Water Science and Technology **Vol 41 No 2 pp 67–74** © IWA Publishing 2000

Integrated Urban Water Systems (IUWS) – an international postgraduate course

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Abstract In this paper we describe the background, the concept and the current status of an international postgraduate course on the subject of integrated urban water systems. The course aims to overcome the typical fragmentation of the engineering curricula in that field. Hence, the objective is to give a comprehensive overview on the total urban water and pollutant cycle, thus hoping to provide the students with a wider perspective on the problem. The course is structured into 22 modules that can also be taught in certain combinations. Emphasis is given to engineering problem solving and modeling.

Keywords Environment; environmental engineering education; integrated urban water systems; postgraduate course; water; urban water cycle

Introduction and problem statement

In the early days of higher technical education, around the turn of the century, relatively small civil engineering departments or faculties taught and developed technology to create and build the infrastructure that laid the basis for the industrial upswing in Europe. Examples with respect to water-related infrastructure are the various hydraulic laboratories that played a central role in the development of hydropower, shipping canals, urban drainage systems, etc. Subsequently, new branches of water engineering developed from the traditional laboratories. Whether these spin-offs were a necessity of an ever-increasing complexity of water-related problems during times of industrial growth, or whether it was the accompanying economic growth that created a comfortable environment for the fragmentation of water-related disciplines remains a question to be answered.

However, it is a fact that the fragmentation has continued until today: two generations ago, a typical civil engineering faculty (sanitary, bio-, and environmental engineering did not exist then) had one professorship covering water-related subjects. Today there might be several faculties dealing with environmental engineering education, and they might have a dozen professorships, ranging from "coastal protection" via "transport in porous media" to "microbiological processes in wastewater systems". While this is reasonable from a scientific point of view, the effect of such fragmentation on environmental engineering education is dangerous: there is a natural tendency for each of the disciplines involved to claim/believe to be central for solving the problems that the student will be exposed to in her/his professional life. Consequently, also the engineering education given will be detailed and focused on the specific subject. However, the learning capacity of students is limited and, before being overloaded with facts from the various disciplines, students typically restrict themselves to a limited selection of subjects.

In short, present environmental engineering education has a tendency to create experts instead of generalists.

The consequence is that the student is not able to filter the important from the bulk of the material. Typically, he will not see that by solving a problem in one compartment of the water cycle a new problem might be created in the neighbouring compartment. Classical examples are, among many, the flood that is created downstream by the dike upstream, or the sludge disposal problem that is generated by wastewater treatment.

In the worst case, engineers will be educated who are not able to understand the complete water and pollutant cycle. Consequently, their advice will be fragmented according to their respective speciality, and major decisions on environmental projects or policies will be influenced by other "experts" who discredit the engineer (with good reason) but, at the same time, claim to oversee the complete scope of the problem (with more doubtful justification).

History

Most university curricula on urban water systems are fragmented as described above. They concentrate on selected elements of the system in depth, but do not cover the system comprehensively in its breadth. Within the former EU COST-682 action (1993–1998) the working group focusing on the integrated urban wastewater system identified the considerable knowledge gaps existing between professionals active in this multidisciplinary field. As a result, it was agreed upon as one objective of the new EU COST 624 project (1998–2001) to tackle this problem and to try to reverse the trend of specialisation by educating multidisciplinary generalists. A postgraduate university course on "Integrated Urban Water Systems" (IUWS) will be developed, aiming to include all relevant environmental engineering aspects of UWS with particular focus on the dynamics of the processes and the interactions between the various compartments of the system.

The group of people that have converged to this idea and that are motivated to spend considerable time into this have a common vision. This is the result of the networking that has been going on during the last seven years. Intense communication lines were established and communication problems due to differences in terminology and methodology (e.g. Carstensen *et al.*, 1997) were gradually cleared. The convergence of thinking certainly benefited from the homogeneous background the group now has. This common background was gradually established during a considerable number of intense working group meetings that were organized on different topics of IUWS. Convergence was certainly also easier due to the similar age of the group members, the fact that all of them are computer skilled and have done and still do research on different aspects of IUWS, typically with a modeling perspective. Finally, the group members have reached a professional position that gives them the necessary flexibility to invest considerable time and effort in this endeavor.

