INTEGRATED URBAN WASTEWATER MODELLING SUPPORT TO MUNICIPALITIES

CJ Brouckaert, BM Brouckaert, S Dhlamini

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Report to the
Water Research Commission

by

CJ Brouckaert, BM Brouckaert, S Dhlamini
WASH R&D Centre, University of KwaZulu-Natal

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Obtainable from
Water Research Commission
Bloukrans Building
Lynnwood Bridge Office Park
4 Daventry Street
Lynnwood Manor
Pretoria

orders@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

BACKGROUND

Inadequately treated effluent discharges from poorly operated and maintained and/or overloaded municipal wastewater treatment plants (WWTPs) are a key cause of deteriorating river quality. This threatens the health of vulnerable communities living along river banks and negatively impacts the suitability of the water for downstream re-use. Overflows from blocked and overloaded sewers threaten the health of communities with poorer communities being the most affected. The lack of available wastewater treatment capacity is also a barrier to new housing, commercial and industrial developments in many municipalities.

Improving wastewater management from collection to treatment to effluent discharge and re-use is a critical part of addressing these challenges. The efficient management of water and wastewater contributes to human health and enhances the quality of life. Modelling and data integration are powerful tools which municipalities can use to identify synergies, optimize wastewater system performance, ensure appropriate operational practices and find more cost-effective solutions to achieve the desired effluent and receiving water quality. Modelling is also a powerful tool for estimating the capacity of existing infrastructure under various scenarios as well as for designing upgrades including those which allow the recovery of water, nutrients and energy from wastewater.

AIMS

The main aim of this study was to provide modelling and training support and to document the progress of the wastewater modelling initiatives undertaken by eThekwini Water and Sanitation (EWS) and Umgeni Water (UW). The specific objectives of the project included the following:

1. Develop methods and materials for training municipal personnel in integrated wastewater management modelling
2. Provide training and support to EWS and UW engineers.
3. Field test the methodology by supporting EWS and UW in modelling their systems.
4. Extend the training and support to other municipalities.
5. Establish a sustainable support structure for building integrated wastewater management modelling capacity, including a website, a Water Institute of Southern Africa (WISA) specialist group, and a database of wastewater profiles and WWTP models.

METHODOLOGY

Training materials on WWTP and Integrated Urban Water Systems (IUWS) modelling were developed, presented and discussed in online or hybrid in-person/online sessions held at 2-week intervals. The training materials which include notes, slides, exercises, models and modelling tools were placed on an open-access website.

The WISA Modelling and Data Division was established, and its online platform was used to host a webinar to disseminate the project outcomes.

KEY OUTCOMES

GENERAL

The most significant outcome of the project has been the development of a modelling group within EWS familiar with the concepts and techniques of integrated urban water modelling. It is already providing a modelling service to EWS, and will be able to assist other municipalities similarly.

Other significant outcomes have been the establishment of the WISA Modelling and Data Division and the website devoted to integrated urban water modelling.

CONCLUSIONS

EWS has gained a group of engineers trained in the concepts and techniques of Integrated urban water system (IUWS) modelling, who are in a position to provide a modelling service to the eThekwini municipality, and to other municipalities. For such a service to be effective, some institutional measures need to be in place. The most important of these are the involvement of decision-makers in modelling efforts, continuous improvement of data acquisition and management, and more open communication and data-sharing between municipal departments. These could be addressed by a long-term policy commitment to a modelling framework. The skills that have been development need to be put to use in practical projects.

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Reference Group	Affiliation
Dr John Ngoni Zvimba	Water Research Commission (Chairman)
Dr Enrico Remigi	Danish Hydraulic Institute, DHI
Dr Chris Gaszynski	Danish Hydraulic Institute, DHI
Dr Sven Sotemann	City of Cape Town, CoCT
Dr Farai Mhlanga	Aguatech Consulting Engineers
Mr James Topkin	Ekurhuleni Water Care Company, ERWAT
Dr David Ikumi	University of Cape Town, UCT
Mr Mluleki Mnguni	Umgeni Water
Dr Xavier Flores-Alsina	Danish Technical University
Mr Mohammed Dildar	eThekwini Water and Sanitation

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ACRONYMS & ABBREVIATIONS

CoCT	City of Cape Town
CoT	City of Tshwane
CSCMS	Coastal, Stormwater and Catchment Management Services
DANIDA	Danish International Development Agency
DHI	Danish Hydraulic Institute
DTU	Danish Technical University
ESRI	Environmental Systems Research Institute
EWS	eThekwini Water and Sanitation
FAO	Food and Agriculture Organisation of the United Nations
IUWM	Integrated Urban Water Management
IUWS	Integrated Urban Water Systems
LCD	Litres per Capita per Day
NSWR	National Strategy for Water Re-use
NW&SMP	National Water and Sanitation Master Plan
PES	Process Engineering Services (group in EWS)
RDI	Rainfall derived inflow
SWMM	Storm Water Management Model
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
USEPA	United States Environmental Protection Agency
UW	Umgeni Water
WRRFs	Water and Resource Recovery Facilities
WWTP	Wastewater treatment plant

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

South Africa is a water scarce country that continues to be faced with challenges related to high water demand, limited supply, deteriorating water quality, poorly operated, maintained and overloaded water infrastructure and lack of skilled personnel affecting all aspects of urban water management. The country faces a serious crisis in terms of both the quantity and quality of water available for human and economic development as well as the health of our aquatic ecosystems. A 17% water deficit is projected by 2030 if current trends continue. This is while 3 million people still do not have access to basic water supply, 14.1 million do not have access to safe sanitation, 56 % of wastewater treatment plants are in poor or critical condition and the number of main rivers in the country classified as having poor ecological condition increased by 500 % between 1991 and 2011 (National Water and Sanitation Master Plan, 2018).

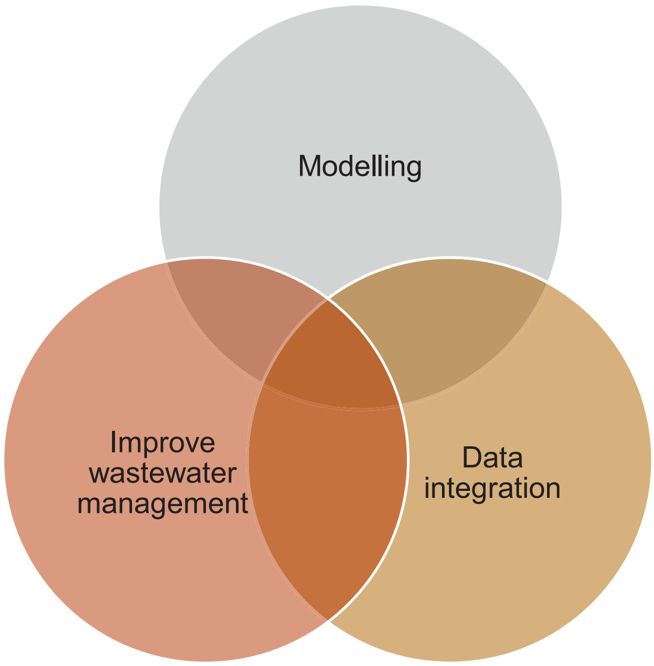


Figure 1.1. Three critical components to addressing the water quality crisis

Inadequately treated effluent discharges from poorly operated and maintained and/or overloaded municipal wastewater management and treatment systems as well as runoff from un-serviced informal settlements are a key cause of deteriorating river quality. This threatens the health of vulnerable communities living along river banks and negatively impacts the suitability of the water for downstream re-use. Overflows from blocked and overloaded sewers also threaten the health of communities with poorer communities being the most affected. The lack of available wastewater treatment capacity is also a barrier to new housing, commercial and industrial developments in many municipalities.

As a result, many municipalities are in a state of crisis with respect to urban wastewater management. Improving wastewater management from collection to treatment to effluent discharge and re-use is a critical part of addressing these challenges. The efficient management of water and wastewater contributes to human health and enhances the quality of life. Furthermore, better wastewater management is an important part of addressing the country's water shortages. There is a growing global awareness that wastewater treatment needs to move beyond focusing primarily on pollution prevention to maximizing resource recovery (water, energy and nutrients) to reduce waste disposal requirements, better manage scarce resources and mitigate climate change. The Department of Water and Sanitation's National Strategy for Water Re-use (NSWR), (Department of Water Affairs, 2013) identifies the performance of existing wastewater treatment plants in terms of reliably meeting discharge standards as being critical to the successful implementation of water reuse to reduce stress on existing water supplies. The National Water and Sanitation Master Plan (NW&SMP) includes several key actions relating to wastewater treatment and resource recovery which are listed in Table 1.1.

