche Forschungsgemeinschaft and by the Netherland Organization for Scientific Research allowed establishing of a research platform called the “Environmental Fluid Dynamics Laboratory in the Field (EFDL)”. EFDL was initiated by the Ecohydraulics group of IGB in 2005 and joined by the Environmental Fluid Mechanics Section of Delft University of Technology in 2006 [4].

EFDL was launched with a series of pilot-studies which were focused on flow hydrodynamics around a finite size patch of aquatic vegetation [5] and on the dynamics of shallow lateral shear layers [6]. Those studies were carried out on the lowland river Spree and employed two types of experimental control techniques. In the case of aquatic vegetation the experimental control was established by selection of position specific for the vegetation patch and its composition (plant species, size of the plants, and spatial pattern). Population density in the patch was varied between the experimental runs and the response in the flow structure was documented by detailed measurements. This experimental approach has supported the development of several theoretical solutions and a rigorous comparison with laboratory results [5]. In the studies of lateral shallow shear layers experimental control was provided by the regulation of flow rates in two parallel flows separated by a splitter wall. This field experiment included several factors (unhomogeneity of riverbed roughness and pressure distribution) which were excluded in the previous laboratory studies. The results obtained provided new insights into the problem and have facilitated the development of a theoretical approach that accounts for the factors ubiquitous in natural environments [6].

International Research Platform Tagliamento

Since 2008 the studies of EFDL are continuing on the river Tagliamento in Italy, Fig. 1. This almost intact Alpine river system represents a model fluvial ecosystem of European importance on which intensive research has been

carried out by several international teams during the last decade [7]. This research is based on a research station located at the village of Manazzons in Friuli, Italy. The station has an ecological lab, a set of field equipment, a dorm for the personnel and a field vehicle for transportation to the study sites. The region of the Tagliamento River provides highly diverse natural environments suitable for a wide spectrum of scientific research. Typical studies carried out during the last decade include research on bio-diversity of fluvial ecosystems, morphodynamics of braided channels and the effects of riparian vegetation, transport processes of organic matter.

Most recent studies of EFDL have benefited from the advantages of the Tagliamento research platform. In August-September 2012 the studies of hydrodynamics in a vegetated groyne field were carried out there. A series of seven emergent groynes was built of gravel in a straight and shallow river reach. An experimental groyne field was populated with the model vegetation of two kinds: rigid cylinders and flexible silicone models of aquatic plants, Fig. 2. In the experimental runs the population density of vegetation, its submergence and spatial patterns were varied. The experimental setup consisted of portable rails that supported a flat frame with an array of ADV and a bridge for deployment operation. Detailed measurements resolved the flowfield on a fine grid. In total eight experimental runs were successfully completed at the steady conditions of the main flow in the river thus allowing for further direct evaluation of the vegetation effect in this complex recirculation flow.

Perspectives and new directions

The interest to EFDL is steadily growing and more research groups are joining this initiative. Since 2010 the IGB EFDL team was extended by the participation of Prof. H.M. Nepf (MIT, USA) and Prof. G.S. Constantinescu (University of Iowa, USA) in the research project on flow-vegetation interaction at a scale of a patch (DFG SU 629/1). This project exploits the synergy between the field, laboratory and numerical experimental approaches carried on the same methodological platform. The studies of this project will deliver understanding on how relevant are species-specific properties of natural aquatic plants for hydrodynamic processes at the scale of individual plants and a scale of a vegetation patch.
In 2012 the EFDL research program was expanded with a new direction focusing on the

Fig. 3
Measurements of wind profiles over the floodplain of the Tagliamento.

dynamics of atmospheric boundary layers over fluvial floodplains and the role this dynamics play in the dispersal of aquatic insects. Aquatic insects are vital components of fluvial ecosystems. They spend most of their life cycle underwater as benthic invertebrates. To reproduce aquatic insects emerge for short periods of time and are subjected to the aerial flows over river floodplains. Only little is currently known about these linkages between environmental factors and dispersal of aquatic insects and the new research within the context of EFDL seeks to bridge this knowledge gap. In this research the experience gained in EFDL on vegetated flows in rivers will be expanded to the aerial flows and their interaction with riparian vegetation in river corridors. In these studies the EFDL team employs ultrasonic anemometers mounted on the portable expositional musts, Fig. 3

There is strong evidence that field-scale experimentation has become a reliable approach that opens new fascinating perspectives in fluvial hydrodynamics.
Most of the experimental and theoretical research in fluvial hydrodynamics is focusing on idealized flows. In idealized setups researchers eliminate or minimize some processes or components of dynamic systems and thereby seek for particular solutions in the dynamics of complex systems. Field-scale experiments have the potential for encountering solutions of a more general character. For example, recent field measurements on river confluences have clearly demonstrated the importance of lateral fluxes of mean momentum [2] and inspired detailed field experimentation research that addresses the role of those fluxes in the behavior of the lateral shear layers [4].

Although this short article demonstrates the importance and effectiveness of the field experimental approach, field measurements and experimentation remain difficult and rare. One of the principal reasons for a relatively small number of field studies and field experiments is the lack of a specialized education and training of both scientific and technical personnel. Presently this gap in educational programs is not compensated by any occasional training program in framework of summer schools or short courses. Another reason is the absence of specialized equipment for field experiments. For instance, mounting equipment for instrumentation in the field is presently manufactured only on customized basis. There is a lack of guidelines and information on the methodical aspects of field measurements and experimentation is scattered among specialized papers. In conclusion I would like express a hope that the IAHR community might consider these points of concern and can improve the situation by offering some educational courses in the framework of existing summer schools and supporting the preparation of guidelines.

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