Importance of the integrated approach

In recent years the necessity of optimising and operating the urban water system with an integrated approach became more and more obvious. Therefore, the decision to include all the subsystems of urban water management into one course was driven by the conviction that the integrated viewpoint is a need and that students should be aware of the interactions within the system.

An overview over the entire urban water system is given in Figure 1. In an integrated perspective, the surface- and groundwater sources, the receiving water and the settlement must be included in the system as they interact with the water infrastructure. Figure 1 exhibits the settlement on the top level, the transport systems on the second level, the treatment systems on the third level and the natural compartments on the bottom level. The clean water systems (including the drinking water resources) are on the left side of the sketch, the wastewater systems (including the surface waters as receiving waters) are on the right side. An obvious reason to study the complete system would occur if the receiving water also served as a source for drinking water.

The various fluxes between the subsystems indicate the interdependency of the inputs and outputs. Whenever a flux is influenced or disturbed, this will affect most or all of the other subsystems and therefore, an understanding of the entire urban water system is an absolute prerequisite for people who deal with optimisation of only part of the system. Typically, optimisations would be carried out internally in one of the subsystems disregarding the consequences for the neighbouring subsystems. Some brief examples of interactions between the subsystems shall support the statement that individual optimisation cannot account for possibly important consequences.

The assessment of sewer systems performance by just looking at yearly overflow volumes or loads – the so-called emission strategy – does not account for the receiving waters'