Table 1.1. NW&SMP Key Actions relating to wastewater treatment

No.	Key Action
1.3.12	National water and wastewater treatment performance turnaround plan to be developed and implemented. Turn around the functionality of five, currently dysfunctional, large water and wastewater treatment works with an accompanying publicity campaign, followed by a programme to address the rest of South African WWTWs.
1.4.1	Revitalize the Green Drop Programme, the incentives based regulatory programme which encourages sustainable improvements in municipal wastewater management.
2.4.3	All conditional grants to municipalities to be dependent on making improvements towards meeting Green Drop targets amongst other criteria.
2.6.12	Demonstrate appropriate wastewater technologies for cost effectiveness, energy efficiency and beneficiation.
2.6.7	Develop technologies, guidelines and implementation support tools that enable SA to use alternative and appropriate sources (including reclaimed wastewater) as part of the water supply.

The creation of the necessary enabling environment is essential to the successful implementation of the NW&SMP. Critical aspects include better management of data and information, building skilled capacity in the water sector, ensuring the financial stability of municipalities and enhancing research, development and innovation. In terms of the allocation of financial and other resources within a municipality, wastewater treatment has to compete with other critical priorities including housing, health, environmental protection and economic development. However, as discussed above, many of these actually rely on effective management and treatment of wastewater. The problem of prioritizing the allocation of resources is compounded by competing political pressures, which often result in allocations that are objectively non-optimal.

Modelling and data integration are powerful tools which municipalities can use to identify synergies, optimize wastewater system performance, ensure appropriate operational practices and find more cost-effective solutions to achieve the desired effluent and receiving water quality. Modelling is also a powerful tool for estimating the capacity of existing infrastructure under various scenarios as well for designing upgrades including those which allow the recovery of water, nutrients and energy from wastewater. Furthermore, the potential for tracking the incidence of diseases like Covid-19 in communities through sewer network monitoring and modelling has recently gained attention.

Over the last forty years, there has also been a growing interest in the development of integrated approaches to urban water management, where the interactions between different components of urban water systems (water supply, wastewater, storm water and receiving water) are taken into consideration in order to optimize the design and management of the system as a whole. This has stimulated the development of integrated urban water systems (IUWS) modelling tools to support integrated approaches to the assessment and definition of system planning needs, as well as for discharge permit negotiations. This is largely driven by regulatory and economic factors more especially, the financial and capacity constraints faced by many municipalities in being able to meet multiple regulatory obligations for various components of their urban wastewater and storm water management systems (Benedetti et al., 2013). The absence of well-structured training programmes suitability targeted to municipal stakeholders in the integrated urban water management chain is also a constraint that many municipalities are working towards addressing in order to enhance their capacity, experience and knowledge.

South African researchers, most notably the Water Research Group at the University of Cape Town, have made a substantial and internationally recognised contribution to the advancement of wastewater treatment modelling over the last few decades (Van Loosdrecht et al., 2008). However, the uptake of modelling by South African municipalities to improve wastewater management has been very limited so far.

The Process Engineering Services (PES) section of eThekwini Water and Sanitation (EWS) has recently established a process modelling group with support from UKZN with the ambitious long term aim of developing an integrated model of the metro's entire wastewater system, eventually including sewers, treatment works and rivers. It is intended to be a decision support system for the municipality to plan and manage all aspects related to wastewater. This initiative could be an important example for other large South African municipalities to follow.

1.2 PROJECT AIMS

The main research objective for this project was to provide modelling and training support for integrated urban water and wastewater management specifically focusing on the sanitary sewer system, stormwater runoff, wastewater treatment and receiving water quality, and document the progress of the wastewater modelling initiatives undertaken by EWS.

The specific aims of the project were to:

1. Develop methods and materials for training municipal personnel in integrated wastewater management modelling
2. Provide training and support to EWS and UW engineers
3. Field test the methodology by supporting EWS and UW in modelling their systems
4. Extend the training and support to other municipalities, e.g. Cape Town
5. Establish a sustainable support structure for building integrated wastewater management modelling capacity, including a website, a WISA specialist group, and a database of wastewater profiles and WWTP models

1.3 SCOPE AND LIMITATIONS

This project benefitted from synergies with two concurrent initiatives with a common objective of building modelling capacity in South African municipalities in general and in eThekwini in particular:

i. Wastewater treatment modelling training and support of the PES modelling group.
ii. Collaboration with Danish Technical University (DTU), University of Cape Town, EWS and City of Cape Town (CoCT) on the DANIDA funded project Evaluation of Resource Recovery Alternatives in South African Water Treatment Systems (ERASE).

The primary focus of this WRC funded project was on the development of a training program on IUWS modelling, however, since the website, workshops and position paper created under this project were also used to disseminate results from the other initiatives, limited descriptions of relevant results and interlinkages between the projects have been included in this report.

The project was envisaged to provide training in IUWS modelling to personnel from EWS and UW engineers. However only UKZN was contractually bound to the project while participation by EWS and UW was voluntary. EWS participated fully in all the training sessions and exercises, however UW attendance fell away after the first few sessions.

The training had as its nominal goal to develop a model of the entire catchment of a WWTP. This was to ensure that all relevant issues were identified and addressed. However, this goal could not be fully realised during the course of the project, due to the size of the system and the extent of the data requirements. With no history of this kind of modelling in the municipality, much of the necessary data had never been recorded, and one of the objectives of the project was to identify important gaps. What was eventually achieved was a model of an interconnected part of the catchment, which included examples of all the major elements: populated and un-populated areas, sewers, and wastewater treatment plant with sections of river above and below it. Where appropriate data were available, calibration exercises were performed on some of the sub-systems, but an overall calibration of the model was not possible within the scope of the project.

CHAPTER 2: MODELLING TRAINING COURSES

2.1 INTRODUCTION

This chapter describes a set of training courses in wastewater treatment and integrated urban water systems modelling using the WEST modelling platform (MikebyDHI) which were developed by the project team and delivered to wastewater engineers. The main participants were from eThekwini, but personnel from Umgeni Water and City of Tshwane (CoT) also joined some sessions. The runoff model in EPA SWMM was also introduced using calibrated flood models provided by eThekwini's Coastal, Stormwater and Catchment Management Services (CSCMS).

The training sessions culminated in setting up an integrated model of part of one of eThekwini's sewer catchments including different types of sub-catchments, the treatment works and river segments.

The main aim of the training programme was to provide modelling and training support to engineers from EWS and other water service providers to help build their expertise in IUWS modelling, which includes storm water runoff, sewer, wastewater treatment and receiving water modelling. The specific objectives were:

- Develop methods and materials for training municipal engineers in IUWS modelling
- Provide IUWS training and modelling support to municipal engineers

2.2 TRAINING METHODOLOGY

The training course was conducted in three sets of sessions as summarized in Table 2.1.

Table 2.1. Training sessions summary

Training sessions	Participants	Delivery mode
WWTP modelling in WEST	EWS	In-person
IUWS modelling Sessions 1-7	EWS	Virtual or hybrid
IUWS modelling Sessions 8-14	EWS, UW, CoT	Hybrid

The WWTP modelling sessions and IUWS sessions 6 and 7 took place at the Umbilo Wastewater Treatment Works in Durban, however, due to the COVID-19 pandemic and South African government lockdown regulations, the IUWS training sessions 1 to 5 were fully virtual. Sessions 8 to 14 took place at the WASH R&D Centre at UKZN. Virtual participants joined the sessions via Microsoft Teams.

An effort was made to include participants from outside of the EWS PES Modelling Group for Sessions 8 to 14. Since most of the outside participants did not have access to the WEST modelling software, we attempted to split the sessions between general discussion and demonstration of free modelling tools for all participants and hands on WEST exercises specifically for the PES group. Training sessions and exercises were interspersed with discussions which provided feedback from the participants on modelling needs and interests as well as a reality check on the assumptions and data being used in the model set up.

2.2.1 Sessions overview

2.2.1.1 Wastewater Treatment Plant (WWTP) Modelling

This refresher course in WWTP modelling consisted of 8 sessions, attended by 7 engineers from the Process Engineering Services group of eThekwini Water and Sanitation. An introduction to WWTP modelling using the WEST simulation platform led into 4 case-studies involving WWTPs in eThekwini as discussed in Section 2.4.1.

