DOCTORAL DISSERTATION

MATHEMATICAL MODEL-BASED DYNAMIC INFLUENT CHARACTERIZATION TO DESIGN BIOLOGICAL WASTEWATER TREATMENT PLANTS

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by

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This dissertation is submitted for the degree of Doctor of Engineering

DECLARATION

I hereby declare that this dissertation has been composed solely by myself and the data presented in it are my own work. It contains no material previously published or written by another person, except where due reference has been made in the text. This dissertation has not been previously submitted, in whole or in part, to any university or other tertiary institution for any degree, diploma, or the other qualification.

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ABSTRACT

Viet Nam has one of the fastest rates of urbanization in the world, with almost 43% of the country’s population expected to be living in cities by 2030. As an emerging economy could grow at 5% or more per annum until 2030, this is supposed to result in an improvement of living standards. Consequently, the improvement in daily life also increases the consumption demand in general, and the demand for water in particular. The portion of access to toilets was 94% with approximately 90 percent of urban households have septic tanks receiving domestic wastewater, in most cases only from toilets. Although 60 percent of households dispose of wastewater to a public system, much of this is directed informally to the drainage system and only 17 percent is treated.

The combined sewerage system (CSS), in which wastewater and city drainage water are combined, is the main method for sewage collection in Vietnam. Despite the fact that the benefits of costs and ease of implementation can be gained, the use of CSS also results in a very diluted organic loading arriving at the WWTPs. This is mainly due to the installation of septic tank from mostly households connected to the CSS can remove approximately 30 - 40 percent of the BOD prior to this flow being discharged to the CSS. As a result of dilution and decomposition, very low organic content (BOD) is typically found in the influent of the urban WWTPs in Vietnam. Another corollary from the usage of CSS is the influence of urban runoff mostly originated from rain or rainstorm, normally resulting in the high fluctuation of wastewater concentration and flow. All these facts result in the infeasibility of applying traditional method with recommended standards from several available guidelines to estimate wastewater characteristics in Vietnam. Thus, the measurement of the real influent characteristic over a certain continuous period is preferably conducted whenever a new project of wastewater treatment implemented. In this regard, the conventional method of waster sampling combined with analysis is the inevitable answer that comes to mind first.

To determine the influent concentrations besides wastewater flow, on-site water sampling is widely used, and the samples will then be analyzed in laboratories. However, in order to obtain the design basis of organic load comprised of average BOD_5 load, peak daily and hourly BOD_5 load as suggested in the guidelines, an enormous number of wastewater samples needs to be collected and analyzed consuming tons of man-power/man-hour. From these backgrounds, an innovative and simple method to measure the real influent concentrations when inflow data is not available or limited is highly desired to alternate the existing method.

The back-calculation method using IWA Activated Sludge Model integrated with field experiment using a set of lab-scale activated sludge reactors was proved to meet and address the above-mentioned purpose. However, the calculation manner applied in the literature is merely manual manipulation with the simplification of the formula used for calculating biodegradable organics. In this regard, this thesis firstly investigated on broadening the method of using IWA Activated Sludge Model integrated with an optimization tool namely Dynamic Parameter Estimation (DPE) in a process simulator to estimate the weekly concentration of both biodegradable carbonaceous and nitrogenous materials in wastewater. In specific, from the dynamic response of the activated sludge constituents, the weekly concentration of influent biodegradable organic and nitrogen were estimated to demonstrate the approach. Additionally, the proper variables from those the influent biodegradable nitrogen was back-calculated was also comparatively discussed.

In the same manner, the estimating hourly concentration of influent biodegradable compositions was derived from the technique used in the estimating weekly concentration of influent biodegradable materials. From the field experiment, the hourly concentration of influent biodegradable organic and nitrogen were back-calculated from the dynamic response of DO concentration in the activated sludge reactors and nitrate concentration in the effluents. From the outcome that the estimated hourly concentrations of influent materials were comparable to those measured in the 1-day intensive sampling, the feasibility of the developed method was demonstrated.

In addition, the extended application of the approach in wastewater characterization was also described by developing a novel method to determine the blower capacity of wastewater treatment plants for dry and wet weather conditions. Using Extreme Value Distribution (EVD) concept and the median-rank estimator, blower power versus the probability of oxygenation shortage was simulated on a virtual wastewater treatment plant in computer. Based on the Activated Sludge Model No. 1 (ASM1), required blower power per influent flow rate to meet daily maximum influent oxygen demand was predicted.

Furthermore, the sensitivity of the optimization tool used in the developed approach thoroughly examined via the comparative analysis of several factors that might influence the operation of optimizer in particular, through which it might affect the quality of estimating influent concentrations. The obtained results highlighted the significant dependence of the estimating hourly concentration of influent biodegradable constituents on the time step of numerical integration, the type of objective function and the data density for optimization required to setup when running optimizer.

ABBREVIATIONS

A2O	Anaerobic-anoxic-oxic process
AO	Anoxic-oxic
AS	Activated sludge
ASM	Activated Sludge Model
BOD	Biochemical Oxygen Demand
CAS	Conventional Activated Sludge
CEPT	Chemically Enhanced Primary Treatment
COD	Chemical Oxygen Demand
CSS	Combined Sewerage System
DO	Dissolved Oxygen
DPE	Dynamic Parameter Estimation
FBR	Fixed Bed Reactor
HCMC	Ho Chi Minh City
IWA	International Water Association
MONRE	Ministry of Natural Resources and Environment in Vietnam
OD	Oxidation Ditch
SBR	Sequencing Batch Reactor
SSS	Separated Sewerage System
TF	Trickling Filter
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solid
USD	US Dollar
VND	Vietnamese Dong
WWTP	Wastewater Treatment Plant

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CHAPTER 1. INTRODUCTION

1.1. Urban water and sanitation in Vietnam

1.1.1. Current status of water supply and consumption in urban areas

Viet Nam with a population of approximately 96.5 million and a GDP of 261.9 billion USD in 2019 has gained positive achievement in economic growth and poverty reduction in the last thirty years [1]. During the period from 2010 to 2017, the national poverty rate has reduced significantly from 21.0 percent to 9.8 percent [2]. The population is mainly concentrated in big cities where the economy is developed. Urban population has been constantly increasing over time and unevenly distributed over geographical regions. In 2017, the highest population density reached 4025 people/km^2 in Ho Chi Minh city followed by Hanoi capital with 2279 people/km^2 [3]. Although the population growth rate of Vietnam has balanced at around 0.96% (2019) from a high of 3% (1960), the rapid growth in urban population has been existing due to inward migration. This is because of the employment opportunities in the growing industrial sector in cities and the reduced employment in agriculture due to mechanization.

Viet Nam has one of the fastest rates of urbanization in the world, with almost 43% of the country’s population expected to be living in cities by 2030 [4]. People's income tends to increase annually with the much higher real incomes of urban people than people living in rural areas. Viet Nam as an emerging economy could grow at 5% or more per annum until 2030 and this is supposed to result in an improvement of living standards. Consequently, the improvement in daily life also increases the consumption demand in general, and the demand for water in particular. In the past two decades, Viet Nam has made progress in increasing the coverage of water supply with 110 urban water supply companies operating approximately 800 centralized water supply systems and providing water to people in urban centers, district towns and surrounding areas [5]. Access to improved water supply increased nationwide, from 65 percent in 2000 to 95 percent in 2017, while access to basic sanitation jumped from 52 percent to 84 percent during the same period [2]. The current water demand of people living in urban areas for drinking, sanitation, business and services are estimated at 8 to 10 million m^3/day in 2017. The total design capacity of water treatment plants in urban areas is about 5.4 million m^3/day that meets less than 70% of the urban water demand [4]. The average urban water consumption varies considerably ranging from 33 to 213 L/c/d. Generally, the average water consumption ranges from 100 to 120 L/c/d, reaching 130 L/c/d in highly urbanized areas [4, 5]. Since 2010, the average non-revenue water (water loss) has been reduced from 31.0 percent to 24.5 percent [5]. The total annual municipal water usage is projected to increase to 5.7 billion m^3 by 2030.

1.1.2. Urban wastewater management in Vietnam

Since 1998, the Government of Vietnam has initiated policies and provided investment to improve urban sanitation. Prior to year 2000, sewage treatment in Vietnam comprised primarily of on-site treatment such as septic tanks which were introduced by the French in their colonization of Vietnam in the 19th Century. From that period onward, it became customary and is now a government regulation that all households be constructed with some form of on-site wastewater treatment. In large urban areas, it is estimated that over 90 percent of households utilize on-site treatment, generally in the form of septic tanks [5, 6]. The impact of the generated wastewater on local receiving waters created a demand for treatment and safe disposal of the collected wastewater as urban population densities increased. The first planning for wastewater treatment in Vietnam commenced around year 2000 and by year 2012 there were a total of 17 centralized urban wastewater treatment systems in the country, still relatively few in number for a country of over 87 million inhabitants at that time. Twelve of these wastewater systems are located in the three cities of Hanoi, Ho Chi Minh City and Da Nang, with five other WWTPs scattered throughout the provincial towns and cities. The three large cities of Hanoi, Ho Chi Minh City and Da Nang are considered separately from other cities due to their unique characteristics. For these large cities, the development of wastewater infrastructure has been influenced by the need to resolve critical urban sanitation problems associated with high population densities and inadequate drainage facilities for dealing with the increasing volumes of wastewater generated. The first large urban area in Vietnam to receive wastewater infrastructure was the City of Hanoi, for which the JICA-funded drainage and sewerage collection systems with two wastewater treatment plants (WWTPs) of Kim Lien and Truc Bach were commissioned in year 2005. With treatment capacities of only 3,700m^3/day and 2,300m^3/day respectively, these two wastewater systems were intended as pilot (demonstration) facilities to provide local authorities with a better understanding of how urban sanitation could be applied in large city areas [6]. The combined sewer catchment areas supported by the WWTPs were designed to mitigate the effects of pollutants which had previously entered the urban canals and lakes as untreated combined sewage. Activated sludge treatment technology (anaerobic-anoxic-oxic, or A2O) was utilized for these WWTPs. Each project only treats a portion of the catchment area.

A subsequent JICA-funded project in north Hanoi, Bac Thang Long WWTP, was constructed with the intention to serve a residential catchment area with a design population of 150,000 residents. Whereas the WWTP was placed into operation in 2009, the combined sewers were never constructed as this component was not included within the JICA-funding but was intended to be constructed from local funds. Subsequently a flow of 7,000 m^3/day of primary treated wastewater was diverted from a nearby industrial park WWTP to the Bac Thang Long WWTP, but this only constitutes 17 percent of the total design capacity of 42,000 m^3/day [6]. This example demonstrates the need for a holistic approach to wastewater collection and treatment to optimize investments.

In 2012, the addition to the City of Hanoi sanitation infrastructure was the construction of the Yen So WWTP, a 200,000m^3/day activated sludge treatment plant featuring sequencing batch reactors (SBRs) [6]. The wastewater catchment included all drainage tributaries to Kim Nguu River (125,000m^3/day) and Set River (75,000m^3/day), as these water courses are the principal sources for influent wastewater to the Yen So WWTP [6]. A planned sewerage system was not constructed and the Kim Nguu River conveys the total combined sewage to the intake of the Yen So WWTP. This has impacted on the operation of the facility as the lengthy retention time in the river results in the reduction of Biological Oxygen Demand (BOD) concentration in the wastewater. This decrease in BOD has created an imbalance in the Carbon to Nitrogen (C:N) ratio of the influent wastewater which has led to operational difficulties at the WWTP.

In Ho Chi Minh City, three projects have characterized the development of urban sanitation. Firstly, a Belgian-funded project in Binh Hung Hoa district provided wastewater treatment for combined sewage collected in a local drainage canal. An aerated lagoon and stabilization pond system was constructed as the available 37-hectare land area permitted a unique, low-tech solution for such a densely populated urban area. Operational since year 2006, the Binh Hung Hoa WWTP has a design capacity of 46,000m^3/day, although only 30,000m^3/day is utilized [6]. A second sanitation project in Ho Chi Minh City (HCMC) was the JICA-funded HCMC Phase 1 project, which developed a combined sewerage collection system from the densely populated catchments of District 1 and District 5 in HCMC and conveyed the sewage to the Binh Hung WWTP. The project was commissioned in 2009 but the implementation period was substantially longer than expected due to complications arising from the construction of large interceptor drains in busy urban streets. The initial plant capacity, served by conventional activated sludge (CAS) wastewater technology, allowed for treatment of 141,000m^3/day, and is planned for expansion in the Phase 2 project to 512,000m^3/day in conjunction with expansion of the sewerage collection system [6]. The third urban sanitation project in HCMC is the on-going World Bank funded Nhieu Loc – Thi Nghe (NL-TN) combined sewerage collection system. This system did not include a WWTP, but has resulted in significant improvements to the local environmental conditions of the area. This area was once the site of densely-populated slums constructed over polluted drainage canal which long operated as the final depository for all sewage being generated within the drainage catchment. The finalization of this project in year 2011 demonstrated that significant environmental benefit could be gained by providing a sewerage interception system which allowed for the rehabilitation of the receiving water body. Prior to the project the NL-TN area was heavily polluted contributing to serious social problems. Combined sewage, which had previously been discharged directly to this canal contributing to its degradation, is now being intercepted at combined sewage overflows (CSOs) for diversion to new interceptor pipelines. The second phase of this project will include construction of a new WWTP to be constructed in District 2 with design capacity of 480,000m^3/day for replacing the current disposal of wastewater directly into the Saigon River. A separate sewerage collection system has been proposed for District 2.

For Da Nang, the sanitation infrastructure is characterized by a combined sewer system network which supplies influent wastewater to four WWTPs each featuring covered anaerobic pond technology. These WWTPs were originally designed and constructed as open-top anaerobic ponds. However, as a result of limited buffer zone distance and odor generation concerns, all four WWTPs were subsequently covered as part of a World Bank-funded project which was completed in 2008. With a combined design capacity of 64,400m^3/day, the four WWTPs in the Da Nang wastewater system service a population of 378,000 residents or approximately 40 percent of the current City population [6]. However, the collected combined sewage has a characteristically low organic load concentration (in terms of BOD), for which treatment is actually not required during the rainy season, causing the operators to discontinue the use of the Combined Sewer Overflow (CSO) pumping stations and release the diluted wastewater to the receiving water bodies including the beach areas on the Son Tra peninsula.

To date, there are numerous significant achievements obtained from the unceasing efforts of water sector development in Vietnam. The portion of access to toilets is 94% with approximately 90 percent of urban households have septic tanks receiving domestic wastewater, in most cases only from toilets [5, 6]. It was reported that 60 percent of urban households have access to piped drainage and sewerage systems primarily comprising combined systems [5-7]. Although 60 percent of households dispose of wastewater to a public system, much of this is directed informally to the drainage system and only 17 percent is treated [5]. According to the data of Ministry of Natural Resources and Environment (MONRE) , the proportion of urban areas invested in constructing a centralized wastewater treatment system is 39%. Specifically, by the end of 2018 there were 43 centralized wastewater treatment plants put into operation with total design capacity is up to 926,000 m^3/day.

Table 1.1 In-operation wastewater treatment plants in Vietnam

No	Plant	City	Year in service	Capacity (m^3/d)		Treatment process/technology
				Designing	Function	
1	Kim Lien	Hanoi	2005	3,700	3,700	A2O (AS)
2	Truc Bach		2005	2,500	2,500	A2O (AS)
3	Bac Thang Long		2009	42,000	7,000	AO with nitrification
4	Yen So		2012	200,000	120,000	SBR
5	Ho Tay		2014	22,800	-	SBR
6	Bay Mau		2016	13,000	11,000	CAS
7	Cau Nga		2016	20,000	-	Adv. SBR
8	Binh Hung	HCM City	2009	141,000	141,000	CAS
9	Binh Hung Hoa		2008	30,000	30,000	Aer. Ponds + Mat. Ponds
10	Canh Doi (Phu My Hung)		2007	10,000	10,000	OD
11	Nam Vien (Phu My Hung)		2009	15,000	15,000	A2O (AS)
12	Son Tra (old)	Da Nang	2006	15,900	15,900	Ana. Pond w/float cover
13	Hoa Cuong		2006	36,418	36,418	Ana. Pond w/float cover
14	Hoa Xuan		2015	20,000	-	SBR
15	Phu Loc		2006	36,430	36, 430	Ana. Pond w/float cover
16	Ngu Hanh Son		2006	11,629	11,629	Ana. Pond w/float cover
17	Bac Giang	Bac Giang	2010	10,000	8,000	OD
18	TP Bac Ninh	Bac Ninh	2013	17,500	-	SBR
19	Tu Son		2015	33,000	-	SBR
20	Vinh Yen	Vinh Phuc	2014	5,000	-	CAS
21	Bai Chay	Quang Ninh	2007	3,500	3,500	SBR
22	Ha Khanh		2009	7,000	7,500	SBR
23	TP Hai Duong	Hai Duong	2013	13,000	-	SBR

No	Plant	City	Year in service	Capacity (m^3/d)		Treatment process/technology
				Designing	Function	
24	Ho Me	Ha Nam	2015	2,500	-	AO
25	Sam Son	Thanh Hoa	2015	4,000	-	Aer. lagoons
26	Vinh	Nghe An	2013	25,000	-	SBR
27	Cua Lo		2014	3,700	-	SBR
28	TP Dong Hoi	Quang Binh	2014	10,000	-	Ana. pond
29	Nhon Binh	Binh Dinh	2014	14,000	-	Biofilter
30	Quy Nhon 2		2014	8,000	-	OD
31	Chua Cau	Quang Nam	2018	2,000	-	Trick. Filt.
32	Da Lat	Da Lat	2006	7,400	6,000	Imhoff tank + Trick. Filt.
33	Buon Ma Thuot	Dak Lak	2006	8,125	5,700	Stab. Ponds (AP, FP, MP)
34	Phan Rang – Thap Cham	Ninh Thuan	2012	5,000	-	Aer. lagoons
35	Phan Thiet	Binh Thuan	2015	5,000	-	Stab. Ponds
36	Thu Dau Mot	Binh Duong	2013	17,650	-	SBR
37	TX Thuan An		2017	17,000	-	Adv. SBR
38	TP Nha Trang	Khanh Hoa	2014	40,000	-	OD
39	TP Chau Doc	An Giang	2016	5,000	-	A2O
40	TP Vung Tau	Ba Ria - Vung Tau	2016	22,000	-	OD
41	TP Soc Trang	Soc Trang	2013	13,200	-	Prim. Sed.
42	Tra Vinh	Tra Vinh	2016	18,135	-	Prim. Sed.
43	Tra Kha	Bac Lieu	2018	2,400	-	A2O

Including projects under construction, there were totally about 80 centralized wastewater systems with design capacity of 2.4 million m^3/day approximately. However, it was reported that although many plants had completed the construction of wastewater treatment systems, the synchronous water supply and drainage system of those plants have not yet completed resulting in the under capacity of operation (about 20% of the design capacity) [3]. The wastewater treatment technologies utilized vary widely among urban WWTPs in Vietnam. Generally, activated sludge technology is the most common comprising several variant of conventional activated sludge, A2O process, SBR or Oxidation Ditch (OD) [5, 6]. Of which, SBR technology seems most commonly accepted due to its capacity to simultaneously remove nitrogen and phosphorus and having a small footprint. Also, some other projects applied trickling filter technology (i.e. Can Tho, Da Lat, Quy Nhon). There are also urban WWTPs in Vietnam that use low-cost wastewater treatment technologies such as Waste Stabilization Pond systems (Da Nang city, Buon Ma Thuot city, Thanh Hoa city), Aerated Lagoon and Pond systems in series (Binh Hung Hoa in HCMC, Duc Minh in Dong Hoi city), Imhoff tank – Trickling filter and Maturation Pond (Da Lat city), Chemically Enhanced Primary Treatment (CEPT) and Trickling Filter (Quy Nhon city), Primary clarifier (Soc Trang and Tra Vinh), and Aerated lagoons (Chau Doc, An Giang and Phan Rang - Thap Cham, Ninh Thuan) (Table 1.1) [5]. Despite the number of urban wastewater treatment projects has increased over the years, this is still a very small compared to the actual demand of wastewater treatment. The estimated results of the amount of domestic wastewater generated per area unit in regions across Vietnam also demonstrate the highest pressure on domestic wastewater treatment in Red River Delta followed by Southeast region. In Hanoi, there is only 20.62% of the total domestic wastewater is treated while the proportion of treated municipal wastewater in HCMC is approximately more than 10% [3]. These are two areas with strong economic development, accompanied by a large amount of domestic wastewater generated.

The combined sewerage system (CSS), in which wastewater and city drainage water are combined, is the main method for sewage collection in Vietnam. This is because traditions, ease of implementation and lower investment cost compared to the construction of a drainage and sewerage system separately. Thus, in Vietnam, residential development follows the construction of basic infrastructure (i.e. roads, drainage, water supply, electrical power) with sewerage traditionally being combined with the drainage system out of necessity and to save costs [5]. This fact leads to a consequence that new wastewater projects have to accept existing CSS as the way to transport wastewater in combination with drainage water. The reason for this is related to both costs saving and to the ease of implementation, as CSS can be implemented with far fewer pipelines creating less construction impact in residential neighborhoods. Furthermore, CSS generally utilizes the existing drainage system as secondary sewers for collecting wastewater from the household. Doing so only requires intercepting wastewater flows by the use of combined sewer overflow structures (CSOs) and transportation to a WWTP for treatment through the drainage pipes.

Table 1.2 In-progress wastewater treatment plants in Vietnam

No	Plant	City/Province	Capacity (m^3/d)	Technology	Status
1	Yen Xa	Hanoi	275,000	CAS	Under design
2	Phu Do		85,000	SBR	Design completed
3	Tham Luong - Ben Cat	HCM City	250,000	SBR	Under construction
4	Nhieu Loc - Thi Nghe		480,000	SBR/CAS	On going bidding
5	West Sai Gon		100,000	OD	Call for investor
6	North Sai Gon		139,000	Multitank A2O and FBR	Call for investor
7	Suoi Nhum		65,000	SBR	Under construction
8	Son Tra (new)	Da Nang	51,000	Ana. Pond w/float cover	Under construction
9	Phu Loc (new)		46,000	Ana. Pond w/float cover	Under design
10	Lao Cai	Lao Cai	5,700	Slow Trick. Filt.	Under design
11	Thai Nguyen	Thai Nguyen	10,000	OD	Under construction
12	Viet Tri 1	Phu Tho	5,000	OD	Under construction
13	Viet Tri 2		10,000	OD	Under construction
14	Vinh Niem	Hai Phong	36,000	CAS	Construction completed. Under commissioning.
15	Hai Duong	Hai Duong	13,500	SBR	Under construction/connection
16	Thai Binh	Thai Binh	10,000	A2O	Under construction
17	Ba Don	Quang Binh	3,000	OD	Under construction
18	Dong Ha	Quang Tri	5,000	Aer. Pond	Under construction
19	Ha Thanh	Binh Dinh	14,000	CEPT + TF	Under construction

No	Plant	City/Province	Capacity (m^3/d)	Technology	Status
20	Hue	Hue	30,000	CAS	Under construction
21	South Nha Trang	Khanh Hoa	40,000	OD	Under construction
22	Cai Sau	Can Tho	30,000	OD	Under construction
23	Can Tho		30,000	SBR	Under construction
24	Ba Ria	Ba Ria – Vung Tau	12,000	OD	Under construction
25	My Xuan		21,700	Aeration	Under construction
26	Tan Hoa		8,000	Aeration	Under construction
27	Go Giang		2,260	Aer. Pond	Under design
28	Long Son		5,460	Aer. Pond	Under design
29	My Hoa – Long Xuyen	An Giang	20,000	OD	Under construction
30	Binh Duc		20,000	OD	Under construction
31	Cao Lanh	Dong Thap	10,000	A2O	Under construction

Despite the fact that the benefits of costs and ease of implementation can be gained when sewage flow and drainage water are combined, this also results in a very diluted organic loading arriving at the WWTPs. In this regard, there are several factors listed:

– The installation of septic tank from mostly households connected to the CSS can remove approximately 30 - 40 percent of the BOD prior to this flow being discharged to the CSS;

– Due to the characteristics of CSS in residential neighborhood catchments are of flat-bottomed, rectangular covered channels having little or no slope with open joints, these factors allow significant infiltration from groundwater and enhance decomposition processes by bacteria;

– CSS by design, and by primary function, are intended to collect rainwater runoff (drainage) from city streets and public areas.

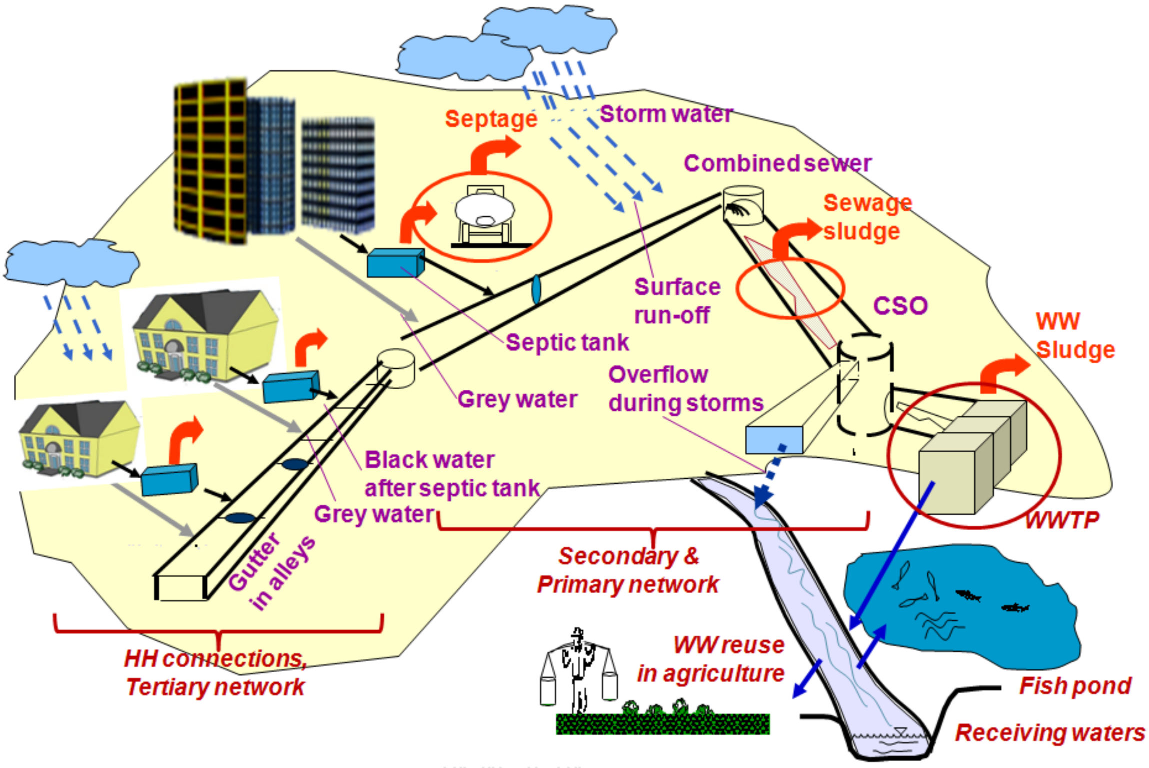

Figure 1.1 Typical combined sewerage system (CSS) in Vietnamese cities

As a result of dilution and decomposition, very low organic content (BOD) is typically found in the influent of the urban WWTPs in Vietnam. This creates difficulty in the biological wastewater treatment process as the low C/N ratio slows down or inhibits bacterial growth. The alternative to CSS is the construction and use of a separate sewerage system (SSS). In Vietnam, the use of SSS is only seen in very few projects, such as in Da Lat, Buon Ma Thuot and Binh Duong. The wastewater influent to the WWTP in these projects shows a significantly higher BOD concentration compared to CSS. Other use of SSS includes applications in new residential areas that have either their own wastewater treatment station or not. The treated or untreated effluent in these cases is conveyed by a CSS to a WWTP in city for treatment.

Septic tank is known as the most popular pre-treatment method of sanitation in Vietnam.

Most septic tanks in Vietnamese households receive only black wastewater. On the other hand, grey wastewater from kitchen, bathroom and sink washing is generally discharged directly to the combined sewerage system or discharged to the environment, by-passing the septic tank. In urban areas, the septic tank plays an important pre-treatment role for locations having combined sewers. Typically, it is often made from bricks (for individual houses) or reinforced concrete (for individual houses and public buildings) and placed in the basement surrounded by the foundation. The tank is enclosed by concrete base and cement mortar to create airtight condition for activities of anaerobic bacteria. In terms of structure, septic tank often consists of two or three chambers. The first, a receiving chamber, is regularly built with largest portion of the total tank volume, making space for solids accumulation and anaerobic digestion. Total volume of household septic tank depends on accessible space and funding availability. Normally, the total volume of household septic tank ranges from 1.5 to 5.0 m^3 [7].

Table 1.3 Sludge characteristics in Vietnamese cities

	Kim Lien WWTP (Hanoi)	**Truc Bach WWTP (Hanoi)**	**Hoa Cuong WWTP (Da Nang)**	**Septic Tanks Hanoi**
Percentage Water	98.8 - 99.4	97.9 - 98.0	97.7	n/a
COD (mg/L)	7,173 - 12,405	7,083 - 23,681	n/a	2,833 - 83,833
TS (g/L)	6.5 - 11.5	19.9 - 21.4	23.4	1.7 - 74.8
TN (g/kg TS)	47.2 - 66.8	53.5 - 58.2	15.1	182 - 3,954
TP (g/kg TS)	26.7 - 32.9	27.8 - 33.5	5.7	27 - 2,490

Basically, accumulated septic tank sludge (septage or fecal sludge) is pumped out periodically for treatment and disposal. However, it was revealed that septage (sludge) deposited in septic tanks is not removed regularly by Vietnamese households [5]. In addition, the illegal dumping of sludge removed from septic tanks is a very common practice in all cities in Vietnam. Despite the fact that 90 percent of households dispose wastewater to septic tanks, only 4 percent of septage is treated and disposed satisfactorily [5-7]. The amount of sludge generated from urban sewer lines and canals in Vietnam is estimated to be 4.7 – 11.7 million m^3 per year [5]. Of which, the amount of fecal sludge generated from septic tanks in Vietnam is estimated to be 1.3 – 2.2 million m^3 per year with Hanoi, Hai Phong, and Ho Chi Minh city generating 280,000, 166,500 and 894,000 m^3 per year, respectively [5]. Sewer lines and canals in Hanoi city are estimated to generate 2.4 million tons of sludge per year. The amount of sludge dredged from sewer lines in Ho Chi Minh city is estimated to be 0.45 – 0.70 million tons per year with an additional 2 to 3 million tons per year dredged from canals. Sludge characteristics for cities in Vietnam are given in Table 1.3. Theoretically, the method mostly adopted for the safe treatment and disposal of sludge is drying and dumping at landfills. However, increasingly a number of cities are facing difficulties in allocating space for sludge disposal. Currently there is no effective septage management being practiced anywhere in Vietnam. The scheduled emptying of septage from septic tanks is practiced only in one city (Hai Phong). Some cities provide treatment of septage at wastewater treatment plants or at solid waste dumping sites. Poor design and operation of most household septic tanks plus uncontrolled fecal sludge emptying, transportation and dumping, mostly by private service providers, are common in Vietnamese cities. As a result, these persistent issues are day by day contributing to a growing environmental problem in Vietnam.

It is estimated that 70 percent of the households located in urban areas are connected to public sewerage or drainage systems [5, 6]. The degree of connection varies from city to city depending on the density of the residential development and the underlying geology. The latter determines whether or not a household can dispose of its wastewater on-site by means of percolation into the soil. The level of household connection has a significant impact on the effective operating capacity of the municipal WWTP. In Vietnam, operating capacity varies between 18 and 128 percent [5]. Low operating capacities originate from delayed construction of sewerage networks and an over estimation of the design flow of the WWTP.