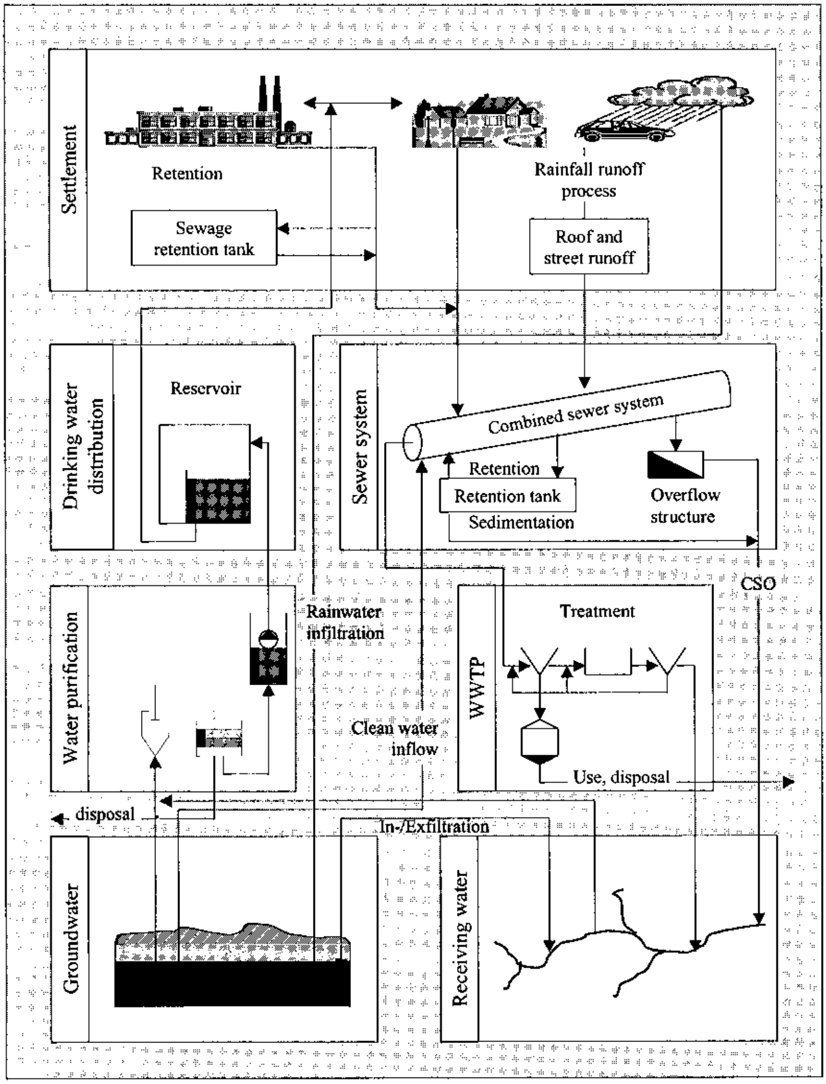

Figure 1 Subsystems and links of the integrated urban water system. Source: Krebs (1996)

characteristics and quality. Starting from the various facets of receiving water quality (Schilling *et al.*, 1997) an optimisation analysis may lead to totally different improvement measures, such as improving the rivers morphology. Also, if the river is sensitive to chemical concentrations, the decisive constellation for the impact is a high overflow load of single events meeting base flow in the receiving water (Rauch and Harremoës, 1996; Krebs *et al.*, 1996). Usually, this does not coincide with a high overflow volume.

In a combined sewer system, the erosion of sewer sediments – irrespective whether it leads to a first flush or not (Bertrand-Krajewski *et al.*, 1998) – is important for the combined sewer overflow (CSO). However, it is important also for the wastewater treatment plant (WWTP) operation and especially for the sludge handling for a relatively long time period after the rain event. Moreover, reducing the overflow rate and load by installing storage means that the WWTP is loaded – while the storage tanks are emptied – with the dissolved compounds that were stored, on top of the total dissolved compound load from the sewage. Therefore, load peaks on the WWTP are also influenced by the characteristics of the sewer system and its storage facilities and not just by the usual diurnal variations.

An increased water demand and a subsequent increase of groundwater yield may lower the groundwater table in the long term. Small running waters where groundwater exfiltration significantly contributes to the base flow during dry summer periods are then adversely affected. The base flow is reduced and thus CSO events may cause higher concentrations of toxicants (Krejci *et al.*, 1998). In the worst case, a small running water may even fall dry temporarily. Another possible effect of the lowered groundwater table is that through leaking sewers, exfiltration of sewage into the groundwater may occur instead of clean water inflow into the system. However, this is only one example of how the receiving water quality is linked to drinking water use in a way that can only be understood by including the integrated systems approach.

Course objectives

The course should cover the urban water system as introduced in Figure 1 in balanced detail. To enter the course a basic knowledge of urban water management is required; ideally, the students have passed basic courses on several subsystems. On the other hand, it should be possible to compensate for a lack of know-how in a few subjects by individual preparation.

Flexibility in the structure of the course is given high priority. The course material is split into modules (see Table 1) which are grouped in chapters. Although the modules can be taught independently, the interfaces between neighbouring modules – also from different chapters – are given special attention. In the prerequisites of each module the knowledge required and/or other modules that must have been passed before are indicated. Furthermore, we aim at introducing two levels within each module: topics corresponding to (A) a basic level and (B) an advanced one.

In the content of the course, we put the main emphasis on the engineering approach, interpreting “engineering” as oriented towards problem-solving rather than just focusing on design and construction aspects. The natural science approach is given as background knowledge wherever necessary. To our understanding, modelling is an important part of today’s engineering approach. Teaching students to understand models and being able to critically analyse and assess input data and results of numerical simulation is an important objective of the course.

Exercises include the application of models since this is the only way to experience dynamics and the interactions within the complex system.

