ECOLOGIA BALKANICA

2019, Special Edition 2 pp. 207-215

Synopsis

Modelling of Water Systems in a Convenient Way

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Abstract. Protection of water resources requires many decisions, which, in turn, can be aided by a model of the respective water system. Such a model then can be used, for example, for the analysis of various scenarios (of external forces) and various action options (which can be influenced). On the other hand, modelling often is perceived as something hard or laborious to do (and often, it is). This paper presents some examples of modelling concepts and of their implementation in an easy-to-use simulator, focusing on the combination of dynamic process models with water-balance models, assisting in the management of water resources. The contribution presents examples from various countries.

Key words: biochemical processes, modelling, river water quality, Water-Energy-Food Nexus, water systems, wastewater treatment plant.

Introduction

Management of water resources and water systems becomes ever more important. This holds true in particular in times of climate change and increased pollution of water bodies. Among the core tools supporting sustainable water management, mathematical models have emerged and are used for a wide range of tasks (BACH *et al.*, 2014). Models are considered as simplified representations of reality, often in a simplified way, aiming at assisting in certain tasks. Such tasks include not only design and operation of water systems, but also the visualisation (also to the non-expert) of relevant processes and interactions – thus models can play an important role in stakeholder participation and decision making processes. Furthermore models are useful for education and system understanding.

On the other hand, also a certain reluctance about the use and application of models can be observed. Notwithstanding the fact that modelling indeed involves a number of challenges to be addressed in any given modelling task, this paper aims to motivate the application of modelling in water management, illustrating the use of models for a number of examples. Model application is also greatly enhanced when a user-friendly and easy-to-use simulation system can be applied. The present paper illustrates modelling applications using the simulation framework Simba#, which emerged from 25 years' experience from research and application projects and now forms one of the key simulation systems in water management applied in research and practice all over the world.

Why modelling water systems?

When buying a car, it is generally accepted to be prudent to do a test drive before taking the final purchase decision. Such a test drive can assist to identify strong and weak characteristics of the car and, together with a large number of criteria usually considered (e.g. purchase price, operational costs, demand on petrol, space, colour, …), forms an important base for the decision of whether to buy the car or not. When decisions on water systems, for example, construction or extensions of wastewater treatment plants are to be made – wouldn't it also be desirable to do a "test drive" first. But how to do that, before the plant has been built? Here, modelling can assist – models, even if not calibrated and validated against data, can provide an estimate on the behaviour of the plant to be built. Design and operational options can be tested using the model, often leading to a better design of the plant and/or its better operation, resulting in considerable cost savings or reduction of energy consumption.

Obstacles to modelling of water systems

Whilst dynamic modelling of the physical, biological and chemical processes in wastewater treatment is quite widespread, using, for example the Activated Sludge Models of the International Water Association (HENZE *et al.*, 2000) and their implementation in various computer simulation programs, and, whilst also river water quality modelling is advocated, using, for example, the River Water Quality Model of the International Water Association (SHANAHAN *et al.*, 2001), or less complex models, such as those of the QUAL2 family, there is also some reluctance in uptake and use of modelling when addressing practical issues of water management.

Some obstacles to application of modelling are based on the perception that always a detailed calibration-validation process is necessary prior to any model application. For many applications this is true, and any step taken to increase confidence that the model is able to represent reality to a sufficiently accurate degree for the study under question is appreciated; however, for many applications modelling approaches these days have been established to such a degree that, at least for typical conditions (e.g. wastewater treatment modelling for typical domestic wastewater and common plant layouts), models can well be applied using default parameters. For example, DZUBUR *et al.* (2019) discuss a methodology for estimating wastewater treatment plant influent characteristics under data-scarce conditions.

