# Taking control of wastewater treatment: *laying the foundations for a new era of modelling and management*

● Decades of research and cooperation are behind a new report on benchmarking of control strategies for wastewater treatment plants, which brings together the latest developments in modelling and control in order to truly understand the processes taking place. **LIS STEDMAN** spoke to **PETER VANROLLEGHEM, ULF JEPPSSON, JOHN COPP** and **KRIST GERNAEY,** who co-edited the report, on the contribution of the work and the long-lasting friendships that have developed from and sustained the initiative.

**It is not often a book can be said to have changed a research area as fundamentally as the new Scientific and Technical Report (STR) on benchmarking of control strategies for wastewater treatment plants. The project, as well as providing a painstakingly researched foundation for modern wastewater treatment plant control and modelling, has also been an exemplar in terms of friendship and global cooperation (see following page).**

The project has been 22 years from conception to completion of this book. Professor Peter Vanrolleghem explains: 'In 1993 at an IWA conference there was the idea of using computer simulations to reflect on control, and how control could improve wastewater treatment. It allows you to predict what will happen if you make changes.'

Dr Ulf Jeppsson recalls that 'Bengt Carlsson was working mainly on traditional automatic control and had recently participated in a competition in another conference, for which the conference participants could download software describing a system and devise the best control system they could to meet certain criteria. We said maybe we should do that for wastewater treatment systems, but it took three to four years before the idea had matured and we actually started doing something.'

**Wastewater settler tank. Credit: Kekyalyaynen / Shutterstock.**

## Changing the face of wastewater modelling

Years later, Vanrolleghem says that the key achievement of the project is increasing the quality of wastewater treatment models and control strategies. 'The book is about control and how it can benefit treatment plants,' he says. 'What we have done is put state of the art in modelling into the field, so people can feel confident about the models and simulators.'

The work has also stimulated the development of new models, he adds. 'Water professionals are able to do things they could not do ten years ago in terms of treatment plant improvements and design.'

The group has also trained a lot of people – there are some 20 groups around the world still working on the project, each having students who are being exposed to modelling and what it can do, Vanrolleghem adds.

Control is not discussed a lot in the water profession; 'unfortunately', he notes. 'Modelling has become mainstream, control is not [yet]. It seems a hard thing to get across – modelling is often part of an environmental engineering curriculum, control often is not, and it takes of course effort to learn.' This project and the resultant book are, therefore, a nice bridge that helps people into that vital area of expertise.

The simulation tools produced by

the project are being used in courses throughout the world, and the key project contributors have given many talks at conferences. Vanrolleghem states: 'Modelling is almost standard practice. Our work has helped to move it there.'

The work has been a huge effort – 'very many man-years', Vanrolleghem estimates. 'It was a long effort, a large volume of work, with a huge impact on the field, the main impact being an increased acceptance of modelling of wastewater treatment works.' This has also led to improvement and refinement in the world of control – all advances that the next generation of researchers will take forward.

The work, says Dr John Copp in the book's preface, gives students entering the field a compendium of work that allows them to start a lot further along than that initial group all those years ago. 'They get to focus on their project – it allows them to do more work,' he notes.

Jeppsson adds that 'it gets students off to a flying start, they are not recoding models and searching for errors, it is a really good starting opportunity.'

### Project beginnings

Vanrolleghem remembers that those present began developing the idea on the side of their normal research. 'A few of us put students on, there has never really been project money, it has been about convincing students or our voluntary work.' Nevertheless, he points out, 'it has been a terribly valuable task, its impact on the field has been enormous – 500 papers and numerous PhDs that have benefitted from the work'.

From around 1996 to 2004 the project benefited significantly from two tranches of European COST funding – this was not for research per se, but for travel and networking. It allowed a group of 10 to 20 people to meet two or three times a year. Vanrolleghem calls it 'the best money ever spent by Europe in terms of return on investment, if you see what has come out of it, it's incredible.'

One benefit of bringing together people from far and away was that 'we learned what was jurisdictionally different around the world,' recalls Copp. 'Our eyes were opened.'

Jeppsson says that the original intention was to spend a short period of time making a fairly simple model of a wastewater treatment plant that allowed for some sensors that people could use to obtain data for controlling the plant.