Approach

Team of authors

The course will be created by a team of 16 international experts in the field of integrated urban water systems, most of them affiliated to different universities and research institutions all over Europe. This unusually high number of authors is clearly making the course development a difficult management task. However, it also offers a number of advantages. First and most importantly, only this large team makes it possible to develop such a course at all within a reasonable period of time. This is simply due to the potential that tasks can be shared among the authors. Thus the total load of the course development is broken into items that can be handled by the individual team members within the time restrictions imposed.

Other positive aspects of involving as many experts are:

- the topical diversity within the team which is a necessity for covering the wide spectrum of the course;
- the geographical diversity of the affiliation of the team members which allows for an equally wide geographical (European) coverage of problems;
- the coverage of different schools of thinking within the field;
- the possibility to have an internal but still international review process.

Content

Table 1 outlines the course content in chapters, modules and keywords. In essence, the course will cover the whole spectrum of problems arising within urban water systems in 22 modules, preceded by an introduction module. Each module is created by one responsible author, with one or more backup authors acting mostly as internal reviewers.

Although the concept of independent modules forms the backbone of the course, a topical division of the course into chapters proved to be essential. Thus the modules are ordered in a sequence of 8 chapters, each of those covering a wider topical perspective. For example chapter I: *Systems analysis and control* consists of five modules that deal with (1) modeling and analysis of dynamic systems, (2) basic hydraulics, (3) modeling of physical, chemical and biochemical processes, (4) real-time control, and (5) measurements and monitoring systems. By taking all modules in this chapter the student is expected to gain a basic understanding of principles, concepts and application of systems analysis, most of which is a necessary background for the rest of the course.

The three succeeding chapters deal with the technical infrastructure of urban water systems, i.e. water supply, urban drainage systems and wastewater treatment. The aim is here to give a basic understanding of the processes that affect the water cycle in urban areas and of the concepts underlying the technical infrastructure. The main topic of Chapters V to VII is the integrated view of the system. Here, the combined impact of the technical system on the receiving waters is discussed from both a quantitative and a qualitative point of view. The final Chapter VIII deals with the problems of engineering decision making and environmental management.

Teaching materials, media and simulation tool

Following the underlying concept of modularity it was decided to create a consistent format of teaching material for each module. Compulsory in that respect are: written text material, overheads and exercises; the formats of those are discussed in more detail later. These basics can be accompanied by supplementary material such as:

- multi-media, organised such that it can be down-loaded from the Internet
- slides, photos, videos
- real world project descriptions (cases)
- commercial program links/applications

Table 1 Course contents

Ch. No.	Chapter	Mod. No.	Subject of module	Key words
I	Systems analysis and control	0	Introduction to urban water management	
		1	Modelling and analysis of dynamic systems	state, input, output, models, model types, model building, uncertainty, calibration
		2	Hydraulics and transport processes	basics to flow description, transport phenomena
		3	Modelling of phys., chemical and bio-chemical processes	stoichiometric and kinetic models, mass and energy balances.
		4	Measurement and monitoring systems	objectives, problems, accuracy
		5	Real time control	general concepts, control strategies, continuous – discrete control, RTC systems
II	Water supply	6	Raw water resources	groundwater analysis, surface water analysis
		7	Water treatment	unit processes modelling
		8	Water distribution	hydraulic and water quality modelling
III	Urban drainage	9	Physical urban hydrology	rain, snow, runoff, infiltration, groundwater recharge, water use
		10	Hydraulic analysis of urban drainage systems	sewer flooding analysis; modelling of wave propagation
		11	Pollutants behaviour (in sewers)	production, transport, storage, measurements
IV	Wastewater treatment	12	Physical-chemical wastewater treatment	physical-chemical processes
		13	Biological wastewater treatment	biological processes
		14	Sludge and residual management	unit processes, mass balances, options
V	Receiving water analysis and control	15	Receiving water ecological quality	objectives, key variables, key processes
		16	Assessment of urban drainage impacts to the receiving waters	Water quality modelling
VI	Total pollution analysis and control	17	Storm water management	city planning, total system analysis, water resources, pollutant fluxes
		18	Interactions in the integrated wastewater system	emissions, systems interactions
		19	Pollution based and integrated RTC of wastewater systems	storage, CSOs, treatment rates, etc.)
VII	Integrated analysis	20	Integrated regional water resources analysis	ground and surface water, water supply, waste water
		21	Integrated regional pollutant flux analysis	incl. C, N, P, heavy metals, xenobiotics, solids
VIII	Decision support	22	Decision support	Decision analysis and making, risk, uncertainty, Environmental management tools

- discussion forum /bulletin board
- etc.