2.2.1.2 Integrated Urban Water Systems (IUWS) Modelling.

The focus of the IUWS modelling sessions was on learning to use the IUWS model in WEST to model the catchment and sewers of one of eThekwini's smaller WWTP catchments. The sessions also covered the use of SWMM models of the catchment to generate calibration data. Topics covered in each session are listed in Table 2.2.

Table 2.2. List of topics covered

Session No.	Topic	Duration
1.	a. Introduction to Integrated Urban Water Systems Modelling and overview of IUWS and KOSIM models	(12 Aug. 2021) 3 Hrs
	b. Introduction to case study catchment and data requirements	
2.	a. Setting up a pre-built catchment model	(03 Sept. 2021) 3 Hrs
	b. Discussion: Modelling objectives, data availability and requirements	
3.	a. Setting up a catchment model from sewer model blocks	(06 Sept 2021) 3 Hrs
	b. Data preparation	
4.	a. Modelling the storm water drainage system	(20 Sept. 2021) 3 Hrs
	b. Discussion: Interactions between the storm and sanitary sewers	
5.	a. Review of model components and data requirements	(04 Oct. 2021) 2 Hrs
	b. Generating reference data using SWMM	
6.	Calibrating the WEST runoff model	(18 Oct. 2021) 2 Hrs
7.	a. Predicted vs observed sanitary sewer flow	(08 Nov. 2021) 2 Hrs
	b. Discussion: how should we divide the case study catchment into sub-catchments	

Table 2.2. cont.

8.	Review of previous training sessions and discussion of modelling needs	(22 Aug. 2022) 3 Hrs
9.	a. Dry weather flow and evaporation models	(5 Sept. 2022) 3 Hrs
	b. **Hands on WEST tutorial:** Generators	
10.	a. Sub-dividing the WWTP catchment in the IUWS model using EPA SWMM flood models	(19 Sept 2022) 3 Hrs
	b. **Exercise:** Using SWMM and R to generate run-off calibration data for the IUWS sub-catchments	
11.	a. Using rainfall data in SWMM	(3 Oct. 2022) 3 Hrs
	b. Estimating and modelling rainfall derived inflow (RDI) to the sanitary sewers	
12.	a. River models in WEST and SWMM	(31 Oct. 2022) 3 Hrs
	b. Dynamic settler modelling in WEST	
	c. **Hands on WEST tutorial:** setting up the WWTP model in IUWS	
13.	a. Chemical precipitation in ASM2dmod	(14 Nov. 2022) 3 Hrs
	b. **Discussion:** relationship between chemical precipitation and SVI	
	c. Model connector blocks in WEST	
	d. Hands on WEST tutorial: i. Completing the WWTP model ii. Investigating dynamic SST performance under various scenarios	
	e. **Discussion:** Modelling maturation ponds	
14.	a. **Hands on WEST exercise:** Calibrating the WWTP model	(28 Nov. 2022) 3 Hrs
	b. **Discussion:** impact of sewage spills on WWTP inflow	
	c. Setting up the integrated model with river sections	
	d. **Hands on exercise:** Transferring parameters from the plant model to the integrated model	

2.2.2 Collaboration with eThekwini Coastal, Stormwater and Catchment Management Services (CSCMS)

One of the known barriers to the implementation of integrated modelling and management approaches is the siloing of expertise and data in different organizations or departments. The research team initially approached CSCMS about obtaining data on rainfall and stormwater drainage systems. In the meeting with the head of CSCMS it was discovered that they had already set up and calibrated EPA SWMM models of all the river catchments within eThekwini's municipal boundaries, which they are able to share with the project team. These models predict the runoff generated from rain events and are used for flood forecasting. They contain detailed information on drainage catchment characteristics and boundaries and can be used as a reference models for calibrating the wet weather flow in the WEST IUWS models. It was also determined that EWS and CSCMS have a mutual interest in quantifying the storm water getting into the sanitary sewer and sewage getting into the storm water drainage system. It was decided to include an engineer form CSCMS in the training sessions to foster collaboration between UKZN, EWS PES and CSCMS.

2.2.3 Modelling software

The wide range of issues involved in an integrated urban water model, and the diverse sets of data available, require a range of software tools. The choice of specific packages will be influenced by factors other than their intrinsic capabilities, such as cost, institutional IT policy, and modeller's familiarity. The following software was used in our project.

2.2.3.1 WEST (DHI, 2022)

WEST is a wastewater treatment modelling package from the Danish Hydraulic Institute (DHI) that includes IUWS modelling capabilities. This was obviously an important reason for choosing it, but it was also relevant that the project team, both from the university and from the municipality, were already familiar with using it for modelling of wastewater treatment plants. It includes very detailed models related to wastewater treatment, a somewhat simplified river water quality model, and very simplified models of hydraulic aspects. This is expensive software, but it was already available to the project.

2.2.3.2 SWMM (Storm Water Management Model)

SWMM, in its basic form, is a free package from the USEPA (2022). It complements WEST in that it provides detailed hydraulic modelling, but only a rudimentary treatment of water quality. An extended version of SWMM is used by the eThekwini Storm Water division for flood warning, and they provided a ready prepared model to the project, which could be run on the basic version of the software. This was used for modelling runoff and river flows, which could be used to prepare input to the WEST model.

2.2.3.3 ArcGIS

ArcGIS is Geographic Information System from ESRI (2017). This is an expensive package, but is the one used by eThekwini for many purposes, including asset management, so was available to the project. It was a key tool for many purposes, as it held information on the sewer network, the rivers, water supply connections etc. It also interfaced directly with SWMM so that items of municipal infrastructure could be accurately located in the hydraulic model (Figure 2.1).

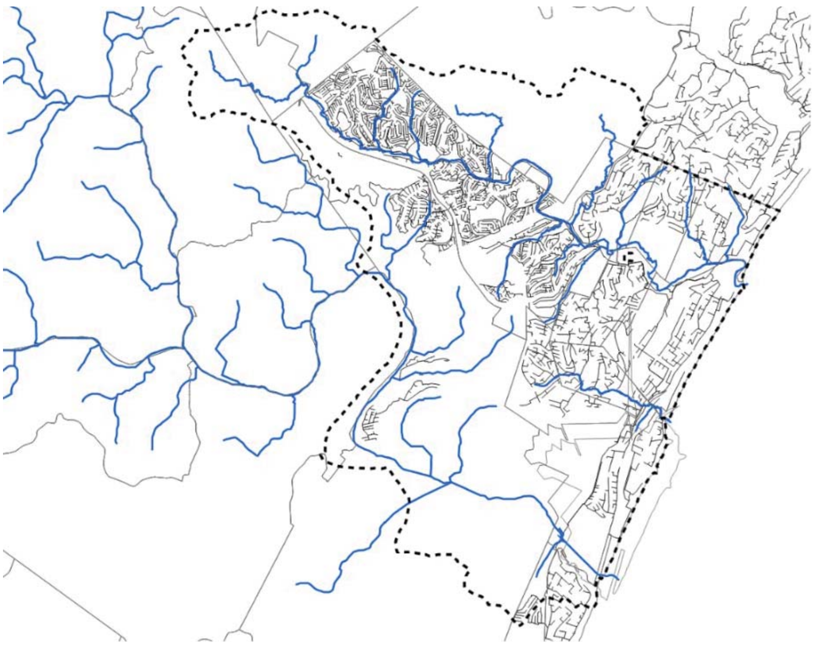


Figure 2.1. GIS map showing the distribution of rivers and sewers in relation to a WWTP catchment in eThekwini.

2.2.3.4 EXCEL and R

Excel is the spreadsheet package from Microsoft, and R is an open-source modelling language aimed primarily at statistical modelling and data analysis (R-Project, 2023), Apart from the specialised modelling packages, these general packages were extensively used for data preparation and manipulation, and for manipulating model outputs for presentation. In some cases, they were even used for simple water balance sub-models of parts of the system.

2.2.4 Data

2.2.4.1 Data requirements for IUWS modelling

Models require data for two main purposes: **input data** that are absolutely required for a model to run, and **calibration/validation data** which are compared to model outputs to check their correctness and adjust model parameters. A full integrated catchment model, by virtue of its size and complexity, has very extensive data requirements that fall into a number of categories (Table 2.3).