Another obstacle to practical application of models is seen in the lack of user-friendliness of simulation software. This indeed can be quite a limiting constraint, as in daily practice – such as often in engineering consultancies and water authorities – not everyone is a modelling specialist as many other tasks are also to be carried out in daily routine. Based on this experience and on over two decades experience in cooperation with consultancies and water authorities and companies, the dynamic simulation environment Simba# has emerged, which meets the needs of practice – easy-to-use and quick-to-comprehend simulator, but also provides sufficient flexibility to the researcher and experienced modeller (see, for example, the feature to modify the pre-defined biochemical process models, such as those by HENZE *et al.*, 2000, or to define and solve the user's own sets of differential equations for biochemical transformations in a user-friendly way) (ALEX *et al.*, 2013, IFAK, 2018). The present paper illustrates some examples of modelling applications of the Simba# simulator and its extensions for different areas of water management.

Dynamic modelling of wastewater treatment plants

As an example, Fig. 1 illustrates a simple dynamic model for wastewater treatment plants, which also can be used to model (and to optimise) operation of the plant. The various components of the model (clarification and aeration tanks) simulate the physical and biochemical transformation processes, using, in this example, the Activated Sludge Model No. 3 (HENZE *et al.*, 2000).

Assessing of impacts of urban discharges on river water quality

River water quality in urban areas is often affected by discharges from sewer systems (e.g. combined sewer overflows), from wastewater treatment plants (treated effluents) and industrial discharges. These discharges are of quite different nature (e.g. treatment plant effluents have usually lower contents of readily biodegradable organic matter (SS fraction of Chemical Oxygen Demand) than combined sewer overflows) and their impacts are overlapping – thus making simple mixing calculations inappropriate. In order to assess the impacts of such discharges on river water quality – after cooperation projects between biologists and engineers - criteria related to duration and frequency of exposure to critical concentrations of Dissolved Oxygen and ammonium/ammonia (with their balance affected by temperature and pH of the water body) have been established in the British Urban Pollution Management Manual (FWR, 1998) and, in a similar manner, in the BWK-M3/M7 guidelines in Germany (BWK, 2004). Driven by the request of the Ministry of the Environment of the German Federal State of Hesse to develop an easy-to-apply river model, the Simple Water Quality Model (SWQM), considering the main processes related to Dissolved Oxygen and ammoniacal nitrogen (reaeration, decay, nitrification, …) has been developed (SCHÜTZE *et al.*, 2011, HMUELV, 2012) and implemented in the Simba# simulation framework.

The treatment plant model shown above is combined, within the same simulation environment, with a river model using the Simple Water Quality Model and with a hydrological sewer system model, thus forming an integrated wastewater model of a typical city in Germany (Astlingen, see SCHÜTZE *et al.*, 2017) (Fig. 2).

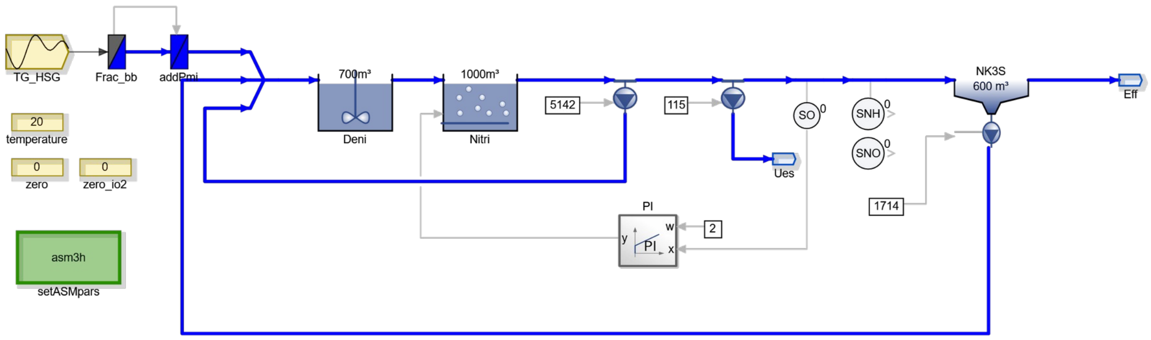

Fig. 1. Example model of an activated sludge treatment plant.