1.2. Characteristic of municipal wastewater in Vietnam

Sanitary sewage or municipal wastewater refers to the domestic wastewater as well as those discharged from commercial, institutional, and similar facilities. It is a combination of wastewater released by residences, businesses, restaurants and shopping centers, institutions such as hospitals, prisons, rest homes, and schools, recreational facilities, storm water, infiltration, and industries in a certain community [8]. Domestic wastewater includes typical wastes from the sinks, faucets, toilets, showers, dishwashers, floors cleaning, and laundry, as well as any other wastes that people may pour down to the drainage system. In short, domestic wastewater is normally comprised of black water from toilet (containing mainly feces and urine) and grey water from washing, bathing, and meal preparation [8, 9]. From these backgrounds, the typical characteristic of domestic wastewater is that contains abundant nutrients, suspended solids, carbonaceous and nitrogenous organic compounds, and large amounts of coliforms. Besides, domestic wastewater also contains grease and surfactants derived from the use of detergents in human daily life. Major organic and inorganic constituents of untreated domestic sewage are presented in Table 1.4 [9].

Table 1.4 Typical composition of untreated domestic wastewater

Contaminants	Concentration (mg/L)		
	Low	Moderate	High
Solids, total	350	720	1200
Dissolved, total	250	500	850
Volatile	105	200	325
Suspended solids	100	220	350
Volatile	80	164	275
Biochemical oxygen demand	110	220	400
Total organic carbon	80	160	290
Chemical oxygen demand	250	500	1000
Nitrogen (total as N)	20	40	85
Organic	8	15	35
Free ammonia	12	25	50
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorous (total as P)	4	8	15
Organic	1	3	5
Inorganic	3	5	10

Source: from C.P. Gerba and I.L. Pepper (2019) [8].

Table 1.5 Characteristics of domestic wastewater collected from inlet of several WWTPs in Vietnam (2013)

No.	WWTPs	City	Treatment process	Sewage system	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	NH_4-N (mg/L)	T-N (mg/L)	T-P (mg/L)	Coliform (MPN/100 mL)
1	Kim Lien	Hanoi	A2O (AS)	CSS	115	145	85	18	40	6.5	0
2	Truc Bach		A2O (AS)	CSS	135	155	85	-	34	6.5	0
3	Bac Thang Long		A2O (AS)	CSS	85	135	65	-	38	5.4	100
4	Yen So		SBR (AS)	CSS	45	132	51	28	34	7.2	-
5	Binh Hung	Ho Chi Minh City	Aer/Mat Ponds	CSS	42	135	103	-	11	-	175
6	Binh Hung Hoa		CAS	CSS	78	203	49	17.9	-	-	-
7	Son Tra	Da Nang	OD (AS)	CSS	37	67	38	-	18	1.7	-
8	Hoa Cuong		A2O (AS)	CSS	63	115	59	-	23.6	1.9	-
9	Phu Loc		Ana. pond	CSS	96	169	71	-	28.3	2.2	-
10	Ngu Hanh Son		Ana. pond	CSS	31	60	27	-	15.6	1.4	-
11	Bai Chay	Quang Ninh	Ana. pond	CSS	36	80	196	1.3	-	-	13
12	Ha Khanh		Ana. pond	CSS	45	68	41	1.1	-	-	43
13	Da Lat	Da Lat	SBR (AS)	SSS	380	604	792	68	95	19.7	-
14	Buon Ma Thuot	Buon Ma Thuot	SBR (AS)	SSS	336	564	286	36.4	93.7	11.2	15000
15	Bac Giang	Bac Giang	Imhoff Tank/ TF	CSS	90	120	-	-	-	-	-

Characteristics of wastewater varies from location to location depending upon land uses, variations in lifestyle, discharges of industrial and commercial wastewater, interference between surface and groundwater, degree of separation between storm water and sanitary wastes, and both diurnal and seasonal fluctuation. In case of Vietnam, there is a clear distinction in wastewater characteristics between combined sewerage (CSS) and separate sewerage systems (SSS) as illustrated in Table 1.5. Among total 17 centralized wastewater treatment plants surveyed in 2013 by Nguyen (2013), only four are served by SSS systems, whereas the other thirteen WWTPs are all served by CSS systems. The WWTPs receiving wastewater from CSS-based systems had influent BOD concentrations ranging from 31 to 135 mg/l with an average of 67.5 mg/l compared with those receiving wastewater from SSS-based systems (Buon Ma Thuot and Da Lat) which had influent annual average BOD concentrations ranging from 336 to 380 mg/l and an average of 358 mg/l. Other parameters also showed similar variations (Table 1.5).

In brief, the organic and solid matters in sewerage conveyed to WWTPs in Vietnam are founded at significantly low concentration compared to the typical. On the other hand, the concentration ammonium nitrogen, total nitrogen and total phosphorous ranges from low to moderate values. Similarly, the survey conducted by JICA in 2018 selected 20 different households and public facilities for sampling and assessment of water quality from the effluent of septic tanks. The summarized results of typical parameters for 20 collected samples are demonstrated in Table 1.6.

Table 1.6 Effluent quality of 20 surveyed septic tanks from households and public facilities in Hanoi and Haiphong (2019)

No	Parameters	Concentration	
		Hanoi	Hai Phong
1	BOD_5 (mg/L) (average)	96 – 1906 (462)	81 – 1259 (339)
2	COD (mg/L) (average)	173 – 3960 (810)	194 – 2112 (561)
3	TSS (mg/L) (average)	53 – 5110 (587)	66 – 1447 (321)
4	NH_4-N (average)	49 – 559 (176)	47 – 174 (93)
5	T-P (mg/L) (average)	21 – 298 (92)	27 – 110 (61)
6	T-N (mg/L) (average)	77 – 1542 (366)	78 – 483 (196)
7	Total E.Coliform (average)	$0.8\times10^6 – 460\times10^6$ (68.4×10^6)	$0.9\times10^6 – 920\times10^6$ (144.1×10^6)

Source: JICA report [7]

It can be recognized that the analyzing results of all parameters highly varies over the sampling points in two surveyed cities. Compared to the typical composition of untreated domestic wastewater, the concentration of organic matters in the effluent of septic tanks is relatively high, especially BOD concentration. Solid constituent is also in the same tendency with organic matters. Additionally, the extremely high concentration of ammonium nitrogen, total nitrogen and total phosphorous are also noticed.

Although living habits of resident in a community is one of the reasons affecting to the characteristic of discharged water in the area, the very high variation in the effluent concentration of septic tanks from JICA report indicates a big difference in the septic tank operation between households. The first reason is that there is a high proportion of household self-constructing their individual septic tank without any design plan. According to Japan International Cooperation Agency (JICA) (2019), in Da Nang there are up to 68.6% of septic tanks are self-constructed while the rest are from houses which are just bought or rented for use by current owners. Additionally, the main reason to explain for the problem is attributed to the poor management. Effective operation of septic tanks requires regular de-sludging, but Vietnamese households generally only clean septic tanks when the tank overflows [6, 7]. As a result, a high proportion of septic tanks are overloaded, non-functional or less than effective in providing even marginal pre-treatment of wastewater prior to discharge to the public sewer system. Poorly treated discharge from septic tank systems can contribute to solids carryover to the often poorly draining combined sewers, which can lead to blocked drains and odor generation.

1.3. Thesis structure

To clearly demonstrate the research topic, the dissertation is comprised of seven chapters of which each chapter concentrates and elucidates the scientific issues introduced below:

- In Chapter 1, the development of water and sanitation in urban areas in Vietnam is reported. The typical characteristic of municipal wastewater in Vietnam is also reviewed to provide a general insight in the challenges of wastewater treatment in Vietnamese urban.

- In Chapter 2, several techniques to characterize the biodegradable composition, especially carbonaceous and nitrogenous constituents in wastewater are introduced. Additionally, design basis for WWTP projects in terms of flowrate and concentration is described based on several technical guidelines. In final, the challenges in wastewater characterization for WWTP design by conventional methods in general and in case of Vietnam are stated.

- In Chapter 3, the back-calculation method to determine concentration of biodegradable constituents in wastewater using IWA-Activated Sludge Model No.1 (ASM1) as mathematical framework is briefly introduced. Also, the prerequisite materials and essential laboratory analyses for the method are also demonstrated.

- In Chapter 4, the back-calculation method using ASM1 was demonstrated by estimating weekly concentration of biodegradable constituent in wastewater in an automatic manner with Dynamic Parameter Estimation (DPE) tool. Furthermore, the comparative analysis of setup for calculation approach is also discussed thoroughly.

- In Chapter 5, the dynamic estimation of hourly concentration of influent biodegradable composition using ASM1 integrated with DPE is demonstrated. The advantages of the developed method are also discussed to reveal its capability to alternate conventional method in characterizing wastewater constituent.

- In Chapter 6, the application of back-calculation method developed in Chapter 4 and

Chapter 5 on the determination of blower capacity for aeration tank against the fluctuation of influent concentration is described in both dry and wet weather conditions.

– In Chapter 7, the comparative analysis for the back-calculation method is conducted. The influential parameters when configurating DPE are thoroughly examined. Moreover, other factors of operational conditions potentially affected to estimated results are also discussed.

– In Chapter 8, the key findings throughout the research are summarized. Simultaneously, the recommendations for further studies were also deliberated.

CHAPTER 2. LITERATURE REVIEW

2.1. Characterization of biodegradable composition in wastewater

2.1.1. Importance of wastewater characteristics

Characteristics of wastewater is regionally varied which mostly depends upon land uses, variations in lifestyle and local discharges of industrial and commercial wastewater. Other factors affecting to wastewater characteristics could be interference between surface and groundwater, degree of separation between storm water and sanitary wastes, and both diurnal and seasonal fluctuation [9]. The effective wastewater management cannot be achieved without the accurate knowledge of its characteristics. Wastewater characteristics are necessary for design, operation, collection, treatment, disposal, and reuse purposes. Due to the fact that individual water-using activities occur intermittently and contribute to the quantities variation of pollutants, this leads to a consequence that the strength of the wastewater generated from a residence fluctuates with time. Accurate quantification of these fluctuations is extremely difficult or even impossible.

Wastewater characteristics can be classified in terms of physical, chemical, and biological constituents. The terms of odor, color, temperature, turbidity, and solid contents are mainly used to demonstrate physical characteristics of wastewater. The main chemical characteristics of wastewater include: organic matter, nitrogen contents, phosphorous, chlorides, sulfur, alkalinity, heavy metals and gases.

a) Physical characteristics

Physically, wastewater is usually characterized by a grey color, musty odor, solid contents of about 0.1%, and 99.9% water content. The main physical characteristics of wastewater are: odor, color, temperature, turbidity, and solid contents. Fresh municipal wastewater has a slightly soapy or oily odor. Stale wastewater has offensive odor due to the anaerobic decomposition, which produces undesirable gases such as hydrogen sulfide, mercaptans, and skatole.

Extensive biochemical oxidation under aerobic condition causes dark grey or black color to the wastewater. The blackening is due to the production of various sulfides, in particular ferrous sulfide. Fresh wastewater is cloudy and tan colored. The temperature of wastewater is usually higher than that of the water supply due to the addition of warmer water from households such as washing and bathing wastewater. Bacterial synthesis and activities are temperature dependent, so temperature has a great effect on the efficiency of biological treatment in wastewater treatment plants.

Turbidity is an indicator of suspended and colloidal contents. Excessive turbidity (colloidal solids that interfere with light penetration) can block sunlight, harm aquatic life (e.g., by blocking sunlight needed for plants), and lower the ability of aquatic plants to increase dissolved oxygen in the water column. In drinking water, turbidity is aesthetically displeasing and interferes with disinfection. The total solid content is defined as all the mater that remains as residual upon evaporation at 103–105^{o}C. The total solids are classified as filterable solids (dissolved solids) and nonfilterable solids (suspended solids). The dissolved solids mainly consist of bicarbonates, carbonates, sulfates, chlorides, and nitrates and phosphates of calcium, magnesium, sodium, and potassium. For water ruse in irrigation, dissolved solids are very important criteria due to their effect in salinity of soil, thus cause depreciation in land productivity. The ignitable solids at 550°C are called volatile solids, while remaining fractions after ignition are called nonvolatile solids. Volatile solid content is considered a rough measure of organic matter, or biological solid concentrations such as bacteria and protozoa, while the concentration of nonvolatile solids is a measure of mineral content in the wastewater.

b) Chemical characteristics

∗ *Organic matter*

Organic matter exists in both soluble and particular forms in wastewater. Chemically, they can be also classified as biodegradable and non-biodegradable organic constituent. The amount of biodegradable organic determines the degree of biological treatment required. Many parameters are used as organic matter indicators. These parameters include: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and theoretical oxygen demand (ThOD). BOD is defined as the amount of oxygen consumed by microorganisms to oxidize the biodegradable organic (carbonaceous BOD) and inorganic (ammonia) matter through biochemical processes. This is the most widely used parameter to represent organic matter applied for both wastewater and surface water. Common incubation periods for BOD test is usually 5 days at 20°C (BOD_5), but other lengths of time and temperature can be used [9]. During 5 days of the BOD_5 test, the amount of oxygen consumed by a mixed population of heterotrophic bacteria in the dark at 20°C is measured. In this test, aliquots of wastewater sample are placed in a 300-mL BOD bottle (Winkler bottle) and diluted in phosphate buffer (pH 7.2) containing other inorganic elements (N, Ca, Mg, Fe) and saturated with oxygen. Sometimes acclimated microorganisms or dehydrated cultures of microorganisms, sold in capsule form, are added to municipal and industrial wastewaters, which may not have a sufficient microflora to carry out the BOD test. In some cases a nitrification inhibitor is added to the sample to determine only the carbonaceous BOD [8, 10]. Because of depletion of the carbon source, the carbonaceous BOD reaches a plateau called the ultimate carbonaceous BOD. The ultimate CBOD can be estimated by running the experiment until all of the organic carbon is oxidized. However, this can take between 20-50 days or in some cases much longer [11]. The BOD test is carried out on a series of dilutions of the sample depending on the source of the sample, the BOD value is expressed in milligrams per liter.

The organic matter can be oxidized chemically by using strong oxidizing agent in an acidic medium. Chemical oxygen demand (COD) is the amount of oxygen necessary to oxidize all of the organic carbon completely to CO_2 and H_2O. COD is measured by oxidation with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid and silver and is expressed in milligrams per liter [8, 10]. COD test need 2 hours for boiling, compared with 5 days for the BOD_5 test, so it is considered as a rapid measurement of organic matter. There is no constant correlation between BOD and COD, but for untreated domestic water the ratio of BOD_5/COD ranges from 0.4 to 0.8 [8, 9]. When this ratio falls below 0.3, it means that the sample contains large amounts of organic compounds that are not easily biodegraded.

Another method of measuring organic matter in water is the TOC or total organic carbon test. The TOC test is a measure of organic matter in terms of organic compounds. It involves the injection of an acidified sample in a high-temperature furnace where it is oxidized. The organic carbon content is calculated from the amount of CO_2 generated during the oxidation process. It is a rapid, but a costly method. Both TOC and COD represent the concentration of both biodegradable and nonbiodegradable organics in water.

ThOD is defined as the amount of oxygen theoretically required to oxidize the organic matter. If the chemical formula of the organic matter is known, the ThOD may be calculated. In this method, it is assumed that all organic matter will be oxidized and all environmental conditions are properly controlled.

∗ *Nitrogen Compounds*

Total nitrogen consists of organic nitrogen, nitrogen, ammonia, nitrite, and nitrate. Kjeldahl nitrogen is the total organic and ammonia nitrogen. Usually raw wastewater contains high concentration of ammonia up to 100 mg/L. Nitrite is relatively unstable and is oxidized rapidly to nitrate, and seldom exceeds 1 mg/L in municipal wastewater [9]. Nitrogenous compounds (mainly NH_3/NH_4^+) also consumed oxygen during the oxidation to nitrate with nitrite being an unstable intermediate (nitrification). The amount of oxygen consumed by bacteria for to oxidize nitrogen compounds through nitrification is defined as nitrogenous BOD (NBOD). However, different from carbonaceous BOD (CBOD) only two classes of bacteria are believed to be responsible for the oxidization of reduced nitrogen [11]. The NBOD does not become discernable until approximately 7 days of incubation have occurred. This is not uncommon as the nitrifiers typically have slower growth rates and do not flourish until the food supply for the heterotrophic (CBOD consuming) microbes has diminished [11]. To accurately quantify the amount of ammonia in water and wastewater, the colorimetric method is widely used. Alkaline phenol and hypochlorite react with ammonia to form indophenol blue that is proportional to the ammonia concentration. The blue color formed is intensified with sodium nitroprusside and measured colorimetrically [10, 12].

Nitrogen is necessary for biological treatment because it forms about 23% of the total bacterial body weight. Similar to nitrogen, phosphorus is essential to the growth of biological organisms, including algae. The presence of phosphorus in the effluent wastewater causes eutrophication phenomenon in the receiving water bodies (lakes, rivers) which causes oxygen depletion, offensive odor, increases turbidity and reduces transparency to light, and undesirable appearance. For this reason, control of phosphors in the effluent treated water is very important. The organic phosphorus is the amount of phosphors presents in organic compounds such as protein, while most of inorganic phosphorus is in the form of PO_4. Municipal wastewater may contain low concentrations of phosphorus in the range of 4 – 15 mg/L [9]. Phosphorus is usually present in orthophosphate, polyphosphate, and organic phosphate forms. Organically bound phosphorus is of little importance in domestic sewage whereas polyphosphate forms undergo hydrolysis to revert into the orthophosphate forms, although this conversion is quite slow.

c) Biological characteristics

In terms of wastewater treatment, the most important microorganisms in biological treatment are the bacteria, algae, fungi, protozoa, and rotifers. Bacterial counts in raw sewage water may be expected to range from 5×10^5 to 5×10^6/ml [9]. The most basic test for bacterial contamination is the test for total coliform bacteria. Total coliforms include bacteria that are found in the soil, in water that have been influenced by surface water, and in human or animal waste. Fecal coliforms are the sub-group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms. The average counts of total and fecal coliforms in municipal wastewater are $10^{10} – 10^{12}$ and $10^8 – 10^{10}$/mL, respectively [9].

In terms of oxygen requirement, bacteria are classified as aerobic, anaerobic or facultative.

The optimum temperature ranges for bacterial growth are 12 – 18°C, 25 – 40°C, and 55 – 65°C for psychrophilic, mesophilic, and thermophilic bacteria, respectively. Most bacteria cannot tolerate pH levels above 9.5 or below 4, so municipal wastewater is considered as a suitable environmental condition for its growth. Fungi have ability to grow under low moisture content, low nitrogen source, and tolerate to a wide range of pH (2 – 9). For these reasons, fungi are used for industrial wastewater treatment. The major food source of the protozoa is the bacteria, so it is considered as polisher of the effluent from biological treatment. Rotifers feed on bacteria and protozoa; hence their presence is a good indication of relative stability of treated waste.

2.1.2. Wastewater characterization for treatment plant design

Since individual water-using activities occur intermittently and contribute varying quantities of pollutants, the strength of the wastewater generated from a residence fluctuates with time. Accurate quantification of these fluctuations is impossible.

In characterizing wastewaters, quantitative and qualitative characteristics are often expressed in terms of other parameters which might be known as design units. These parameters vary considerably depending on the type of establishment examined. For residential dwellings, daily flow values and pollutant contributions are expressed on a per person (capita) basis. The used units in wastewater analyses are presented in Table 2.1 [9].

Table 2.1 Used units for wastewater analyses

Parameter	Unit	Notes
Concentration	mg/L	-
Per capita hydraulic loading	L/c/d	Or other volume units/c/d
Per capita mass loading	g/c/d	Or other mass units/c/d
Plant hydraulic loading	m^3/d	Or other volume units/d
Plant mass loading	kg/d	Or other mass units/d
Sludge loading	kg/d	Or other mass units/d
EC	dS/m	-

Due to the prevalence of organic matter in most types of wastewater, organic loading/organic capacity is known as one of the key requirements in design of wastewater facilities. According to several guidelines for municipal wastewater and sewage treatment, the design basis in terms of organic loads is comprised of design average BOD_5, design daily average BOD_5, design maximum day BOD_5 and design peak hourly BOD_5 [13-15]. When aeration with nitrification is selected as the main process for biological treatment, design peak daily TKN loading also needs to be considered according to Ontario (2008). The terms of design average BOD_5, design maximum day BOD_5 and design peak hourly BOD_5 defined by Great Lake - Upper Mississippi River (2014) as:

- Design average BOD_5 is generally the average of the organic load to be received for a continuous 12-month period for the design year expressed as weight per day. However, the design average BOD_5 for facilities having critical seasonal high loading periods (e.g., recreational areas, campuses, industrial facilities) shall be based on the average organic load to be received during the seasonal period.

– Design maximum day BOD_5 is the largest amount of organic load to be received during a continuous 24-hour period expressed as weight per day

– Design peak hourly BOD_5 is the largest amount of organic load to be received during a one-hour period expressed as weight per day.

In another way, the guideline of Ontario (2008) recommends that the average daily BOD_5 can be based on design average daily flow of influent wastewater. Similarly, the peak daily TKN can be based on design peak daily flow. In this manner, it is understood that the design average daily load can be calculated from design concentration and average daily flow of influent wastewater. However, the method to determine the design concentration of influent wastewater (e.g., average concentration of wastewater over a 24-hour or 12-month period) is not mentioned in the guideline. It was reported that the design approaches in most guideline are usually based on daily average values [14-17]. However, in the case of procedures with short retention times of only a few hours, it is recommended that special peak values may be necessary if the homogenization of the influent in the sewer system or in the upstream treatment units is small [18]. This is all the more true in warm climates, where load peaks can be more severe due to the comparatively small dimensions of the plants. In these cases, peak value analyses are to be carried out for sensitive parameters by means of individual peak values or daily hydrographs of the inflow [18]. Similarly, Japan Sewage Works Association (2013) also recommends that design inflow and influent quality shall consider variation along the time. However, it is noted that the determination of wastewater variation is undoubtably not an easy task. In existing systems, when the historical data of operation including influent and effluent concentration is available, the variation in influent concentrations can be practically assumed or estimated. The actual data that accurately represent organic load should be used to calculate projections for organic capacity. On the other hand, for the new construction of a wastewater systems or even upgrading an existing, the information of grab or composite samples of the influent parameters is surely needed. Daily hydrographs plotted by 2-hour composites is recommended by DWA (2019) for obtaining the variation of influent concentration. Nonetheless, the amount of data required (e.g., how many sets of daily hydrographs needed) for determining design parameters was not mentioned in the guideline.

According to the guideline of Ontario (2008), where it is found that sewage characteristics vary significantly over the year due to excessive infiltration/inflow, population variations and/or seasonal changes in industrial or commercial operations, estimates should be made of the expected average, maximum and minimum BOD_5 and suspended solids concentrations in the sewage for each month of the year. If nitrification is required, short- and long-term variations in TAN (total ammonia nitrogen) and TKN (Total Kjeldahl Nitrogen) concentrations should also be estimated. The guideline recommends typical organic loading rates for domestic sewage are 75 and 90 g/c/d for BOD_5 and SS, respectively [15]. Similarly, South Dakota Department of Environment and Natural Resources (1991) and Great Lake - Upper Mississippi River (2014) also suggest that domestic wastewater treatment design shall be on the basis of at least 77 g-BOD_5/c/d, and 90 g-SS/c/d. If nitrification is required, 16 g-TKN/c/d may be used [14, 17]. In addition, where garbage grinders are commonly used in areas tributary to a domestic plant, the design basis should be increased to 100 g/c/d of BOD_5 and 113 g/c/d of SS, respectively. The TKN load in this case should also be increased to 21 g/c/d if nitrification is required [14, 17].

2.2. Determination of influent flow for design of wastewater facilities

2.2.1. Importance of flow measurement

The required hydraulic capacity for wastewater treatment system is determined initially from the estimated wastewater flow. Reliable data on existing and projected flows should be used if onsite systems are to be designed properly and cost effectively. The usefulness of these data includes:

- Design the volume of treatment units.
- Determine the capacity of the required pumps.
- Design the overflow rate mitigations.
- Estimate the available quantity of treated water.
- Estimate the amount of chemicals and materials used for the treatment.
- Estimate the volume of generated sludge.
- Determine the expected gas production from digestion unit.
- Maintain the minimum required flow for treatment or pumps.

Each city will have its own characteristics, hence wastewater flowrate varies according to the life style of people, water consumption, weather condition, economical activities, and the season of the year. The volume of wastewater generated from a community varies from 190 to 950 L/c/d, and the common value is 450 L/c/d which includes residential, commercial, and infiltration wastewater [9]. Quantity of wastewater generated in a certain home depends on the number of fixtures used. The water flow from a typical residential dwelling is approximately 700 L/c/d. Actually the volume of municipal wastewater generated from a small residential community under shortage of water is smaller than these values and ranges from 90 to 110 L/c/d [9].

Wastewater flow rate is affected significantly by infiltration rate. The amount of infiltration to be expected will be depend upon the care with which the sewer is constructed, age of sewers, the height of the groundwater table, types of sewers, types and number of joints, length of pipes, and types and characteristics of the soil [9]. The variation in wastewater flow rate occurs daily, weekly, and monthly. Hourly wastewater flow rates range from 20% to 250% of the average daily rate for small communities and from 50% to 200% for larger cities. There are generally two peaks in daily wastewater flow corresponding to sewage generated in the early morning as people get ready for the day and early evening when they return home. In residential districts the greatest use of water is in the morning, once daily activities begin at 6 a.m. Hence, the peak flow will be quite pronounced and occurs at about 9 a.m. In some cities a peak flow occurs shortly before noon, lunchtime (11 a.m.), and after evening, dinnertime (10 p.m.), while the lowest flows occur in early morning about 4 a.m.

In addition to the water consumption, the time when the peak flow occurs depends on the length of working day, type of food, lifestyle, and length of sewer pipes. It is important to mention that, if the sewage flow is measured near its origin, a short delay occurs between water demand peak flow and sewage peak flow, while a long delay occurs when the sewage must travel a long distance [9].

A weekly variation also occurs, and the maximum day is usually Monday, and the minimum is usually Sunday. In small communities where most people are working in other cities and come back to their homes at weekend, the peak flow occurs during these days due to the increase in water consumption [9]. In contrast, in the industrial and large cities, the peak flow occurs during the working days and decrease significantly during the holidays. A monthly variation in flow is also recognized and usually the maximum monthly flow occurs during the summer season, while the minimum monthly flow occurs during the winter season. Concerning the per capita hydraulic load, it was found that the hydraulic load has the lowest values in November and the highest values in August. This is expected due to the increase of water consumption in summer [9].

2.2.2. Determination of influent flow in wastewater treatment design

The design basis in terms of flow normally consists of design average flow, design maximum daily flow, design minimum daily flow, design minimum daily flow, design peak hourly flow and design peak instantaneous flow [14, 15]. Specifically, the definition for these types of flow can be expressed as below:

– Design average flow is the average of daily volume to be received for a continuous 12-month period expressed as a volume per unit time. However, the design average flow for facilities having critical seasonal high hydraulic loading period (e.g., recreational areas, campuses, industrial facilities) shall be based on the average of the daily volumes to be received during the seasonal period.

– Design maximum daily flow is the largest volume of flow to be received during a continuous 24-hour period expressed as a volume per unit time.

– Design minimum daily flow is the smallest volume of flow to be received during a one-day period expressed as a volume per unit time.

– Design peak hourly flow is the largest volume of flow to be received during a one-hour period expressed as a volume per unit time.

– Design peak instantaneous flow is the instantaneous maximum flow rate to be received.

Obviously, the determination of those flow types for wastewater facilities design is not an easy task. In case of existing systems, actual flow data that accurately represent average and peak flows in required to calculate projections for hydraulic capacity [14, 16]. In addition, the probable degree of accuracy of data and projections for all critical design flow conditions shall be evaluated. The impact of infiltration/inflow reduction or elimination of sanitary sewer overflows, backups, or hydraulic restriction also needs to be considered. Furthermore, graphical displays of critical peak wet weather flow data should be includes for a sustained wet weather flow period of significance to the project [14, 16]. On the other hand, in design of hydraulic capacity for new systems, flow estimates for the design average flow and design peak hourly flow, including origin of the flow estimates and any assumptions, shall be identified [16]. Where it is not possible to base estimates of sewage flows and characteristics upon actual field measurements, the flow records and sewage characteristics of similar serviced communities may provide data upon which estimates can be based [15]. In estimating sewage flows, it is recommended that a range from 225 – 450 L/c/d be used for average domestic sewage flows, exclusive of extraneous flows [15]. From another approach, an average daily flow of 380 L/c/d plus wastewater flow from industrial plants and major institutional and commercial facilities should be used to identify the size of new wastewater collection system [14, 17]. In addition to

5 types of flows for design of hydraulic capacity mentioned above, South Dakota Department of Environment and Natural Resources (1991) advised a term of peak design defined as the rate generally used to determine hydraulic sizing and mass loading of treatment units by multiplying a factor of 2.0 to 2.5 times the design average flow rate. The guideline also recommends that minimum daily flow would be based on 50 percent of the average daily flow if flow measurements are not available [17]. To estimate peak hourly flows, the design average flow should be multiplied by the peaking factor determined from Harmon (Equation (2.1)) or Babbitt formula (Equation (2.2)).

Harmon formula

$$M = \frac{18+\sqrt{P}}{4+\sqrt{P}} \tag{2.1}$$

Babbitt formula

$$M = \frac{5}{P^{0.2}} \tag{2.2}$$

where:

M = ratio of peak hourly flow to design average flow

P = population in thousands

2.3. Challenges in design of wastewater facilities for new treatment systems

2.3.1. Improper guidance in estimation of influent flow and concentration

It can be recognized a slight difference between the guidelines for recommended typical value to estimates average daily flow when designing sewage or domestic wastewater treatment. For example, Ontario (2008) recommends the average daily flow varied of 225 – 450 L/c/d for domestic wastewater while the value of 380 L/c/d is suggested by South Dakota Department of Environment and Natural Resources (1991) and Great Lake - Upper Mississippi River (2014). This again leads to the difference of peak hourly flow as directedly estimated from the average daily flow (multiplied times the peaking factor) between these guidelines. In fact, the design for various components of the treatment plant will be based upon either design average flow or peak hourly flow. Generally, the organic loading of a wastewater treatment unit is based on the design average flow and the hydraulic loading of a unit is based on the peak hourly flow [17]. Thus, the conflict between the guidelines or handbooks in estimating the design basis in terms of flow can results in the under/overestimation of treatment plant capacity. For example, in the guidelines for sewage works of Ontario (2008), the Equation (2.3) is recommended to determine peak sewage flows for municipal sewer design for residential areas.

$$Q_{(d)} = \left(\frac{PqM}{86.4}\right) + IA \tag{2.3}$$

where:

$Q_{(d)}$ = peak domestic sewage flow (including extraneous flows) in L/s

P = design population, in thousands

q = average daily per capita domestic flow in L/c/d (exclusive of extraneous flows)

I = unit of peak extraneous flow, in L/ha/s

A = gross tributary area, in hectares

M = peaking factor (as determined from Harmon or Babbitt Formula)

In this guidance, the suggested value for the average daily per capita domestic flow (q) fall within a range of 225 – 450 L/c/d. Considering a case that municipal sewer is design for a megacity with population of approximately 10 million people, the part of *PqM* in Equation (2.3) would be calculated as ranging from 29.5 to 59.1 m^3/s, with the peaking factor is calculated from Harmon formular. If the suggested value of 380 L/c/d was selected for q according to Great Lake - Upper Mississippi River (2014), the peak domestic sewage flow excluding extraneous flows would be estimated as of 49.9 m^3/s. In another case, when municipal sewer is designed for a small city with population of around 50 thousand people, the peak domestic sewage flow excluding extraneous flows is calculated to vary in range of 295 – 590 L/s according to instruction of Ontario (2008), whilst the value of 498 L/s is provided by Great Lake - Upper Mississippi River (2014). Obviously, the difference in suggested value could be confusing for designer to decide which one should be the proper design basis. Because the suggested design value is based on population equivalent, a small difference in selection of average design flow per each capita can also results in a huge difference of total domestic flow when population is big enough (i.e. in big cities or megacities where people more concentrated). Once too big value was selected, this results in larger volume or size of sewer would be required. However, in case that real value of the peak domestic sewage flow excluding extraneous flows is much lower than the design, sewage might potentially flows slowly due to the large size of sewer. Consequently, the long detention time of sewage inside sewer might enhance the corruption of organic compounds during path of conveying to receiving WWTP. Another example to demonstrate the uncertainness hold by the traditional method of estimating design average flow from several guidance is about design of equalization tank. According to Japan Sewage Works Association (2013), the capacity of equalization tank shall be decided to store the excess wastewater over design flow to the downstream process. It is advisable to have equalization when peak flow exceeds 1.5 times of daily average flow and when biological nutrient removal process is used. To take the peaking factor into consideration, it must be noted that the minimum permissible peaking factor is 2.0. Based on this, it can be concluded that the equalization tank is always recommended to install rather than seeking an optimized operational condition to reduce the effects of excessive flows. Thus, estimating design average as well as peak flow when designing sewage facilities is unreliable. To cope with this, the continuous measurement during a certain period to accumulate real informational data of wastewater objects is undoubtedly desired. Thanks to the advance in nowadays technologies, this issue can be damped by the installation of water flow meter with data logger.