Table 2.3. Categories of data required for a comprehensive IUWS Model

<table>
<tr><th colspan="2">Input Data</th></tr>
<tr><td>

Geographical
Catchment boundaries
Rivers
Topography
Population distribution
Economic activities
Municipal Infrastructure
Water supply connections
Sanitary sewers
Storm sewers
Pump stations
Wastewater treatment plant configuration
Wastewater and stormwater outfalls to river or sea

</td><td>

Climate
Rainfall
Evaporation
Radiation
Wind
Temperature
Humidity
Operating data
Water supply
Sewage flow
Wastewater plant operation

</td></tr>
<tr><th colspan="2">Calibration/validation data</th></tr>
<tr><td>

Sewers
Flows
Contaminant loads
Rivers
Flows or levels
Contaminant loads

</td><td>

WWTP
Influent flow and composition
Treated water flow and composition
Sludge production

</td></tr>
</table>

Data used in models can be directly measured, for example, weather station and effluent monitoring data, data estimated from measurements, e.g. COD fractions in wastewater (Brouckaert et al., 2022) and data generated by more detailed models of the various sub-systems. For example, in Figure 2.2, calibration data for the storm water flows are generated using a SWMM (USEPA) model of the catchment.

The data that are available are typically not in the format, nor include all the details, required by the model. Therefore, the bulk of the work of setting up and calibrating a model involves the preparation and analysis of the available data. Figure 2.2 provides a schematic overview of the data requirements and sources for the different components of the IUWS model.

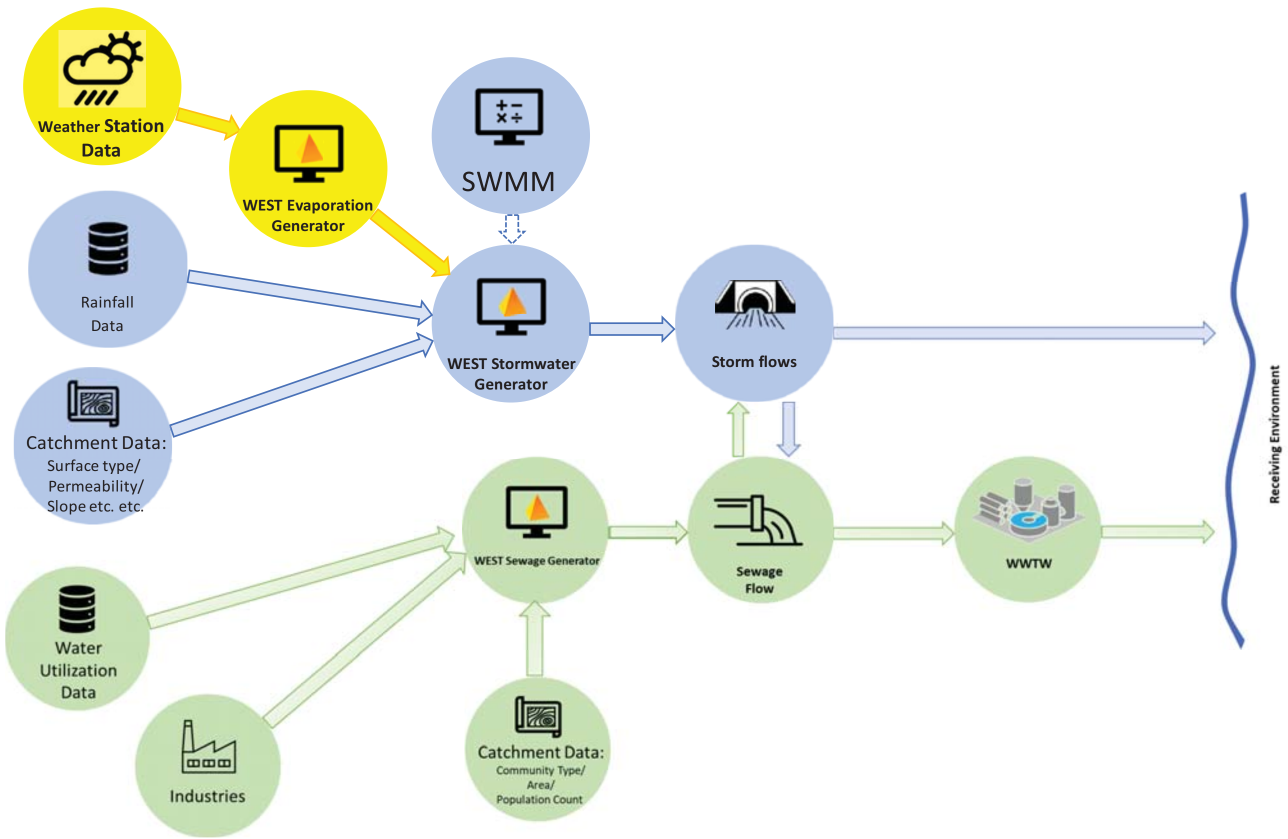


Figure 2.2. IUWS Modelling data requirements and sources

Note: groundwater infiltration into the sewers it is not a significant factor in eThekwini due to the local geology but in general can be estimated from base flow measurements or catchment data.

2.2.4.2 Data available

Table 2.4 and Table 2.5 summarize the data available for the catchment used in the IUWS modelling exercises. As shown in the tables, data needed to be retrieved from several different municipal divisions and data storage systems.

Table 2.4. System data

Source	Type of data
GIS	Sewer pipes: size, length, slope Pump stations and WWTP locations Topography Sub-catchment areas SWMM sub-catchments Rivers, gauges and sampling points Water connection locations
	Pumping network diagrams
SWMM models provided by CSCMS	Sub-catchment areas Slope Impervious fraction Pervious and impervious storage Drainage nodes
Plant operating and maintenance manual, works manager	Treatment works design data

Table 2.5. Time series data

Type of data	Source	Date range	Resolution
Rainfall	https://data.ethekwinifews.durban/	From 2013 but varies by rain gauge	5 min
Weather station data: solar radiation intensity, wind speed, air temperature and humidity		2020-	15 min
Plant inflow	Operations	2013-	Daily total
Works data: influent, effluent, process stream composition data	Operations	2013-	2-5x per week
River water quality	CSCMS	2016-2021	1x per month
Sewer blockages	Fault Management System	2019-	Date and street address
Water consumption: sewered, unsewered, domestic and non-domestic connections	Water billing data	August 2020 to January 2021	Data dumps up to once per month

2.2.4.3 Data confidentiality

The project team used water billing data provided by eThekwini to calculate dry weather flow parameters used in the model however none of the raw data was shared with the participants. Instead, an example consisting of typical water consumption data was constructed to illustrate the principles used in the calculations.

In consultation with the EWS project team members, it was decided that the name of the treatment works used in the IUWS modelling exercises would be removed from this report and the materials uploaded to the website.

2.3 MODELLING TOOL DEVELOPMENTS

2.3.1 Penman Monteith Evaporation Generator

The built-in climate models in WEST IUWS were set up for northern European and Canadian conditions. A new evaporation generator model block based on the FAO Penman-Monteith equation method (Allen et al., 1998) was developed and added to the WEST model base. This block uses location and weather station data to generate the evapotranspiration rates for the study area.

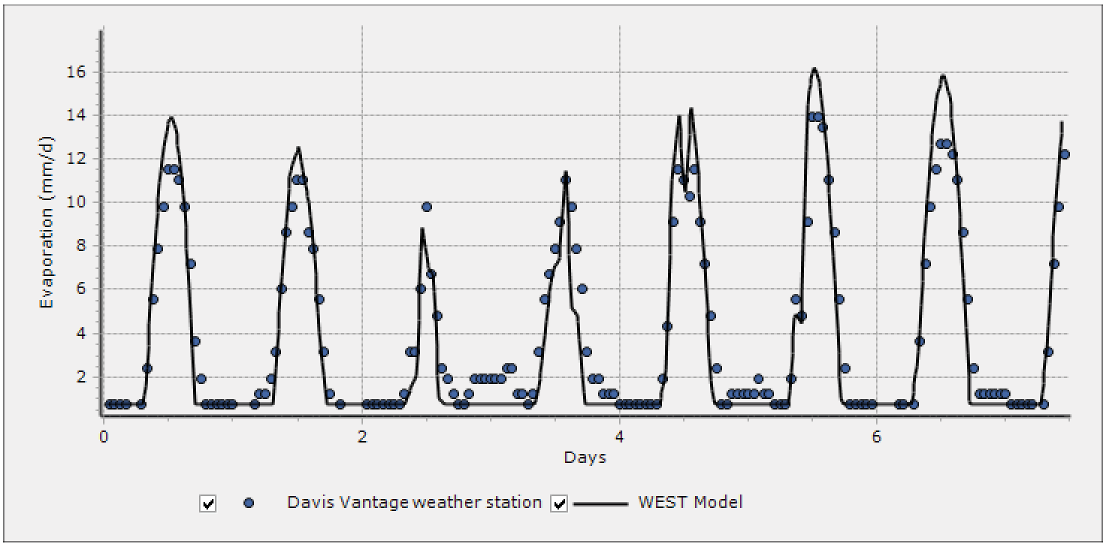


Figure 2.3. Validation of the Penman-Monteith evaporation model

2.3.2 Estimating dry weather flow from water billing data

A methodology for estimating dry weather flow and household size from water billing data based on the Litres per Capita per Day (LCD) model of du Plessis et al. (2020) was presented in **Session 9**.

