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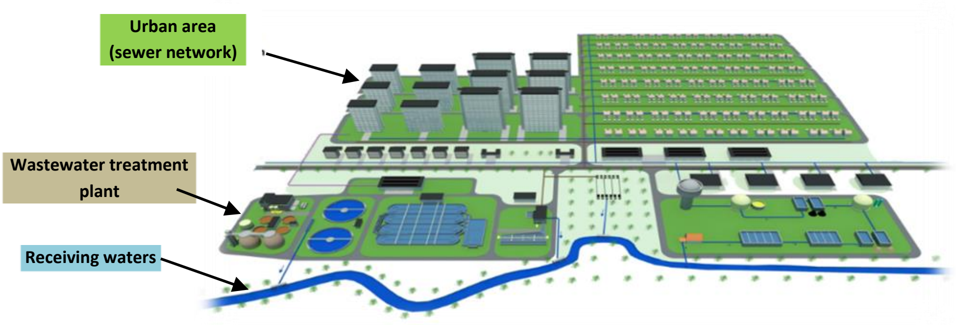
Investigation of integrated model for optimizing the performance of urban wastewater system

Ahmed Naeemah Bashara, Farhad Qaderi*

Department of Civil and Environmental Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran.

GRAPHICAL ABSTRACT



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ABSTRACT

Due to the rapid population and economic growth, the demand for water has increased. In addition, the natural resources are limited and degrade because of several factors such as the climate change. These challenges lead to reduce the ability of providing water at the required quantity and quality. One of solutions to maintain the sustainability of water supply from different sources is reuse of wastewater. For this aim, it is crucial to optimize wastewater systems. This research paper aims to describe different modelling possibilities and optimization methods for various components of integrated urban wastewater systems. The main conclusion of this research paper is the lack of study of optimum design and operation of urban wastewater systems in a holistic method. Moreover, most of previous studies on integrated wastewater management have been conducted on combined sewer systems.

1. Introduction

All biological and human activities depend on water. Recently, with development of technology and industry, Greater use of water resources, climate change, irregular urbanization and increasing population lead to increased pressure on water resources. The pollution of environment is happened as a result of human activity and harmful substances. Most of pollution (dangerous materials) is conveyed by water to dozens of kilometers away due to disposal of the wastewater on the receiving water. Therefore, there is need to collect wastewater without harming human being and environmental haleness and removing the harmful substances from the environment without causing detrimental impacts. The collecting, transporting, treating and finally releasing of wastewater into the environment (or reuse) in safe manner need to a complex system consists of the urban wastewater system. Integrated urban wastewater management poses significant challenges, but also presents a major opportunity to minimize both the impact on aquatic ecosystems and the associated costs (Benedetti et al., 2013). There are two major parts of an urban wastewater system (UWS): sewer system and wastewater treatment plant (WWTP). Each of these components can be studied separately. However, the performance of sewer system affects that of WWTP and the performance of the later influences the receiving water quality. Thus, in order to be able to optimize the performance of an UWS for the intent of reducing its effect on quality of receiving water, the interactions between these two components and the impact of the final effluent on quality of receiving water must be considered in a holistic manner.

This research paper introduces an explore the most popular modeling techniques for the components of UWS analysis, in addition to understanding their characteristics in terms of simulation techniques, interaction mechanisms, and simulations software (this is followed by a discussion on how to optimize the UWS performance, and this will be done by considering the interaction between UWS components).

2. Modelling of UWS

2.1 Modeling of sewer system

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*Corresponding author Email: F.Qaderi@nit.ac.ir

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Sewer system collects urban wastewater and conveys it to a wastewater treatment plant before disposal or recycling. Sewers can be classified into three types: sanitary, storm and combined sewer (Metcalf & Eddy, 2014). Generally, sewer system models involve convey models for quantity (hydraulic) and quality (Pollutant) through the urban sewer system. different approaches such as Saint Venant's equations and conceptual reservoir models are used to realize the hydraulic behaviour of flow within the sewers.