In case of estimating influent pollutants load for wastewater facilities design, it is found that the difference of recommended average organic load for design of sewage treatment is very minor between the guidelines. Specifically, South Dakota Department of Environment and Natural Resources (1991) and Great Lake - Upper Mississippi River (2014) suggests design average organic load is 77 g-BOD_5/c/d while the value of 75 g-BOD_5/c/d is advised by Ontario (2008). Although the recommended value for design average organic load is mostly identical between the three guidelines, it must be recalled that the suggested average daily flow is distinct. Consequently, once the average daily flow of wastewater influent was improperly selected, the average concentration of wastewater influent is also wrongly estimated. Specifically, the average concentration of municipal wastewater was suggested to be approximately 203

$mgBOD_5/L$ according to the guidance of South Dakota Department of Environment and Natural Resources (1991) and Great Lake - Upper Mississippi River (2014), whilst the design average BOD_5 of 167 – 333 $mgBOD_5/L$ for sewage is recommended by Ontario (2008). In fact, influent characteristic and effluent requirements are always considered for either process selection or facilities design of wastewater treatment systems. As a result, the treatment systems can be design and operated under or over the real capacity if the inflow data is not accurately estimated or measured. For example, also in the guidance of Japan Sewage Works Association, sludge retention time (SRT) of reactor in conventional activated sludge process is calculated from Equation (2.4) below.

$$\theta_X = \tau \cdot X \Big/ \left(a \cdot C_{S-BOD,in} + b \cdot C_{SS,in} - c \cdot \tau \cdot X \right) \tag{2.4}$$

where:

τ = hydraulic retention time (HRT), day

X = Mixed Liquor Suspended Solids (MLSS), mg/l

$C_{S\text{-}BOD,in}$ = soluble BOD in influent to reactor, mg/l

$C_{SS,in}$ = suspended solids in influent to reactor, mg/l

a = yield from soluble BOD to MLSS, g-MLSS/g-SBOD, 0.4 – 0.6

b = yield from suspended solids to MLSS, g-MLSS/g-SS, 0.9 – 1.0

c = endogenous decay coefficient, 1/day, 0.03-0.05

Considering a case that design of activated sludge reactor with assumed HRT is of 8 hours, expected MLSS is of 2000 mg/L, influent SS of 180 mg/L and the coefficient of a, b and c are selected as 0.5, 0.95 and 0.04 respectively. Also, assuming that the 40% of BOD and 50% of SS are removed from first sedimentation, and the proportion of soluble BOD is 67% of total BOD. In this way, the soluble BOD concentration of influent to reactor should be in range of 45 – 89 mgBOD/L based on the suggestion of design organic load from the guidance of Ontario (2008), whilst 54 mgBOD/L of influent to reactor is the corresponding value recommended by Great Lake - Upper Mississippi River (2014). As a result, the SRT is calculated to fall within the range of 6.4 – 8.2 day based on the guidance of Ontario (2008). On the other hand, the SRT of 7.7 day is the value calculated based on the instruction of Great Lake - Upper Mississippi River (2014). An obvious consequence of setup long SRT is that greater amount of waste sludge will be generated, leading to the higher cost in solid waste treatment and disposal. On the other hand, the selection of short SRT for aeration tank design might results in poor nitrification if the process is required together with organic removal. Through this example, the traditional method of estimating average flow and organic load is once again proved itself to hold certain limitation in designing WWTP facilities.

Based on the above issues in designing WWTP by traditional method, the alternative and promising solution is to determine the real characteristic of influent wastewater by directly measurement over a certain continuous period. Unlike flow measurement, since available online device for continuously measuring the concentration of wastewater compositions with high accuracy is scarce, the solution become more difficult to be conducted. In addition, the use of on-line sensors still remains complicated, since the sticky materials of raw wastewater and the heavy deposit of pollutants make their maintenance cost considerable [19].

2.3.2. Challenges in projection and design of new wastewater systems in Vietnam

Despite the fact that the approach to determine design basis of influent flow and concentration described in the above-mentioned guideline has been commonly approved in the regions (EU, US), the feasibility of this method for wide or even global usage is still in doubt, especially in Vietnam. This is due to the inequality of both sewage collection system and domestic wastewater concentration between regions or countries. As introduced in Chapter 1, septic tank which plays an important role in preliminary treatment of domestic wastewater is obligated to be installed prior to sewer systems for each household. The very high variation in concentration of effluent from septic tanks is found, indicating a fact that the construction, operation, and maintenance of septic tanks is not homogeneous between households. Indeed, it is reported that instead of frequent de-sludging for septic tank, Vietnamese household merely sanitate when the tank is overflow. In contrast, the very low BOD concentration is typically found in the influent of municipal WWTPs. This is mainly due to the deterioration of organic during the path that effluent from septic tank conveyed to WWTP via the sewer system. It must be recalled that most of wastewater collection systems in Vietnamese urban areas is CSS. They are typically constructed as flat-bottomed and rectangular-covered channels having little or no slope with open joints. This leads to the consequence that wastewater often flows quite slow inside the sewer, especially in dry season, allowing the settle of particulate constituents to sewer bottom as well as the enhancement of decomposition from bacteria during the conveyance of wastewater to receiving WWTPs. In addition, the infiltration from groundwater to the sewer systems leading to the dilution of wastewater is also believed as one the possible reason.

Another corollary from the usage of CSS to collect domestic wastewater in Vietnam is the influence of urban runoff mostly originated from rain or rainstorm. During the initial phase of a rainstorm, surface pollutants conveyed by surface runoff enter to sewer system via drains, followed by the penetration of rainwater during the remainder of the rainstorm. As a result, the water pollution at the beginning of a rainstorm is typically more concentrated compared to the latter, leading to the rapid change in water quality (pollutant concentration or load) of the recipient. All these facts result in the infeasibility of applying the recommended standards from the guideline to estimate wastewater characteristics in Vietnam. Thus, the measurement of the real influent characteristic over a certain continuous period is preferably conducted whenever a new project of wastewater treatment implemented. In this regard, the conventional method of waster sampling combined with analysis is the inevitable answer that comes to mind first. However, in order to obtain the design basis of organic load comprised of average BOD_5 load, peak daily and hourly BOD_5 load as suggested in the guidelines, an enormous number of wastewater samples needs to be collected and analyzed consuming tons of man-power/man-hour. From these backgrounds, either a proper instruction of estimating influent concentrations or an innovative and simple method to measure the real influent concentrations when inflow data is not available or limited is highly desired to alternate the existing method.

CHAPTER 3. FIELD EXPERIMENTAL MODULE AND PRELIMINARY EXPERIMENTS FOR BACK-CALCULATION APPROACH TO ESTIMATE THE CONCENTRATION OF INFLUENT BIODEGRADABLE CONSTITUENTS

3.1. Introduction

As mentioned in the previous chapters, some hindrances in the design and management of wastewater treatment in Vietnam still existed which mostly due to the unrealistic influent wastewater of combined sewer system. The lack of influent characteristics that varies in very long range and depends much on the season in the tropical countries like Vietnam brings many negative consequences to environmental management. The maintenance staffs cannot get the right implementation with "unknown wastewater" appear in specific time. Therefore, the need of determining the real influent characteristics is the prerequisite for any activities of wastewater treatment design and management in Vietnam undoubtedly.

In normal, the direct on-site sampling together with laboratory analysis is very popular way to determine the wastewater concentration. To the combined sewage system, this method requires the high cost, man-power as well as a number of samples to obtain the tendency of municipal wastewater characteristics. Due to the fluctuation of wastewater by day, by seasons and even by hours in a day, it requires the reliable and reasonable approach to catch the compositions. In this regard, considering that the responses of activated sludge reactor (activated sludge constituents, dissolved oxygen (DO) concentration in reactor, oxygen uptake rate (OUR) of activated sludge, nitrate concentration in the reactor…) are the direct consequences of the influent and the operating conditions, the back-calculation of the influent material concentrations from the responses of activated sludge reactor might be an attractive option. To meet the purpose, a simple and reliable mathematical framework is needed to be thoroughly considered and selected for the calculation works. In this regard, Activated Sludge Model 1 (ASM1) is a theoretical mathematical model depicting the biological processes occurring in the activated sludge section of a wastewater treatment plant [20]. It was developed in 1986 by the task group formed from the International Association on Water Quality (IAWQ, formerly IAWPRC). The primary aim was to set out a standardization of biological WWTP design by building a mathematical model able to realistically describe carbon oxidation, nitrification and denitrification. The first model developed for municipal activated sludge ASM1 describes the removal of organic carbon compounds and ammonia-nitrogen, with facultative consumption of oxygen or nitrate as the electron acceptor, depending on the conditions in the activated sludge system. Other models, ASM2 and ASM2d, which include chemical precipitation processes and phosphorus removal, have also been developed. To correct a number of shortcomings of the ASM1 model, the ASM3 model was developed based on the ASM1 model.

a) Organic components in ASM1

In ASM1, the total COD is divided into three main fractions comprised of non-biodegradable, biodegradable and active biomass. The non-biodegradable COD has two fractions, non-biodegradable particulate also known as particulate inert (X_I) and non-biodegradable soluble also known as soluble inert (S_I). In the same manner, the biodegradable COD also has two fractions consisted of the slowly biodegradable (X_S) and readily biodegradable COD (S_S), while the active biomass consists of heterotrophic biomass ($X_{B,H}$) and autotrophic biomass ($X_{B,A}$). Particulate products arising from biomass decay X also contribute to the total COD. The COD fraction up to total COD in ASM1 was shown in Figure 3.1.

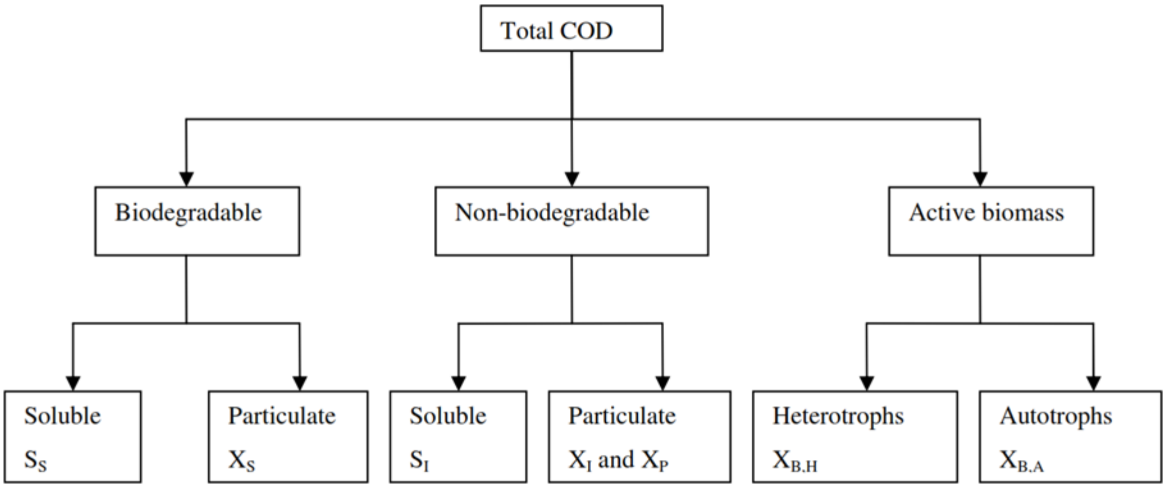

Figure 3.1 COD fraction in ASM1

b) Nitrogen components in ASM1

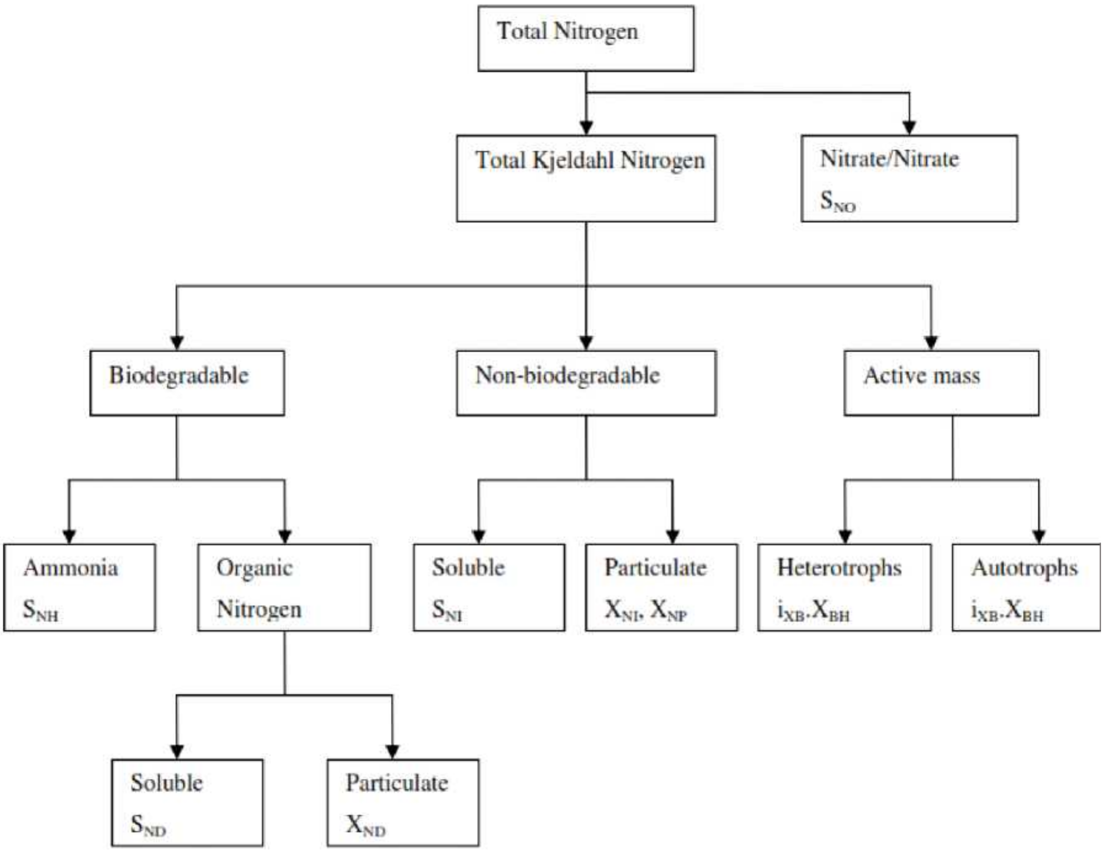

Figure 3.2 Nitrogenous fraction in ASM1

The Total Kjeldahl Nitrogen (TKN) in ASM1 is then subdivided into three categories as similar to the COD, which consists of the biodegradable, non-biodegradable and the active biomass. The biodegradable component is comprised of soluble ammonia nitrogen (S_{NH}) and two organic nitrogen fraction which are soluble organic nitrogen (S_{ND}) and particulate organic nitrogen (X_{ND}). The non-biodegradable components are not included as separate components in the ASM1 model. The particulate non-biodegradable organic nitrogen (X_{NI}) is linked to non-biodegradable particulate components of COD while the soluble non-biodegradable organic nitrogen (S_{NI}) occurs in negligible amounts. The active biomass is also associated with a nitrogen fraction (X_{NB}) which is split between heterotrophic and autotrophic biomass $i_{XB}.X_{B,H}$ and $i_{XA}.X_{B,A}$ respectively. The particulate products (X_P) and inert particulate (X_I) are also associated with nitrogen fractions (X_{NP} and X_{NI}) respectively. The total nitrogen fraction in the influent wastewater of ASM1 was given in Figure 3.2.

c) Process in ASM1

Four processes are considered in ASM1: the growth of biomass, decay of biomass, ammonification of organic nitrogen and the hydrolysis of particulate organics which are entrapped in the bio-flocculation. The growth of the biomass is represented by three processes comprising aerobic growth of heterotrophs, anoxic growth of heterotrophs and aerobic growth of autotrophs.

∗ *Aerobic growth of heterotrophs*

Aerobic growth of heterotrophic biomass occurs at the expense of soluble substrate (S_S) and results in the production of heterotrophic biomass. It is associated with the utilization of oxygen, which is represented by the negative COD in the process model matrix. Ammonia nitrogen is removed from solution and incorporated into cell mass. Monod kinetics is used to describe the process in the model matrix.

∗ *Anoxic growth of heterotrophs*

Anoxic growth of heterotrophs is the denitrification process which occurs at the expense of readily biodegradable substrate and results in heterotrophic biomass while nitrate nitrogen serves as the terminal electron acceptor. As in aerobic growth, ammonia nitrogen is converted to organic nitrogen in the biomass. The same Monod kinetics as the aerobic process is used to represent the process, but a correction factor, η_g is included to account for the anoxic process rates being slower than the aerobic process rates.

∗ *Aerobic growth of autotrophs*

Aerobic growth of autotrophs results in autotrophic cell mass and nitrate nitrogen as end products. This is the nitrification process where ammonia nitrogen S_{NH} is oxidized to nitrate S_{NO}. Soluble ammonia nitrogen serves as the energy source for the growth of the nitrifiers. Oxygen is used in proportion to the amount of ammonia nitrogen oxidized.

The decay of biomass is represented by two processes which are decay of heterotrophs and decay of autotrophs.

∗ *Decay of heterotrophs*

In the decay process of heterotrophs, the biomass is converted to a combination of particulate products and slowly biodegradable substrate. The slowly biodegradable substrate is hydrolyzed in the hydrolysis process. No loss of COD is involved in the split and no electron acceptor is utilized.

∗ *Decay of autotrophs*

The decay of autotrophs is modelled in a similar manner to that of heterotrophs of which the autotrophs biomass is simultaneously converted to undegradable particulate and slowly biodegradable substrate hydrolyzed in the hydrolysis process.

∗ *Ammonification of organic nitrogen*

In this process, organic ammonia (S_{ND}) is converted to ammonia nitrogen (S_{NH}) through a first order reaction accompanied by alkalinity changes. Hydrolysis of particulate organics is represented by two processes: the hydrolysis of entrapped organics and the hydrolysis of entrapped organic nitrogen.

∗ *Hydrolysis of entrapped organics*

In this process slowly biodegradable substrate (X_S) is broken down into readily biodegradable substrate (S_S). A correction factor, η_h is included to account for the reduced hydrolysis rate under anoxic conditions.

∗ *Hydrolysis of entrapped organic nitrogen*

The hydrolysis of entrapped organic nitrogen is modelled in a similar way to the hydrolysis of entrapped organics.

It was proved that mathematical modelling of wastewater treatment processes has become a widely accepted tool and is used for research, plant design, optimization, training, and model-based development and testing of process control. Starting with the activated sludge system and now moving into whole plant modelling, the modelling community has produced a significant number of models describing the processes occurring in wastewater treatment plants. However, due to the usage of distinctive notation from many unit process models available in the field of wastewater treatment, the problems in documentation, implementation, and connection of different models are generated (using different sets of state variables). In case of ASM1, the list of state variables was shown in Table 3.1.

ASM1 was based on the South African work but was presented in a new format (the Gujer or Petersen table, composed of a stoichiometric matrix, a rate vector and extra information as units and names) and with a new and standardized notation. The latter notation had its roots in the work of another IAWPRC/IUPAC task group, led by Prof. Grau *et al.* (1982a,b, 1987) [21-23]. There are many models published with their own notation, sometimes using different names for the same compound or parameter, or the same name for different compounds/parameters. In this regard, the need for a common international notation standard in biological wastewater treatment was already highlighted in Henze *et al.* (1982), where examples were given of abuse of notation (e.g. double notation, double meaning, misdirection, etc.). It was concluded that notation is a common cause of confusion due to the absence of a universally agreed system of terminology. At the same time a proposal for unifying the notation used in the description of biological wastewater treatment processes was presented by Grau et al. (1982a,b, 1987). This proposal was presented by a Working Group set up by the IAWPRC and the Commission on Water Quality of the International Union of Pure and Applied Chemistry (IUPAC). This notation standard has been followed for many years. However, the complexity of wastewater treatment models has significantly increased over the last 25 years and new modelling concepts have been introduced [25]. The need to re-address this problem arose during the work of the IWA task group on a book on Biological Wastewater Treatment [26].

Table 3.1 State variables used in ASM1

State variables	Description	Units
Inorganic Suspended Solids		
xii	inert inorganic suspended solids	g/m^3
Organic Variables		
si	soluble inert organic material	gCOD/m^3
ss	readily biodegradable substrate	gCOD/m^3
xi	particulate inert organic material	gCOD/m^3
xs	slowly biodegradable substrate	gCOD/m^3
xbh	active heterotrophic biomass	gCOD/m^3
xba	active autotrophic biomass	gCOD/m^3
xu	unbiodegradable particulates from cell decay	gCOD/m^3
xsto	internal cell storage product	gCOD/m^3
Dissolved Oxygen		
so	dissolved oxygen	gO$_2$/m^3
Nitrogen Compounds		
snh	free and ionized ammonia	gN/m^3
snd	soluble biodegradable organic nitrogen	gN/m^3
xnd	particulate biodegradable organic nitrogen	gN/m^3
sno	nitrate and nitrite	gN/m^3
snn	dinitrogen	gN/m^3
Alkalinity		gN/m^3
salk	alkalinity	mole/m^3

Given all of the above, it appears that a new and extendable notational framework is needed. Fortunately, Corominas *et al.* (2010) had successfully developed a new framework provides a structured system to specify the symbols for state variables and parameters used in wastewater treatment modelling. The structured framework allows the development of new symbols for new models (in different subfields of wastewater treatment modelling) and the extension of the same framework for future developments. Based on this work, the state variables as well as the processes in ASM1 were standardized and summarized in Table 3.2.

Table 3.2 The ASM1 process matrix

No	Description Process	Units	XC_B	S_B	X_{OHO}	X_{ANO}	S_{O2}	S_{NHx}	$S_{B\_org,N}$	$XC_{B\_org,N}$	X_U	X_I	X_{Ig}	S_{NO}
1	Aerobic growth of heterotrophs	$gCOD/m^3/d$		$-1/Y_{OHO}$	1		$-(1-Y_{OHO})/Y_{OHO}$	$-f_N$						
2	Anoxic growth of heterotrophs	$gCOD/m^3/d$		$-1/Y_{OHO}$	1			$-f_N$						$-(1- Y_{OHO})/(2.8\times Y_{OHO})$
3	Aerobic growth of autotrophs	$gCOD/m^3/d$				1	$-(4.57-Y_{ANO})/Y_{ANO}$	$-f_N-1/Y_{ANO}$						$1/Y_{ANO}$
4	Decay of heterotrophs	$gCOD/m^3/d$			-1					$f_N(1-f_U)$	f_U			
5	Decay of autotrophs	$gCOD/m^3/d$				-1				$f_N(1-f_U)$	f_U			
6	Ammonification of soluble organic nitrogen	$gN/m^3/d$						1	-1					
7	Hydrolysis of particulate biodegradable COD material	$gCOD/m^3/d$	-1	1										
8	Hydrolysis of particulate biodegradable nitrogen	$gN/m^3/d$							1	-1				
			Slowly biodegradable substrate	Readily biodegradable substrate	Active heterotrophic biomass	Active autotrophic biomass	Dissolved oxygen	Ammonium and ammonia	Soluble biodegradable organic nitrogen	particulate biodegradable organic nitrogen	Unbiodegradable particulates from cell decay	Particulate inert organic material	Inert inorganic suspended solids	

In concept of ASM1, it can be recognized that during the growth process of heterotrophic and autotrophic organisms, active biomass of these bacteria species and nitrate are the direct products of the readily biodegradable substrate and soluble ammonium and ammonia. In addition, dissolved oxygen is also an essential and direct reactant together with substrate in the reaction of bacteria growth. The concept of back-calculation is that unknown input parameters are accordingly calculated from a provided datasets of output parameters. In case of this study, unknown input parameters are supposed as the influent concentrations while the output parameters might be the factors of organism active biomass, DO concentration or nitrate concentration as mentioned above. In a brief description for the back-calculation method using ASM1, a field experimental module is certainly needed, of which the responses of the module are monitored to obtain the output parameter for back-calculating the concentration of influent fed into the module. In addition, because the mathematical equations in ASM mostly consist of many constants known as kinetic and stoichiometry parameters, the determination for these factors is also essential to obtain a reliable results for back-calculation work. However, the exact measurement of all relevant kinetic and stoichiometry parameters for an organism species is supposed to be an impossible task due to many potential factors that can affect measured results. For that reason, this study simply focused on the experiment to estimate the specific decay rate of ordinary heterotrophic organism (OHO) and the specific growth rate of autotrophic nitrifying organism (ANO) while other kinetic and stoichiometry parameters were adopted from literatures. From these backgrounds, to demonstrate the back-calculation approach, the estimation of weekly and hourly concentration of influent biodegradable carbonaceous and nitrogenous material will be introduced and discussed in Chapter 4 and Chapter 5.

3.2. Field experimental module of activated sludge reactors

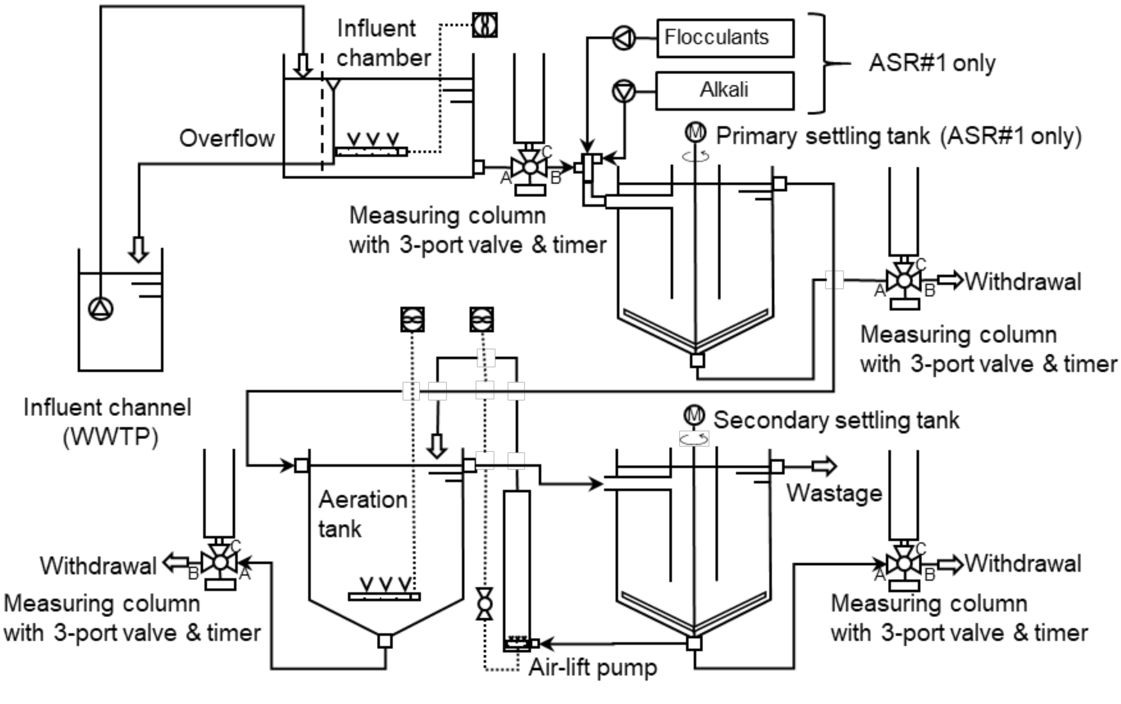

Figure 3.3 Schematic flow of conventional activated sludge module

Sources: from Nguyen et. al. (2017) [28]

A field experimental module composed of two set of lab-scale activated sludge reactors (ASRs) was installed for measuring the response of activated sludge. As illustrated in Figure 3.3, the field experimental module comprised of two activated sludge reactors (ASR). The first

ASR was composed of a primary settling tank followed by an aeration tank and a secondary settling tank (ASR#1) whilst the other was duplicated from ASR#1 except that no primary settling tank was equipped (ASR#2). In this way, ASR#1 was operated to measure the soluble biodegradable fractions in the influent whilst ASR#2 was used to obtain the total biodegradable substance concentrations in the influent including suspended particulates.

The influent was pumped by a submerged pump (S-500LN, Tereda Pump Co. Ltd., Tokyo, Japan) covered by a course screen. All tanks had 23-L of working volume with conical cylinder shape. A solid scraper rotating at 1 rpm was equipped with each settling tank whilst each aeration tank had an air diffuser made of air stone and a blower having maximum capacity of 6 L-air/min (OP-N026D, Iwaki Pumps Co. Ltd., Tokyo, Japan). An air-lift pump made of 12.5-cm PVC tube integrated with a blower (APN-057R, Iwaki Pumps Co. Ltd., Tokyo, Japan) was used for the recirculation of activated sludge from secondary settling tanks to aeration tanks.

The wastewater was pumped at around 30 L/min of flowrate, continuously circulated and stored in a 50-L influent chamber. A course screen was additionally placed in the influent chamber to prevent from clogging by big particles, the overflow wastewater was conveyed through a small ditch from the top of the influent chamber to the effluent container, at where the excess was pumped back into the WWTP. To feed the influent for reactors, two 2.5-L PVC measuring columns were connected to the bottom of influent chamber via 3-port ball valves (common-port, A-port and B-port which were closed and opened respectively by default) (EALB100-UTNE15A, Kitz Co. Ltd., Chiba, Japan) controlled by on-off periodic timers (H3CA-A, OMRON Co. Ltd., Kyoto, Japan). The wastewater from the influent chamber will be filled in measuring columns during "on" period followed by "off" period during which the wastewater was then fed to both ASRs. In the same manner, the primary settling tank and aeration tanks were also equipped with an accordant measuring column for each to withdraw excess sludge. Two plastic containers with 2 liters of volume were equipped for dosing poly-aluminum chloride (PAC) and anion polymer (Organo Corp., Tokyo, Japan) using electromagnet metering pumps (EHN-B11, Iwaki Pumps Co. Ltd., Tokyo, Japan). This dosing chemical reagents is to maximize the solid-liquid clarification of primary settling tank. Additionally, a 2-L plastic container of NaOH solution was also equipped for each reactor to maintain the pH of activated sludge during the operation.

3.3. Laboratory analysis for kinetic measurement

3.3.1. Measurement of heterotrophic biomass

After the start-up period, the activated sludge was sampled from the aeration tanks to perform a set of batch experiment for measuring kinetic parameters (the specific decay rates and the specific growth rates). About 1,000 mL of the activated sludge was sampled from each reactor and immediately delivered to the laboratory within the sampling day. Using ASM1-based Equation (3.1), the endogenous oxygen uptake rate (OUR_{e_OHO}) of heterotrophs, the specific decay rate (b_{OHO}) of heterotrophs and the heterotrophic organism concentration ($X_{OHO(0)}$) present in the sample were measured respectively [20, 29, 30].

$$\begin{cases} OUR_{e\_OHO(t)} = (1 - f_U^{'}) b_{OHO}^{'} X_{OHO(0)} e^{-b_{OHO}^{'}.t} \\ b_{OHO} = \dfrac{1}{1-(1-f_U)Y_{OHO}} b_{OHO}^{'} \\ f_U^{'} = \dfrac{f_U}{1-(1-f_U)Y_{OHO}} \\ b_{OHO(T)} = b_{OHO(20)}.\theta_b^{T-20} \end{cases} \tag{3.1}$$

where:

b_{OHO} = the specific decay rate of heterotrophic organism (d^{-1})

$b_{OHO(T)}$ = the specific decay rate of heterotrophic organism at temperature T (d^{-1})

$b_{OHO(20)}$ = the specific decay rate of heterotrophic organism at 20°C (d^{-1})

f_U = the fraction of unbiodegradable organic from decay (0.08 g-COD/g-COD) [20]

$b^{'}_{OHO}$ = the endogenous respiration rate of heterotrophic organism (d^{-1})

$f^{'}_U$ = the fraction of particulate inert produced in endogenous respiration (g-COD/g-COD)

T = incubation temperature (°C)

t = incubation time (day)

$OUR_{e\_OHO(t)}$ = the endogenous oxygen uptake rate of heterotrophic organism at time = t (mg-O_2/L/d).