Figure 2.4. High-end residential % sewer flow model as a function of annual average daily water demand (AADD). Green dots are calculated % return flow for household sized of 1 to 7 and low, average or high water use. Dashed lines are Red Book design guidelines for estimating return flow for different sizes and densities of higher income residential stands

2.3.3 Sub-catchment net runoff

A tool which can extract the net runoff from a group of SWMM sub-catchments was coded in R. This tool was presented in **Session 10.**

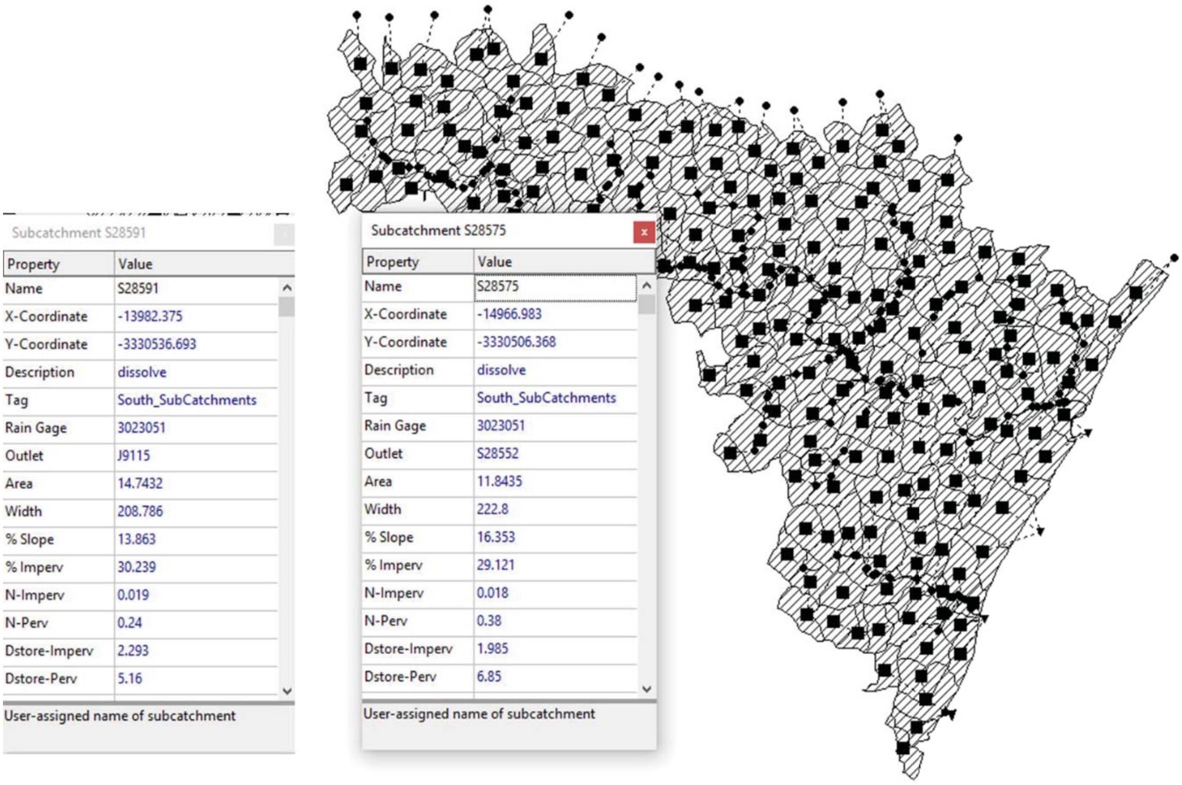


Figure 2.5. Sub-catchment properties and outlets in SWMM

2.3.4 Estimating rainfall derived inflow

A cross-correlation tool which can be used to determine the impact of rainfall on the WWTW inflow was coded in R. This tool was presented in **Session 11.**

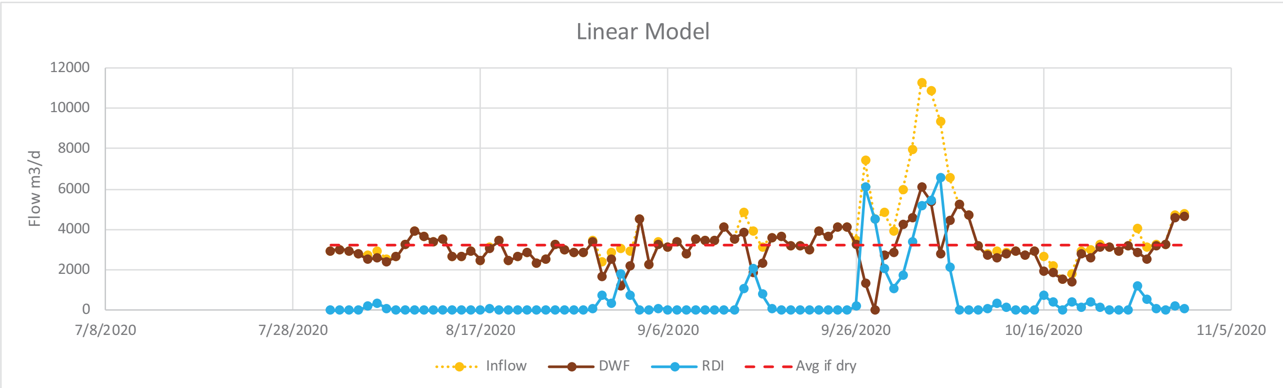


Figure 2.6. WWTW inflow, dry weather flow and rain derived inflow calculated using a linear model based on cross correlation analysis

All of the new tools are available from the website described in **Section 3.1**.

2.4 TRAINING OUTCOMES

Two series of training sessions were conducted: the first series before the Covid-19 lockdown, which covered WWTP modelling, and the second after lockdown, which presented IUWS modelling.

2.4.1 WWTP modelling

The training started with a refresher course in modelling of biological wastewater treatment processes (Section 2.2.1.1). A number of case studies of WWTPs were completed using the Plant Wide Steady State Design Model (PWSSD) (Wu, 2015) and WEST (MikebyDHI) dynamic simulation platform. These included models of EWS's Kingsburgh, KwaMashu, Phoenix and Umbilo plants. These models highlighted different aspects of WWTP modelling, including capacity estimation, design for upgrade, assessing resource recovery potential, response to varying loads and risk assessment. The KwaMashu case study started during these training sessions was further developed and published under the ERASE project (Brouckaert et al., 2022).

The training emphasised the use of a *probabilistic fractionator* to convert routine plant measurements into the required model influent components, originally developed for case studies of eThekwini's Umhlanga WWTP and Umgeni Water's Darvill plant (Brouckaert et al., 2016). This avoids the need for expensive and time-consuming measurement campaigns to generate all the influent data required for the models. During the ERASE project a COD fractionator and mass balance reconciliation tool was developed to estimate the influent COD fractions from plant operating data e.g. reactor solids, effluent COD and TSS, and sludge production and inorganic solids (IS) content (Brouckaert et al., 2022). This tool is also able to estimate some operating parameters such as the activated sludge plant sludge retention time (SRT) and anaerobic digester hydraulic retention time (HRT) where these data are missing or unreliable. The use of these tools was demonstrated as part of the various case studies and training.

During the course of the training a model of the Phoenix WWTP was adapted to allow rapid assessment of the effect of failure or impairment of a range of critical items of equipment (aerators, filter presses, pumps etc.) on process performance. This kind of model can be used as a tool for quantitative dynamic risk assessment (Figure 2.7).