'The idea was for a future conference to have a little competition, but the whole thing took on a life of its own and it started to expand and expand,' he notes. 'We thought we should be able to quickly build models so we could develop control strategies and use them, but we got caught up in it and it became a major development work. That is why we kept going for 20 years.'

### Commercial interest

Key to the work was the use of four or five of the main commercial simulators. Copp explains: 'Every single treatment works is different – each has some unique feature. By defining an artificial plant we were able to control all of the inputs and set them appropriately.' Simulation results could thus be compared.

Copp adds that the five or six research groups involved would go back from meetings and do the proposed work, and would invariably come back with completely different results despite the fact that the groups thought the processes had been completely defined. That was a complete surprise.

'We realised that particular things had impacts, that there were all kinds of little bits and pieces that have an impact, and we had to dive down into the detail of the models to get the answers. That is how we found a lot of the errors, because they were absolutely buried – very small typos, in one case just a constant, such a small number, a small enough difference in magnitude that you couldn't see it except when you were trying to match to three to four decimal places.'

Jeppsson notes that 'it does not have a big impact in a real system with big uncertainties, where you are happy if you get within 10% of the real measurements, but still it should be correct and it was not'.

As a consultant, Copp adds: 'We apply models for a purpose, but what became quite obvious to me was that it was not just a case of applying a model and it spitting out answers. These people were so focused on getting this right that we did get it right.'

Key to this was the wide range of people involved, Copp explains. 'Some came in with an interest in sensors, and we had just a simple (ideal) model for them but they said "no, no, you have to actually model the sensors in more detail (for example delays)". Someone came in with expertise in settling behaviour – we had just a simple settler, but they said that had to be modelled as well.' And so it went, with layers of expertise being brought in to give the modelling far greater depth and complexity, encompassing a range of control that genuinely reflects the operation of a wastewater treatment plant.

Professor Krist Gernaey notes: 'With some of the mathematical models the group has proposed significant changes, particularly in implementing the anaerobic digestion model.' He adds: 'Another thing we have contributed is to make people not just look at the model as a process, but as a complete plant.'

### Project development

Vanrolleghem says that another key aspect of this project is that the core group of people met regularly and became good friends (see box). 'We motivated and stimulated each other, brainstormed topics when we got stuck. There was consensus building with regular reports back and new homework assigned.'

The main group consisted of around 20 to 30 post-docs and PhD students, and a few non-academic contributors. As the project went beyond its COST funding period it became more difficult to meet – plus the eager young researchers were now fully-fledged academics, associate or full professors with workloads and less time for hands-on modelling and simulation.

'This is the reason it dragged on to 2007-08, just to write down and solve the last bits, we did not have the voluntary time or sufficient capacity to delegate. The core group of four had to finish off, the nice bits had been done and the cleaning up was left,' Vanrolleghem says.

## IWA Task and Working Groups

The core group members all belong to two IWA Specialist Groups – the Instrumentation, Control and Automation SG and the Modelling and Integrated Assessment SG. These are also the SGs that hosted the Benchmarking Task Group within IWA. As part of its Task Group programme, IWA supported some networking costs of the Task Group leadership.

With the publication of the STR, the Benchmarking Task Group has now formally delivered what it was supposed to, Jeppsson says. 'We hope to form a working group within the framework of IWA and WEF so we have an umbrella organisation for future work. An IWA Working Group is a good possibility to have structure around the ongoing effort.'

## A project based on friendship

One of the key aspects of this project is that it has created deep and lasting friendships that have benefited not only this work, but far more.

John Copp notes that for him the most important aspect of the project 'was the camaraderie, the friendships – the sense of community'. He came into the project in 1998, as a postdoc, and says: 'Without this project and the goal of creating the STR I would not have been there and met this really interesting group of people, each coming to the group with a different expertise and focus of interest.'

He adds: 'It was just great to get together with people who would come with concerns about things they had found in the benchmark simulation model we were trying to develop, and have a reasonable discussion and reach a consensus.'

'If we didn't like and respect each other it wouldn't have worked,' he observes, concluding: 'I am certain I will be friends with these people till the day I die.'