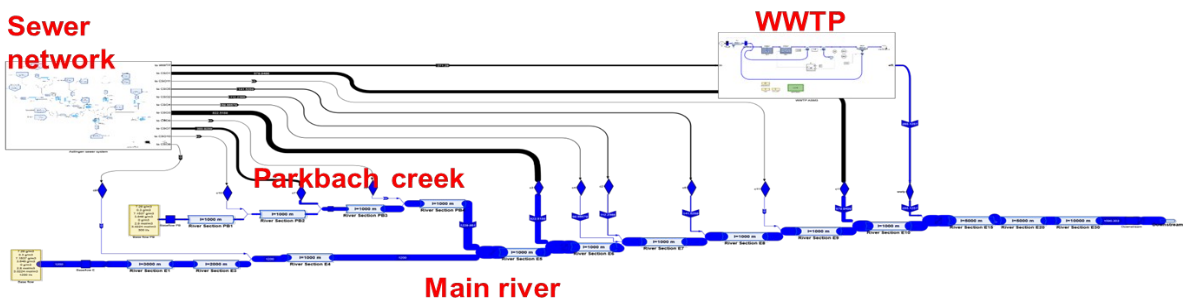

Fig. 2. Integrated model of the Astlingen wastewater system.

Such an integrated modelling setup then allows to analyse the impact of discharges and of operational measures on the river. For example, Fig. 3 and Fig. 4 compare the effects on Dissolved Oxygen of (a) limiting the influent to the wastewater treatment plant to its standard setting of 330 l/s and (b) permitting the inflow to the WWTP to be increased for one hour. MUSCHALLA *et al.* (2009) provide useful guidance to carrying out such integrated modelling studies.

Visualisation of resource fluxes in sanitation systems

Currently, there is a significant amount of discussion in Germany – and elsewhere – about new and alternative sanitation systems. Attempts are called for to reduce water demand for flushing toilets and to make better use of the resource "wastewater", calling also for increased recovery of its nutrients contents. In order to aid such discussions, a simple simulator ("SAmpSONS"), modelling and visualising resource fluxes of user-defined sanitation systems has been developed (SCHÜTZE *et al.*, 2019a), based on earlier work by ORMANDZHIEVA *et al.* (2014). Fig. 5 illustrates a simple example of a sanitation system with separate greywater treatment and co-digestion of kitchen waste and blackwater.

Combining system modelling with Life Cycle Analysis

When discussing upgrades or changes to (waste)water systems, a number of different criteria are to be considered. These often include, besides capital and operational expenditure, criteria such as energy consumption/generation, emissions of greenhouse gases, eutrophication potential, among others. Traditionally these are estimated in separate calculations, sometimes involving additional, often cost-intensive, software. Within the SAmpSONS simulator (a freely available subset of the Simba# simulation system, ifak.eu), these calculations – often forming part of separate Life Cycle Assessment (LCA) studies – are integrated with the process simulation modules. Therefore the mentioned criteria are calculated – once input data, such as unit process costs, have been provided – as a by-product of the process simulation.

Holistic system modelling

Extending the modelling scope of urban wastewater modelling to a wider system perspective, also Integrated Urban Water System models (according to the classification by BACH *et al.*, 2014) can be implemented. Such models, covering the water supply system – including groundwater resources, albeit in a rather simplified way – can assist in overall water management, in particular in water-scarce regions. In a cooperation with researchers from Israel, a (simplified) overall model of a general urban water system has been set up (see Fig. 6). This is currently being adapted to selected case study cities in Israel and in Germany. The modelling modules implemented here allow the special consideration of water demand (communicated "from right to the left") and water availability (communicated "from left to the right"), attempting to balance availability with demand of water resources. Stochastic modelling of rainwater tank utilisation allows to find optimum tank sizes and operational strategies of rainwater tank usage (SNIR *et al.*, 2019, SCHÜTZE *et al.*, 2019b). Reuse strategies of (treated) greywater and wastewater streams provide important feedback loops in the system and could be shown to alleviate pressure on scarce water resources.