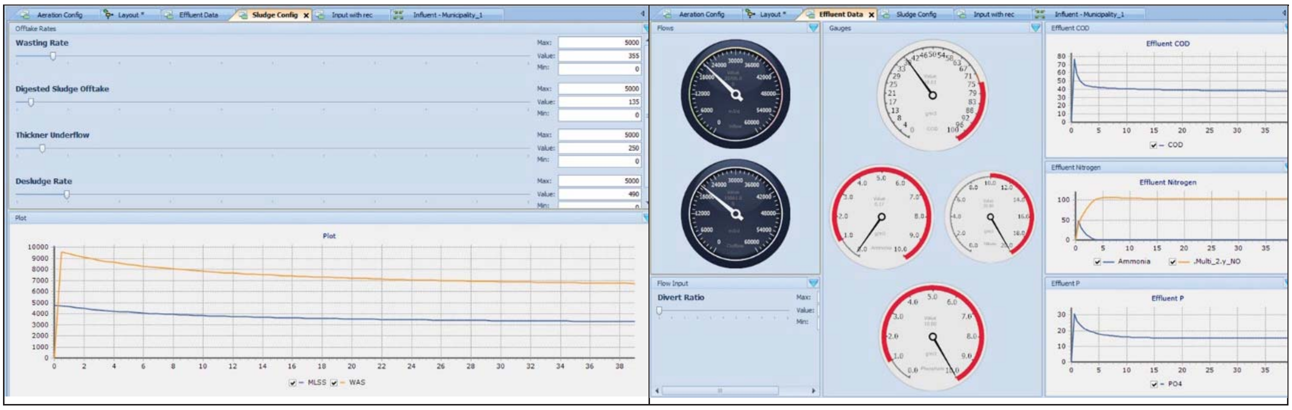


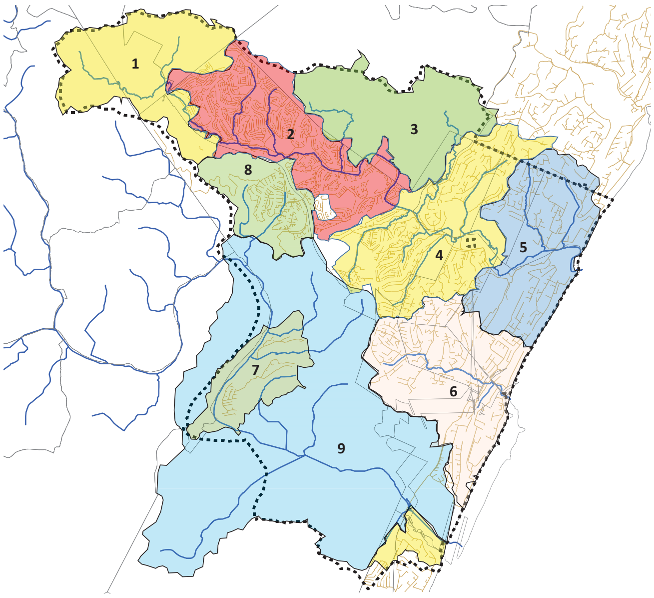
Figure 2.7. Dashboard of the equipment failure risk assessment model of the Phoenix WWTP.

2.4.2 IUWS modelling

The training had as its nominal goal the development a model of the entire catchment of a WWTP in the eThekwini metro area, including the river catchments it overlaps with. This was to ensure that all relevant issues were identified and addressed. However, it was also recognised that this goal was unlikely to be fully realised during the course of the project, due to the size of the system and the extent of the data requirements.

With no history of this kind of modelling in the municipality, much of the necessary data has never been recorded, and one of the objectives of the project was to identify important gaps. What was eventually achieved was a model of a connected part of the WWTP catchment which included examples of all the major elements: populated and un-populated areas, sewers, and wastewater treatment plant with sections of river above and below it.

The sub-division of the WWTP catchment into sub-catchments with different runoff drainage and land-use characteristics is shown in Figure 2.8.



Runoff from sub-catchments 1 to 6 drains to the smaller northern river catchment
Runoff from 7 to 10 drains to the larger southern river catchment
1, 3 and 9 are un-sewered areas
5, 6 and 10 are commercial areas;
4 contains affluent suburbs;
2, 7 and 8 contain lower income townships

Figure 2.8. Division of the case study WWTP catchment into sub-catchments

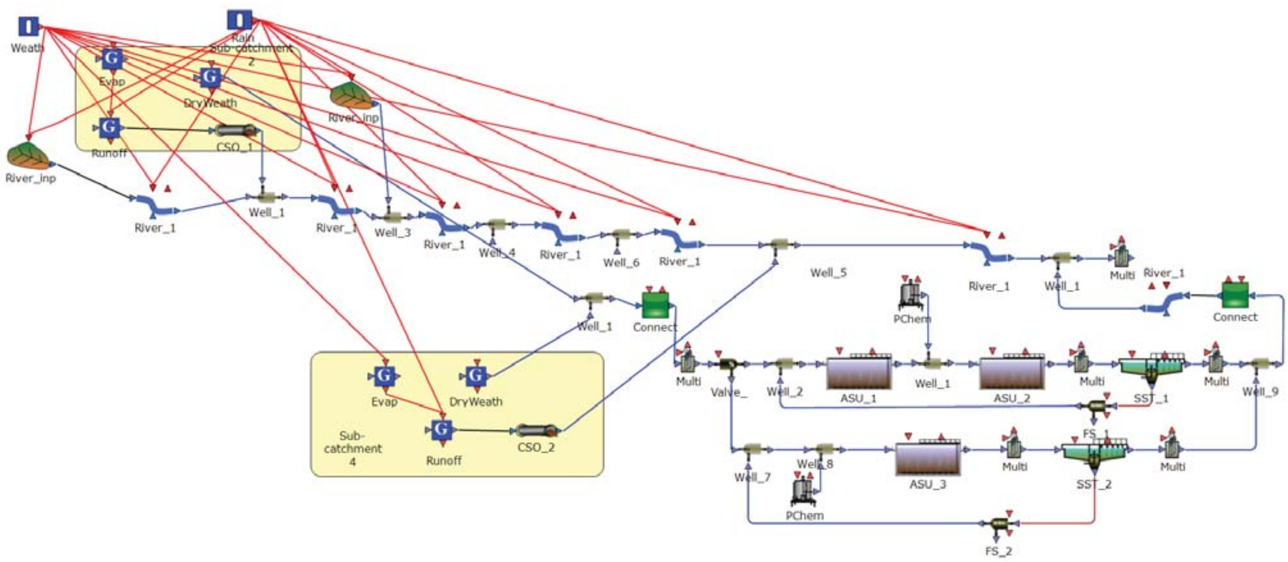


Figure 2.9. WEST layout for integrated model including the river sections in sub-catchments 1-4. Sub-catchments 2 and 4 are populated and have associated dry weather and run-off generators while sub-catchments 1 and 3 are unpopulated and represented by river inputs only.

Figure 2.9 shows the partial WEST model of the catchment in Figure 2.8 which includes the WWTP, sub-catchments 1 to 4 and the sections of river which run through them. Where appropriate data were available, calibration exercises were performed on some of the sub-systems. In particular, the SWMM models set up by eThekwini's Coastal Stormwater & Catchment Management division could be used to generate calibration data for the stormwater runoff and river models, illustrating the importance of different departments and organizations in the water sector working together to share data, tools and expertise in order to build integrated models. However, an overall calibration of the model was not possible within the scope of the project.

2.4.3 Data gaps

The most critical data gaps related to the temporal and spatial resolution of the available flow data. Higher resolution flow data is required to, for example, determine where storm water enters the sewer system and when and where sewer overflows occur. Ideally, there should be at least one flow measurement point for each of the sub-catchments in the model.

As indicated in Table 2.5, rainfall and weather measurements were available at 5- and 15-minute increments respectively but the only measurement of the sewer flow was the inflow to the WWTP provided as a daily total. There was also no pump station operating data which could have been used to estimate the flow in some of the sub-catchments. This is a fairly typical situation for most catchments in most municipalities since detailed high resolution flow data are not required for regulatory compliance purposes. The lack of these data constitutes a significant barrier to the proper calibration of IUWS models. However, the modelling exercise itself can help to identify the critical points in the network where additional flow measurements are required.

Other challenges relate to data which are much more difficult to measure, for example, pollutant loads in runoff from informal settlements and sewage spills due to blocked and damaged sewer pipes. The municipality's sewer fault reporting system mentioned in Table 2.5 can provide valuable data on the cause, frequency and general location of sewage spills but provides no information on the volume or duration of spills. Incorporating these effects into an IUWS model calibrated for South African conditions will likely require the development of new sub-models for wastewater loads from unsewered settlements and stochastic models for sewer blockages.