2.1.1. Hydraulics of sewer

Saint-Venant's equations developed to describe unsteady one dimensional flow in open channel. The Saint-Venant's equations consists of two parts of equations: one for continuity equation for unsteady one-dimensional flow and other part of equations represents the dynamic equation (momentum equation) of flow as shown below:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\partial Q^2}{A}\right)+gA\frac{\partial y}{\partial x}+gAS_f-gS_o=0 \tag{2}$$

where; A is area of flow (m^2), Q is flowrate (m^3/s), t is time (s), x is distance along the direction of main flow (m), g is gravitational acceleration (m^2/s), y is flow depth (m), S_0 is longitudinal bottom slope, and S_f is friction slope.

The main assumptions which used to drive the Sanit-Venant equations are:

- The pressure distribution is hydrostatic.
- The velocity distribution is uniform.
- The slope ((pipe/channel)) is small.
- The flow is homogeneous and incompressible.

The Sanit-Venant equations are partial differential equations and cannot be solved analytically therefore numerical procedures have to be used. Usually, input-output behavior of simulation might need to determine the flow in each pipe of the sewer network. In addition, the required detailed information and long computation times are an obstacle to the saint-Venant equations methods so there is need to simplify method to overcome these drawbacks which is called simplified reservoir model.

A conceptual tank is modeled to mimic the behavior of flow transported through the sewer network. The conceptual reservoir model can be classified into; linear reservoir models, multi-linear reservoir models and non-linear reservoir models (Saagi, 2017). The approach of linear reservoir models is based on the concept of Nash cascades simplification. The volume balance and the relationship between volume and outflow for a single reservoir are expressed as:

$$\frac{dV}{dt}=Q_{in}-Q_{out} \tag{3}$$

$$V=kQ_{out} \tag{4}$$

where; V is tank volume (m^3), Qin is the inflow to the tank (m3/s), Q_{out} is the outflow discharge from the tank (m^3/s), K is the residence time constant (sec). Multi-linear models are incorporation of various linear relationships. The function of storage volume is given as:

$$\frac{dV}{dt}=Q_{in}-Q_{out} \tag{5}$$

$$V=k(xQ_{in}-(1-x)Q_{out}) \tag{6}$$

where, x represents the relationship between inflow, outflow and volume.

Linear reservoir is modified to involve the nonlinearity between reservoir volume and outflow. The mass balance is written as:

$$\frac{dV}{dt}=Q_{in}-Q_{out} \tag{7}$$

$$Q_{out}=kV^{1.5} \tag{8}$$

2.1.2. Pollutant transport in sewers

Pollutant transport in sewer system can either be represented by advection and dispersion processes or by using completely mixed tank in series (Butler *et al.*, 2018). Advection-dispersion equation can be used to describe the transmission of soluble pollutant which is represented by (Butler et al., 2018):

$$\frac{\partial C}{\partial t}+v\frac{\partial C}{\partial x}=\frac{\partial}{\partial x}\left[D\frac{\partial C}{\partial x}\right] \tag{9}$$

where, x is the distance (m), t is the time (s), c is the concentration of pollutant (kg/m^3), v is the mean velocity of flow, D is the longitudinal dispersion coefficient.

The term of dispersion can be neglected in the case of sewer system the Eq. 9 becomes;

$$\frac{\partial C}{\partial t}+v\frac{\partial C}{\partial x}=0 \tag{10}$$

The advection-dispersion equation is a partial differential equation and therefore, requires more complicated numerical solvers, so simplified approach can be used to describe the quality model in sewers system. A simplified approach is to deal with each pipe length as a conceptual tank in which the flow and pollutants are fully mixed. The conceptual tank can be descibe by the follwing equation (Butler *et al.*, 2018) :

$$\frac{d(Vc)}{dt}=Q_Ic_I-Q_oc_o \tag{11}$$

where; c is concentration in pipe length (kg/m^3), Cl is Concentration at inlet pipe (kg/m^3), C_o is concentration at outlet pipe (kg/m^3), Q_I is flow at inlet pipe (m^3/s), Q_o is flow at outlet pipe (m^3/s), V is volume of liquid in the pipe length (m^3).