Modelling the Water-Energy-Food-Waste Nexus

Considering that the water and wastewater system constitutes just one element of the urban infrastructure system or "urban metabolism", prudent use of the urban infrastructure would also consider the interactions and potential synergies of the water, energy, solid waste and urban food systems. Whilst some interactions between these subsystems are obvious (e.g. electricity demand for pumping and treating of water), others might appear, whilst equally important, less obvious. For example, energy generation from waste incineration or from co-digestion of wastewater sludge and kitchen waste, production of fertilizer from waste composting and others) constitute relevant transsectoral interactions. Modelling and visualising related resource fluxes and, thus, increasing system awareness among stakeholders, also might assist in strategic pre-planning of urban infrastructure systems, considering water, energy, food and waste in a joint manner.

Within the "Rapid Planning" project (rapid-planning.net), currently models of the cities of Da Nang (Vietnam) and Kigali (Rwanda) are being built, which assist in this preplanning process (Fig. 7). These models assist in the analysis of various scenarios of future developments of these cities and their resource and infrastructure needs. The underlying modelling principles are described by RAMÍREZ CALDERÓN *et al.* (2015) and ROBLETO (2019). This work, thus, has a wider scope than other Nexus-related studies such as, for example, the study by LANDA CONSIGNO *et al.* (2019), who focussed mainly on the water system.

Fig. 7 shows the model setup of the infrastructure systems of the rapidly growing city of Da Nang. Fig. 8 provides a concise summary of the main resource fluxes obtained from the detailed simulation of the "transsectoral" future scenario of the city of Da Nang. This diagram representing some of the material flows in the system is a by-product of the detailed simulations carried out. Whilst it is indeed a challenge to select and to represent the "most interesting" simulation results for the decision maker and end-user, such visualisations can help to increase the understanding of the importance of joint planning of infrastructure systems.

Conclusions

This paper has illustrated some applications of modelling in water system management in different contexts. Modelling examples range from detailed biochemical process kinetics modelling in wastewater treatment and river water quality over modelling and visualisation of nutrient fluxes in sanitation systems to modelling of the entire Water-Energy-Food-Waste Nexus of large agglomerations. Such modelling applications appear now to be more feasible than ever before as simulation systems have gained considerably in user-friendliness both for the novice user as well as for the simulation expert in research. It is believed that model building and application could be useful complements to field-work based ecological studies such as those carried out by IHTIMANSKA *et al.* (2014). Also novel modelling concepts, such the linkage of process modelling with LCA-type calculations within the same modelling framework and the integration of availability-demand balancing with process modelling have been demonstrated. It is hoped that this paper stimulates additional modelling applications, motivated by the statement that "all models are wrong, but some are useful."

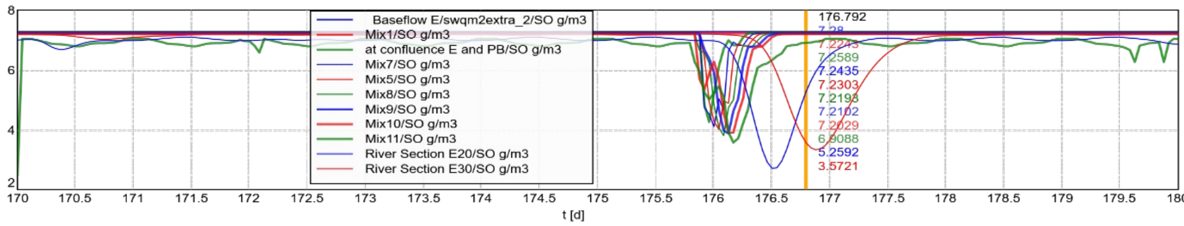

Fig. 3. Dissolved Oxygen results in selected river sections of the Astlingen system – Inflow to WWTP restricted to default.