$X_{OHO(0)}$ = heterotrophic organism present in the sample (mg-COD/L)

Y_{OHO} = the biomass yield coefficient of heterotrophic organism (0.66 g-COD/g-COD) [20]

θ_b = the temperature coefficient of specific decay rate (1.029) [20]

For the measurement of $OUR_{e\_OHO,}$ the activated sludge sample was put in a temperature-controlled beaker and kept aerated for a week. The pH of the sample was daily adjusted to around pH = 7.0 using NaOH solution. Everyday about 100 mL of the sample was transferred from the beaker to a Winkler bottle with addition of 20 mg/L of allylthiourea to inhibit the oxygen uptake by nitrifiers [20]. The conditioned sample was stirred at around 100 rpm and the elapsed time versus DO concentration from 7.0 mg-O_2/L to 1.0 mg-O_2/L was measured with a DO meter (TPX-1000, Tokyo Chemicals, Tokyo, Japan). This procedure was routinely conducted for 7 days, and thus the dataset of $OUR_{e\_OHO(t)}$ was obtained. Based on the linear regression of semi-logarithm plot of $OUR_{e\_OHO(t)}$ along with the incubation time, $X_{OHO(0)}$ in the activated sludge sample and $b_{OHO(20)}$ were obtained.

3.3.2. Measurement of autotrophic biomass

In order to determine the autotrophic nitrifying organism concentration (X_{ANO}) in the activated sludge and its maximum specific growth rate (μ_{max_ANO}), the nitrifier's maximum oxygen uptake rate (OUR_{max_ANO}) was daily monitored in the batch incubation experiment. The part of activated sludge sample was maintained under 50 mg-N/L of ammonium nitrogen (using ammonium chloride) over the incubation period. Similar to the procedure of the above OUR_{e_OHO} test, the dataset of $OUR_{max\_ANO(t)}$ was obtained from the decrement time of DO concentration from 7.0 to 1.0 mg-O_2/L of activated sludge sample. Based on the exponential elevation of the $OUR_{max\_ANO(t)}$ along with the incubation time, the μ_{max_ANO} and $X_{ANO(0)}$ in the activated sludge were obtained from Equation (3.2) [31, 32]. The kinetic parameter was normalised at 20°C [20, 33]. During the experiment, the ammonium nitrogen concentration was also checked and adjusted everyday together with the pH to keep about pH =7.0.

$$\begin{cases} OUR_{\max\_ANO(t)} = \dfrac{\left(4.57 - Y_{ANO}\right)}{Y_{ANO}} \mu_{ANO} X_{ANO(t)} + (1 - f_U) b_{ANO} X_{ANO(t)} \\ X_{ANO(t)} = X_{ANO(0)} e^{(\mu_{ANO} - b_{ANO})t} \\ \mu_{ANO} = \mu_{\max\_ANO} \dfrac{S}{K_{S\_ANO} + S} \\ \mu_{\max\_ANO(T)} = \mu_{\max\_ANO(20)} . \theta_{\mu}^{T-20} \end{cases} \tag{3.2}$$

where:

$OUR_{max\_ANO(t)}$ = the maximum oxygen uptake rate of autotrophic organism at time = t (mg-O_2/L/d)

μ_{ANO} = the specific growth rate of autotrophic nitrifying organism (d^{-1})

b_{ANO} = the specific decay rate of autotrophs (0.15 d^{-1} at 20°C) [33]

$X_{ANO(t)}$ = autotrophic nitrifying organism present at time = t (mg-COD/L)

Y_{ANO} = biomass yield coefficient for autotrophic organism (0.24 g-COD/g-N) [20]

t = incubation time (day)

$X_{ANO(0)}$ = autotrophic nitrifying organism present in the sample (mg-COD/L)

μ_{max_ANO} = the maximum specific growth rate of autotrophs (d^{-1})

S = ammonium nitrogen concentration (mg-N/L)

K_{S_ANO} = the half-saturation growth coefficient of autotrophic organism (1.0 mg-N/L at 20°C) [20]

$\mu_{max\_ANO(T)}$ = the maximum specific growth rate of autotrophs at temperature T (d^{-1})

$\mu_{max\_ANO(20)}$ = the maximum specific growth rate of autotrophs at 20°C (d^{-1})

T = incubation temperature (°C)

θ_μ = the temperature coefficient of specific growth rate (1.072) [20]

To be specific, the ($\mu_{ANO} - b_{ANO}$) was firstly obtained from the slope of regression line of OUR_{max_ANO} versus time (t). Secondly, the μ_{ANO} and μ_{max_ANO} were respectively calculated with the assumption of b_{ANO} = 0.15 (1/d), K_{S_ANO} = 1.0 mg-N/L and S = 50 mg-N/L. Finally, the $X_{ANO(0)}$ was then accordingly calculated from the intercept of regression line.

CHAPTER 4. CHARACTERIZATION OF WEEKLY CONCENTRATION OF INFLUENT BIODEGRADABLE CARBONACEOUS AND NITROGENOUS USING IWA-ACTIVATED SLUDGE MODEL

4.1. Introduction

Nowadays, it is obviously undeniable that sustainable growth requires not just accumulation of physical capital, technologies and labor or increasing Gross Domestic Product (GDP), but also the preservation of the natural resources as well as the protection of environment. This message is especially becoming more and more important for the Asian region where the population and economies unceasingly continue to grow leading to the increase of pollution caused by poor sanitation and wastewater discharges. Among the Asian countries, Vietnam is facing the challenge of trying to keep pace with increasing environmental pollution associated with rapid urbanization, especially in big cities. It was reported that despite 60 percent of households dispose of wastewater to a public system, only about 17 percent is treated adequately in some 43 WWTPs in urban areas [3, 5, 6]. A remarkable fact was that septic tank obligated to be installed prior to public sewerage systems for each household in Vietnam. Unfortunately, low contribution of septic tanks to water quality conservation is pointed out with only 20 – 30% of BOD removal, because of having no specific policies, legal and institutional frameworks for proper septage management [34-36]. In addition, the sewerage systems in those countries are still kind of off-site and combined, which is normally characterized of the pipelines having a large diameter to transport not only the sewage flow but mainly rainwater. In this case, the design of WWTPs receiving the wastewater has to consider the corresponding fraction of rainwater that is allowed to enter the treatment works. Besides, as a tropical country, sewage flows slowly in these large diameter pipes during the dry season, leading to long detention times which allow decomposition and generation of malodor [37]. All these facts lead to a huge challenge in projection and design of WWTPs due to the impossibility of applying default influent concentration based on population equivalents as normal [13-15, 17].

As usual, the "average values" of influent load are normally analyzed or assumed in traditional method for WWTPs design. However, in case that wastewater cannot expressed in the unit population equivalent (m^3/c/d, gBOD/c/d…), on-site water measurement of flow and concentration are supposed to be conducted to obtain the actual inflow data. In normal, to characterize the concentration of wastewater composition, conventional method of water sampling and analysis is offered. However, the composition of municipal wastewater varies significantly from location to location. Also, the characteristic of wastewater generated from a residence fluctuates with time on a given location. This fact leads to a consequence that a considerable number of water samples must be surely collected and immediately analyzed in laboratory due to the rapid decomposition of organics. For that reason, an innovative and simple method is desired to replace the conventional.

According to Nguyen *et al.* (2017), back-calculation method using IWA Activated Sludge Model [20] integrated with field experiment using a set of lab-scale activated sludge reactors can meet and address the above-mentioned purpose. Specifically, based on the activated sludge constituents including active biomass concentrations of heterotrophs and autotrophs with its known kinetic and stoichiometry parameters, the weekly concentrations of biodegradable organics and nitrogen in influent wastewater are calculated [28]. However, the calculation manner applied in the research is merely manual manipulation with the simplification in the formula used for calculating biodegradable organics. Additionally, the author also mentioned about the important of measuring maximum autotrophic growth rate instead of assumption, which can produce low accuracy of estimating influent concentration in terms of biodegradable nitrogenous materials. In this regard, Nguyen (2017) pointed out that an optimization tool namely Dynamic Parameter Estimation (DPE) from GPS-X simulator software [39], could use in determining the influent organic from activated sludge constituents in an automatic manner. Basically, this tool allow user to estimate unknown input dataset (input) of a process from provided output dataset (output). Specifically, the tool tries to adjust the input so that the output calculated from adjusted input can fit to provided output. According to the research, the estimated results provided from this tool are reliable compared with the back-calculation. From these backgrounds, this chapter focuses at broadening the method of using IWA Activated Sludge Model integrated with DPE tool to estimate the weekly concentration of both biodegradable carbonaceous and nitrogenous materials in wastewater.

To meet that purpose, a lab-scale activated sludge module was installed at a WWTP in Vietnam and operated for several months. From the routine measurement of activated sludge constituents including biomass, organics and solids concentration, the weekly concentrations of influent biodegradable organics and nitrogen were dynamically back calculated by a process simulator using Activated Sludge Model No. 1 (ASM1) as mathematical basis. Moreover, the know-how to select and configure output parameters for the back-calculation is also discussed and elucidated through comparative analysis.

4.2. Materials and Methods

4.2.1. Field-test activated sludge reactors module

a) System installation

A field experimental module composed of two set of lab-scale activated sludge reactors (ASRs) was installed at two distinctive WWTPs in Vietnam and operated for couple of months. The first is Vinh Niem WWTP located in Hai Phong city as in Northern Vietnam while the second is Chua Cau WWTP located in Hoi An as in Center Vietnam. The schematic diagram of experimental module was illustrated in Figure 3.3 with the detail description for each unit was mentioned in section 3.2 in Chapter 3.

b) Operating conditions

The influent flowrate was set at 138 L/d, hydraulic retention time (HRT) of the aeration tanks was 4 hours and the sludge retention time (SRT) was steadily controlled at 7 days. The dosage of poly-aluminum chloride and anionic polymer was 10 mg-Al/L and 0.5 mg/L, respectively. An aqueous NaOH solution of 5 g/L was also added to neutralize pH in the aeration tanks, ranging from 6.8 to 7.2. The air flow of aeration tanks was carefully fixed at 2 L-air/min. The water temperature in the aeration tank varied between 20.0^{o}C and 32.0^{o}C during the experimental period.

After about two weeks of preliminary continuous operation, the activated sludge was sampled from the aeration tanks to perform a set of batch test experiment for measurement of kinetic parameters including specific decay and specific growth rates of microorganisms.

4.2.2. Laboratory Analysis

The specific decay rate of heterotrophic and the specific growth rate of autotrophic organism together with their active biomass was estimated in weekly routine. The detail description of batch experiments to estimate these kinetic parameters were mentioned in section 3.3 of Chapter 3.

4.2.3. Dynamic estimation of weekly concentration of influent constituents

On the basis of ASM1, the DPE tool is used for the dynamic estimation of weekly concentration of influent carbonaceous and nitrogenous composition. This is an interesting module provided by GPS-X software to estimate the input parameter by optimizing the simulated results with observed dataset. The term of optimization involves adjusting certain model parameters to maximize or minimize an objective function. In GPS-X context, the tools used for works of optimization called the GPS-X optimizer. It can be used to fit a model to measured data or to optimize process performance. The procedure of fitting a model to measured data is called "parameter estimation" and involves adjusting selected model parameters to achieve the best possible fit between the model responses and the measured data. It is noted that instead of estimating parameters from an entire set of data, GPS-X optimizer calculates a set of parameter estimates for each time step using the parameter estimates from the previous time step as a starting guess. The length of the time step controls how often the parameters are updated. The shorter the time step, the more often the parameters are updated.

A typical configuration to run DPE comprised of three steps: setup target variables, setup optimized variables and setup objective function. In definition, the target variables are the variables desired to minimize, maximize, or fit to the measured data. The optimized variables will be adjusted by the optimizer as it attempts to minimize the objective function used as an indicator to determine whether the model response fit to measured data. Specifically, the optimized variable concentrations were assumed to be constant at each time step and were alternatively changed at the next time step in stepwise manner. By registering each specific value of the optimized variables as input parameters, the DPE firstly calculated the responsible user-defined target variables and then compare these datasets from model response to those measured, which were manually imported, by using a specific objective function. By this way, the optimized variable concentrations were adjusted within the pre-determined range until the calculated values of user-defined target parameters possibly fit to those of the measured values, which equal to the minimization of the objective function value. There were five objective functions provided by GPS-X when performing DPE, which are Absolute Difference, Relative Difference, Sum of Squares, Relative Sum of Squares and Maximum Likelihood. Based on the suggestion of GPS-X user guide and technical reference, Maximum Likelihood option of the objective function was selected for the parameter regression [39]. It was also noted that the regression process was programmed to be terminated when one of the below termination criteria was satisfied:

- Parameter Tolerance: by dividing the range between the largest and the smallest value which were considered as the possible values of a specific optimized variable by the difference between the upper and lower bounds for this optimized variable, a term of "singular maximum size" was obtained. If the maximums size for all the optimized variables are less than the parameter tolerance, the regression process is terminated.

- Objective function tolerance: if the range (largest minus smallest) of objective function values is less than the objective function tolerance, the regression process was terminated.

- Scaled termination value for objective function: if the objective function value at the current best point in the simplex is less than the user-specified final objective function value, the optimization process is terminated. This final value should be positive and small in magnitude. This criterion is not used with the maximum likelihood objective function. It is only applicable for the other objective functions because their values have a lower bound of zero (a perfect fit).

– Maximum number of optimizer iterations: The optimization process was terminated if the maximum number of iterations is reached.

For the ease of comprehension, the termination criteria were selected as Parameter Tolerance = 1.0×10^{-6} and the maximum number of optimizer iterations was set at 200 number due to no significant improvement recognized when more trials (the higher maximum number of optimizer iterations) were performed. It was also noted that the only meeting the criterion of the objective function tolerance without satisfying the criterion of the parameter tolerance would indicate that the objective function was not very sensitive to some parameters, therefore the criterion of the objective function tolerance was disabled by setting a large negative value (-1×10^{10}) [39]. The scaled termination value for objective function was selected as the default of 0.1.

Based on the concept of DPE, two kinds of carbonaceous state variables (soluble biodegradable organics (S_B) and particulate biodegradable organics (XC_B)) and two kinds of nitrogenous state variables (soluble biodegradable nitrogen including ammonium-N (S_{B_N}) and particulate biodegradable organic nitrogen ($XC_{B\_org,N}$) are defined as optimized variables while the active biomass of heterotrophs (X_{OHO}) and autotrophs (X_{ANO}) are selected as target variables. From which, the DPE will adjusts S_B, XC_B, S_{B_N} and $XC_{B\_org,N}$ so that the response of X_{OHO} and X_{ANO} from model fit to those measured data. In detail, based on the system condition (b_{OHO}, μ_{max_ANO}, HRT, SRT), S_B concentration was firstly estimated from X_{OHO} in ASR#1, then XC_B concentration was estimated from the increment of X_{OHO} between ASR#1 and ASR#2. In same manner, S_{B_N} was firstly estimated from X_{ANO} in ASR#1 followed by an estimation of $XC_{B\_org,N}$ from the difference of X_{ANO} between ASR#2 and ASR#1. In this study, the S_B and XC_B concentrations were randomly selected in the pre-determined range of 0 – 200 mg-COD/L while the S_{NHx} and $XC_{B\_org,N}$ were fixed to vary between 0 and 50 mg-N/L. In parallel, the particulate unbiodegradable built from biomass decay (X_U) was automatically determined from X_{OHO} and X_{ANO} concentration together with system operational condition. Next, the concentration of influent particulate unbiodegradable organics ($X_{U,Inf}$) will then be estimated from COD-based activated sludge concentrations (X_{sludge}) converted from measured MLVSS concentrations multiplied times a stoichiometry value (icv_{sludge}) (X_{sludge} = MLVSS × icv_{sludge} = $X_{OHO} + X_{ANO} + X_U + X_{U,Inf}$). Afterward, the concentration of particulate inorganic (X_{Ig}) was estimated from the difference between MLSS and MLVSS concentration of activate sludge. Finally, the concentration of influent soluble unbiodegradable organics (S_U) was estimated based on the soluble COD of effluents.

When performing the DPE method to estimate the influent concentration, along with the selected objective function options and termination criteria, other parameter also needed to take into account were the time step. The length of the time step was defined the interval at which the optimized variables (S_B and S_{NHx}) were assumed to be constant whilst the calculation frequency was defined the frequency to calculate and update the output parameter values (DO and nitrate) from the optimized variables. In this context, the time step was setup at 7 days to produce an estimation of weekly concentration of influent constituents [28, 38].

To justify the estimated results, the influent composite samples made from 24 individual samples, collected at every 1-hour interval during a day, was also analyzed in terms of soluble ammonia, total nitrogen, total COD, and soluble COD. The concentration of nitrate in the effluents was also measured. For laboratory apparatus, the concentration of influent ammonium and effluent nitrate were measured using portable reflectometer (RQflex® plus 10) integrated with selective test strips kit (16899-1M Ammonium test and 16995-1M Nitric acid test, MiliporeSigma Cor., Burlington, Massachusetts, USA) whilst the portable colorimeter (HACH DR/850, Hach Com., P.O. Box 389 Loveland, Colorado, USA) and selective test tubes were used for measuring total nitrogen (Set 27140, Hach Com., P.O. Box 389 Loveland, Colorado, USA), soluble COD and total COD (TNT821, Hach Com., P.O. Box 389 Loveland, Colorado, USA). The concentrations of MLSS, MLVSS and activated sludge COD were measured according to standard methods [10].

4.3. Results and Discussion

4.3.1. Kinetic parameters and concentration of Heterotrophic and Autotrophic Organism

As shown in Figure 4.1, the weekly values of b_{OHO} in both ASR#1 and ASR#2 were together plotted with 95% of confidence interval after normalization at 20°C with a temperature coefficient $\theta_b = 1.029$ [20, 33]. The length of period examined for the estimation of influent weekly concentration in case of Vinh Niem WWTP is 126 days.

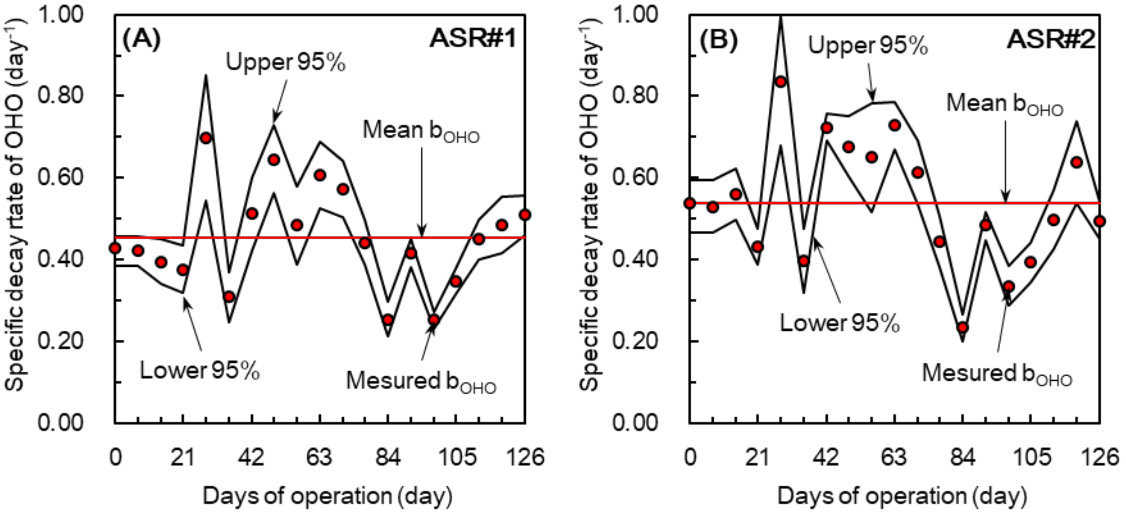

Figure 4.1 Specific decay rate of ordinary heterotrophic organism in basis of ASM1 (at Vinh Niem WWTP)

It was shown that the b_{OHO} of ASR#1 varied from 0.25 – 0.70 d^{-1} whilst the b_{OHO} of ASR#2 felt within the range of 0.23 – 0.84 d^{-1}. These obtained results seemed to be in accordance with the published results from the literatures [20, 33, 40]. In addition, the average b_{OHO} of that total 19 individual data for each ASR#1 and ASR#2 were determined as 0.45 d^{-1} and 0.54 d^{-1} respectively. It was recognized that the mean b_{OHO} of ASR#2 was slightly higher than ASR#1. This can be attributed to the presence of some particulate hydrolysable organics in the mixed sample of activated sludge when performing the batch experiment.

Similarly, the dataset of weekly μ_{max_ANO} estimated from OUR_{max_ANO} regressions was then normalized to accordant values at 20°C with temperature coefficient $\theta_\mu = 1.072$ [20, 33] and plotted in Figure 4.2 with 95% of confidence interval. From the graph, it was demonstrated that μ_{max_ANO} of both ASR#1 and ASR#2 was fairly comparable as it scattered at around 0.27 – 0.55 d^{-1} for ASR#1 and 0.26 – 0.41 d^{-1} ASR#2, respectively. Additionally, the mean μ_{max_ANO} of ASR#1 and ASR#2 are obviously close to each other, which was approximately 0.34 d^{-1}.

These results are in agreement with literature [20, 33, 35].

Despite there was a slight difference in measured average b_{OHO} between ASR#1 (0.45 d^{-1}) and ASR#2 (0.54 d^{-1}), the mean of these measured average b_{OHO} is selected for the specific decay rate of heterotrophic organism to simplify the work of estimating influent concentration latter. As a result, assuming that b_{OHO} and μ_{max_ANO} are consistent kinetic parameters at WWTP [33], the b_{OHO} = 0.495 and μ_{max_ANO} = 0.34 d^{-1} were selected for the dynamic estimation/simulation while other relevant kinetic and stoichiometry parameters were assumed and consulted from literature [20, 33]. It can be recognized from the results that an absence of μ_{max_ANO} during the period from day 0 to day 55 due to the lack of conducting experiments. Thus, the estimation of weekly concentration of influent state variables is merely focused on the operational period of day 56 to day 126.

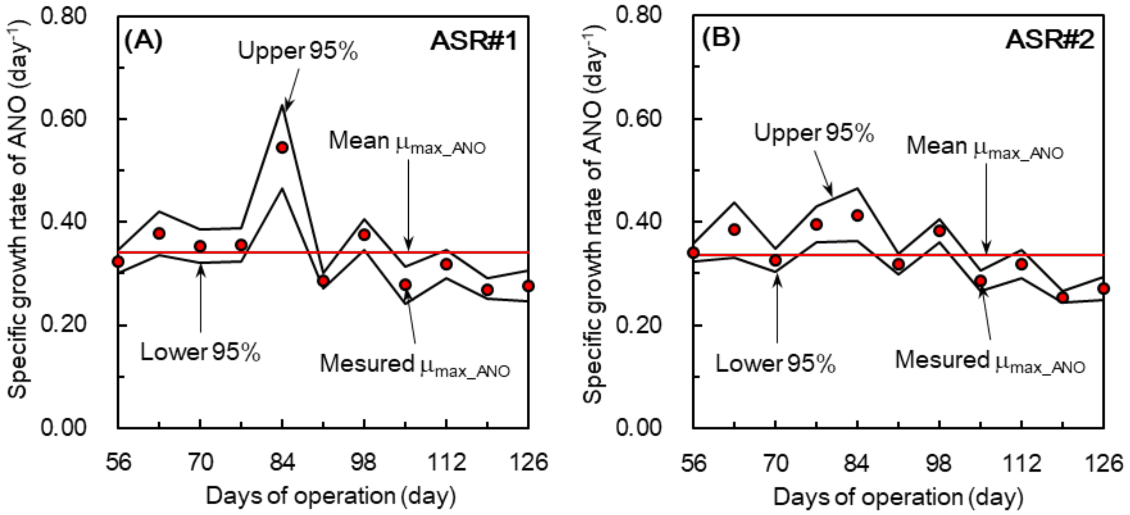

Figure 4.2 Specific growth rate of autotrophic nitrifying organism (at Vinh Niem WWTP)

From the regression of OUR_{e_OHO} and b_{OHO}, X_{OHO} concentrations in the activated sludge of both ASR#1 and ASR#2 were estimated respectively. In the same manner, the X_{ANO} concentrations in ASR#1 and ASR#2 were obtained from the regression of OUR_{max_ANO} and μ_{max_ANO}. Due to the presence of both soluble and particulate biodegradable organics and nitrogen in the influent of ASR#2 whilst the influent of ASR#1 contains only the soluble composition, it was understandable that both X_{OHO} and X_{ANO} concentration in ASR#2 were higher than those in ASR#1 (Figure 4.3). It was shown that the X_{OHO} and X_{ANO} concentration during this period tended to fluctuate over time in a sinusoidal manner, indicating a significant variation in the concentration of influent biodegradable organics and nitrogen.

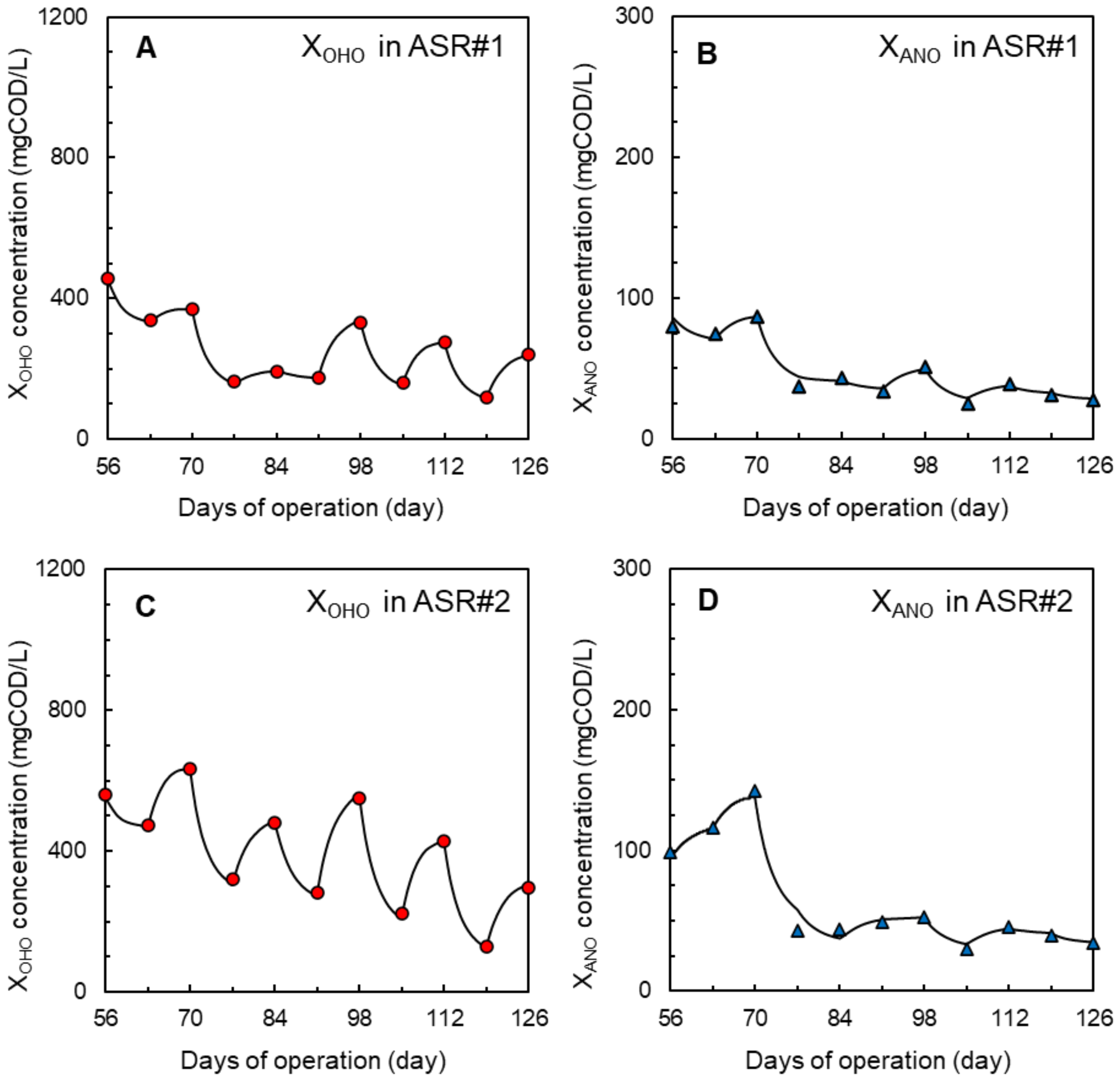

Figure 4.3 The concentrations of X_{OHO} and X_{ANO} in the ASR#1 and ASR#2 at Vinh Niem WWTP (plots: measured from experiments, curves: simulated from DPE)

4.3.2. Estimation of weekly concentrations of influent biodegradable composition

From the optimization of DPE, the influent concentrations (optimized variables) were modelled to be changed in a stepwise manner at every time step of 7 days so that the simulated X_{OHO} and X_{ANO} concentration fit to the measured data of X_{OHO} and X_{ANO} concentration (target variables) obtained from batch experiments. As shown in Figure 4.3, the estimated S_B and S_{B_N} could well reproduce the measured initial X_{OHO} and X_{ANO} concentration in ASR#1 in every week. Similarly, weekly concentration of X_{OHO} and X_{ANO} in ASR#2 were also correctly simulated from the estimated XC_B and $XC_{B\_org,N}$ together with S_B and S_{B_N} estimated former.

As shown in Figure 4.4, the MLSS and MLVSS concentrations in both ASRs were adequately expressed from the estimated concentration of influent state variables, demonstrated by the considerably match between simulated curves and measured data. It was obvious that the fraction of $X_U + X_{U,Inf}$ and X_{OHO} were dominant in MLVSS concentration whilst the fraction of X_{ANO} was quite minor. In particular, the X_{OHO} and $X_U + X_{U,Inf}$ accounted for approximately 38 - 47% and 46 - 55% of MLVSS concentration, respectively. Of course, the XC_B also needs to be included in MLVSS constituents. However, due to the long sludge retention time, the organics degradation almost occurred completely resulting in negligible amount of XC_B in the reactors as well as the effluents (data not shown). Despite ASR#1 was equipped with primary settler, meaning that very small amount of particulate material transferred into reactors, the particulate inorganics seemed to be still recognized in the influent of ASR#1 because of considerable difference between MLSS and MLVSS concentrations. This can be attributed to a consequence of uptake and/or precipitation of soluble inorganics for the biomass growth (e.g. uptake of phosphate, precipitation of calcium, etc.).