Krist Gernaey concurs. 'It was a special collaboration because it was all friends that were involved. It is one of the things that was special. It really was an excellent collaboration.'

Ulf Jeppsson adds: 'For us, the friendship and collaboration we have established so deeply over the last nearly 20 years is the most fundamental thing, and it has led to other joint projects at European and intercontinental levels, PhD exchanges, and postdoc exchanges. It forms the fundamental basis for a lot of things. The benchmarking work has been a platform from which other ideas and collaborations could easily be established.'

He adds that 'without all the personal meetings and the close friendship that developed, it would not have been so great a work. It would not have developed as it did, people would have dropped out.'

### Sharing success

Gernaey notes that another reason for the project's success is the willingness of the participants to openly share their results. 'Now, the first thing universities talk about is protecting their intellectual properties. We made our results available to people. We said, "We've checked the model, see what you can do with it," rather than repeating the obvious.' He says that 'one of the unique things was that we managed to convince the major software providers to make our results part of their software.'

Jeppsson confirms: 'They were willing and excited about the idea of putting these developments into their commercial platforms.' This helped in terms of spreading the work, as it spread to consultants and wastewater treatment plants as it became available within the software. 'The collaboration between academic and commercial interests worked excellently,' he concludes.

## Benchmarking of control strategies for wastewater treatment plants

*Editors: Krist V Gernaey, Ulf Jeppsson, Peter A Vanrolleghem, John B Copp*

Wastewater treatment plants are large non-linear systems subject to large perturbations in wastewater flow rate, load and composition. Nevertheless these plants have to be operated continuously, meeting stricter and stricter regulations.

Many control strategies have been proposed in the literature for improved and more efficient operation of wastewater treatment plants. Unfortunately, their evaluation and comparison – either practical or based on simulation – is difficult. This is partly due to the variability of the influent, to the complexity of the biological and biochemical phenomena and to the large range of time constants (from a few minutes to several days). The lack of standard evaluation criteria is also a tremendous disadvantage.

The IWA Task Group on Benchmarking of Control Strategies for Wastewater Treatment Plants has developed models and simulation tools that encompass the most typical unit processes within a wastewater treatment system, as well as tools that will enable the evaluation of long-term control strategies and monitoring tasks.

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Jeppsson adds: 'It was always agreed that everything we developed should be completely free for others to use. It is the true academic spirit of not keeping knowledge to yourself – instead distributing it for no personal gain other than the privilege and acknowledgement of doing something in a good way that other people can use.'

### Moving forward

The project still goes on – Gernaey notes that 'we have several people doing additional development work on the next version of the platform.' He adds: 'One of the main things we wanted was for the younger generation to take over – it's nice to see it actually is happening.' He says that there are discussions on the work spreading into the sewer system and receiving waters to give modellers the ability to create a complete picture of a fully integrated urban wastewater system.

Jeppsson also stresses that the STR does not encompass all of the most recent research. 'A number of the new benchmarking systems are not mentioned, things we are currently working intensely on, some of which will be available in a couple of years.'

He adds that there is much still to do. 'In the future benchmark systems we are moving towards, we are starting to develop brand new models and many are just on the verge of being published. They probably do not have total acceptance from everyone in the academic community but these are more at the forefront of development.'

The new models look at such issues as greenhouse gas production in wastewater treatment works, occurrence and fate of micropollutants and pharmaceuticals, physico-chemical aspects, he adds. 'We are looking at areas that have not been so extensively researched – areas where we have to be on the front line of modelling to provide relevant and interesting results.'

The work is certainly not finished. Vanrolleghem says: 'There are things we want to do, that could be done. We need new volunteers.' He is optimistic that it will happen. 'Young people will see the opportunity – it is very visible, very rewarding, it is just time, the "old guys" don't have it any more. We are still good at helping the young people. It will be good to pass it on to a younger generation.'

Jeppsson adds: 'We need the younger generation to take our place, and spend time doing the modelling and coding, and we will take on the role of coordinators.' There are, it is clear, younger researchers excited by the opportunity to pick up this torch and move forward into an extremely promising future. ●