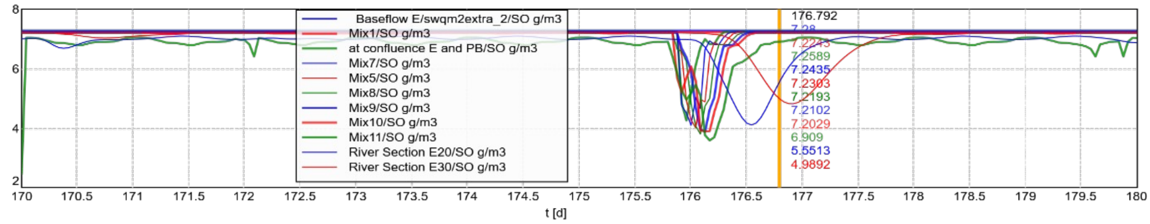

Fig. 4. Dissolved Oxygen results in selected river sections of the Astlingen system – Inflow to WWTP temporarily increased.

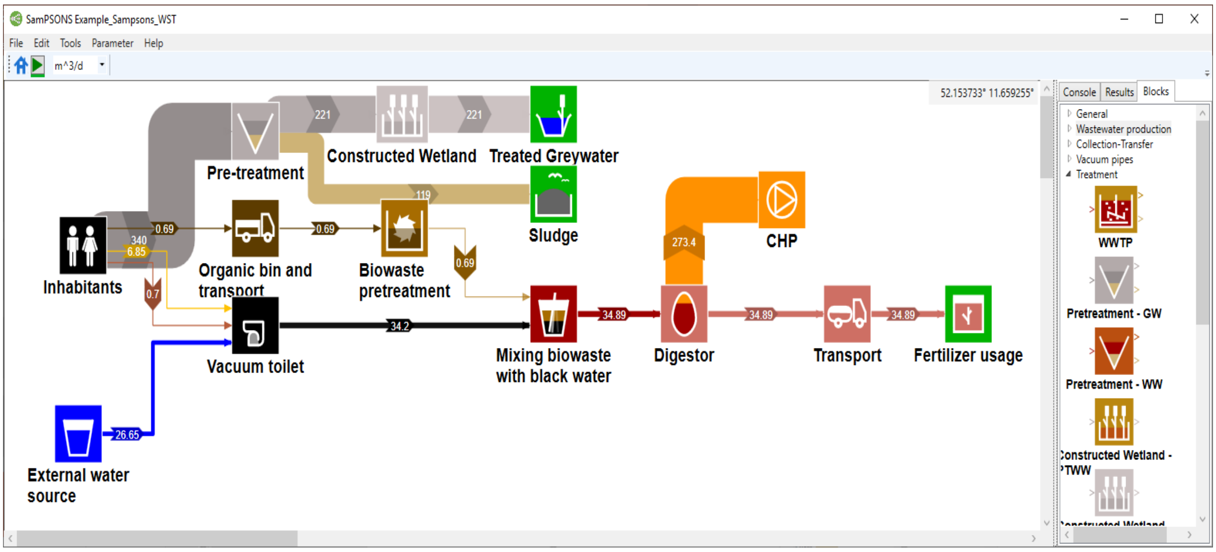

Fig. 5. Example of a sanitation system modelled in the SAmpSONS simulator.