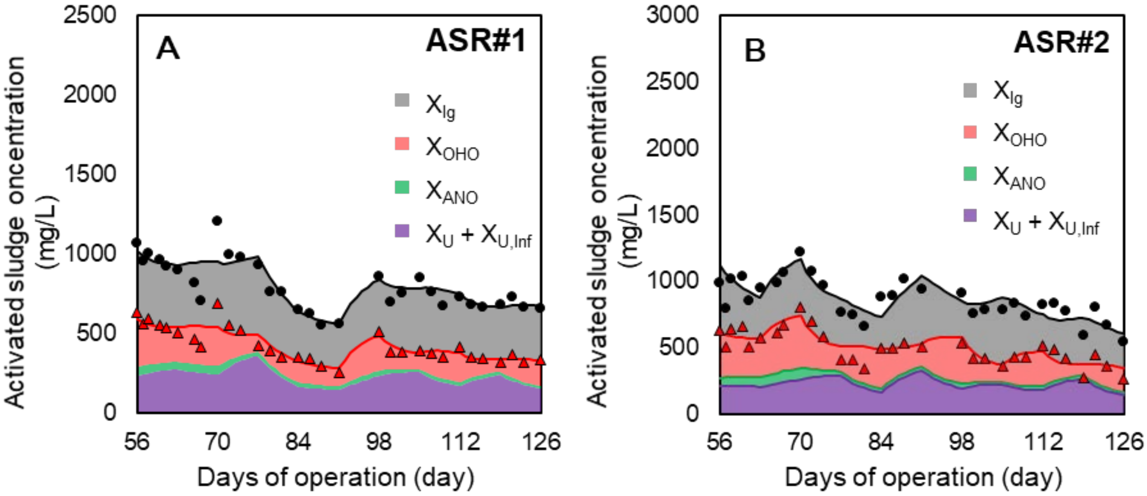

Figure 4.4 Dynamic simulation of activated sludge constituents at Vinh Niem WWTP
(circle: measured MLSS; triangle: measured MLVSS
black curve: simulated MLSS; red curve: simulated MLVSS)

From the estimated concentrations of state variables given from DPE, the characteristic of influent organics for both ASRs were determined and compared to measured data, shown in Figure 4.5A and Figure 4.5B. It must be noted that the influent of ASR#1 is supposed actually from primary settler whilst the influent of ASR#2 is directly from the influent chamber. From the simulation results, it can be recognized that the simulated concentration of influent soluble COD reasonably matched to those measured in case of ASR#1. For ASR#2, although there was an underestimation of soluble COD concentration, the simulated results given from DPE was still trendy with the measured data. The reason for this can be attributed to the ability of coagulant dosed into primary settling tank that can capture not only particulate components but also the soluble materials in the influent. Once a specific amount of S_B was settled in primary settling tank, the estimated concentration of X_{OHO} would be lower than it supposed in reality. In addition, because the concentration of S_B in the influent of ASR#2 are identical to the S_B concentration in the influent of ASR#1, the more X_{OHO} concentration underestimated, the more soluble COD concentration of influent underrated. Furthermore, from the measured soluble COD concentration in both effluents shown in Figure 4.5C and Figure 4.5D, it is stated that the slightly higher concentration of soluble COD was obtained in ASR#2 effluent compared to that of ASR#1. In this regard, the soluble unbiodegradable organics is supposed to also be captured by the coagulants used for primary settling tank. Although the exact reason was still uncertain, the capability in capturing soluble materials of the coagulants was believed to be one of the possible causes for the underestimation of soluble COD in ASR#2 influent. In this regard, a set of preliminary Jar tests are recommended to be thoroughly conducted for the identification of optimal dosing coagulants.

In terms of total COD, the calculated result was generally underestimated. A possible reason that can explain for this trend is the sludge bulking, which is potentially occurred when the influent concentrations is low, especially for lab-scale experimental modules. Once the sludge bulking takes place in secondary settling tank, the loss of biomass from activated sludge is undoubtable, resulting in lower concentration of activated sludge constituents. In case of ASR#2, the lower concentration of X_{OHO} results in underestimation of XC_B concentration whilst the lower COD concentration of X_{sludge} causes the underestimation in $X_{U,Inf}$. These two underestimations obviously lead to lower calculated concentration of particulate COD than that measured. A promising solution to deal with this problem is to slightly modify the structure of ASRs module. In particular, two out-selectors would be newly installed prior to each reactor, through that the activated sludge can be internally circulated between the main reactors and out-selectors.

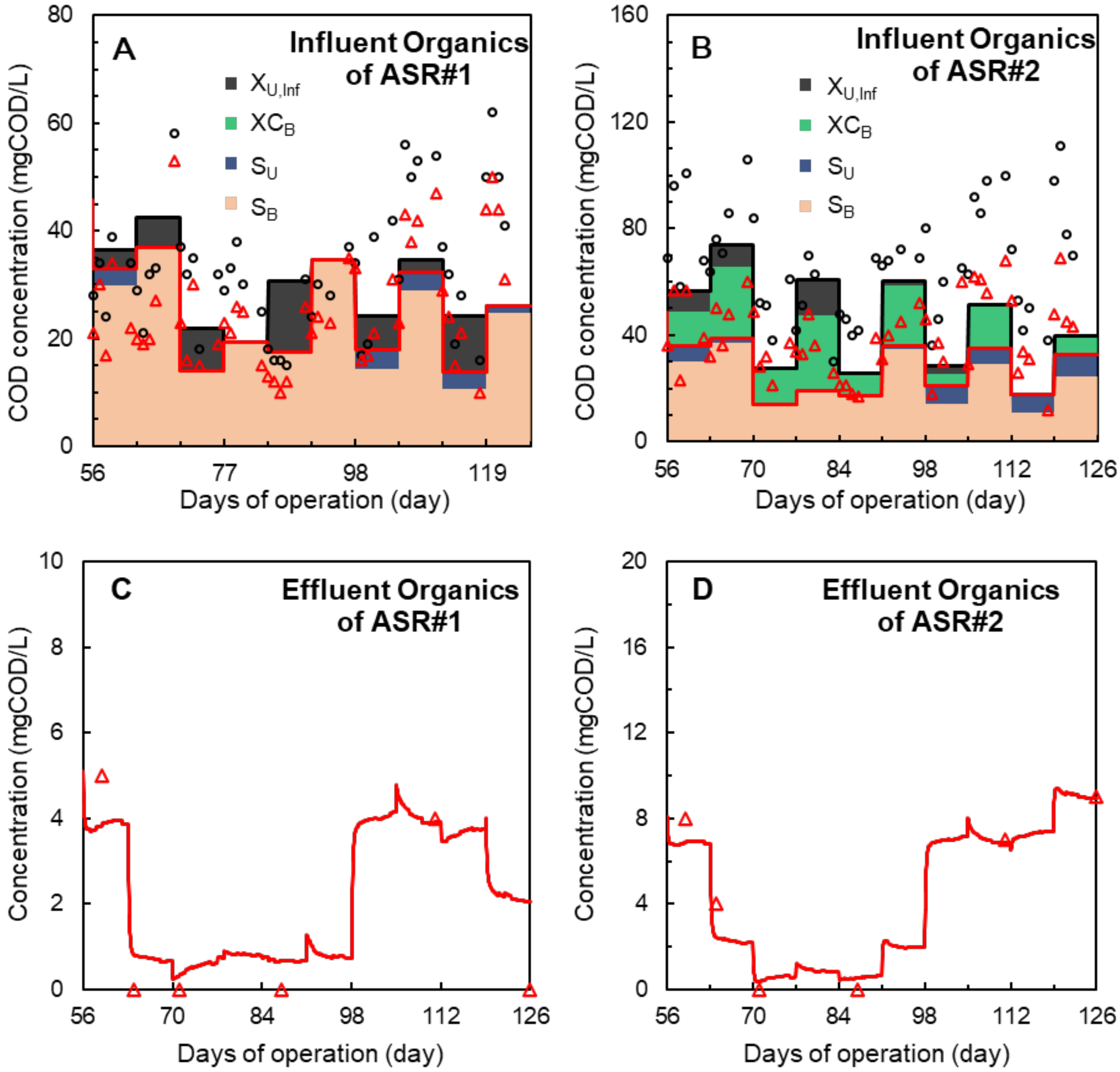

Figure 4.5 Characteristic of influent and effluent organics in ASR#1 and ASR#2 at Vinh Niem WWTP (circle: measured total COD; triangle: measured soluble COD; black curve: simulated total COD; red curve: simulated soluble COD)

With respect to the influent biodegradable nitrogen, the concentration of S_{B_N} and $XC_{B\_org,N}$ obtained from X_{ANO} concentration in ASRs were used to express the concentration of soluble (STKN) and total Kjeldahl nitrogen (TKN) in the influents (STKN = S_{B_N} ; TKN = S_{B_N} + $XC_{B\_org,N}$). Because this wastewater quality parameters were not exactly analyzed during the experimental period, the measured concentration of ammonium was alternatively used to represent the measured concentration of influent organic nitrogen. As shown in Figure 4.6, the estimated result of TKN concentration in ASR#1 and ASR#2 were reasonably trendy with the measured results. It was shown that there was generally an underestimation of influent TKN in both ASR#1 and ASR#2. Since the batch experiment to measure μ_{max_ANO} is quite sensitive, the analytical errors in measurement of OUR_{max_ANO} are understandable, resulting in the underestimation of initial concentration of X_{ANO} as well as S_{B_N} when back-calculating. In addition, the wrongly assumption of kinetic and stoichiometry parameters of X_{ANO} are also supposed to be one of the possible reasons. For instance, assuming that if the real autotrophic yield coefficient was higher than the assumption, the S_{B_N} concentrations would be underestimated consequently. However, it also must be noted that the measured concentration of X_{ANO} from the batch experiment is directly estimated from Equation (3.2), meaning that estimated result of X_{ANO} concentration it is affected by the assumption of other kinetic and stoichiometry parameters of autotrophic organism.

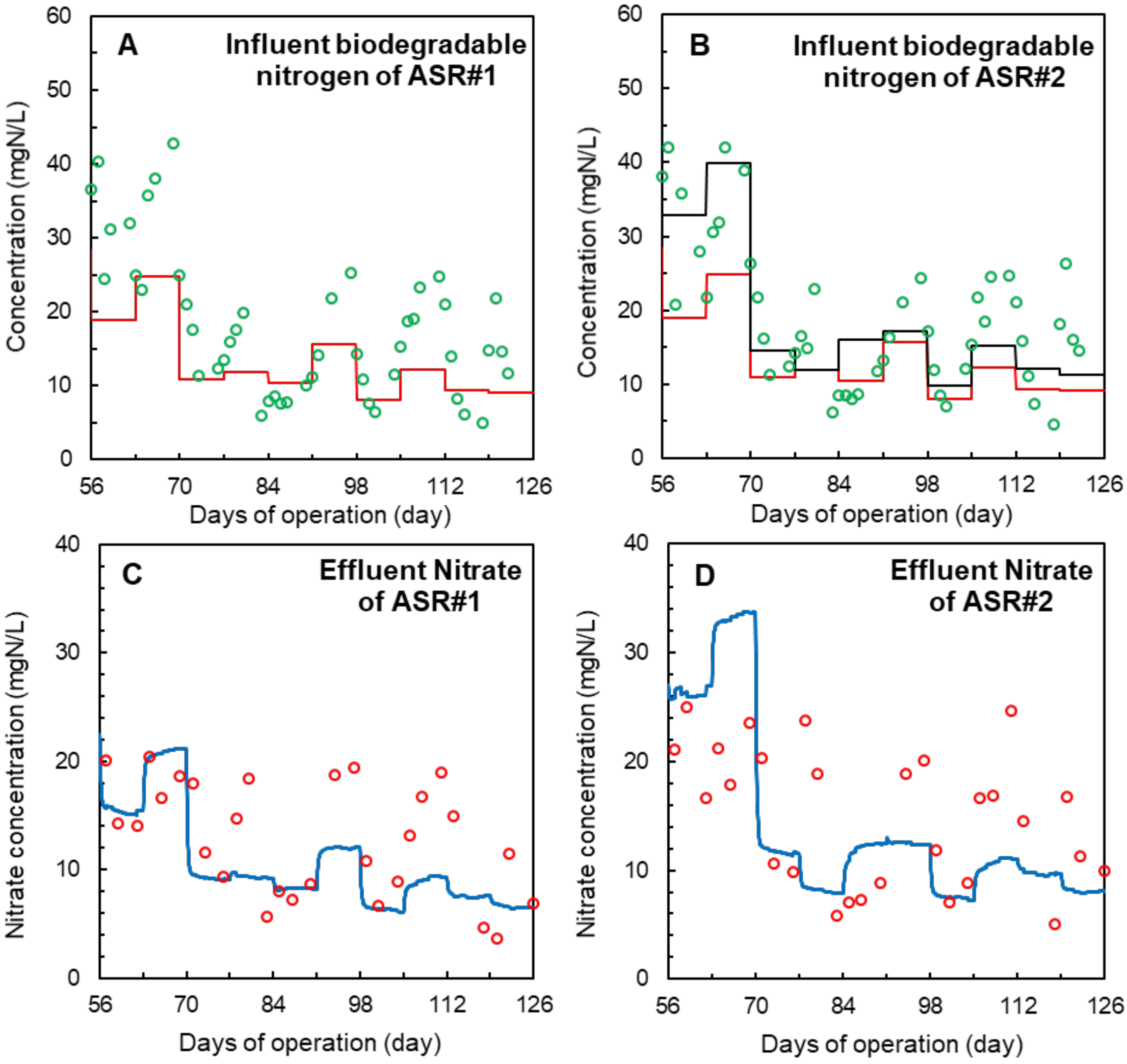

Figure 4.6 Characteristic of influent nitrogen and effluent nitrate in ASR#1 and ASR#2 at Vinh Niem WWTP (green circle: measured influent ammonium; red circle: measured effluent nitrate; red curve: simulated influent STKN; black curve: simulated influent TKN; blue curve: simulated effluent nitrate)

When the lower yield coefficient of autotrophs was applied, the measured X_{ANO} concentrations was also slightly/moderately decreased. Because the back-calculation of influent nitrogen based on both autotrophic concentration, kinetic, and stoichiometry, the proportionally variation of these factors can result in the almost unchanged of estimated results before and after the assumption. Specifically, in this case study, when the autotrophic yield coefficient was assumed at 0.22 gCOD/gN (lower than the initial value at 0.24 gCOD/gN), there was very minor difference between the two datasets of S_{B_N} before and after assumption (data not shown). As illustrated in Figure 4.6C and Figure 4.6D, the underestimation of nitrate concentrations in the effluents was mostly recognized as the direct consequence of underestimation in S_{B_N}. Additionally, during the period from the day 56 to 70 the simulated concentration of nitrate in ASR#2 effluent was overestimated while STKN or evenly TKN was still underestimated. The reason for this mismatch might be attributed to analytical errors in nitrate measurement. Also, it is noted that due to the number of auto-sampler was limited in this study, the samples collected from the effluents for analysis were simply snapshot instead of composite as in case of influent samples. Therefore, the dataset of effluent nitrate sometime was just able to refer to the instantaneous state at a specific time point within an operation day instead of representing the average values of whole day.

In contrast, during the remainder of operation (from day 71 to 126), the influent ammonium and effluent nitrate concentration of both ASR#1 and ASR#2 were reasonably underestimated compared to measured data. The main reason of this matter is mostly due to the accuracy of batch experiment to estimate μ_{max_ANO} and X_{ANO}.

4.3.3. Alternative approach to estimate weekly concentration of influent biodegradable nitrogen

a) Case study at Vinh Niem WWTP

In the relation to the limitation of the existing approach to back-calculate the weekly concentration of influent biodegradable nitrogen, it should be recalled that nitrate measurement is supposed to be more trustworthy than the kinetic estimation of autotrophs in terms of accuracy. Also, in activated sludge process without denitrification, nitrate in effluent is known as final product from direct conversion of ammonia and organic nitrogen in influent, excluding the portion of ammonia for nutrient uptake in growth of bacteria.

Based on these backgrounds, the back-calculation of influent biodegradable nitrogen based on the effluent nitrate instead of autotrophic organism biomass is supposed to be more reliable. To clarify this hypothesis, another simulation was simultaneously performed, in which the biodegradable nitrogen in the influent was estimated from the nitrate in the effluents. The estimated results of the new approach were also compared to the initial method. As demonstrated in Figure 4.7, the new approach can produce the considerable fitting between simulated and measured dataset in both case of influent ammonium and effluent nitrate. For more specifically, the statistical analysis, including Nash-Sutcliffe efficiency coefficient (NSE) and Root Mean Square of Residuals (RMSR), to determine the difference in the model fitness between the two back-calculation approach was performed [41].

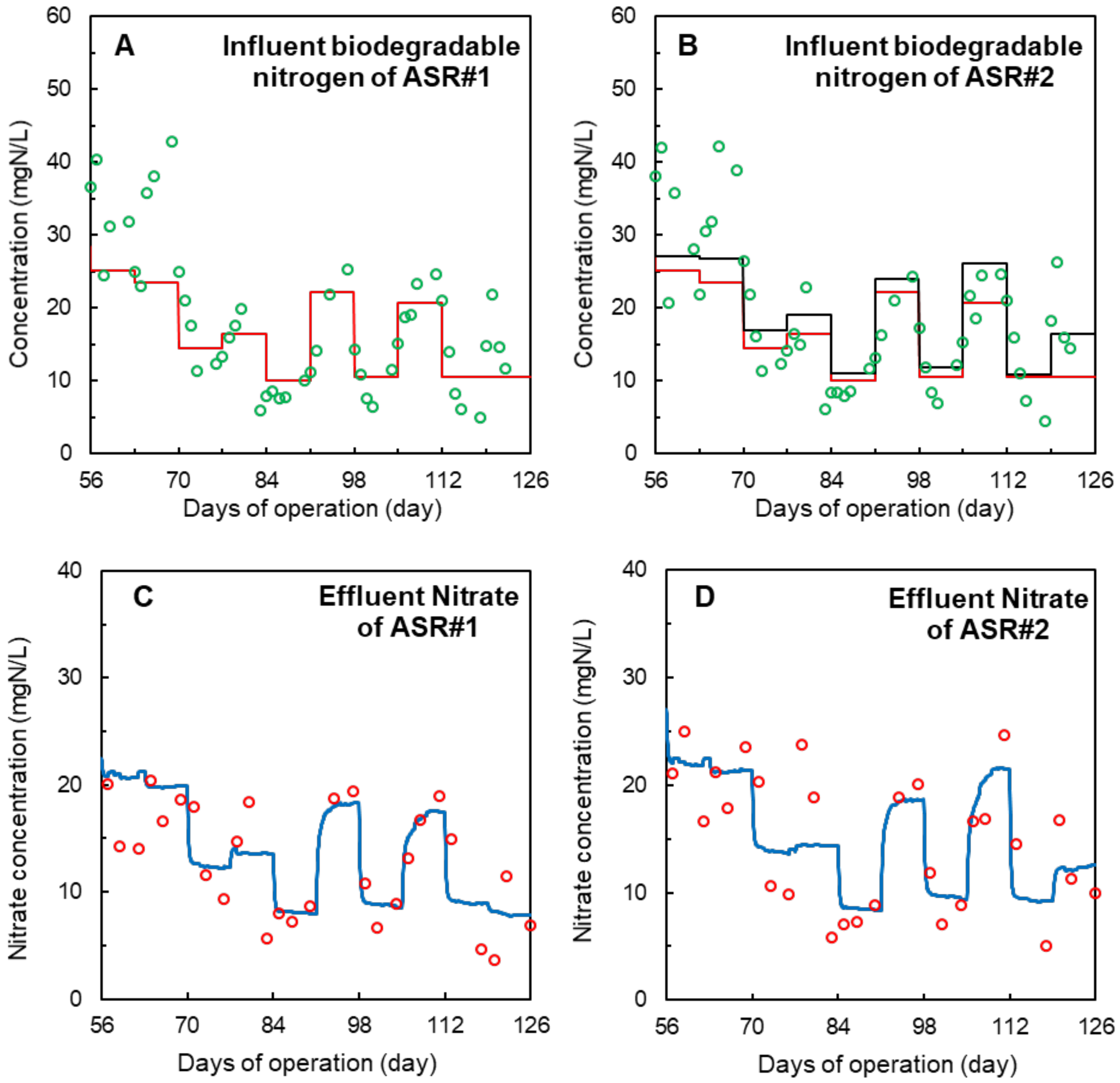

Figure 4.7 Weekly concentration of influent nitrogen and effluent nitrate in ASR#1 and ASR#2 at Vinh Niem WWTP obtained from new approach (green circle: measured influent ammonium; red circle: measured effluent nitrate; red curve: simulated influent STKN; black curve: simulated influent TKN; blue curve: simulated effluent nitrate)

Table 4.1 Statistical analysis for the model fitness of two different approach in back-calculating influent biodegradable nitrogen (Vinh Niem WWTP)

	Nash-Sutcliffe model efficiency coefficient			
	Ammonium estimation		Nitrate simulation	
	ASR#1	ASR#2	ASR#1	ASR#2
Initial method (based on X_{ANO})	0.27	-0.06	0.00	-0.62
Modified method (based on effluent nitrate)	0.52	0.44	0.52	0.55
	Root Mean Squared of Residual			
	Ammonium estimation		Nitrate simulation	
	ASR#1	ASR#2	ASR#1	ASR#2
Initial method (based on X_{ANO})	8.3	9.9	5.8	7.9
Modified method (based on effluent nitrate)	6.7	7.2	4.0	4.2

As shown in Table 4.1, very low or even negative values of NSE are found in the initial approach in case of both influent ammonium and effluent nitrate. It should be recalled that the zero value of NSE indicates that the model merely predicts the mean of the dataset. In contrast, both the higher Nash-Sutcliffe coefficient and the lower Root Mean Square of Residuals were obtained in case that the influent biodegradable nitrogen was back-calculated based on effluent nitrate. Obviously, these results indicate that the more reliable of new approach in the work of influent characterization. The simulated results of X_{OHO} and X_{ANO} reproduced by the dataset of influent biodegradable organic and nitrogen estimated from the new approach were shown in Figure 4.8.

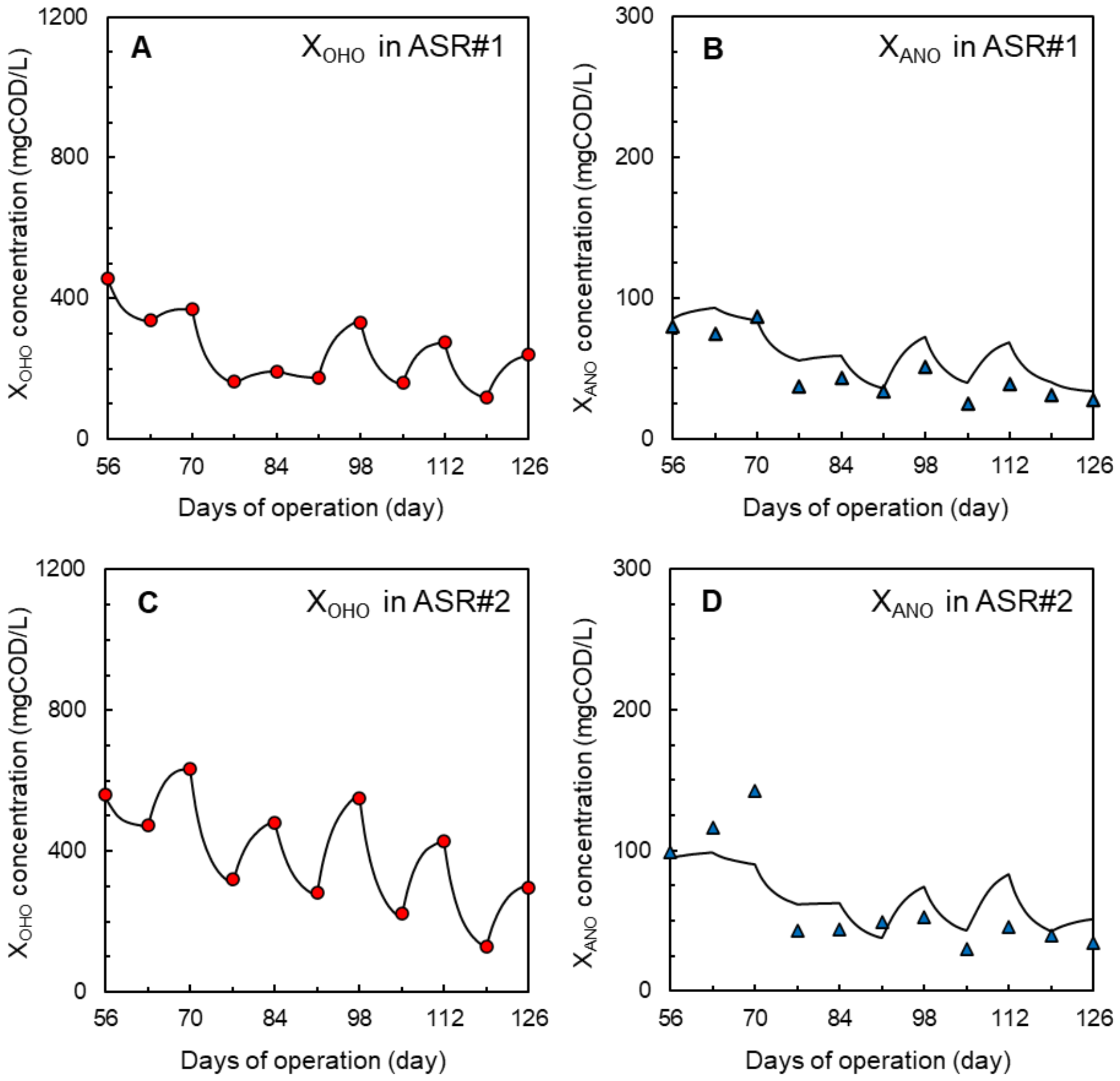

Figure 4.8 The estimated concentrations of X_{OHO} and X_{ANO} in the ASR#1 and ASR#2 at Vinh Niem WWTP from the new approach
(plots: measured from experiments, curves: simulated from DPE)

Because there was no difference in the manner of estimating influent biodegradable organic between two approaches, the simulated result of X_{OHO} in both ASR#1 and ASR#2 from the initial and new approach are identical. On the contrary, although there was mostly overestimation of X_{ANO} in both ASR#1 and ASR#2 when applying the new approach, the simulated results of X_{ANO} for ASR#1 and ASR#2 were still trendy with the measured dataset. Recalling the measurement of nitrate is not only easier but also less sensitive when comparing to batch experiment to measure X_{ANO}, the new approach is proved itself in the feasibility to adequately estimate the weekly concentration of influent biodegradable constituents in automatically manner.

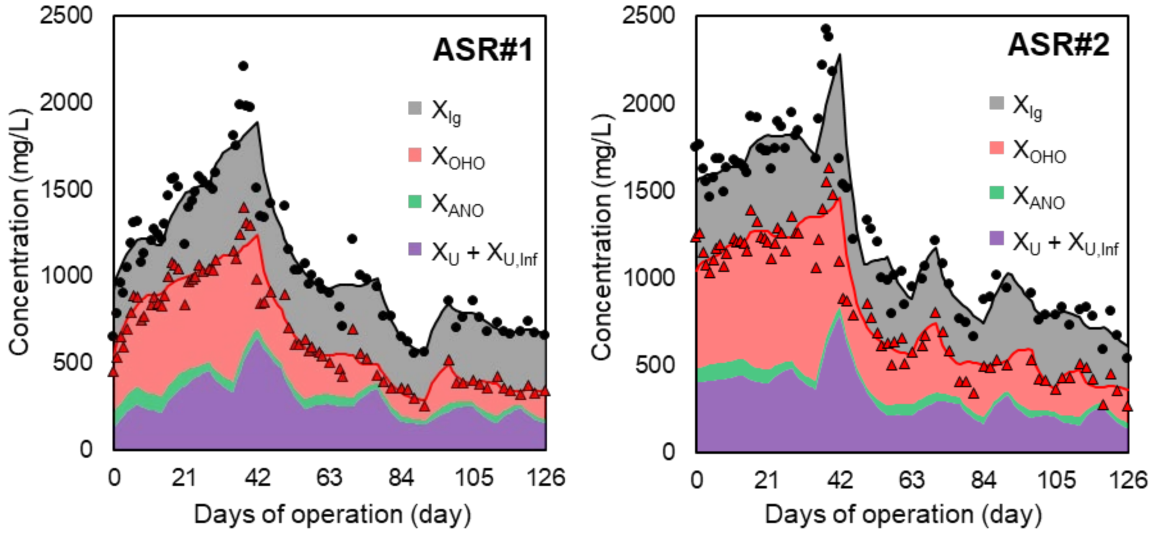

Figure 4.9 Activated sludge constituents during 126-day operation at Vinh Niem WWTP
(circle: measured MLSS; triangle: measured MLVSS
black curve: simulated MLSS; red curve: simulated MLVSS)

It is reminded that there was lack of dataset for μ_{max_ANO} and X_{ANO} during the operational period from day 0 to day 55, thus the estimating weekly concentration of influent biodegradable nitrogen was infeasible to conduct by the initial approach. Fortunately, the nitrate concentration in the effluents of bott ASRs were measured during in that period. With the capability of estimating influent biodegradable nitrogen from effluent nitrate without the dataset of autotrophic organism, the new approach is applied to back-calculate the weekly concentration of influent biodegradable organic and nitrogen during the whole operation period of 126 days.

Repeatedly, the MLSS and MLVSS concentrations in both ASRs were successfully reproduced from the estimated concentration of influent organic and nitrogen, expressed by the significantly fit between simulated curves and measured data as shown in Figure 4.9. In the same trend with the operational period from day 56 to day 126, generally the fraction of X_U + $X_{U,Inf}$ and X_{OHO} were still dominant in MLVSS concentration with a small contribution of X_{ANO} fraction. In particular, the X_{OHO} accounted for 45 – 50% while the fraction of X_U + $X_{U,Inf}$ accounted for 43 - 47% MLVSS concentration, respectively. Besides, the particulate inorganics (X_{Ig}) was significantly found not only in ASR#2 but also in ASR#1. The contribution of X_{Ig} to activated sludge constituents was about 41% and 37% for ASR#1 and ASR#2, respectively.

The estimated result of the weekly concentration of influent Kjeldahl nitrogen and effluent nitrate during 126-day operation are demonstrated in Figure 4.10. Despite there was an underestimation of influent Kjeldahl nitrogen during the period from day 49 to day 70, in general, the estimated results were reasonably fit to the measured data. In particular, the quality of model fit in terms of Kjeldahl nitrogen is reasonable with the NSE value was 0.57 and 0.53 for ASR#1 and ASR#2, respectively (data not shown). Similarly, the pretty high value of NSE was also achieved in case of effluent nitrate. It was 0.71 and 0.68 of NSE for ASR#1 and ASR#2 respectively, indicating a considerable fitting between estimated and measured results of effluent nitrate. From these results, the broadening of the new approach for other purpose of back-calculation is supposed to be promising. For example, to back-calculate the hourly concentration of influent biodegradable nitrogen, the hourly variation of effluent nitrate supposed to utilized as one of the key target parameters. Integrated with logging the hourly variation of DO concentration in activated sludge reactors, the hourly concentration of influent biodegradable organics can be estimated simultaneously because of their reaction with oxygen in the growth process of heterotrophic autotrophic organisms.