2.2. Modeling of WWTP

Usually, municipal wastewater is collected and transported to wastewater treatment plant by sanitary sewers. Based on the kind of pollutants and the required level of removal, the wastewater may be treated using physical, chemical processes or biological processes before being drainage to the environment.Traditional processes of wastewater treatment plants are included: preliminary treatment, primary sedimentation and secondary treatment. Biochemical processes and physical processes are broadly the key unit operations in a WWTP. Therefore, primary settling tank model, biological reactor model and secondary clarifier model are the major sub-model of the wastewater treatment plant for modeling the urban wastewater systems (Saagi *et al.*, 2017).

2.2.1. Primary settling tank model

The main objective of primary sedimentation unit is to take out floatable and organic settleable solids. Usually the primary settling unit predicted to remove (25-35%) BOD5, (40-60%) total suspended solids and (90-95%) settleable solids. There are many models introduced and improved to demonstrate the behavior of primary sedimentation tank. A dynamic model was developed by Lessard and Beck for describing the settling behavior in primary settling tank(Lessard and Beck, 1988). They assumed that the transported fluid and mixing properties of sedimentation tank as one or more continuous stirred tank reactor (CSTR) elements.Takacs and Nolasco developed a dynamic model to mimic the solids profile through the settling column in primary and secondary sedimentation tank based on the concept of solids flux and mass balances around each layer of one dimensional flux (Takacs I, Patryioand and Nolasco, 1991). Otterpohl and Freund developed model to describe dynamic behavior of buffered influent or sludge water concentrations of primary sedimentation tank(Otterpohl and Freund, 1992), . The development model by Otterpohl and Freund is commonly used to describe primary sedimentation tank (Saagi, 2017). Gernaey K et al. presented a development model to simulate primary settling tanks to be used in WEST simulator(Gernaey, Vanrolleghem and Lessard, 2001). The benfit of their effort is that the model is compatible with the Activated Sludge Model Number 1 (ASM1).

2.2.2. Modeling of biological reactor model

The biological treatment objectives are to coagulate and remove the non-settleable colloidal solids and stabilize the organic matter. Although there is exists many type of municipal wastewater treatment plants, this review explains on the activated sludge treatment in detail because this type of treatment now mostly used in municipal wastewater treatment plants (Metcalf & Eddy, 2014). In 1914 The activated sludge process was observed in the UK by Edward Arden and Lockett ((Metcalf & Eddy, 2014). This mechanism has been used to degrade the organic levels in effluents of urban area and industrial plants. Normally, the activated sludge treatment consists of three types of biological processes: carbon removal, nitrogen removal and phosphorus removal. Biologically, the removal of the component (carbon, nitrogen, and phosphorous) is accomplished using bacteria.. The process of activated sludge in nature is too complex to understand in detail. So, the differential equations is used to represent the complexity of activated sludge processes through the mass balances analysis which are required for most activated sludge models. For a given component , the mass balance takes the form (Metcalf & Eddy, 2014):

$$\text{Net rate of accumulation in control volume} \\ = \text{rate of flow into the control volume} - \text{rate of flow out of the control volume} + \text{net rate of generation in the control volume} \quad (12)$$

Or simply;

$$\text{Accumulation} = \text{input} - \text{output} + \text{generation} \quad (13)$$

In order to anticipate and realize certain aspects of reality, The model can be used.The activated sludge models (ASMs) was developed in 1983 by a task group of IAWQ (International Association on Water Quality) to describe the processes of biological wastewater systems. ASM1 was subsequently introduced in 1987 by IAWQ. In the community of research, enhancement and extensions of the ASM1 have been developed, although ASM1 is remains being used. the nitrification, denitrification, biological phosphorous process were described by other models (see Table 1).