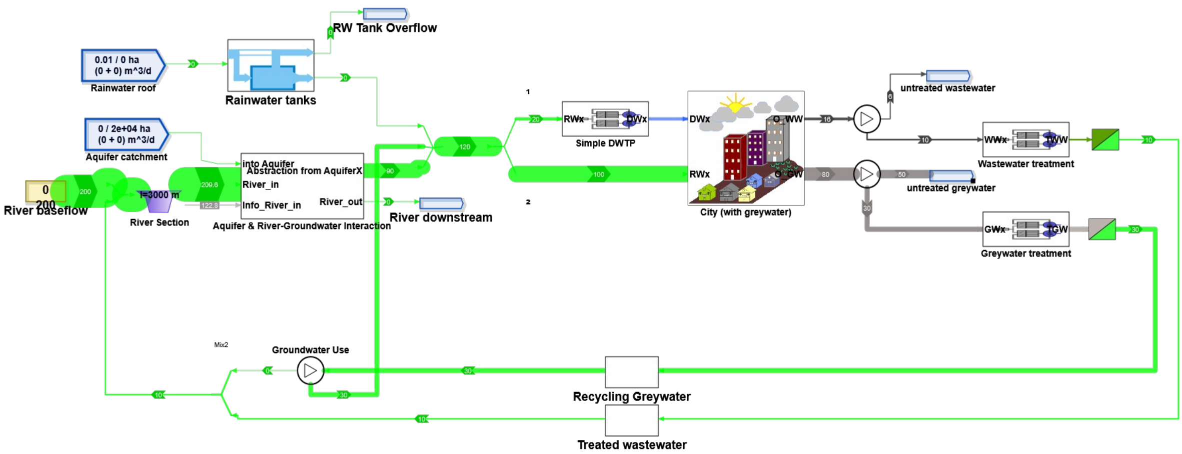

Fig. 6. Model of a generalised water system, including rainwater harvesting, groundwater abstraction, greywater and wastewater reuse.

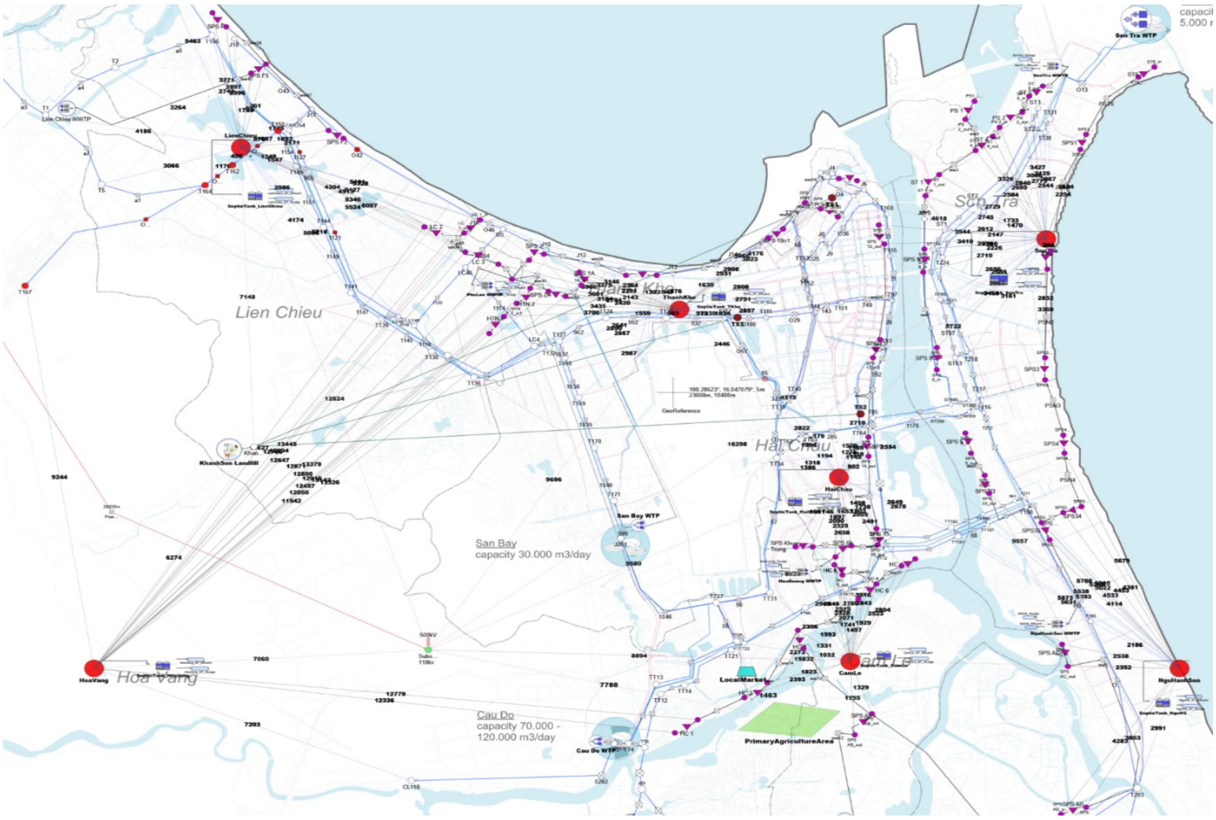

Fig. 7. Model setup of Da Nang (Vietnam) (SCHÜTZE & ROBLETO, 2019).