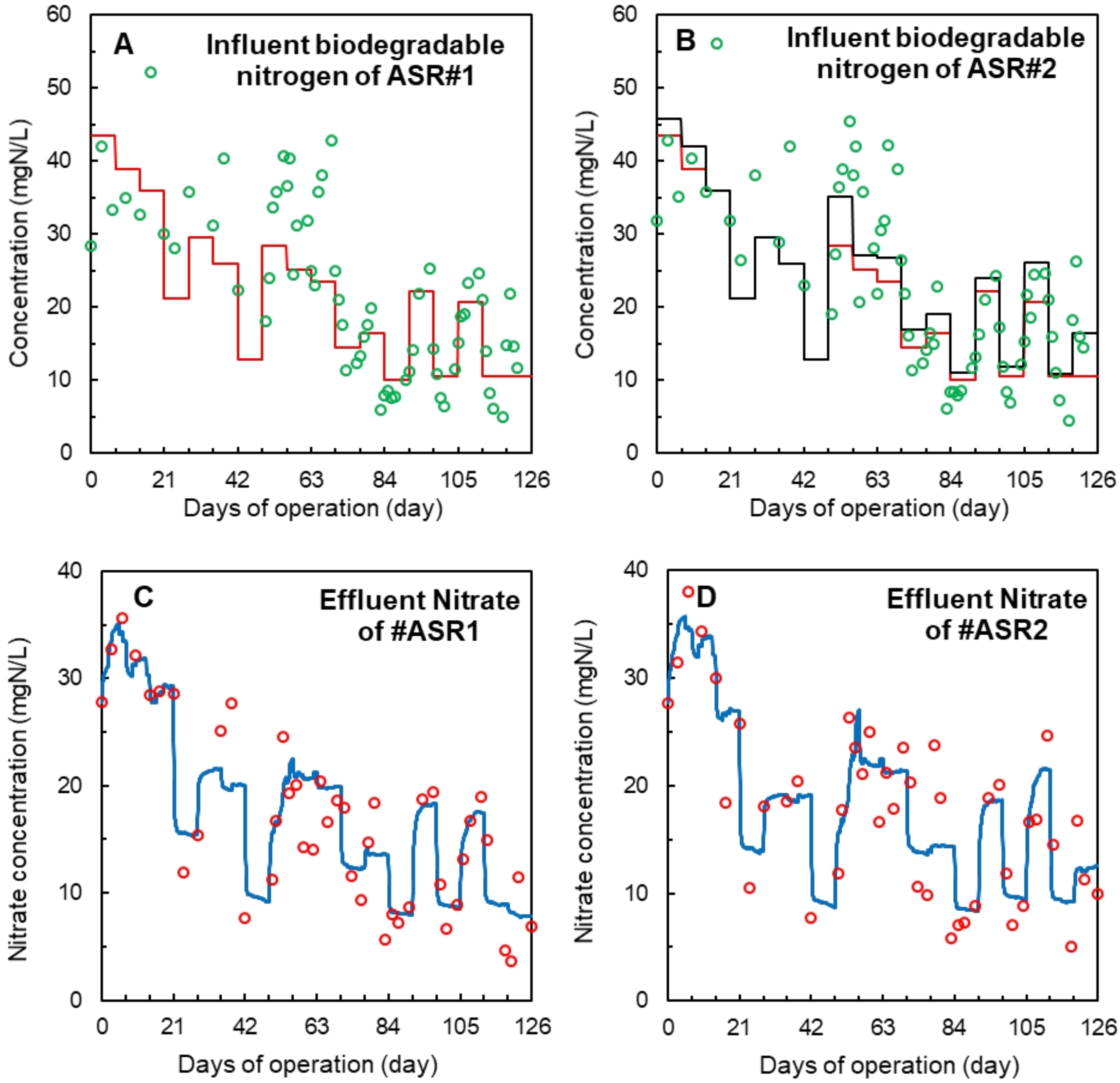

Figure 4.10 The weekly estimated concentration of influent nitrogen and effluent nitrate in ASR#1 and ASR#2 during 126-day operation (green circle: measured influent ammonium; red circle: measured effluent nitrate; red curve: simulated influent STKN; black curve: simulated influent TKN; blue curve: simulated effluent nitrate)

b) Case study at Chua Cau WWTP

Based on the outcomes obtained from the developed method, the weekly concentration of influent wastewater at Chua Cau WWTP was reasonably estimated. As shown in Figure 4.11, the estimated weekly concentration of influent state variables reasonably reproduced the MLSS and MLVSS concentrations in both ASRs, indicated by the considerably match between simulated curves and measured data. In similar to the case of Vinh Niem WWTP, the fraction of $X_U + X_{U,Inf}$ was repeatedly dominant in MLVSS concentration. In particular, the proportion of $X_U + X_{U,Inf}$ in activated sludge constituents was approximately 57 - 59% of MLVSS concentration. The existence of particulate inert inorganics seemed to still take place in the influent of ASR#1, indicating by considerable difference between MLSS and MLVSS concentrations. The proportion of particulate inert inorganics in activated sludge MLSS of ASR#1 was even slightly higher than that of ASR#2. Specifically, the proportion of particulate inert inorganics in ASR#1 was approximately 40% of activated sludge MLSS whilst the contribution of particulate inert inorganics in activated sludge MLSS of ASR#2 was around 33%. Of course, the existence of particulate inorganics composition in ASR#1 was attributed to a consequence of uptake and/or precipitation of soluble inorganics for the biomass growth as mentioned. However, for the purpose of estimating the weekly concentration of biodegradable materials, that existence is believed to have no effect on the estimated results.

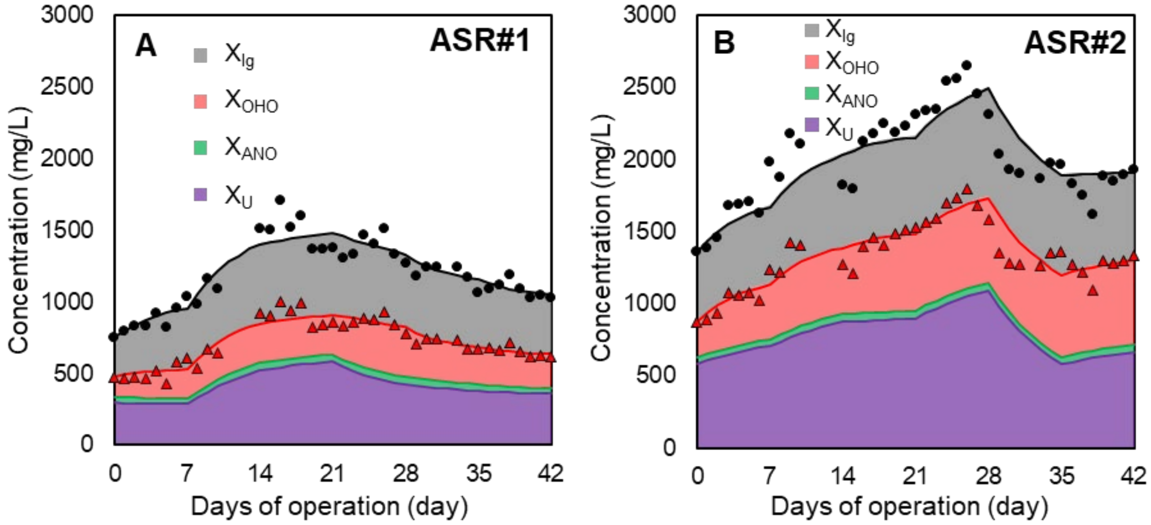

Figure 4.11 Activated sludge constituents during 42-day operation of field-test module at Chua Cau WWTP (circle: measured MLSS; triangle: measured MLVSS black curve: simulated MLSS; red curve: simulated MLVSS)

The estimated and measured dataset of influent organics and nitrogen for both ASRs were demonstrated in Figure 4.12. From the simulation results, it can be recognized that the simulated concentration of both influent soluble and total COD reasonably matched to those measured. It should be specified that there was a considerable difference of mean b_{OHO} between two case study. Specifically, the mean b_{OHO} of ASR#1 and ASR#2 (after normalization to 20^{o}C) during the field experiment at Chua Cau WWTP was 0.66 d^{-1} and 0.80 d^{-1}, respectively (data not shown). This might be the consequence of higher concentration in receiving influent in case that field experimental module operated at Chua Cau WWTP compared to Vinh Niem WWTP. In the same approach, the average value of two mean b_{OHO} (0.73 d^{-1}) was selected for the estimation work. In case of μ_{max_ANO}, the selected value for estimating influent biodegradable nitrogen was 0.40 d^{-1} (average of mean μ_{max_ANO} of 0.41 in ASR#1 and 0.37 in ASR#2), compared to 0.34 d^{-1} of μ_{max_ANO} in case study at Vinh Niem WWTP.

Despite the fact that the estimated results of influent total and soluble COD were trendy with those measured, it must be pointed out that there was a difference of measured soluble COD of wastewater between the influent chamber (influent feeding of ASR#2) and primary settling tank (influent feeding of ASR#1). In particular, it was found that the concentration of soluble COD in the inflow can be reduced 17 – 67% after primary sedimentation (average of 41%). As mentioned in previous sub-section, the reason for this is believed to be caused by the ability of coagulant dosed into primary tank that can also capture soluble organic compounds. When soluble organics are grabbed by coagulant, it might result in a decrement of specific amount of S_B and thus the calculated result of S_B from DPE was underestimated. Because the concentration of XC_B was calculated from X_{OHO} in ASR#2 with the assumption of S_B obtained, once S_B was underestimated XC_B would be overestimated consequently. In this case study, however, the estimated results of both soluble and total COD still reasonably matched to those measured. To explain for this, it should be mentioned that the starting time of the laboratory measurement for kinetic and biomass concentration of organism was just after 1 weeks from the startup of field-test module. According to Nguyen *et al.* (2017), the back-calculation method required a start-up phase to acclimate the inoculum activated sludge to the experimental site. Indeed, the measured b_{OHO} of ASR#1 during first three weeks starting from the beginning of laboratory analysis for kinetic measurement significantly scattered far from the mean b_{OHO}. Specifically, the values of b_{OHO} in ASR#1 during this period were normally lower than the selected b_{OHO} for estimation work. Thus, the S_B concentration was supposed to be overestimated during this period. This overestimation of S_B was supposed to accidentally compensate the impact of lowering concentration of soluble organics compound caused by the coagulant in ASR#1 primary settling tank, leading to a reasonable fit between estimated and measured soluble COD of the influent.

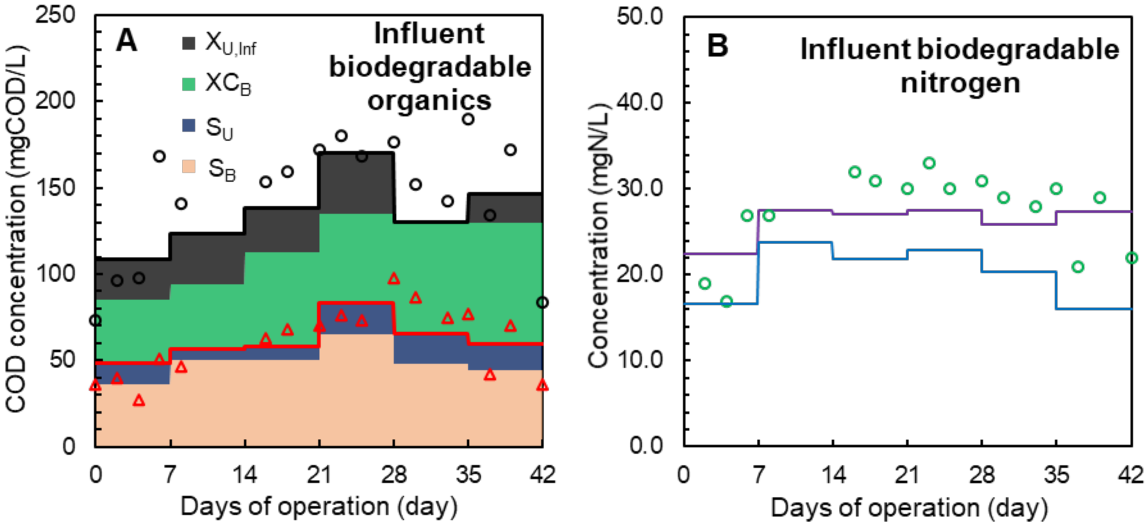

Figure 4.12 Estimated and measured concentration of influent biodegradable organics and nitrogen in ASR#1 and ASR#2 at Chua Cau WWTP
(black circle: measured total COD; triangle: measured soluble COD;
black line: simulated total COD; red curve: simulated soluble COD;
green circle: measured TKN; blue line: simulated STKN; violet line: simulated TKN)

In terms of biodegradable nitrogen, the estimated result of influent TKN concentration (consequently calculated from influent state variables of biodegradable nitrogen) was considerably trendy with the measured results. In specific, there was a slight underestimation of influent TKN during the time of day 14 to day 35. This might be due to the analytical error of TKN measurement at laboratory. Also, the one-shot samples of effluent might not represent the daily concentration of nitrate for the estimation. Because influent TKN concentration was directly estimated from effluent nitrate and kinetic of autotrophic nitrifying organism, as a result, influent TKN might be over/underestimated due to the improper sampling of effluent.

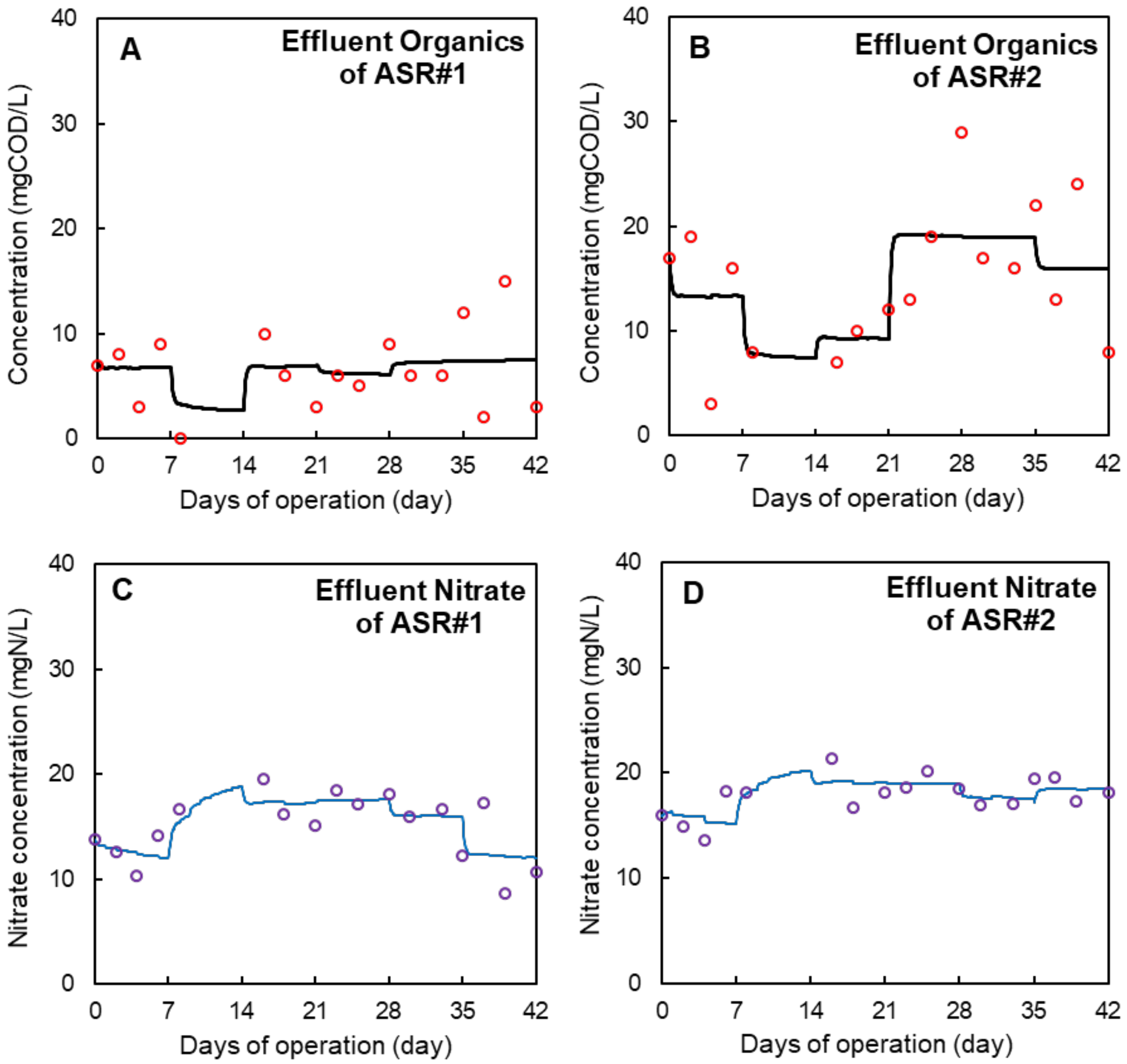

Figure 4.13 The weekly estimated concentration of effluent organics and nitrate in ASR#1 and ASR#2 during 42-day operation at Chua Cau WWTP (red circle: measured soluble COD; black curve: simulated soluble COD; violet circle: measured effluent nitrate; blue curve: simulated effluent nitrate)

The estimated and measured weekly concentration of the effluent soluble COD and nitrate in both ASR#1 and ASR#2 were also demonstrated in Figure 4.13. Without a doubt, because the effluent soluble COD was defined as target variable for estimating soluble non biodegradable organic (S_U) of influent with known S_B dataset, whilst the effluent nitrate was selected for estimating influent TKN, the estimated curve of these two constituents given by DPE smoothly matched to the measured results.

4.4. Conclusions

The utilization of the optimization tool DPE integrated with ASM1 to back-calculate the concentration of influent biodegradable constituent in an automatic manner was investigated in this chapter. Based on the obtained outcomes, the main conclusions are withdrawn as below:

(1) The weekly average concentration of influent biodegradable organic and nitrogen were reasonably estimated from kinetic and biomass concentration of heterotrophic and autotrophic organism using DPE instead of manually back-calculating as in existing

technique.

(2) For the know-how to obtain better results in the back-calculation, it is recommended that the effluent nitrate should be defined as target parameter to estimate weekly concentration of influent biodegradable nitrogen instead of biomass concentration of autotrophic organism, while the influent biodegradable organic is simply estimated from the biomass concentration of heterotrophic organism.

CHAPTER 5. DYNAMIC ESTIMATION OF HOURLY FLUCTUATION OF INFLUENT BIODEGRADABLE CARBONACEOUS AND NITROGENOUS MATERIALS USING ACTIVATED SLUDGE SYSTEM

5.1. Introduction

Along with population boom, a rapid development of the economy is one the most reason for the initiation of new wastewater treatment plants (WWTPs) in developing counties, especially in Vietnam. According to the report published by World Bank in 2013 [6], the average ratio of urban household connected to public sewerage or drainage system in Vietnam was estimated at around 60 percent and the local coverage depends on the residential density and fundamental infrastructure of each area. In order to deal with the potential pollution of water bodies, Vietnamese Government have been putting effort into improving urban sanitation with more than 30 projects implemented over the country as of 2013 [6, 42].

Another fact revealed from the report that 60 percent of household discharging wastewater to septic tank placed prior to sewer was a compulsory regulation. Since septic tank is a kind of decentralized component contributing to reduction of pollutant load, a portion of biodegradable materials is decomposed during the period of retention [35]. Nevertheless, due to accumulation of pollutant associated with lack of regular maintenance, it is recognized that the septic tank process cannot produce high performance which remarkably differs over areas and household [36, 43]. Accordingly, the constituents and concentration of effluent from septic tank to combined sewage system which was the typical class in urban areas considerably varied, e.g. BOD_5: 36 - 135 mg/L, SS: 27 - 196 mg/L and Total Nitrogen: 11 - 40 mg-N/L [6]. In addition, because the combined sewerage systems in Vietnam play a role in collecting both wastewater and storm water which probably carries surface pollutant, the variation in influent concentration possibly becomes more enormous. All of these facts lead to a challenge in planning and designing WWTPs due to the impossibility of applying default influent concentration.

Usually, in order to determine the characteristic of wastewater, on-site water sampling combined with laboratory analysis is supposed to be the most common procedure. However, in case that the constituent and concentration of the objective fluctuate over time, a considerable number of water samples must be required to collect and then be analyzed in laboratory. Furthermore, for the reason that some materials in wastewater are readily decomposed in short time, a requirement of immediate analysis with abundant of manpower is undoubtable. For the purpose of timely catching the fluctuation of concentration besides wastewater flow, innovative and simple methods are desired to replace those cumbersome ones.

Recently, Nguyen *et al.* (2017) demonstrated a back-calculation method using a set of lab-scale activated sludge reactors, whereby the composition of activated sludge which was the direct consequence of the influent materials were analyzed and those were then calculated respectively [28]. Nonetheless, the research merely revealed the approach on weekly estimation of influent concentration associated with the acceptance of influent unchangeability during a specific time step (7 - 8 days). In reliance on the concept of this approach, considering that decomposition of biodegradable carbonaceous and nitrogenous compounds in wastewater, which consumes dissolved oxygen (DO), are responsible for the fluctuation of DO concentration in reactor, and the biodegradable nitrogenous materials are converted totally into nitrate form in effluent, the back-calculation of these constituents from dynamic response of the above-mentioned parameters using IWA Activated Sludge Model No.1 (ASM1) [20] as a mathematical calculation method may enable to detect the fluctuation of influent concentration over short interval. Thanks to the advance in sensory technology with numerous portable measurement devices which are available in commercial markets, the monitoring of DO and nitrate concentration over short interval are totally obtainable. Once this developed method would be applied, a significant amount of time and labor could be saved comparing to the conventional method. For instance, in the purpose of catching influent constituents and its fluctuation in concentration during first flush of storm weather, conventional method with on-site sampling followed by laboratory analyzing tons of sample is absolutely impossible solution to meet the initial purpose. In contrast, the continuous monitoring of sudden variation in parameter's information, which was DO concentrations in reactor and nitrate concentrations in effluent, can be totally obtained with the great assistance from modern portable meter combined with relevant probes. By this way, the possibility to estimate the sudden fluctuation in influent concentrations is anticipated. Based on the background, a lab-scale activated sludge module was installed at Hue Citadel area in Vietnam and operated for several months. From the intensive analysis for 24 hours, the DO concentration in aeration tank and nitrate concentration in the effluent were monitored with on-line probes. Using the dataset for ASM1, the municipal wastewater constituents and concentration at every 1-hour were calculated.

5.2. Materials and methods

5.2.1. Field Experimental Module

a) Installation of system

An activated sludge module, with the structure is completely identical to the set of activated sludge reactor ASR#1 described in section 3.2 of Chapter 3 (comprised of primary settling tank, main aeration tank and secondary settling tank) was installed in Hue Citadel area, Vietnam. All households in this area had water-flush toilets connecting to each septic tank [44]. Since no full-scale WWTP was available in Hue, both the wastewater and storm water collected from the city's combined sewerage system were directly discharged to Ngu Ha canal and 41 lakes [45]. The region where the module was set up was located in the center of study area and close to the end discharge point of the local sewerage system prior to Tinh Tam lake.

5.2.2. Operating conditions

The hydraulic loading of the influent was set at 264 L/d, meaning that HRT of the aeration tank was 2 hours. The SRT was steadily controlled to be 10 days. Inoculum activated sludge was obtained from a brewery located in a specific industrial zone nearby Hue Citadel area.

The dosage of poly-aluminum chloride and anionic polymer (used for the improvement of sedimentation in primary settling tank) was 10 mg-Al/L and 0.5 mg/L, respectively. A small amount of NaOH 5 g/L solution was also added to neutralize pH in the aeration tank ranging from 6.8 to 7.2. The air flow of aeration tank was carefully fixed at 2 L-air/min whilst the water temperature in the aeration tank varied between 24.5^{o}C and 26.0^{o}C during the experimental period.

After about 1 month of preliminary continuous operation, the activated sludge was sampled from the aeration tank to measure kinetic parameters including specific decay and specific growth rates of microorganisms. The DO concentration in the aeration tank and the nitrate concentration in the effluent were continuously monitored where the DO concentration was measured by a portable on-line meter (Multi 3630 IDS) with attached sensor (FDO 925)

(WTW-Xylem Corp., Weilheim, Germany) and the nitrate concentration was measured using a test kit including a main reflectometer (RQflex® plus 10) and test strips (116971-Nitric acid test, MiliporeSigma Cor., Burlington, Massachusetts, USA) with a set of standard concentration, whilst the sampling of influent was also conducted at fixed interval. The volumetric mass transfer coefficient (K_La) of oxygen was also measured to calculate the biological oxidation rate in the aeration tank.

5.2.3. Laboratory Analysis

The specific decay rate of heterotrophic and the specific growth rate of autotrophic organism together with their active biomass was estimated from the batch experiments using Equation (3.1) and Equation (3.2) mentioned in section 3.3 of Chapter 3.

To estimate K_La value, influent feeding was discontinued for a while until the DO concentration in the reactor reached air saturation. Afterward, the ammonium chloride solution was dosed at 100 mg-N/L of concentration, and the measurement of oxygen uptake rate together with monitoring of DO concentration that gradually reached a constant value were conducted. In gas-liquid system, the mass balance of DO in a given complete mixing reactor was described in Equation (5.1) [46, 47]. In this study by fixing the air flow at 2 L-air/min, the obtained K_La value was 17.5 h^{-1}.

$$\frac{dC_L}{dt} = K_L a(C^* - C_L) - Xq_{O_2} \tag{5.1}$$

where:

dC_L/dt = process rate of DO in the liquid phase (mg-O_2/L/h)

C^* = the saturation DO concentration in the liquid phase (mg-O_2/L)

C_L = the actual DO concentration in the liquid phase (mg-O_2/L)

X = the biomass concentration (mg-COD/L)

q_{O_2} = the specific oxygen uptake rate of the microorganism (1/h)

From the Equation (5.1), the part of $K_La(C^* - C_L)$ represented the oxygen transfer rate (OTR) from the gas to liquid phase, in which C_L was determined as the constant value whilst Xq_{O2} was the oxygen uptake rate of microorganism (OUR). When dC_L/dt became almost zero, K_La could be obtained from $(C^* - C_L)$ and Xq_{O2} in numerical manner [46, 47].

5.2.4. Dynamic Estimation of Influent Constituents and Concentration.

The DO concentration in the aeration tank and the nitrate concentration in the effluent were monitored and measured using the above-mentioned apparatus (the DO portable meter with sensor and reflectometer with test strips). Apart from these target variables associated with active biomass (X_{OHO} and X_{ANO}) and kinetic parameters (b_{OHO} and μ_{max_ANO}), concentrations of soluble biodegradable carbonaceous material (S_B) and soluble biodegradable nitrogenous material (S_{NHx}) were back-calculated respectively on basis of activated sludge model [20, 27].

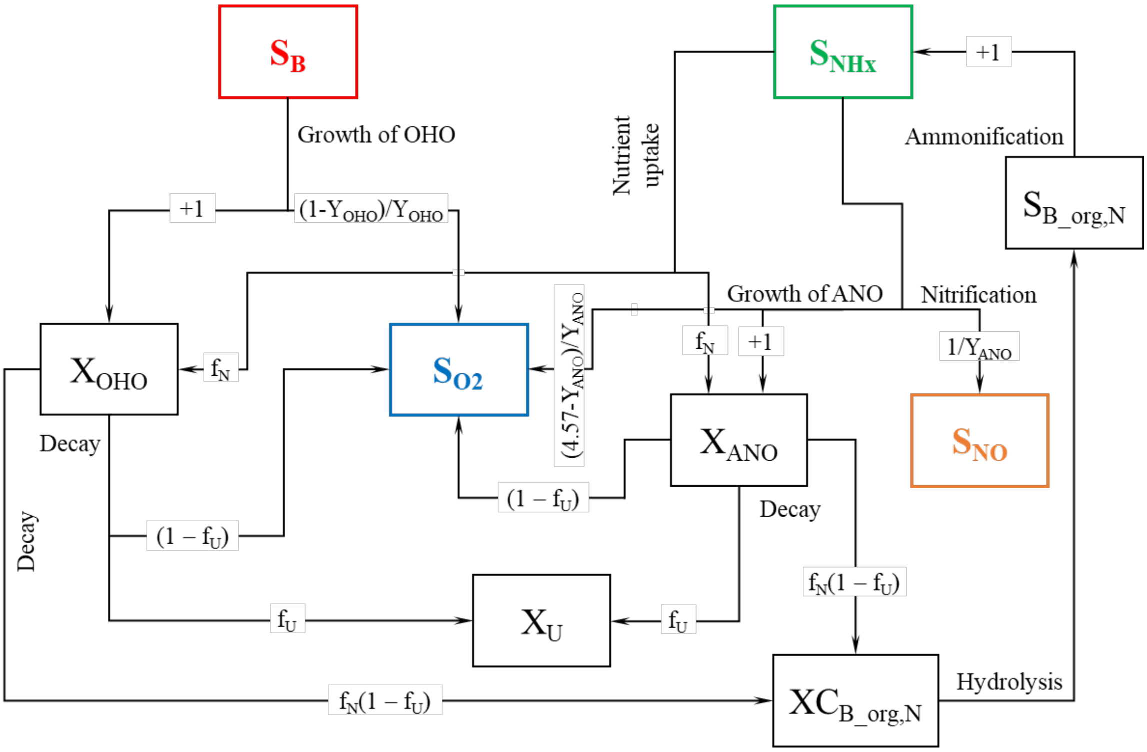

Figure 5.1 Fate of influent materials in the activated sludge process

As illustrated in Figure 5.1, S_B concentration was mainly estimated from DO utilization whilst S_{NHx} concentration was estimated from the nitrification, DO utilization and nutrient uptake. Along with the physical and operational parameters of the activated sludge module, the obtained datasets including the kinetic parameters, DO and nitrate concentrations were transferred to a simulation layout created by a process simulator (GPS-X ver. 7.0, Hydromantis Inc., Hamilton, Ontario, Canada). The S_B and S_{NHx} concentration were back-calculated with Dynamic Parameter Estimation (DPE) method programmed in the simulator.

In this chapter, the S_B and S_{NHx} concentrations were randomly selected in the pre-determined range to reproduce the minimal and maximal DO concentrations during the sampling event (between 0 and 120 mg-COD/L for S_B and between 0 to 24 mg-N/L for S_{NHx}), Maximum Likelihood of the objective function was selected for the parameter regression.

For the setup of time step, in case that the time step was set as greater than the data collection frequency, it was unmeaningful due to a certain number of consecutive data points were calculated as same result. For instance, when the time step was set at 2 hours, the optimized variables (S_B and S_{NHx}) were assumed to be constant for 2 hours, leading to same calculated results for each pair of two consecutive data point (at the 1-hour interval) of the optimized variables. On the other hand, in case that the time step was set as smaller than the data collection frequency, there would be a significant scattering in the calculated results of the optimized variables due to no provision of data within each pair of consecutive output data point (at 1-hour). For these reasons, the time step was set at 1 hour as same as the interval of data collection frequency.

To justify the above dynamically estimated influent concentrations, hourly sampling of the influent was conducted using an auto sampler equipped with portable refrigerator (Avalanche, Teledyne ISCO, Lincoln, USA), whereby carbonaceous BOD_{30} (C-BOD_{30}) and ammonium nitrogen concentrations were measured according to standard methods [10], which were approximated to be S_B and S_{NHx} respectively. For the conversion between C-BOD_{30} and S_B, as C-BOD_{30} was the consequence of ultimate biomass growth (Y_{OHO}) and decay (f_U'), S_B was given from C-$BOD_{30}/(1 - Y_{OHO} \times f_U')$. For simplification, ammonium nitrogen was assumed to be the dominant soluble biodegradable nitrogen in the influent.

5.3. Results and discussion

5.3.1. Kinetic parameters and concentration of Heterotrophic and Autotrophic Organism

As shown in Figure 5.2, OUR_{e_OHO} and OUR_{max_ANO} were reasonably plotted with a high correlation coefficient, especially the OUR_{max_ANO} ($R^2 = 0.99$). The b_{OHO} was estimated to be 0.270 1/d whilst μ_{max_ANO} was calculated to be 0.654 1/d. From these kinetic parameters and the intersection of the graphs (t = 0), the initial concentration of heterotroph and autotroph in the activated sludge were calculated as $X_{OHO(0)}$ = 1,049 mg-COD/L and $X_{ANO(0)}$ = 105 mg-COD/L respectively. For the purpose of providing a probable range of specific decay rate and growth rate as well as active biomass concentration, a linear regression with 95% confidence interval was applied. For heterotroph, the statistical analysis revealed that the specific decay rate and the biomass concentration were placed into a range between 0.183 - 0.230 1/d and 855 - 1308 mg-COD/L whilst those of autotroph were placed into a range between 0.601 - 0.707 1/d and 98 - 114 mg-COD/L respectively.