Table 1. Overview of the activated sludge models (Gernaey et al., 2004).

Models	Nitrification & denitrification	Bio-P	State variable	Processes
ASM1	×		13	8
ASM3	×		13	12
ASM2	×	×	19	19
ASM2d	×	×	19	21
B&D	×	×	19	36
TUDP	×	×	17	21
ASM3-bio-P	×	×	17	23

Generally, the processes of activated sludge can be described by: 1- continuous stirred tank reactor (CSTR) models, 2- one dimensional and 3- two-dimensional models.
The equation describing CSTR model is:

$$V.\frac{dC_A}{dt} = F_0.C_{A_0} - F.C_A + r_A.V \quad (14)$$

where; F_0 and F are the volumetric flow rates of the influent and effluent, C_{AO} and C_A are the concentrations of A in the influent and effluent (or reactor), respectively, t is time, and r_A is the reaction rate of A. Activated sludge system is described by the one dimensional model which is expressed by equation 15. :

$$\frac{\partial C_k}{\partial t} + \frac{1}{A}\frac{\partial(u \,.\, A \,.\, C_k)}{\partial x} = \frac{1}{A}\frac{\partial}{\partial x}\left(A \,.\, E_L \frac{\partial C_k}{\partial x}\right) + r_k \quad (15)$$

where; C_k is the concentration of a specific component k, A is the cross-section area of reactor, t is the time, x is the distance along the axis of reactor, u is the velocity along reactor, EL is the longitudinal dispersion coefficient, r_k is the source/sink term for wastewater constituent k. Two-Dimensional Activated Sludge Model is described by the equation 16:

$$\frac{\partial C_i}{\partial t} + \frac{\partial}{\partial x}(u\, C_i) + \frac{\partial}{\partial y}(w\, C_i) = \frac{\partial}{\partial x}\left[k_x \frac{\partial C_i}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial C_i}{\partial y}\right] + R_i \quad (16)$$

where, C_i is the concentration of component-I, u is the flow velocity component in x-direction (longitudinal axis), w is the flow velocity component in y-direction (vertical axis), kx and ky are the dispersion coefficient in x and y-direction, respectively and R_i is the reaction term of component-i as specified by ASM1. The analytical solution for the equations of the ASMs model is impossible so numerical techniques must be used Table 2 lists different computer programs that are used activated sludge models.

Table 2. Activated sludge simulator.

Owner	Simulator
EAWAG in Switzerland	ASIM
EnviroSim in Canada	BioWin
DHI in Denmark	EFOR
Hydromantis in Canada	GPS-X
IFAK-System Gmbil in Germany	SIMBA
WRc Group in UK	STOAT
Hemnis N.V. in Belgium	WEST

2.2.3. Secondary settling tank model

The integral part of the activated sludge process is the secondary clarifier which is used to separate the treated wastewater effluent from the sludge. Some portion of sludge is recycled back to aeration tank and the remain is transported to the sludge thickener. The separated treated effluent from sludge is either discharge as an overflow or delivered to tertiary treatment. The complexity of the secondary settler behavior and it is large importance for the successful working of the activated sludge operation have made the settling process is a major issue for researchers. For that reason, different models are presented. Takacs 's model for secondary settling tank is commonly used for the majority of the WWTP (Saagi, 2017). Takacs and Nolasco developed a dynamic model to simulate the clarification-thickening process. Takacs's model used to mimic the solids profile throughout the settling column. The settler in this model is divided into five different layers: top layer, layer above the feed layer, feed layer, layer below feed point and bottom layer. Based on the solids flux concept and mass balance around each layer of one-dimensional settler. Takacs 's model is simulated the profile of solids (Takacs I, Patryioand and Nolasco, 1991).

2.3. Modeling of river systems

A body of water which receives treated or untreated wastewater such as ocean, river, lake or other similar body of water is referred to as receiving water. Generally, seas, lakes and rivers can be distinguished as the main types of receiving water. Usually, in most countries' rivers are utilized as a discharge point for WWTP effluent.