2.4.4 Key lessons and challenges

The training sessions included opportunities for the participants and trainers to engage in in-depth discussions on topic areas that were presented. This allowed participant to contributed their experience and knowledge, and identified prospective areas to improve on. The key lessons and challenges that emerged were as follows:

1. Current versions of the IUWS model were developed for European and Canadian conditions and need to be adapted to better reflect South African conditions. Specific issues which were identified include the built-in climate models, the representation of separate vs combined sewers, and the representation of greywater flows from informal settlements.

2. 90 % of the modelling effort involves identifying, acquiring, analysing and preparing the data required to set up and calibrate the IUWS model for a specified urban water system.

3. Given the complexity of catchments and sewer networks and the limited data available on the actual conditions, it is easy to get lost in the details, particularly with respect to what data are and are not available, and consequently what can and cannot be modelled with any certainty or level of detail. Therefore, it is important to have clearly defined and realistic modelling objectives and to keep them in mind in determining the modelling approach, and where the main efforts need to be focused.

4. Remote learning has the advantage that participants who would not otherwise be able to attend can join from different locations. However, remote participation is vulnerable to connectivity and other technical problems. It is also more difficult to help participants with software and licence problems and to get feedback on whether they are struggling to follow the material (participants generally kept their cameras off to save bandwidth). For hybrid sessions, it is important to ensure that remote participants are able to hear any discussions occurring in the in-person meeting room.

5. Every effort should be made to ensure that participants have working versions of the software and that all compatibility issues have been resolved by the first session so that they can participate fully in the training exercises.

2.5 CONCLUSIONS

A training course on the Integrated Urban Water Systems model in WEST using an eThekwini WWTP sewer catchment as a case study was developed and presented to a group of municipal wastewater engineers with the aim of building capacity in this type of modelling. Although a fully calibrated system model could not be achieved within the time and with the data available, all the elements of the model and types of data available were presented and discussed. Several tools were developed to convert the various types of data into the inputs required for the IUWS model. An important development was the coding of an evaporation generator block based on the Penman-Monteith equation, which uses local weather station data as inputs. All training materials and tools are being uploaded to a dedicated website currently hosted by the WASH R&D Centre. In consultation with participants from EWS, steps have been taken to protect the confidentiality of some of the municipal data used where deemed appropriate.

CHAPTER 3: COMMUNICATION AND DISSEMINATION

3.1 IUWS MODELLING WEBSITE

A webpage was developed on the University of KwaZulu-Natal WASH R&D Centre website to publish material associated with the training courses delivered as part of this project. The website structure is illustrated in Figure 3.1 and detailed descriptions for each of the webpage subcategories are provided below.

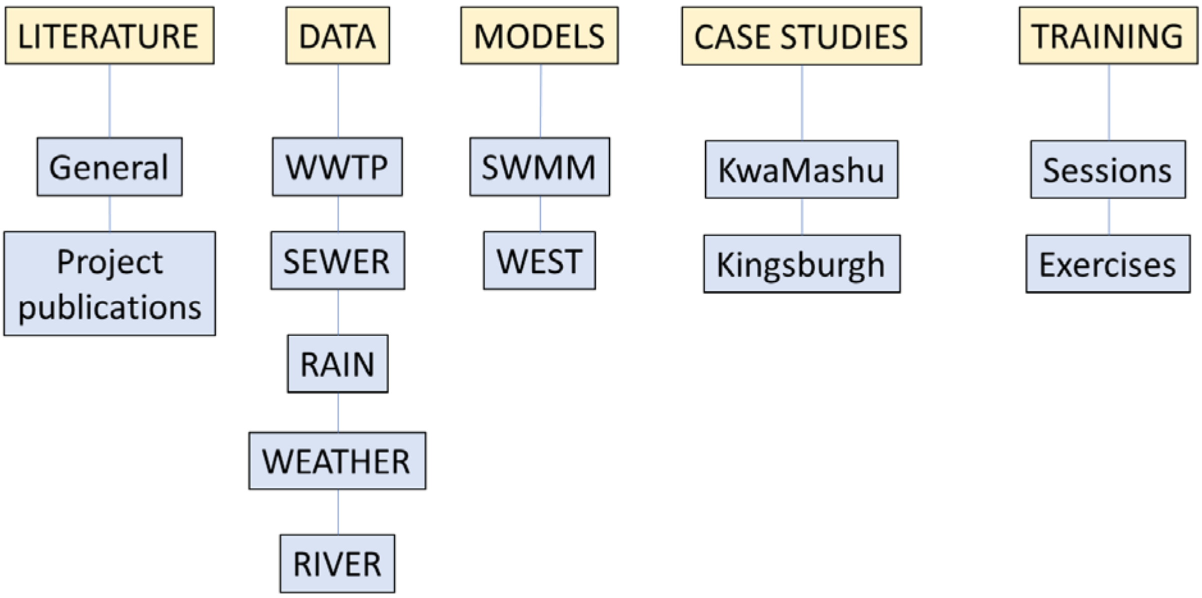


Figure 3.1. Modelling website structure

- The LITERATURE subcategory contains a list of papers that were found useful in compiling the training courses and publications that emanated from the project itself.
- The DATA subcategory contains various categories of data used in models that were constructed for training purposes, either as illustrative case studies or as training exercises.
- The MODELS subcategory contains the models used for training sessions and exercises. These include the model set-up files for the EPA SWMM (Storm Water Management Model) and the WEST modelling platforms, but not the installation files for the platforms themselves, as these are available from their respective websites.
- The CASE STUDIES subcategory contains modelling studies conducted in collaboration with EWS which extended beyond what was presented and discussed in the training sessions.
- The TRAINING subcategory contains the material presented in the training sessions and exercises. Training sessions include slides and notes that were presented or discussed, while the exercises consist of problem statements, relevant data files and modelling tools, spreadsheets, and worked solutions.

The web page can be accessed on the following link:
https://washcentre.ukzn.ac.za/integrated-urban-water-modelling-website/

3.2 WISA MODELLING AND DATA DIVISION

The establishment of the Water Institute of Southern Africa (WISA) Modelling and Data Division was approved by the WISA Board on 25th March 2021. An online inaugural workshop to launch the new division and to publicise its mission was held on 7th May 2021. The inaugural committee of the division consisted of modelling research colleagues from the Universities of KwaZulu-Natal and Cape Town, and from eThekwini Water and Sanitation. This was Deliverable 2 of this project.

The specific aims of the Division are:
Data acquisition for the water and sanitation sector through

- Advancing and improving efficient data generation collection techniques/processes
- Establishing a centralised virtual network for water and sanitation data across various universities and research institutes in Southern Africa, and promote means by which the virtual network would enable water systems analysis.
- Connecting data to models of water systems that support holistic management strategies.

Modelling:

- To address and promote all aspects of modelling, simulation and the formal methods of applying systems analysis to managing and improving the quality of the aquatic environment. This includes the development and application of mathematical models and modelling tools across all levels of complexity, such as optimisation algorithms, time-series analysis and forecasting, computational procedures for decision analysis and support, and uncertainty analysis.
- To stimulate and promote transfer of knowledge between academia, industry, authorities, and decision-makers across different areas within the water cycle. This is achieved through maintaining a vital support base and an electronic forum for the connection of ideas and discussion of inter-disciplinary issues, that require quantification through scientifically sound principles (i.e., using the models) within WISA to augment the engineering, social and economic elements of problem-solving with those having human, institutional and cultural dimensions to them.
- The development and promotion of the application of systematic procedures for integrated assessment towards offering holistic and tangible solutions to water and resource recovery.
- To support a transition from wastewater treatment to resource recovery in the African context. Furthermore, the paradigm shift towards resource recovery promotes the imperative need for the recycling and reuse of valuable finite materials across the water and sanitation sector.
- To coordinate education and training in modelling and data analytics for the water and sanitation sector.

3.3 WISA 2022 WORKSHOP

A workshop was held at the WISA Biennial Conference and Exhibition 2022 in Sandton, entitled *How can we improve the uptake of modelling for the management of water and wastewater in Southern Africa?* with presentations by Chris Brouckaert (UKZN), Xavier Flores-Alsina (DTU), David Ikumi (UCT), Mohammed Dildar (EWS) and James Topkin (ERWAT).