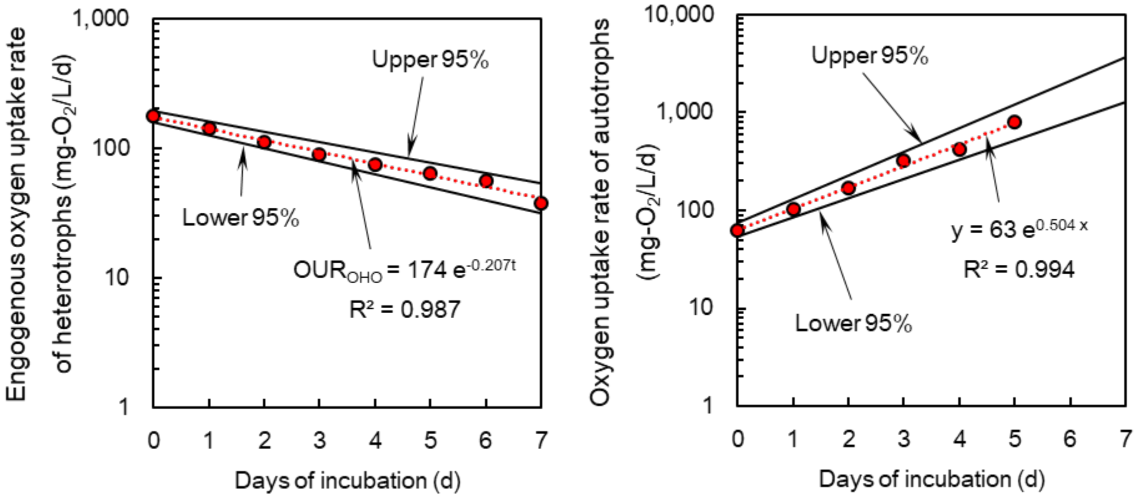

Figure 5.2 Batch test to estimate specific decay of ordinary heterotrophs and specific growth rate of nitrifying autotrophs (water temperature = $27^{o}C$)

For the reason that temperature was an influencing factor on microbial kinetics [20, 33, 48], the b_{OHO} and μ_{max_ANO} were normalized at $20^{o}C$ with the temperature coefficient $\theta_{OHO(20^{o}C)} = 1.029$ and $\theta_{ANO(20^{o}C)} = 1.072$ [20, 33], leading to $b_{OHO(20^{o}C)} = 0.169$ 1/d and $\mu_{max\_ANO(20^{o}C)} = 0.402$ 1/d respectively. These obtained kinetic parameter values from the batch experiments seemed to be comparable to those in literature [20, 28, 30, 35]. The probable ranges of specific decay and specific growth rate after normalization at $20^{o}C$ were respectively calculated as $b_{OHO(20^{o}C)} \approx 0.150 \sim 0.188$ 1/d and $\mu_{max\_ANO(20^{o}C)} \approx 0.369 \sim 0.435$ 1/d.

5.3.2. DO concentration in aeration tank and nitrate concentration in effluent

The variation of DO concentration in the reactor over the monitoring campaign and the effluent nitrate concentration were summarized in Figure 5.3A and Figure 5.3B.

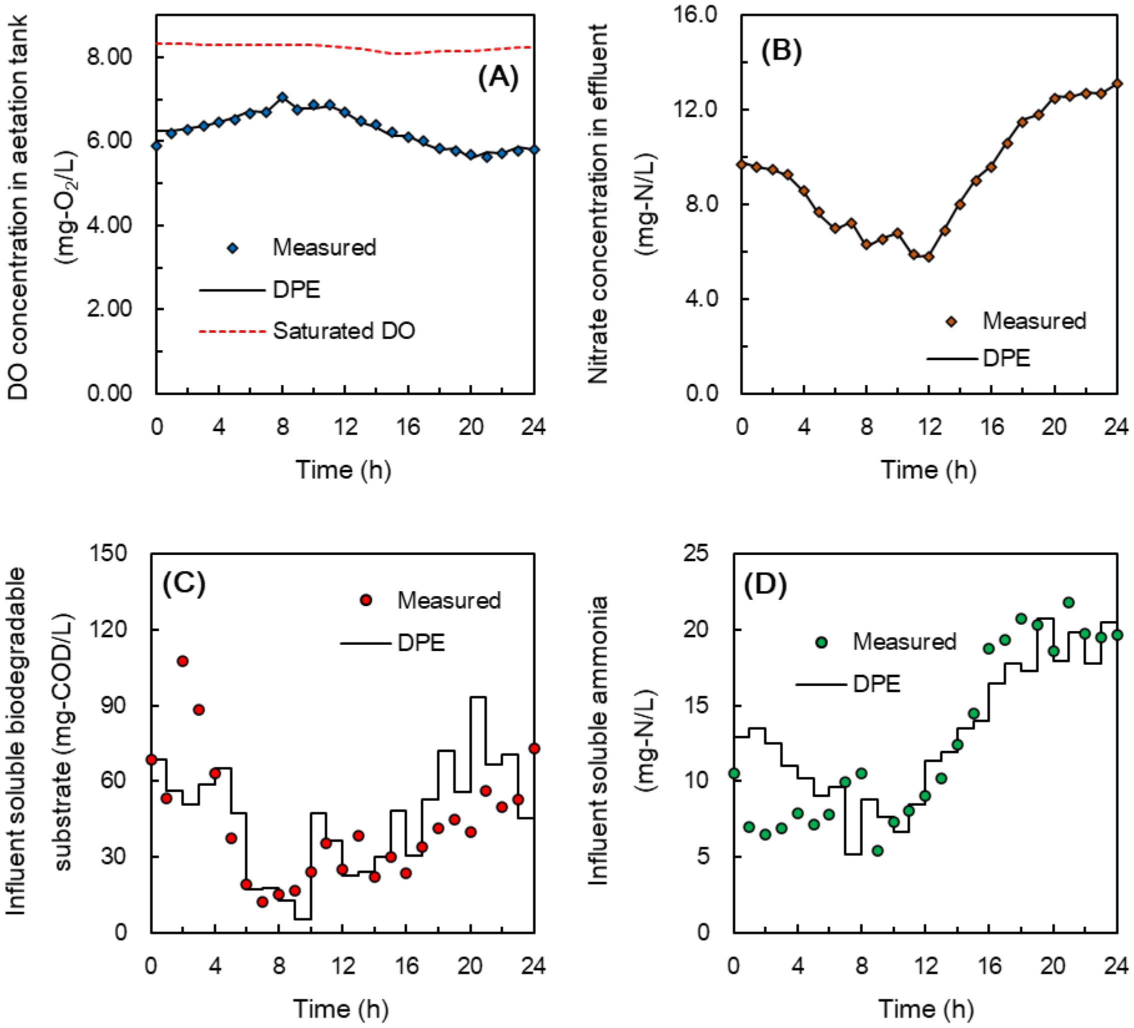

Figure 5.3 The concentration of DO in the reactor (top left), effluent nitrate (top right), influent soluble biodegradable organic (bottom left) and nitrogenous compounds (bottom right)

The datasets obviously revealed that the DO concentration was sinusoidally fluctuated from 5.90 mg-O_2/L at the midnight (0h00) and reached the peak of 7.06 mg-O_2/L at the time of 8h00. During the period from 12h00 to 20h00, the DO concentration gradually decreased to 5.69 mg-O_2/L and seemed to be unchanged during the end of the day (from 21h00 to 24h00). Throughout the experiment, the DO concentration in the reactor was ranged between 5.64 – 7.06 mg-O_2/L within the day and this fluctuation was attributed to the low concentration of influent material due to considerable dilution mostly caused by rain. According to Tran [49], the average concentration of soluble BOD_5 and total nitrogen at the sewer outlet on dry days in wet season was 35.2 mg/L and 16.6 mg/L respectively. It was also noted that the hourly data of the DO concentration in the aeration tank reached in range from 70% to 85% of saturated DO concentration (at corresponding temperatures).

With respect to the nitrate concentration in the effluent, it appeared that an inverse response was obtained comparing to that of DO concentration in the reactor. The nitrate concentration was ranged between 5.8 - 13.1 mg-N/L starting with a decrement from 9.7 mg-N/L at the midnight (0h00) to 5.8 mg-N/L at the time of 12h00 followed by an increment in which the nitrate concentration reached 12.5 mg-N/L at the time of 20h00, and seemed to be unchanged during the period from 20h00 to 24h00. As the dynamic responses of DO concentration and nitrate concentration were distinct, these could be used for reliable keys to calculate the 2 kinds of influent material concentrations as S_B and S_{NHx}.

5.3.3. Back-calculation of influent constituents

Along with the above obtained datasets including kinetic parameters (specific decay rate of X_{OHO} and specific growth rate of X_{ANO}), initial active biomass (X_{OHO} and X_{ANO}), the monitored datasets (DO and nitrate concentration) and K_La of oxygen from the aeration were transferred into a simulation layout. By using the DPE method, each S_B and S_{NHx} within each time step was identified as the "optimized" variable through the curve fitting of DO and nitrate concentration which were selected for the target variables.

As shown in Figure 5.3A and Figure 5.3B, the calculated DO and nitrate concentrations completely fitted with those measured except the initial data plot of DO concentration (Figure 5.3A**)**. This mismatch was believably due to the measurement error caused by device's sensitivity. For the S_B and S_{NHx} concentration, it is obvious that the measured data reasonably appeared around the calculated curve given from DPE feature (Figure 5.3C and Figure 5.3D). In the dynamic simulation, underestimation and/or overestimations of the S_B and S_{NHx} concentrations in some time step were recognized, particularly during the period from 0h00 to 4h00 and from 17h00 to 22h00. Although the exact reasons of the mismatch were not clear, it might be due to the limitation of analytical accuracy of nitrate in the study. Since 1 gram of ammonium required 4.57 gram of oxygen for its oxidation, even small analytical error of nitrate-N would cause large estimation error of S_B as S_B and S_{NHx} were both estimated from DO. For instance, assuming that the true nitrate concentration of effluent at the time of 2h00 and 3h00 were lower than the measured concentration, the DPE method was obliged to underestimate S_{NHx} concentration, leading to the lower oxygen consumption which resulted in overestimation of S_B in the influent. In order to compensate the gap, new S_B concentration should be recalculated to be higher than that of obtained from the first DPE. This could be carried out in such way that the nitrate concentration in the dataset was intentionally manipulated (slight increase of nitrate concentration). In this way the unwanted underestimation of S_B concentration and the overestimation of S_{NHx} concentration could be eliminated. In addition, due to the low concentration of influent biodegradable materials that corresponded to low oxygen uptake rate in the reactor, the DO concentration in the reactor occasionally became close to the saturated concentration. In this case the small driving force (($C^* - C_L$)) caused the part of calculation error for both S_B and S_{NHx} in the influent. On the other hand, one of the possible reasons for the mismatch in the calculated and measured data of S_B and S_{NHx} concentrations was the HRT delay (2 hours), which the change of the nitrate concentrations in the effluent were triggered by the nitrate concentrations in the reactor over 2 hours ago.

With respect to the dynamic simulation, the dataset of the measured S_B and S_{NHx} were imported as the input parameters then the DO concentration in the aeration tank and the nitrate concentration in the effluent were calculated by using the initial-defined simulation layout. The simulated data of the DO and nitrate concentration were compared to those. As shown in Figure 5.4A and Figure 5.4B, the simulated data reasonably matched to those measure in both case of DO and nitrate. Based on these outcomes, it was noted that both the conventional and the developed approach in water analysis hold a certain extent of analytical error. Furthermore, since both analytical approaches provided comparable productivity, a comparison in advantages and disadvantages is going to be discussed in the below sub section.

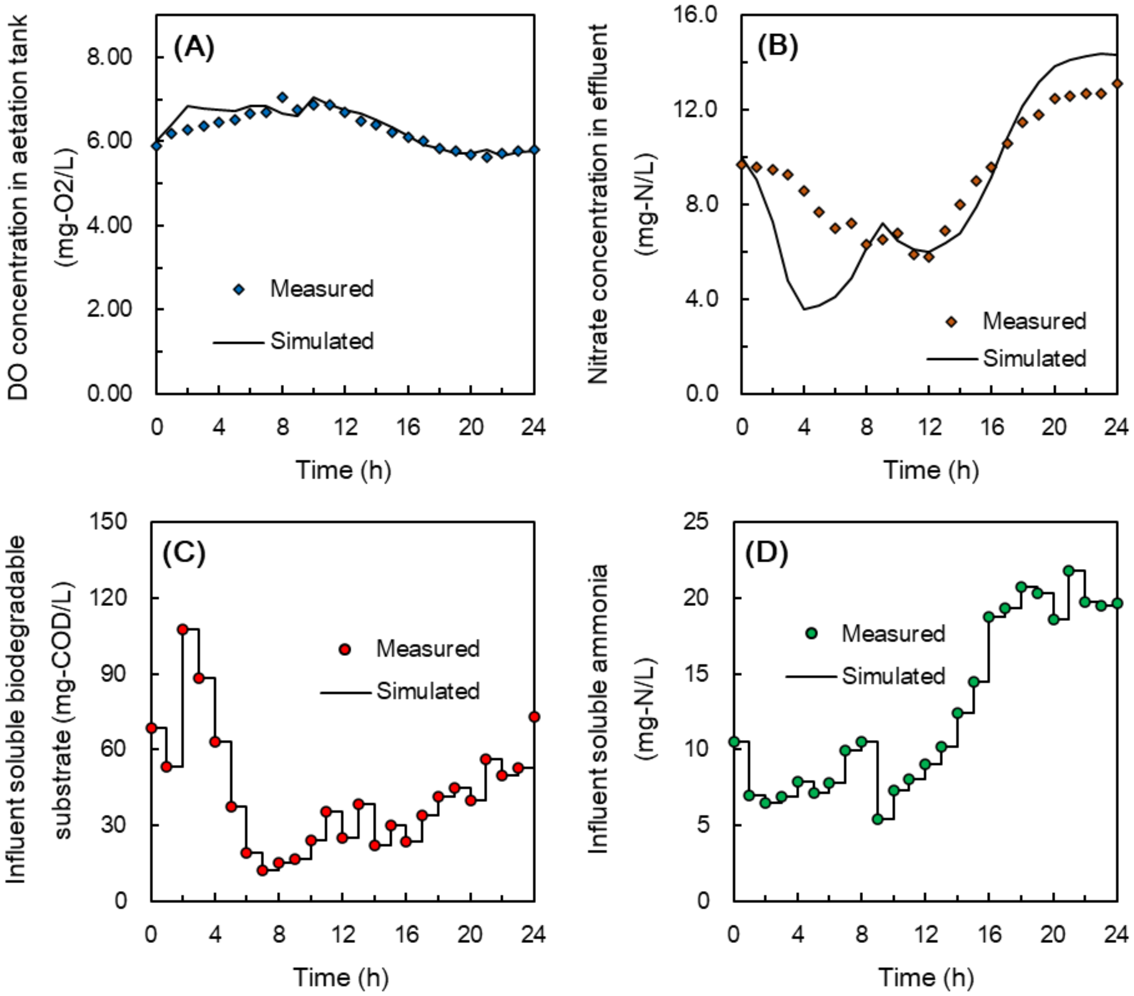

Figure 5.4 Comparison between the measured and simulated results of the DO concentration in the aeration tank (left) and the nitrate concentration in the effluent (right)

From the measured and estimated concentration of carbonaceous and nitrogenous material, the hourly loads of integrated oxygen demand were calculated (integrated oxygen demand = $S_B + 4.57S_{NHx}$) as shown in Figure 5.5. Although the consistency between the calculated and measured data of both S_B and S_{NHx} were at reasonable level, the calculated oxygen demand still properly matched those measured. It is undeniable that the load of influent oxygen demand is considered to be a very important information for designing and controlling the aeration intensity. Because the sudden elevation of pollutants concentrations followed by the decrement of that due to the dilution usually occurs at very short period of time, the specific determinations for the oxygen demand of the carbonaceous and nitrogenous materials are supposed to be infeasible. Therefore, the influent load of integrated oxygen demand is considered an attractive approach. Obviously, from this result the possibility of estimating the load of influent oxygen demand to the aeration tank, in case that the influent concentrations continuously fluctuated over time, was revealed.

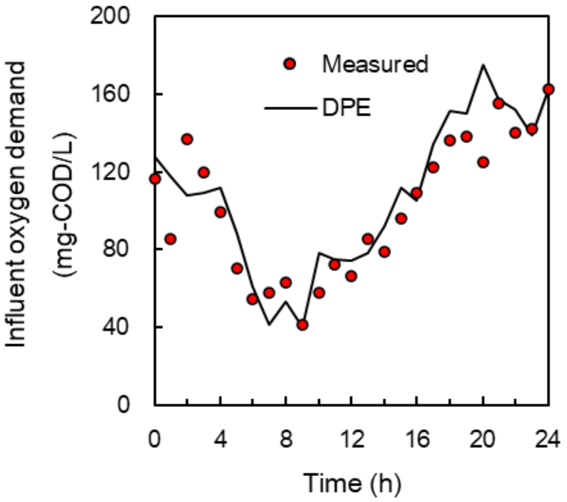

Figure 5.5 Load of influent oxygen demand to the aeration tank

Next, the state variables obtained from the DPE were converted to the conventional water quality indices [28]. In average, the sewage at the sampling area contained approximately 37 mg/L of C-BOD_{30} and 12.8 mg-N/L of ammonium nitrogen respectively. From the DPE, C-BOD_{30} and ammonium nitrogen in the influent were supposed to be approximately 41 mg/L and 13.4 mg/L. Although some data plots were not consistent with the measured ones, the method used in this study seemed to generate accurate 1-day average concentration. These estimated concentrations were comparable to those obtained by Tran [49].

5.3.4. Possibility of the alternative method and further application

Based on the above experimental results and computational analysis, the developed method in this study was thought to reasonably estimate the biodegradable materials in the influent, specifically the carbonaceous and nitrogenous fractions. In accordance with the results demonstrated in Chapter 4, the working load of this developed method was compared to that of the conventional on-site sampling in both cases of estimating weekly concentration and hourly concentration of influent biodegradable constituents, as listed in Table 5.1. According to recommendation from CH2M Hill Engineering Ltd. and Hydromantis Inc. [50], an installation of an auto-sampler equipped with refrigerator was required when performing on-site water sampling. Because of corruptible organics in the influent, the audit manual pointed out that the storage period in the refrigerator could not last 2-3 days and hence the water samples should be immediately delivered to laboratories. In addition, Nguyen *et al.* (2017) also pointed out that total organic carbon concentration in the municipal wastewater was decreased by 20-30% after 2-day storage at 4^{o}C, therefore daily sampling might be required even availability of 1-day delivering at the experimental site [28]. Moreover, it was also mentioned a huge number of analytical items for measuring C-BOD_{30} and ammonium nitrogen in laboratory could be saved by the developed method although a few items had to additionally analyzed (*i.e.* b_{OHO}, μ_{max_ANO} and K_La) and monitored *(i.e.* DO and nitrate).

Table 5.1 List of requirements for analyzing the concentration of influent biodegradable materials

Items	Estimating weekly concentration	
	This study	Conventional method
Sampling and analytical material	Activated sludge	Wastewater
On-site experimental apparatus	Activated sludge reactors (2 units)	Auto-sampler equipped with refrigerator (1 unit)
Sampling and monitoring frequencies	Every week	Every day in case of 2-day delivery of the sample to labs
Analysis for biodegradable organic compounds	Activated sludge COD, MLSS, MLVSS and b_{OHO}	C-BOD$_{30}$ and soluble C-BOD$_{30}$
Analysis for biodegradable nitrogen compounds	Nitrate-N concentration and μ_{max_ANO}	TKN and soluble TKN
Duration of the test	30 days for start-up + net evaluation period	Net evaluation period + 30 days for incubation of BOD$_{30}$
	Estimating hourly concentration	
	This study	Conventional method
Sampling and analytical material	Activated sludge	Wastewater
On-site experimental apparatus	Activated sludge reactors	Auto-sampler equipped with refrigerator
Sampling and monitoring frequencies	Only one time (within a day)	Every hour (within a day)
Analysis for biodegradable organics compounds	K_La, DO concentration (automatic) and b_{OHO}	C-BOD$_{30}$, soluble C-BOD$_{30}$
Analysis for biodegradable nitrogen compounds	K_La, DO, nitrate-N concentration (automatic) and μ_{max_ANO}	TKN and soluble TKN
Duration of the test	30 days for start-up + net evaluation period	Net evaluation period + 30 days for incubation of BOD$_{30}$

In case of 1-day conducting experiment with 1-hour interval of data updating, the conventional method would require 96 analyses (48 analyses for each parameter in both particulate and soluble form) whilst this developed method only required totally 12 analyses (2 analyses for kinetic parameters, 2 analyses for aeration intensity and 2 analyses for target variables for each ASR) which was 1/8 of the conventional working load. With respect to the working load for estimating weekly concentration of influent biodegradable composition, the conventional method required a number of analytical items for C-BOD$_{30}$, soluble C-BOD$_{30}$, N-BOD$_{30}$ and soluble N-BOD$_{30}$. On the other hand, the developed method required only b_{OHO}, μ_{max_ANO}, activated sludge COD, MLSS, MLVSS and nitrate in 2 ASRs (total 12 analytical items) with every-7-day of sampling frequencies. Considering a specific case of determining the design-daily-average BOD$_5$ and TKN, the conventional method requires up to total 1460 analyses whilst the developed method merely needs approximately 626 analyses, saving up 57% of the working load compared to the conventional method.

Table 5.2 List of consumable materials for analyzing the concentration of influent biodegradable materials

Analytical items	Estimating design-daily-average BOD_5 and TKN	
	This study	Conventional method
C-BOD_{30} and soluble C-BOD_{30}	COD test reagents/kit (for activated sludge COD) Glass microfiber filters (for MLSS and MLVSS) Allylthiourea, NaOH (for b_{OHO}) *(Total 417 items)*	Glass microfiber filters (for sample filtration) Winkler bottle BOD test reagents *(Total 1,095 items)*
N-BOD_{30} and soluble N-BOD_{30}	Nitrate-N test reagents/strips (for nitrate-N) Ammonium reagent (for μ_{max_ANO}) *(Total 209 items)*	Glass microfiber filters (for sample filtration) Winkler bottle BOD test reagents *(Total 1,095 items)*
	Estimating design-daily-maximum BOD_5 and TKN	
	This study	Conventional method
C-BOD_{30} and soluble C-BOD_{30}	Sodium sulphite (for K_La) Allylthiourea, NaOH (for b_{OHO}) *(Total 2,190 items)*	Glass microfiber filters (for sample filtration) Winkler bottle BOD test reagents *(Total 26,280 items)*
N-BOD_{30} and soluble N-BOD_{30}	Sodium sulphite (for K_La) Nitrate-N test reagents/strips (for nitrate-N) Ammonium reagent (for μ_{max_ANO}) *(Total 2,190 items)*	Glass microfiber filters (for sample filtration) Winkler bottle BOD test reagents *(Total 26,280 items)*

With respect to the cost and benefit, the consumable materials needed for each analytical item in conventional and developed method were compared and listed in Table 5.2. Specifically, at least total 2190 consumable items needed in order to estimate the design-daily-average BOD_5 and TKN of a WWTP influent by conventional method. In case of developed approach, it merely requires total 626 consumable items indicating approximately 71% of consumable items could be saved. In a broader scale, when determining the design-daily-average BOD_5 and TKN of a specific WWTP influent, the developed method utilizes total 4,380 consumable items compared to 52,560 consumable items of conventional method, which is equivalent to 92% of consumable item saving.

According to the decision of promulgating price of environmental monitoring and analysis in Hanoi approved by Hanoi People's Committee, analysis cost for water quality indices required to estimate wastewater concentration in the two approached was listed in Table 5.3. Due to the fact that kinetic parameters are not water quality indices, the price for this analytical items is assumed to be equal to the price for BOD test because these two experiment are both related to the measurement of oxygen consumption rate of organism during a specific time. Similarly, the price for measuring K_La is presumed to be equal to the price for measuring DO concentration. In addition, it should be noted that in the estimating hourly concentration of wastewater, DO and nitrate concentration were on-site measured at the field experimental module by portable probes, thus the cost for measuring these two parameters must be based on the price for on-site analysis, whilst the cost for other parameters must be based on the price for laboratory analysis.

Table 5.3 List of analytical cost for determining the concentration of biodegradable constituents in wastewater

Unit: million Vietnamese Dong (VND)

Analytical items	Estimating design-daily-average BOD_5 and TKN	
	This study	Conventional method
C-BOD_{30} and soluble C-BOD_{30}	71.8 (~104 samples for COD, MLSS MLVSS and kinetic)	245.5 (365 samples of C-BOD_{30} + 365 samples of soluble C-BOD_{30})
N-BOD_{30} and soluble N-BOD_{30}	51.2 (~104 samples for nitrate-N and kinetic)	184.8 (365 samples of TKN + 365 samples of soluble TKN)
	Estimating design-daily-maximum BOD_5 and TKN	
	This study	Conventional method
C-BOD_{30} and soluble C-BOD_{30}	355.3 (730 samples for K_La, DO and kinetic)	5904.8 (8,760 samples of C-BOD_{30} + 8,760 samples of soluble C-BOD_{30})
N-BOD_{30} and soluble N-BOD_{30}	435.0 (730 samples for K_La, DO, nitrate-N and kinetic)	4447.0 (8,760 samples of TKN + 8,760 samples of soluble TKN)

From the comparison between two methods in terms of analysis cost, it was revealed that the developed method can provide cost savings of up to 70% compared to the conventional method in the work of estimating the design-daily-average BOD_5 and TKN of influent. Moreover, for the purpose of estimating the design-daily-maximum BOD_5 and TKN of influent, the developed method can save the analytical cost up to 90% compared to the conventional method. Based on all gained benefits, it can be concluded that the developed method can promisingly alternate the existed conventional method for the aim of estimating design criterions of influent wastewater for WWTPs design.

Considering the aspect of further application, this developed method was supposed to be applicable to measuring not only the pollutants concentrations but also the load of oxygen demand in storm water for combined sewerage systems. In fact, at the beginning of rain or storm event, pollutant concentration would rapidly increase due to the washing out of materials on the ground and then flew into the sewerage system. Over the time, the concentrations of pollutants reached the peak followed by a significant decrease during the later stage as a result of dilution by rain/storm water. Tran (2016) also point out the dilution of influent wastewater in rainy season in Hue, Vietnam [49]. Furthermore, from the continuous monitoring of DO concentration, the peak of pollutant load and its frequency could be detected. These one is considered as crucial factors for designing the capacity of air blower, which could be obtained from the utilization of this developed method. For instance, from the data shown in Fig. 6, the daily average value of influent oxygen demand was estimated at approximately 108 mg-O_2/L. In addition, the hourly peak recorded within a day was approximately 175 mg-O_2/L; the appearance frequency of values, which was higher than the average value from 1.5 to 1.75 time, was estimated to be 5 time per day. Based on the above data analysis, the maximum capacity of air blower can be easily estimated to be around 200% of the daily average value of influent oxygen demand. In the same manner, by performing the intensive analysis for longer period (within a month, a quarter and a year) or specific time (dry and wet season), the more peak of pollutant load and its appearance frequency can be obtained to utilize for more precise designing of blower capacity.

5.4. Conclusions

An alternative method to back-calculate influent wastewater concentrations from the responses of the activated sludge process in the sampling field was evaluated using IWA ASM1. The following conclusions were obtained in this study.

(1) From the kinetic parameters of activated sludge, the operational conditions of the activated sludge module and the DO and nitrate concentrations, the influent concentrations for readily biodegradable organics and ammonia could be estimated in a dynamic manner. The hourly estimated concentrations of influent materials were comparable to those measured in the 1-day intensive sampling.

(2) The developed method only required 12 analytical items including OUR, b_{OHO}, μ_{max_ANO}, K_La, DO and nitrate per 1-day field test to estimate the hourly concentrations of influent biodegradable carbonaceous and nitrogenous materials, comparing to 96 analytical items including 48 items for each measurement of biodegradable organic and nitrogen of conventional method of on-site water sampling. Moreover, the cost for estimating the design-daily-average and design-daily-maximum BOD_5 and TKN of influent can be saved up to 70% and 90% respectively when applying the developed method instead of the conventional method. These indicating that the working load as well as the cost of the analysis could be significantly saved.

CHAPTER 6. A NOVEL METHOD TO DETERMINE BLOWER CAPACITY OF WASTEWATER TREATMENT PLANTS FOR DRY AND WET WEATHER CONDITIONS

6.1. Introduction

Aeration is a key component to design wastewater treatment plants (WWTPs), particularly activated sludge processes because the aeration energy is supposed to be more than half of the total energy consumption in the WWTPs [51, 52]. In this regard three affairs are considered in the aeration design: air supply system, oxygen transfer and oxygen demand. For the air supply system and the oxygen transfer, the topics have been intensively studied. For instance, with respect to modelling the aeration system and its energy consumption, Schraa *et al.* (2017) developed a fully dynamic model around the aeration header network to simulate the air distribution, and evaluated its limitations with various optimisation options and influent loadings [53]. Juan-Garcia *et al.* (2018) modified their study to the plant controlling systems by integrating a biokinetic model having oxygen uptake phenomena [54]. On the other hand, precise measurement of oxygen demand from the influent is still challenging because numerous influent sampling and analysis are needed to determine blower capacity which is the primary instrument of the air supply system. In fact, designing procedure to determine blower capacity to meet peak oxygen demand (daily maximum) is quite limited in guidelines available in literature [14, 15].

The above-mentioned guidelines only provide default design-daily-average concentrations of BOD_5 and Total Kjeldahl Nitrogen (TKN) with thumb rules to adapt the parameters to the plant design. For example, Schraa *et al.* (2017) and US Environmental Protection Agency (USEPA) selected 150~200 mg-BOD/L and 30~40 mg-N/L as the default BOD_5 concentration and total TKN concentration respectively [53]. With respect to the oxygen demand in design-daily-maximum, the guidelines suggest calculating the load in proportion to the inflow rate of the design-daily-average. The concept assumes that the influent concentration during the design-daily-maximum flow is identical to that during the design-daily-average flow. On the other hand, the guidelines also assume that the mass flow of oxygen demand per catchment area (kg/m^2/d) is independent on the wastewater flow rate (m^3/d). Consequently, they anticipate that the influent concentration during the daily maximum event would be lowered in reality. Therefore, the calculated value of the oxygen demand for design-daily-maximum flow becomes somewhat conservative allowing a safety margin for the design of blower capacity.

Although the above simple approach has been traditionally accepted in the regions, it is not clear whether this method can be also applicable to other regions and countries. This is because the sewer system and wastewater constituents are not always comparable to those of the regions that they analysed. For instance, in Southeast Asian countries (e.g. Vietnam), septic tank is obligatory installed at each household in front of the sewer, which often discharges low BOD_5 wastewater whilst TKN remains its concentration [34-36]. In addition, these countries mostly use combined sewer systems resulting in high fluctuation of wastewater concentration (and flow) over dry and rainy seasons [37]. Therefore, it is desired to measure the influent oxygen demand concentration for daily maximum which may not correspond to the daily average flow rate. This is supposed to the key to design proper air supply system.

One of the reasons that the guideline is obliged to take the simplified approach is due to the fact that numerous influent sampling and analysis are practically infeasible. In order to identify daily maximum concentration, at least 24 samples are required even the concentrations are rounded in 1 hour. When the analytical campaign lasts for a year to obtain design-daily-maximum concentration, at least 8,760 samples (= 24 × 365) must be analysed. Furthermore, in case that the biokinetic model (e.g. the IWA-Activated sludge model (ASMs) [20]) is used for plant design, the total number of the chemical/biological analytical items would reach several ten thousand per project.

To cope with the challenge, one alternative approach is to perform a back-calculation of the influent oxygen demand from the dynamic response of a field-test reactor receiving the influent continuously. When the dynamic responses are recorded as the system outputs, the system inputs (influent) can be mathematically obtained using the ASMs in an inverse manner. Using the method Nguyen *et al.* (2017) successfully demonstrated to obtain the ASM-based weekly-average influent concentrations from the analysis of activated sludge fractions (dynamic changes of heterotrophic/autotrophic biomass and unbiodegradable organic particulates during the 7 days) [28]. Unfortunately, their approach is not possible to estimate the hourly influent concentrations because the increment/decrement of the bacterial fractions within 1-hour are too small to be identified. However, when dynamic responses of dissolved oxygen concentration (DO) and nitrate concentration of the reactor are continuously monitored by using on-line sensors, these monitored state variables would provide us relevant information to back-calculate the influent oxygen demand. This is because the response, increment, decrement per time are electronically detectable even every 5 minutes. In this regard, since DO in the reactor is resulted from the microbial respiration in the reactor and the oxidation of the influent biodegradable materials, the active biomass concentration in the reactor and its biological kinetics must be also obtained by off-line analysis at laboratory. Nevertheless, this labour intensity is supposed to be negligible comparing to that to carry out the huge influent sampling/analysis campaign.