2.3.1. Hydraulic modeling of river systems

De Saint-Venant equations can be used to describe the river flow systems as for sewer system but with some differences, the sewer pipes are prismatic while the river is different. Another method which approximately can be used to describe the flow spreading in river is CSTRs which is known as storage routing method which is used the following Eqs.:

$$\frac{dS}{dt} = I(t) - O(t) \quad (17)$$

$$S = f_1(O(t)) + f_2(I(t) - O(t)) \quad (18)$$

where, I(t) is the inflow at time t, O(t) is the outflow at time t, S is the storage at time t.

2.3.2. Quality modeling of river systems

The pollutants routing in river systems can be modeled either by advection-dispersion equations or by CSTRs in series. Different models have been developed for the convention processes in river water qualitysuch as QUAL2E and RWQM1 models which are the main trends in river water quality modeling. RWQM1 was developed to overcome some of the problem with QUAL2E model also RWQM1 model is compatible with activated sludge models (ASMs).

2.4. Modeling of integrated urban wastewater systems

Modeling interaction between two or more systems is the define of the integrated modeling such as sewer system, WWTP, and river. The entire models of UWS are developed and integrated to depict the whole system and used for holistic analysis of the performance of the UWS. Currently, the components of UWS (sewer system, WWTP, and river) are designed and operated as separated components. Presently, there is trend to enhance the performance of the system and its impact on river via considering the interaction between system elements as a holistic manner. In the last few decades integrated analysis of urban wastewater systems has increased attention between researchers.

Muschalla suggested a six-step standardized procedure to modeling the integrated urban wastewater systems which is summarized as below (Muschalla *et al.*, 2009):

1. System analysis.
2. Processes and criteria.
3. Modeling approaches and data demand.
4. Analysis of data and model.
5. Model calibration and validation.
6. Model application: analysis of scenarios.

There is two approaches of integrated modeling; sequential and parallel modeling. The sequential approach implies the use of sub-models that are run one after other over the period of simulation while the parallel method all elements of the systems are simulated simultaneously. For integrated modeling of UWS there are some commercial/ free software available from different organization such as WEST, SIMBA#, CITY DRAIN and BSM-UWS software simulators. Table 3 presents a summary of previous studies which is conducted on hypothetical or semi hypothetical case studies of UWS.

3. Results and discussion

3.1. Optimization of sewer networks

Optimization can be used to find the optimum design of a sewer system. Consequently, reducing the construction and/ or operation cost under particular constraints are the main goals for the designer. In the last decades, considerable number of researches have been carried out to find the optimal hydraulic design of sewer network. Guo et al. presented a systematic review on optimal design storm sewer networks (Guo, Walters and Savic, 2008). Several advantages of optimal design as compared with traditional approaches were reported in this review, such as, the hydraulic design of the system that can be integrated with the cost.

Table 3. Summary of previous studies for urban wastewater system.

