UNIVERSITY OF EXETER
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COLLEGE OF ENGINEERING, MATHEMATICS AND PHYSICAL SCIENCES

Modelling the Performance of an Integrated Urban Wastewater System under Future Conditions

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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ABSTRACT

The performance of the Integrated Urban Wastewater Systems (IUWS) including: sewer system, WWTP and river, in both operational control and design, under unavoidable future climate change and urbanisation is a concern for water engineers which still needs to be improved. Additionally, with regard to the recent attention around the world to the environment, the quality of water, as the main component of that, has received significant attention as it can have impacts on health of human life, aquatic life and so on. Hence, the necessity of improving systems performance under the future changes to maintain the quality of water is observed. The research presented in this thesis describes the development of risk-based and non-risk-based models to improve the operational control and design of the IUWS under future climate change and urbanisation aiming to maintain the quality of water in recipients.

In this thesis, impacts of climate change and urbanisation on the IUWS performance in terms of the receiving water quality was investigated. In the line with this, different indicators of climate change and urbanisation were selected for evaluation.

Also the performance of the IUWS under future climate change and urbanisation was improved by development of a novel non-risk-based operational control and design models aiming to maintain the quality of water in the river to meet the water quality standards in the recipient. This is initiated by applying a scenario-based approach to describe the possible features of future climate change and /or urbanisation.

Additionally the performance of the IUWS under future climate change and urbanisation was improved by development of a novel risk-based operational control and design models to reduce the risk of water quality failures to maintain the health of aquatic life. This is initiated by considering the uncertainties involved with the urbanisation parameters considered. The risk concept is applied to estimate the risk of water quality breaches for the aquatic life.

Also due to the complexity and time-demanding nature of the IUWS simulation models (which are called about the optimisation process), there is the concern about excessive running times in this study. The novel “MOGA-ANNβ” algorithm was developed for the optimisation process throughout the thesis to speed it up

while preserving the accuracy. The meta-model developed was tested and its performance was evaluated.

In this study, the results obtained from the impact analysis of the future climate change and urbanisation (on the performance of the IUWS) showed that the future conditions have potential to influence the performance of the IUWS in both quality and quantity of water. In line with this, selecting proper future conditions' parameters is important for the system impact analysis. Also the observations demonstrated that the system improvement is required under future conditions. In line with this, the results showed that both risk-based and non-risk-based operational control optimisation of the IUWS in isolation is not good enough to cope with the future conditions and therefore the IUWS design optimisation was carried out to improve the system performance. The risk-based design improvement of the IUWS in this study showed a better potential than the non-risk-based design improvement to meet all the water quality criteria considered in this study.

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LIST OF ABBREVIATIONS

AGA	Accelerating Genetic Algorithm
AMM	Ammonium
A-PIC	High-Performance Integrated Control
AR	Assessment Report
ASM	Activated Sludge Model
B	Behavioural
BC	Base Case
BOD	Biochemical Oxygen Demand
BSM	Benchmark Simulation Model
CC	Climate Change
CCU	Combined Climate Change and Urbanisation
CDF	Cumulative Distribution Function
Conc	Concentration
CSO	Combined Sewer Overflow
DO	Dissolved Oxygen
DSS	Decision Support System
DTM	Digital Terrain Model
DWF	Dry Weather Flow
EA	Environmental Assessment/Environment Agency
EIA	Environmental Impact Assessment
EQSs	Environmental Quality Standards
EU	European Union
FIS	Fundamental Intermittent Standards
FORA	First Order Reliability Analysis
FORM	First Order Reliability Method
FWLAM	Fuzzy Waste Load Allocation Model
GA	Genetic Algorithm
GB	Grey Box
GCM	General Circulation Model
GHG	Greenhouse Gas
GLUE	Generalised Likelihood Uncertainty Estimation
GSA	Global Sensitivity Analysis
IA	Impact assessment/ Impact Analysis

ICM	Integrated Catchment Modelling
ICS	Integrated Catchment Simulator
INCA	Integrated Catchment
IPCC	Intergovernmental Panel on Climate Change
IRA	Integrated Risk Assessment
IRIS	Integrated Risk Information System
IUWM	Integrated Urban Water Management
IUWS	Integrated Urban Wastewater Systems
IWWTS	Integrated WWTP-Sewer Systems
KS	Kolmogorov-Smirnov
LCA	Life Cycle Assessment
LCM	Land Change Modeller
LC50	Lethal to 50% of the organisms
LHS	Latin Hypercube Sampling
LoE	Lines of Evidence
LSA	Local Sensitivity Analysis
MC	Monte Carlo
NB	Non-Behavioural
NLP	Non-Linear Programming
ONS	Office for National Statistics
OPT	Optimisation
OWTS	Onsite Wastewater Treatment System
PCA	Pollution Control Agency
PDF	Probability Distribution Function
POMs	Programs of Measures
QUASAR	Quality Simulation Along River
RA	Risk Analysis/Assessment
RCM	Regional Climate Model
REW	Review Paper
RP	Return Period
RSA	Regional Sensitivity Analysis
RTC	Real Time Control
SA	Sensitivity Analysis
SRES	Special Report on Emission Scenario
SS	Suspended Solids

SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management
TGICA	Task Group on Data and Scenario Support for Impact and Climate Assessment
TUs	Treatment Units
UA	Uncertainty Analysis
UNEP	United Nations Environment Programme
UPM	Urban Pollution Management
Urb	Urbanisation
VSS	Volatile Suspended Solid
WaterRAT	Water quality Risk Analysis Tool
WFD(L)	Water Framework Directive (Legislations)
WGs	Working Groups
WMO	World Meteorological Organization
WQ	Water Quality assessment/management
WUs	Water-Using units
WWF	Wet Weather Flow
WWTP	Wastewater Treatment Plants