Dr Flores-Alsina presented a well-resourced state of the art European case study representing the level of modelling capabilities which can hopefully be built over time. The presenters from UKZN, UCT and ERWAT discussed the challenges and barriers to modelling in South Africa but also stressed that useful results can and have been achieved with simpler and less expensive models. The development of methods and tools for getting quality data for modelling and the use of modelling for training purposes was also emphasized. Mohammed Dildar presented a management perspective on modelling and data integration and highlighted the need for including system thinkers in municipal planning and decision making. Other attendees noted that the potential cost savings that can be achieved from modelling for optimization is a strong selling point.

3.4 ETHEKWINI INFORMATION SHARING WORKSHOP

An online workshop, entitled *Water and wastewater modelling for decision-support*, was held on 17th March 2023 for eThekwini technical personnel to promote awareness of the PES modelling group and the services that they can provide to the municipality. Presentations were made by Chris Brouckaert, Barbara Brouckaert, Kaverajen Pillay, Akash Singh and Mohammed Dildar. This workshop emphasized the importance of including municipal decision-makers in the design of modelling studies to ensure that the results are relevant and useful.

3.5 WISA DISSEMINATION WEBINAR

The *Introduction to Integrated Urban Water Modelling* (IUWM) was a 3-hour webinar aimed at professionals who need an introduction to modelling that supports the holistic management of water in the urban environment. The webinar also served as a WISA Modelling and Data Division event, and was hosted on the WISA Zoom online platform on 16th May 2023. Invitations were sent to all WISA members, and there were 83 attendees.

The programme included presentations by Chris Brouckaert and Barbara Brouckaert of UKZN, and Kaverajen Pillay, Akash Singh and Mohammed Dildar of eThekwini Water and Sanitation. These covered basic theoretical concepts and methodology, data and software requirements, and some examples of models developed during the course of the project. In the summing up, Mohammed Dildar presented a management perspective on how modelling can contribute to better decision making for urban water and wastewater management.

3.6 COCREATE MYCITY DURBAN CONFERENCE

The *Cocreate mycity Durban* conference on 8th June 2023 was sponsored and organised by the South African Embassy of the Kingdom of the Netherlands. A presentation by Akash Singh outlined modelling activities in Durban, including IUWS modelling.

3.7 PUBLICATIONS

As discussed in sections 1.3 and 2.4.1, the IUWS modelling work of this project overlapped with the ERASE (Evaluation of Resource recovery Alternatives in South African water treatment systems) project funded by DANIDA (in collaboration with the Danish Technical University (DTU) and UCT). The resulting publications reflect this collaboration in terms of the authors and topics.

3.7.1 Conferences

- A poster was presented at the 7th IWA Water Resource Recovery Modelling Seminar (WRRMod2021) entitled *Using plant data to estimate biodegradable COD fractions,* by Barbara. Brouckaert, Chris Brouckaert, Akash Singh, Kaverajen Pillay, Xavier Flores Alsina and David Ikumi.
- A poster was presented at the IWA World Water Congress and Exhibition 2022 in Copenhagen, entitled *Estimating COD fractions from routine wastewater treatment works data*, by Barbara Brouckaert, Chris Brouckaert, David Ikumi, Xavier Flores-Alsina, Elham Ramin and Krist Gernaey.
- An oral presentation was made at the 8th IWA Water Resource Recovery Modelling Seminar (WRRMod2022+) in Stellenbosch entitled *Evaluation of resource recovery alternatives in South African (waste)water treatment plants* by Xavier Flores-Alsina, Elham Ramin, David Ikumi, Damien Batstone, Barbara Brouckaert, Chris Brouckaert, Sven Sotemann and Krist Gernaey.

3.7.2 Journal papers

- *Using Plant Data to Estimate Biodegradable COD Fractions – Case Study KwaMashu WWTP,* by Barbara Brouckaert, Chris Brouckaert, Akash Singh, Kaverajen Pillay, Xavier Flores Alsina and David Ikumi. Water Science and Technology (2022) 86 (9): 2045-2058. https://doi.org/10.2166/wst.2022.314

- *Assessment of sludge management strategies in wastewater treatment systems using a plant-wide approach*, by Xavier Flores-Alsina, Elham Ramin, David Ikumi, Theo Harding, Damien Batstone, Chris Brouckaert, Sven Sotemann, Krist Gernaey. Water Research (2021) 190 116714. https://doi.org/10.1016/j.watres.2020.116714

3.7.3 Article

Wastewater Process Modelling by Chris Brouckaert and Barbara Brouckaert, Water & Sanitation Africa, May/June 2022. https://issuu.com/glen.t/docs/wasa_may_june_2022 accessed 2023-06-24.

CHAPTER 4: CONCLUSIONS & RECOMMENDATIONS

4.1 CONCLUSIONS

Integrated urban water modelling is entirely new to South Africa, although it has been applied in Europe and North America (Harremoës et al., 2002; Murlà et al., 2010; Solvi et al., 2005; Weijers et al., 2012). In its fullest realisation, it requires an enormous amount of data from disparate sources, which makes it appear to be a daunting prospect for a municipality to implement. However, our experiences have shown that even partial realisations can provide valuable information for water management decisions. Furthermore, these partial models identify the crucial gaps in the data which limit their scope and usefulness. Consequently, a long-term commitment to IUWS modelling will provide a framework for progressively improving a city's data acquisition and data management systems, and water management decision making.

Since water plays a role in almost all municipal activities, its management is typically distributed across various municipal functions, such as potable water supply and distribution, wastewater collection, wastewater treatment, stormwater management, environmental protection, revenue collection etc. Typically, these tend to operate independently of each other – in cities throughout the world, not just South Africa. Integrated water management requires integrated data management, which together imply high levels of communication and cooperation between municipal departments. Once again, having an integrated modelling framework in place will be useful for identifying gaps in the necessary institutional linkages.

The conclusions that can be drawn at this stage are limited in that they are based on the experience of providing training in IUWM, not its full-scale practical implementation. The success of a project that has training as its main objective depends on the commitment of those being trained to participate. IUWS modelling requires this participation to be very active, because the trainees themselves provide access to the systems and data being modelled.

The primary purpose of IUWS modelling is to provide scientific and technical support for water management decisions. However, decisions cannot be taken on the basis of the models alone. They are also subject to non-technical considerations, such as political priorities, financial constraints, institutional capacity, human resources etc. A decision maker must exercise judgment to strike the balance between all these technical and non-technical considerations. This means that decision-makers must also become members of the modelling team.

An ideal modelling project will be commissioned in order to support a particular decision. The decision maker will be involved in setting its scope and objectives, and specifying which scenarios need to be investigated. They will monitor the progress of the investigation to make sure that it is providing the information needed for the decision, and suggest modifications where it is not. By the time it is decision-ready, they will have a thorough understanding of its outcomes and their associated uncertainties and limitations. There is a well-known aphorism by the renowned statistician George Box that "all models are wrong, but some are useful." The above discussion shows that making a model useful is an extensive, iterative process involving the entire modelling team, which includes the decision-maker(s).

This training project has been successful in developing technical competence in a modelling team of engineers at eThekwini Process Engineering Services. This can be a valuable asset to eThekwini, and to other municipalities that might use them as consultants.

However, the issue of involving decision-makers in the modelling effort was not part of the project scope – its crucial importance was only realized towards the end of the project, after addressing the technical aspects.

Perhaps this should be a topic for future research, however it would need to be very carefully formulated, located and planned. Referring to the ideal modelling project described above, it has an implicit assumption that the decision maker involved is a competent and ethical person, pursuing the best interests of the city and its citizens, and supported by a capable organisation. It appears that the lack of these qualities is currently one of the major causes of the poor state of water management and infrastructure in a large proportion of South African municipalities (Auditor General of SA, 2023). It seems very unlikely that any modelling will prove useful in such environments.

4.2 RECOMMENDATIONS

1. An IUWS modelling framework should be adopted as long-term strategy by EWS to enhance data management and decision making.
2. Decision-makers should become actively involved in the modelling initiatives to ensure that the modelling makes practical contributions to urban water management.
3. The city needs to work towards a more comprehensive and integrated data management strategy.
4. The skills and techniques developed in training should be tested on some practical applications in eThekwini.
5. Methods need to be developed for communicating model results to decision-makers and other relevant stakeholders – for example, something similar to a Sewage Flow Diagram (SFD).
6. A strategy should be developed for extending IUWS modelling to other South African municipalities that are capable of using it effectively.

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