Aim of study	Type of case study	Main finding	Author’s prospective	References
To analyze the potential of integrated control of the UWS in its entirety and to introduce a holistic tool for simulation and optimization.	Semi-hypothetical case study	It was found that the performance of UWS could be enhanced by the integrated control	It was recommended to study an additional framework in practical to predict future state of the system and getting data from the sensor from the river which is located at the downstream of the discharge of wastewater in addition it was suggested to developed model using multiple objective optimization algorithms.	(Schütze et al., 2002)
To investigate of using an integrated modeling and control of urban wastewater systems in order to improve the dissolved oxygen concentration performance in the river using control theory application	Real case study	It was concluded that the application of control theory could be used to enhance the performance of WWTP and the performance of the dissolved oxygen concentration of the river. Also make efficient use of storage capacity for the sewer system	N/A	(Katebi and Graells, 2005)
To study the effect of future climate change and urbanization on the performance of an UWS by optimization.	Semi-real system	The results were obtained indicated that the considering sewer and WWTP systems as integrated systems could give the best/target performance	It was suggested that to test and verify the optimization techniques for realistic case studies in UK and other countries. Also, it was proposed to use UKCIP09 scenarios to improve representation of climate change. Additionally, it was recommended to study other climate change, urbanization and system parameters to analyze the performance of urban wastewater systems.	(Astaraie-Imani, Kapelan and Butler, 2013)
To use mathematical models to control the diluted wastewater which is discharged from over flow system of combined sewer to conserve the water resources	Real system	It was found that the active mixing ratio of rainwater and urban wastewater discharging from combined sewer overflow system is 1:4	N/A	(Pijáková and Derco, 2015)
To present a free toolbox (BSM-UWS) to predict the behavior and evaluate control strategies in UWS. The sub-model of the sewer was formulated as a series of linear reservoirs with different volumes. Otterpohl’s model was used to simulate the primary clarifier, ASM2d was utilized to describe the biological reactor and the secondary settler was simulated using Burger-Dehl’s model. A simplified version of RQWM1 was used to simulate the river system; the stretch of river was represented as a series of tanks	Hypothetical case study	The main conclusion of this work that the BSM-UWS platform can be used to improve the quality of river water and the control strategy to maximize the utilization of wastewater treatment plant capacity	It was proposed to apply the BSM-UWS and adapt it to other catchments	(Saagi et al., 2017)

Multiple conventional optimization methods have been conducted on sewer system, including, Linear Programming, Non-Linear Programming, Successive Linear Programming and Dynamic Programming. However, the efficiency of such methods was limited as a result of the inflexible requirements. Recently, the development and application of various types of evolutionary algorithms have been increased in water resources planning and management. The Genetic Algorithm (GA) appears as the most popular and efficient method in optimization. A comprehensive literature review on GA for optimal design of sewer network can be found in Nicklow, et al. 2010. different studies have been conducted to optimize the hydraulic design of sewer system using GA, which can be found in literatures (Nicklow et al., 2010; Sadeghi, Samani and Samani, 2022;). Other well-known methods have be used to find the optimal design of sewer networks system, such as, Ant colony optimization Moeini, 2017), Particle swarm optimization (Ahmadi, Zolfagharipoor and Nafisi, 2018), Simulated annealing and Tabu search (Haghighi and Bakhshipour, 2015). However, these methods involve the same characteristics of GA when it is conducted on large sewer network system but with less efficiency.

3.2. Optimal design and performance of WWTP

The purpose of the optimal design of WWTP is to reduce the cost of construction and/or operation. This taken in account while maintaining the standard specifications of the disposal wastewater to environment such as BOD and dissolved oxygen. An admissible set of process variables and operating conditions are generally determined by using an objective function. The optimized performance of WWTP can be define as consistently satisfying the performance aims for every unit of treatment processing. Recent, similar to sewer system, there have been several research proposed using different optimization techniques to find the optimal design and/or performance for WWTP (Sinwar et al., 2021; Shen et al., 2023). There are some advantages of optimal design and/or performance of WWTP as presented in the literature including the following:

1. The planner can test different scenarios by using models and optimization techniques.
2. Solution methods might involve composition of operational variables and treatment process.
3. Optimization methods could reduce the cost as compared with classical design methods.

On the other hand, there are several limitations and gaps can be identified from the literature, and they are as following:

1. The objective function of the optimal design of WWTP must be at least has two objective functions (bi- objective function) while it is used a single objective function in some research.
2. Despite reducing the cost function is the main objective function in optimization problems, the definition of cost function needs to be developed in order to represent other additional cost, for example, operational cost not only design cost function.
3. There still lack in literature of optimization for WWTP in using multi-objective optimization methods.