For the essential material it is the intention to summarize the written text and the exercises of each module into a textbook that covers the total course. In order to restrict the size of this final product and to force the authors to concentrate on the essentials, the magnitude of the written material from each module should not exceed 15 pages plus figures, exercises, solutions and appendices. Also with respect to format and layout a concise description is provided that should enhance the required coherence in the teaching material.

In terms of teaching media it is intended to rely on a classical "paper print solution". However, all material should be suitable for electronic publishing as well, which would give the opportunity to run the course either on local networks or even as an open and distance learning (ODL) course.

An important aspect for exercises and case studies is the choice of a coherent simulation tool or simulation environment, respectively. The options are manifold ranging from using commercial products of companies like Danish Hydraulic Institute, Delft Hydraulics, Wallingford Software, etc. to "old-fashioned" programming in Fortran, C/C++, Delphi etc. The authors finally agreed on using the established graphical simulation environment SIMULINK©. As a result of this decision the students will not have a program readily available but they will have to build their own models as part of the exercises. Care has to be taken that the handling of SIMULINK© is not acting as a barrier for taking the course. In the longer run it is the intention to successively build a program library consisting of locally developed routines.

Schedule, implementation and further development

The first ideas of launching this course were discussed in a COST workshop in Dresden 1998 (Krebs *et al.*, 1998). Still, it took nine months of debate and analysis (via email) until the team of 16 authors came together in Trondheim for finalizing the basic outline of the course. One of the major results of this meeting was also a strict schedule with respect to implementation and testing:

The course will be tested in early April 2000 within the framework of a Junior Scientist Workshop (Schilling, 2000). In order to keep that deadline all basic teaching material (text, overheads and exercises) has to be finished at least 2 months prior to this event and handed to the participants for studying. The workshop will then be used to solve exercises, discuss the material and for test lecturing. According to the results of this test the course material will receive a final update before the course is fully initialized for the first time at NTNU, fall 2000. In the future the IUWS-course will hopefully be established at other universities as well and optional also as an ODL course.

Conclusions

With respect to urban water systems, present environmental engineering education is typically focusing on special problems concerning system components rather than on the system itself and the interactions between components. As a result, students often concentrate on particulars but fail to understand and oversee the complete scope of the issue.

The course, as outlined in this paper, aims at tackling this shortcoming by giving a comprehensive overview on the water and pollutant cycle in urban areas as well as on the related engineering concepts. It is neither intended nor expected that the successful student will be an expert on all details afterwards. However, the hope is that this course will create an understanding of the total urban water system and thus will be the stepping stone for further (and more detailed) studies.

Important decisions were taken on SIMULINK© as the modeling platform that will support the student's gain of insight, the timetable for the creation of the course, its contents in chapters and 22 modules that can stand on their own, and the editorial approach. An international team was established that covers the topical diversity of IUWS and the differences among different countries and schools of thought. It was recognized that a significant period of intense communication within the EU COST framework was a necessity to have the 16 contributors converge on the approach of an international course on IUWS with the content as presented.

So far our attempt towards the creation and implementation of such a postgraduate course has been promising, but only the future will show if our ambitions are rewarded.

Acknowledgement

This work was financially supported by the COST-624 action. The work of Peter Vanrolleghem is financially supported by project G.0102.97 of the Fund for Scientific Research (Belgium).

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