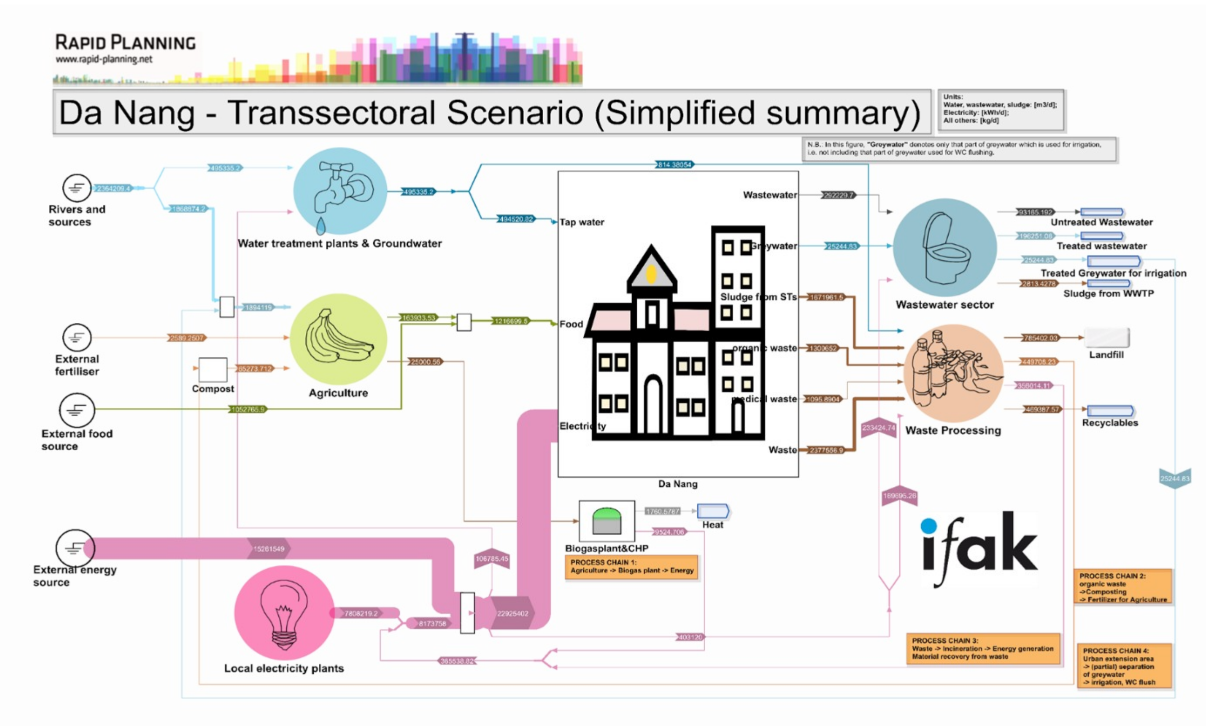

Fig. 8. Summary of main resource fluxes in Da Nang (Vietnam) in a transsectoral scenario (SCHÜTZE & ROBLETO, 2019).

Acknowledgements

Financial support from various sources for various projects leading to the results summarised in this paper is acknowledged (German Federal Ministry of Education and Research-BMBF – projects "Rapid Planning", "CLUWAL"; SaMuWa"; German Federal Ministry of Economics – project "Kommunal4.0"; Deutsche Bundesstiftung Umwelt - project "SAmpSONS").

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Received: 09.08.2019
Accepted: 02.12.2019