3.3. Optimization of the integrated UWS

This section introduced a literature review of previous studies that include the interaction between the elements of design process. As anticipated, there are few research studies exhibit any actual components interaction. In general, the majority of previous studies were driven to discover the optimal control strategies to reduce the detrimental impact on receiving water (Schütze et al., 2002; Saagi, 2017). Such studies have considered the interaction between the sewer system and WWTP for the system under study. Reducing the contamination in receiving water is the main goal of the design of integrated UWS which is reflected the aim of studies found in the literature. some of the applications that have been reviewed involve water quality of river as the objective of the optimization. Moreover,

conceptual models and tank in series are used to simplify the sewer system and the model of water quality in river. In addition, simplification approach sounds to be in line with objectives of optimization. Schütze, et al. carried out various optimizations methods and concluded that the GA is the best and most efficient optimization algorithm. Using the single objective optimization is the main limitation of studies in the optimal design and operation of integrated UWS, although the optimization for integrated approach must be simulated by using multi-objective optimization mechanisms which is recommended by Schütze, et al. Generally, the optimization of UWS has the following components:
1. The objective function and the decision variables of the optimization must be identified to express the optimization problems.
2. To solve the optimization problem, an algorithm must be chosen.
3. The modelling tool must be put up to estimate the objectives.

3.3.1. Objective functions in UWS

All variables in urban wastewater system models must be nonnegative, although more restricted bounds are imposed to some of the variables due to operational and design consistencies such as in Table 4. Different cost functions (objective function) is gathered inTable 5 that may be used to estimate construction and operation costs in urban wastewater system.

Table 4. Design variables and operating parameters.

Unit	Design variable and Operation parameter	References
Sewer system	• Cross sectional area • Velocity • Wetted perimeter flowrate	(Heydarzadeh, Tabesh and Scholz, 2019)
Sedimentation tank	• Detention time • Surface loading rates • Weir loading rate • Scour velocity Type, size and shape of the tanks	(Padrón-Páez, Almaraz and Román-Martínez, 2020)
Aerobic processes	• Dissolved oxygen concentration • Process kinetics (rate expression) • Kinetic parameters (reaction rate constant) • Reactor volume • Residence time • Solid’s retention time and loading • Mass transfer coefficient in aeration process (k_La) Temperature	(Padrón-Páez, Almaraz and Román-Martínez, 2020)

4. Conclusions

The integrated model for UWS is composed of three models: sewer system model, WWTP model and receiving stream model. Sewer system model is composed of two sub-models; flow and water quality models. WWTP model is composed of a number of sub-models; each one is used to simulate specific unit in the considered treatment plant. The receiving stream model is composed of two sub-models: hydrodynamic flow and water quality models. Several mathematical models are available in literature for each sub-model. The selection and execution of available models is based on the following considerations; firstly, model complexity: the mathematical model must be complex enough to accurately depict the real situation. Secondly, suitable process description and state variables of the model must be chosen. The state variables in all selected sub-systems must be described in similar way. Finally, the model needs to maintain close mass and elemental balances.

The reviewed literature illustrates that the research on the field of design and/ or operation optimization of the integrated UWS take into account the interaction between components is early stage and needed more research. Gaps that can be seen in previous studies:
1. The optimum design and operation of UWS in a holistic manner has not been studied widely.
2. Most of previous studies considering integrated wastewater management have been conducted on combined sewer systems. Such studies based on developed countries that faced the problem of discharging untreated wastewater through the overflows of combined sewer systems. Whereas the developing countries faced the problem of discharging badly treated wastewater into the receiving streams from sanitary sewer systems as a result of operation and design problems in these systems.
3. Most studies in literature have been conducted on integrated urban wastewater treatment, which was focusing on the study of the control strategies with oversimplified to represent the system as a holistic manner. Fewer case studies of optimal design and operation have been found in the literature.
4. Less studies in literature used optimization methods to solve the multi-objective optimization problems in the field of UWS.
5. Most of the previous research was conducted on hypothetical and semi-hypothetical case studies. Such studies are carried out while there is need to study the interaction between the components of UWS in real case study. The reason is to understand the actual interaction between urban wastewater system components.

For future work, there are different research directions that can improve the optimal design and operation of integrated urban wastewater system:
1. Previous researches have studied the effect of combined sewer overflow on river quality using control techniques. Further studies could be conducted to optimize the design and operation cost in real case studies of urban wastewater components beside of the control techniques.
2. It is recommended to develop the integrated models using multiple optimization technique to optimize the performance urban wastewater system.
3. Studying the effects of WWTP on receiving water under different operation conditions is also recommended.
4. Recommendation to consider the construction and operation cost as the objectives to the optimization model for the integrated urban wastewater system. Also, energy consumption and carbon emissions can be considered as the objectives of optimization model.
5. Regarding utilizing the model of integrated urban wastewater systems in the literature, it was considered a semi-real (hypothetical) case study. Therefore, it could apply modeling approaches on a real case study.
6. Recently, there are various optimization techniques developed and presented such as Bee Colony Optimization, Bat Algorithm, Gray Wolf Optimization, Elephant Herding Optimization and others, that can be used to optimize the performance of UWS. The reason of such suggestion is that the recent optimization techniques are improved and developed to be more efficient, faster and simpler than old fashion optimization methods.
7. Wastewater treatment can be simulated by using several software or programming packages. For example, SWMM, BIOWIN and WASP to simulate the sewer network, WWTP and the processes in river, respectively. In order to apply the aforementioned models on real case studies, it is suggested to select the city of Amarah, which is located in the south of Iraq. The urban wastewater system of the city of Amara consists of the sewage network, Al-Bterah WWTP and Al-Bterah river. For this, practically, it is possible to study the performance optimization of UWS of the city considering the interaction between its components.

Table 5. Examples of construction and operation cost functions**.**

Unit	Construction cost function	Operation cost function	References

Sewer system	Cmi = km Li Dim	N/A	(Gupta, Ray and Labhasetwar, 2021)
	$\sum_{i=1}^{N} LiKi(di, E_i^{ave})$	N/A	(De Villiers, Van Rooyen and Middendorf, 2017)
Sedimentation tank	2630 $A^{0,678}$	P = θ.A^b	(Gillot, S., De Clercq, B., Defour, D., Simoens, F., Gernaey, K., Vanrolleghem, 1999)
	375$F^{0.7}$ F in m^3/d	11.02$F^{1.01}$ F in m^3/d	(Padrón-Páez, Almaraz and Román-Martínez, 2020)
	$955.5A_s^{0.97}$	$[0.01\Gamma+0.02\Gamma(1+i)^{-10}]148.6(As\ h)^{1.07}$	(Denysiuk, Santo and Costa, 2018)
	2630 $A^{0.678}$ 6338 $A^{0.325}$	N/A	(Panaitescu, Panaitescu and Anton, 2015)
Biological reactor	10304 $V^{0,477}$	$q_{air} = (K_L a_f CsV/A\alpha\rho_{O2}y_{O2})^{1/(B+1)}$ P = $\gamma/(\gamma-1)$.P1/ η.qair. [(P2 / P1)(γ-1) / γ - 1]	(Gillot, S., De Clercq, B., Defour, D., Simoens, F., Gernaey, K., Vanrolleghem, 1999)
	$148.6\ V_a^{1.07} + 7737G_s^{0.62}$	$[0.01\Gamma + 0.02\Gamma\ (1 + i^{)-10}]\ (148.6V^{1.07}) + (1 + i^{)-10}\ 7737G_s^{0.62}$	(Esp, Fernandes and Ara, 2004) (Denysiuk, Santo and Costa, 2018)
	162F+980,820+11, 512$F^{0.4526}$ F in m^3/d	93$F^{0.834}$ + 5.25F+63,043 F in m^3/d	(Padrón-Páez, Almaraz and Román-Martínez, 2020)
	10304 $V^{0.477}$	N/A	(Panaitescu, Panaitescu and Anton, 2015)

Author Contribution

Ahmed Naeemah Bashara: Methodology, Data Curation, Writing original draft.
Farhad Qaderi: Conceptualization, Methodology, Review and editing of original draft, Supervision.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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