When the dataset of hourly influent concentrations is obtained, this dataset is statistically analysed to calculate the blower power for aeration. In definition, the design-daily-average is the mean value of the influent loading in 365 days (a year) whilst the design-daily-maximum is the highest loading occurring in the year [14]. Since the influent oxygen demand concentration is highly fluctuated even within a day, the design-daily-maximum for blower capacity may be interpreted from the instantaneous elevation of the load per hour (hourly influent loading). In this case, 365 data having the highest oxygen demand in the day must be statistically analysed to estimate the risk (probability) of the influent load that exceeds the blower capacity. Extreme Value Distribution (EVD) is the statistical distribution to express such extreme event [55]. Hence adopting the statistical distribution to analyse the back-calculated influent oxygen demand is thought to be relevant. In addition, the approach may enable to evaluate the impact of stormwater on the influent concentration, which is also one of essential scopes to design WWTPs in combined sewer system. At the beginning of rain, so-called first flush is supposed to bring high oxygen demand to the WWTP via runoff. To evaluate the occurrence of the high oxygen demand (= extreme events) caused by the first flush and/or hourly ~ daily maximum concentration of the influent, the measured datasets should be statistically analysed and properly interpreted to the plant design. Based on the above background, to check the feasibility of the above-mentioned alternative approach for blower capacity design, the field experiments were carried out in 3 distinct sites having inherent sewer system (two in Vietnam, one in Japan).

6.2. Materials and methods

6.2.1. Experimental and analytical approaches

As mentioned in the introduction section, the continuous operation of the field-test activated sludge reactor(s) equipped with DO and nitrate sensors was needed to estimate the dynamic change of influent oxygen demand (biodegradable substances) together with off-line batch analysis to measure the kinetics and biomass concentration in the reactors. The datasets obtained from the field experiments were dynamically analysed in the IWA-Activated Sludge Model #1 (ASM1) to perform the back-calculation for the influent characterisation [28, 56]. From the numerical calculation, the estimated concentrations of biodegradable substances were expressed in a discrete form (discrete concentration in every 1-hour). As the computed concentrations depended on the data density from the sensors (e.g. data logging at every 5-minute, 10-minute…), the impact of data density on the calculation was evaluated first in this study. Subsequently, the probabilities of the very high oxygen demand loading to the WWTPs was statistically analysed using EVD concept [57-60]. As the EVD concept was widely used in the field of reliability engineering, this method was thought to be also applicable to analyse the probabilities of the very high oxygen demand loading. Based on the statistical analysis, case studies (calculation examples) to design blower capacity treating the very high oxygen demand were carried out using a process simulator.

6.2.2. Field-test activated sludge reactors

a) System layout

A field-test module of activated sludge reactors with the structure is entirely identical to the module described in section 3.2 of Chapter 3 was installed and operated at the pumping station (South West PS3) located nearby the Vinh Niem WWTP in Hai Phong, Vietnam (Site #1: combined sewer system). After the field experiment for net 40 days excluding the star-up period for about 2 weeks, the unit was moved and operated at Chua Cau WWTP in Hoi An, Vietnam for net 30 days (Site #2, interceptor sewer system in the touristic area). The experiment was also conducted at Hiagari WWTP in Fukuoka, Japan for net 20 days (Site #3, separated sewer system (60%) + combined sewer system (40%)). The overall oxygen mass transfer coefficient, K_La was regularly measured in weekly basis as described in the later section. The DO concentrations in the aeration tanks were continuously monitored using a portable DO meter (Multi 3630 IDS) equipped with two independent fluorescent DO sensors (FDO 925) (WTW-Xylem Corp., Weilheim, Germany). In the same manner, the nitrate concentrations in the effluents were logged using a portable ion meter (LAQUAact D-73, Horiba Co. Ltd., Kyoto, Japan) equipped with two independent selective ion electrodes (LAQUA 6581S-10C, Horiba Co. Ltd., Kyoto, Japan).

b) Measurement of overall oxygen mass transfer coefficient, K_La

The sodium sulphite (Na_2SO_3) oxidation method was chosen to measure the K_La of the aeration tanks [47]. Before dosing the reductant (5~10 mmol/L) and Cobalt catalyst (0.005 mmol/L) to the aeration tanks, the influent feeding and the aeration were discontinued. After the DO concentration reached zero, the aeration was immediately turned on and the DO monitoring was initiated. Based on the elapsed time of aeration until DO detection, the K_La value was obtained using Equation (6.1). To calculate the oxygenation rate precisely, the oxygen uptake rate of the activated sludge was also measured. However the microbial oxygen uptake rate was only 2.3~4.9 % on the basis of the oxidation rate of sulphite (= $K_La \cdot C^*$) and thus negligible.

$$\frac{16}{80}\frac{m}{V \cdot \Delta t} = K_L a \cdot C^* \tag{6.1}$$

where:

C^* = air saturated DO concentration (mg-O_2/L/h)

K_La = overall oxygen mass transfer coefficient (h^{-1})

m = amount of sulphite dosed to the aeration tank (16/80 g-O_2 equivalent/g-sulphite)

V = working volume of the reactor (L)

Δt = elapsed time of aeration until detection of DO in the aeration tank (hour)

In reality the value of K_L would vary depending on the fluctuation of the influent α-factor [61-63] whereas the value of a could be almost fixed by fixing aeration intensity [26, 64]. Therefore, the calculated influent biodegradable concentrations by the DO analysis might be somewhat overestimated or underestimated according to the fluctuation of the α-factor. Nevertheless, as the aim of the measurement was to design blower capacity, it should be pronounced that the calculated influent concentrations using the method could be directly used for the purpose. Because the impact of α-factor on the oxygenation was already and internally included in the measurement as the apparent increment/decrement of the influent oxygen demand concentration. For instance, influent having low α-factor was expressed as an influent having high oxygen demand which required high blower capacity.

c) Operating conditions

The influent flowrate to each aeration tank was kept at 138 L/d to allow 4-hour of HRT of the aeration tank whilst the SRT was fixed to be 7 days. For the chemically enhanced primary settling tank, about 10 mg-Al/L of poly-aluminium chloride and 0.5 mg/L of anionic polymer solutions were dosed to the inflow on the basis of the influent flow rate. A small amount of NaOH solution (5 g/L) was also continuously fed to the aeration tanks to maintain the reactor pH between pH = 6.8~7.2. The air flow rate to the aeration tanks was carefully controlled whilst the water temperature in the aeration tanks varied between 20.0°C and 32.0°C during the experimental periods. The DO concentrations and the K_La values were varied during the experiments as shown in Table 6.1.

Table 6.1 DO concentrations and the reactor K_La during the filed experiments

Site #1	ASR#1 (with primary settler)	ASR#2 (without primary settler)
DO concentration of the aeration tank	3.8~6.6 mg-O_2/L	4.4~6.9 mg-O_2/L
K_La	380~508 d^{-1}	720~784 d^{-1}
Site #2	ASR#1 (with primary settler)	ASR#2 (without primary settler)
DO concentration of the aeration tank	4.9~6.9 mg-O_2/L	4.3~5.9 mg-O_2/L
K_La	483~491 d^{-1}	538~585 d^{-1}
Site #3	ASR#1 (with primary settler)	ASR#2 (without primary settler)

DO concentration of the aeration tank	3.3~7.7 mg-O_2/L	2.9~6.9 mg-O_2/L
K_La	158~366 d^{-1}	308~503 d^{-1}

6.2.3. Laboratory Analysis

The specific decay rate of heterotrophic and the specific growth rate of autotrophic organism together with their active biomass was estimated from the batch experiments using Equation (3.1) and Equation (3.2) mentioned in section 3.3 of Chapter 3.

6.2.4. Dynamic Estimation of Influent Constituents and Concentration

The DO concentration of the reactors and the nitrate concentration in the effluents were chosen as the target variables (the variables to fit to the data) according to Nguyen *et al.* (2019) [56]. The soluble biodegradable organics (S_B), soluble biodegradable nitrogen (S_{B_N}), particulate biodegradable organics (XC_B) and particulate biodegradable organic nitrogen ($XC_{B\_org,N}$) were also selected as the optimised variables of the influent (the regression variables to match the target variables of the data). The identified biomass state variables ($X_{OHO(0)}$ and $X_{ANO(0)}$) were input at the beginning of each day of the dynamic simulation. After this computational set up, focusing on the DO and nitrate concentrations of the ASRs, the hourly concentrations of the above influent biodegradable constituents were dynamically back-calculated. Specifically, the discrete concentrations of $S_{B(t)}$ and $S_{B\_N(t)}$ in 1 hour were obtained from the dynamic behaviours of DO and nitrate in ASR#1. By inputting these estimated influent state variables to the subsequent ASR#2 simulation, the discrete concentration of $XC_{B(t)}$ and $XC_{B\_org,N(t)}$ were obtained from ASR#2 receiving these suspended solid from the influent.

The dynamic estimation was performed using Dynamic Parameter Estimation tool (DPE) programmed in a commercial process simulator, GPS-X Version 7.0 (Hydromantis Inc., Hamilton, Ontario, Canada). For the DPE setting, time step (time length where the optimised variables were treated as constant values) was set at 1.0 hour meaning that the concentrations of the $S_{B(t),}$ $S_{NHx(t)}$, $XC_{B(t)}$ and $XC_{B\_org,N(t)}$ were discretised per hour (= discrete concentration in every 1-hour). In this study the data densities of the target variables (= logging interval of the sensors) were evaluated among every 5-minute per day (12 data per hour) and every 30-minute per day (2 data per hour). Maximum Likelihood method was chosen for the regression [56]. The total days of the influent analysis were 40-day for Site #1, 30-day for Site #2 and 20-day for Site #3 respectively.

6.2.5. Statistical analysis to design blower capacity

To perform the case studies to meet very high oxygen demand from the influents, a virtual WWTP was built on the process simulator.

Table 6.2 Operating conditions of the virtual wastewater treatment plant

Influent
Flow rate = 36,000 m^3/d
α-factor = 0.60
β-factor = 0.95

Operation
HRT = 6 hr
SRT = 10 d
DO = 1 mgO_2/L

Biological kinetic parameters
Maximum specific growth rate of heterotrophic organism $\mu_{max\_OHO} = 6.0\ d^{-1}$
Specific decay of heterotrophic organism $b_{OHO} = 0.62\ d^{-1}$
Maximum specific growth rate of autotrophic organism $\mu_{max\_ANO} = 0.8\ d^{-1}$
Specific decay of autotrophic nitrifying organism $b_{ANO} = 0.04\ d^{-1}$

Air supply system (diffused aeration)
Standard oxygen transfer efficiency = 30%
Diffuser depth from water level = 3.7 m
Diffuser density = 0.2
Diffuser head horizontal surface area = 0.038 m^2

As listed in Table 6.2, the virtual WWTP was modelled to receive the influent at 36,000 m^3/d of constant flow rate with the hourly discretised concentrations which were collected from the analysis of Site #1, Site #2 and Site #3 respectively. The virtual WWTP had a big blower controlled by a DO sensor allowing to manipulate the blower power (kW) in a dynamic manner to maintain 1 mg-O_2/L of DO in the aeration tank [65, 66]. In this way, the highest aeration (peak power consumption of the blower) lasting for one hour was identified in each day. Next, the value of hourly maximum power consumption in each day was ranked from the smallest to the largest over the days in each dataset based on EVD concept. From the statistical distribution of the hourly maximum power consumption of the blower, the required blower capacity to operate the WWTP without DO deficiency at least for 99 days out of 100 days was predicted. For simplification, both HRT and SRT of the virtual WWTP were fixed to be 6 hrs and 10 days respectively.

$$\begin{cases} -\left\{\ln\left[-\left(\ln F_{(x_i)}\right)\right]\right\} = -y_i = \dfrac{1}{\beta}x_i - \dfrac{\mu}{\beta} \\ MR_{(i)} = F_{(x_i)} = \dfrac{i}{i+(n+1-i)F_{2(n+1-i),2i,0.50}} \end{cases} \tag{6.2}$$

where:

$F_{(xi)}$ = median rank-based cumulative probability density function of EVD type I (%)

$2i$ = degrees of freedom (-)

$F_{2(n+1-i),2i,0.50}$ = the F-distribution at the 0.50 point (median) with 2(n+1–i) (%)

i = rank of x_i in the sample size n. (i = 1…n) (-)

$MR_{(i)}$ = median rank at the rank of i (%)

x_i = variable of the function (= hourly maximum blower power consumption within the day) (kW)

β = EVD scale parameter ($\beta > 0$) (kW)

μ = EVD location parameter (kW)

EVD type I (the Gumbel distribution for maxima case) was supposed to be relevant for the statistical analysis because this distribution was commonly used to predict extreme events/disasters such as flooding due to extreme rainfall [57, 58]. To cope with the limited number of the data which might result in scattered distribution in the order statistic, as shown in Equation (6.2), the median rank estimator, $MR_{(i)}$ [59, 60] which was widely used to analyse limited data (e.g. 20~40 data) was chosen. In this way the outliners which might exist in the limited data could be excluded from the analysis. The hourly maximum power consumptions of the blower were ranked in ascending order according to the order statistic of $MR_{(i)}$. Specifically, the EVD was expressed by plotting hourly maximum power consumptions of the blower (x_i) on X-coordinate and the estimated cumulative probability density function, $F_{(xi)}$ of EVD on Y-coordinate (mapped from the median rank estimator ($MR_{(i)}$)). Based on the double semilogarithmic X-Y graph, the probabilities of DO-maintaining failure (%) were calculated along with the blower capacities (net blower power, kW).

6.3. Results

6.3.1. Estimation of the hourly biodegradable substance concentration in the influents

a) Sensitivity of the data logging interval on the calculation results

Basically, the values of the estimated variables (= influent S_B, XC_B, S_{B_N} and $XC_{B\_org,N}$) were given from the dynamic regression to reproduce the target values of the dataset (= DO and nitrate concentrations) in the field-test reactors. Therefore, the values of the estimated influent concentrations should depend on the quality of dataset (variation due to analytical error and/or sensitivity of probe), which might be compensated with the data density (data logging interval per hour). To clarify this, the density of the logged DO and nitrate concentrations of ASR #1 was examined among every 30-minute, 20-minute, 15-minute, 10-minute and 5-minute. In this context, considering that the time step was fixed at 1 hour for the purpose of estimating hourly concentration of influent, the term of data density for optimization was defined as how much data plots of target variables that DPE used for the optimization at each time step. Consequently, five different cases data density for optimization was investigated, including 2 data/time step, 3 data/time step, 4 data/time step, 6 data/time step and 12 data/time step respectively. As shown in Figure 6.1, the calculated discrete values of the hourly influent concentrations for S_B and S_{NHx} of each examination were compared to those measured.

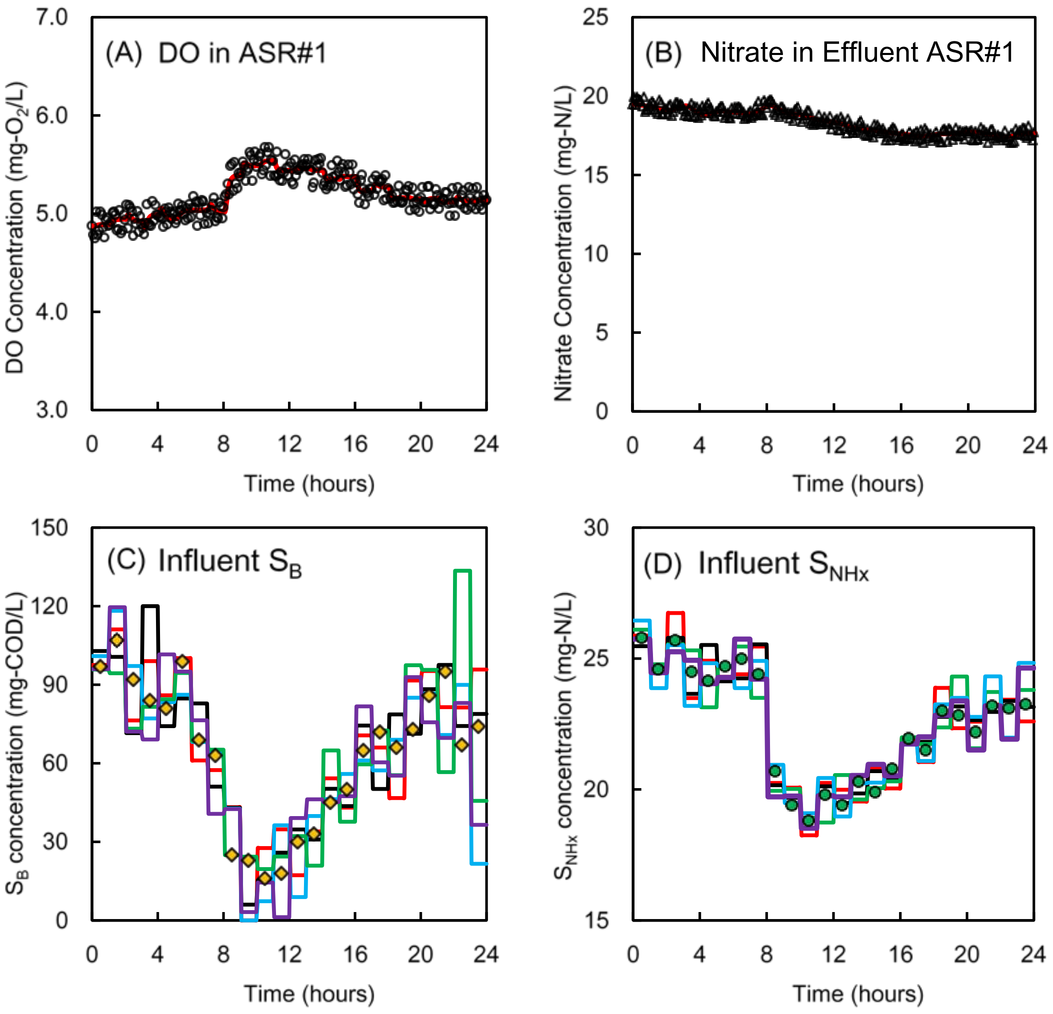

Figure 6.1 Example of 1-day dynamic estimation of ASR#1
(plot: measured; curve: simulation; black: 12 data/time step; red: 6 data/time step,
blue: 4 data/time step; green: 3 data/time step, purple: 2 data/time step)

From the datasets of DO and nitrate concentrations (Figure 6.1A and Figure 6.1B), it appeared that both estimated influent S$_B$ and S$_{NHx}$ concentrations were close to those measured, demonstrating that the back-calculation method developed in this study seemed to successfully estimate the biodegradable substance concentrations. Nevertheless, the calculated discrete values were not consistent over the examinations. In order to investigate which data density for optimization was relevant, as summarised in Table 6.3, Nash-Sutcliff model Efficiency coefficient (NSE = indicator to evaluate the created plots versus simulated data on $Y = X$ line) and Root Mean Square of Residuals (RMSR) were calculated respectively.

Table 6.3 Model fitness versus the logging intervals for DO and nitrate concentrations

	Nash-Sutcliff model Efficiency (NSE)				
	2 data/time step	3 data/time step	4 data/time step	6 data/time step	12 data/time step
Influent S$_B$	0.64	0.50	0.64	0.78	0.78
Influent S$_{NHx}$	0.93	0.89	0.89	0.91	0.94
	Root of Mean Squared Residuals (RMSR)				

	2 data/time step	3 data/time step	4 data/time step	6 data/time step	12 data/time step
Influent S_B	16.28	19.19	16.34	12.77	12.82
Influent S_{NHx}	0.58	0.70	0.70	0.64	0.54

As NSE = 1.0 indicated a perfect match between the model and the measured data whilst NSE = zero indicated that the model was as accurate as the mean of the dataset, the range of NSE indicating model sufficiency was supposed to be NSE ≥ 0.5 [41]. All NSE values obtained in this study were greater than or equal to 0.5 showing that the model (the back-calculation method) was reasonable. Recalling smaller RMSR value indicated better fit of the calculation to the measured data, it seemed that low data density for optimization (less than 4 data/time step) yielded slightly poor regression accuracy comparing to the high data density for optimization of 6 data/hr and 12 data/hr. Correspondingly an improvement of NSE was found when the data density for optimization was prolonged from 4 data/time step toward 12 data/time step. This suggested that about more than 6 data per discrete calculation (≥ 6 data/time step) was desired to attain relevant dynamic simulation. On the other hand, recalling that the time step was fixed at 1 hour, the more data density for optimization increased, the more data logging interval of target variables shortened. Due to mechanical limitation of sensors, the DO probe required at least 2~3 minutes to reach stable output signal whilst the nitrate probe also required 3~5 minutes [67, 68]. Hence very short data logging interval (e.g. every 1 minute) could result in wrong interpretation of the data. Considering this, 10-minute data logging interval was chosen in this study.

b) Hourly concentration of the influent biodegradable substances

To demonstrate the measured and calculated results for the hourly concentrations, an example of dataset of within-one-day dynamic simulation for the DO and nitrate concentrations was shown in Figure 6.2A-D, which were taken from the 40 datasets of Site #1. When DO concentrations were lowered (Figure 6.2A for ASR #1. Figure 6.2B for ASR #2), increased nitrate concentrations in the effluents was recognised in both ASR #1 (Figure 6.2C**)** and ASR #2 (Figure 6.2D). This indicated that the biodegradable nitrogen of the influent was one of the sources of the oxygen demand. As shown in Figure 6.2E-H, The sinusoidal patterns for both influent S_B and S_{NHx} were found where the concentrations were lowered in early morning at around 04:00 and in evening at around 20:00 (Figure 6.2E for S_B, Figure 6.2F for S_{B_N}). Similarly the influent biodegradable particulate fractions expressed as XC_B and $XC_{B\_org,N}$ seemed to be also lowered at around 04:00 and at around 20:00 (Figure 6.2G for XC_B, Figure 6.2H for $XC_{B\_org,N}$). The biodegradable organic fractions of the influent were ranged between 87~150 mg-COD/L for soluble material (S_B) and 1.0~90 mg-COD/L for particulate material (XC_B) respectively. For the influent biodegradable nitrogen, the soluble form (S_{B_N}) was ranged between 17.0~21.3 mg-N/L whilst the concentration of particulate form ($XC_{B\_org,N}$) was relatively low and estimated to be around 1.0~8.0 mg-N/L only. In general, the occurrence of particulate nitrogen seemed to be associated with those of particulate organics and the soluble organics.

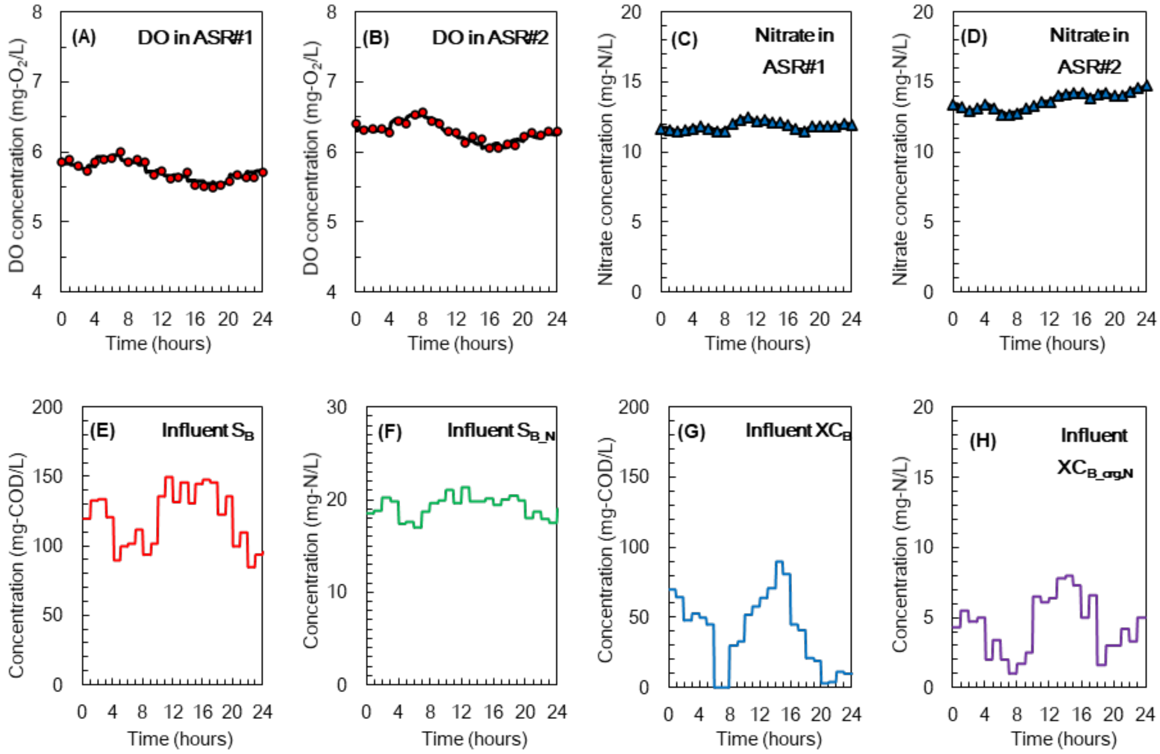

Figure 6.2 An example of 1-day dynamic estimation of the hourly concentration of the influent compositions from the fluctuation of the DO concentration and the nitrate concentration in the field-test reactors at Site #1 (circle: measured DO concentration; triangle: measured nitrate concentration; black curve: simulation)

With respect to the other datasets collected in the different days (total 40 datasets), the fluctuations of the influent biodegradable constituents were almost comparable to the above graphs (figures not shown). Overall, the hourly discrete concentration of the biodegradable substances peaked at around 14:00~20:00 and lowered in midnight/ early morning. From the datasets, the daily maximum and daily average concentrations of the biodegradable organics (S_B, XC_B) and biodegradable nitrogen (S_{NHx}, $XC_{B\_org,N}$) were summarised in box-whisker plots as shown in Figure 6.3. The mean values for S_B fraction of the daily maximum and the daily average were 91 mg-COD/L and 42 mg-COD/L respectively whilst those of XC_B fraction were 85 mg-COD/L and 32 mg-COD/L respectively. Both S_B fraction and XC_B fraction of the daily maximum were about 2~3 times higher than those of daily average. With respect to the biodegradable nitrogen, the mean values for S_{NHx} and $XC_{B\_org,N}$ of the daily maximum were obtained to be 12.7 mg-N/L and 9.6 mg-N/L respectively which were as high as about 1.3 time of the daily average (S_{NHx} = 9.7 mg-N/L, $XC_{B\_org,N}$ = 5.7 mg-N/L).

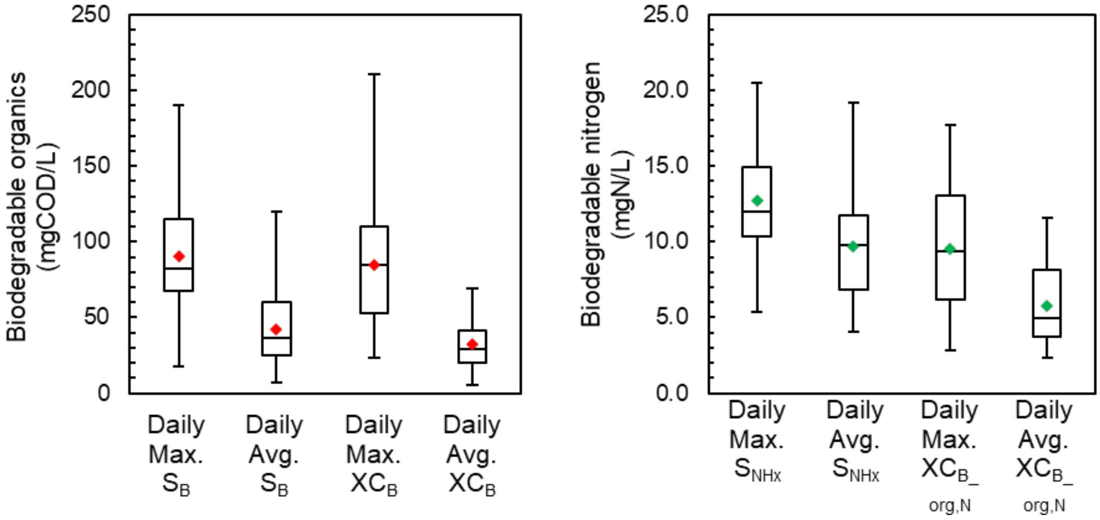

Figure 6.3 The box plot charts of the influent biodegradable constituents at Site #1 (left: biodegradable organics; right: biodegradable nitrogen; plot: mean value; 40 data)

In Site #2, the 30 datasets showed that the biodegradable substances in the influent peaked in midnight (00:00~04:00) and the concentrations were lowered during morning (08:00~12:00) (figures not shown). This was because the site was in the touristic area where restaurants and resort services were active from evening. Site #3 where 20 datasets were obtained demonstrated that the peak of biodegradable substances in the influent took place during 16:00~24:00 whilst the concentrations were reduced during 08:00~12:00 (figures not shown). To compare the influent constituents over the 3 experimental sites, the box-whisker graphs were created as shown in Figure 6.4. For the total biodegradable organic fractions (S_B + XC_B), the composite concentrations of Site #1 and Site #2 were noticeably lower than those obtained from Site #3 in both daily maximum and daily average. This was because the wastewaters of Site #1 and Site #2 were collected in Vietnam where the part of influent biodegradable organics were already decomposed in the septic tanks. On the other hand, the total biodegradable nitrogen (S_{NHx} + $XC_{B\_org,N}$) of Site #2 were comparable to that of Site #3 whilst Site #1 showed the lowest concentration. Since the Site #2 wastewater was collected from the interceptor sewer where the dilution of wastewater by runoff and/or infiltration water to sewer was limited, the nitrogenous concentration was close to the Site #3 wastewater which was the mixture from the separated sewer and the combined sewer. As the Site #1 wastewater was collected from the combined sewer, the low nitrogenous concentration was reasonable. From the total biodegradable nitrogen concentrations between the Site #1 wastewater and the Site #2, it seemed that the Site #1 wastewater from the habitants was diluted by about twice by the runoff and/or the infiltration water.

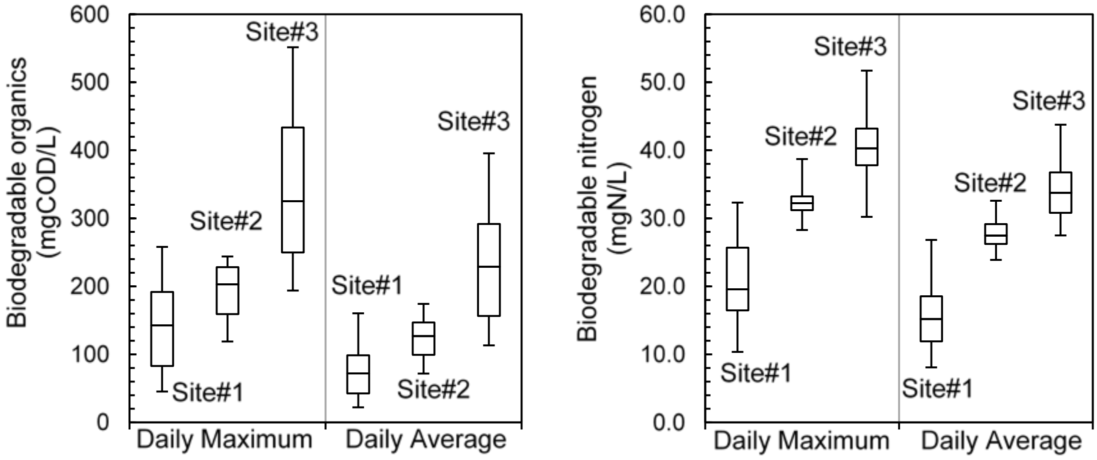

Figure 6.4 The box plot charts of the influent biodegradable organics and nitrogen at three WWTPs (left: biodegradable organics; right: biodegradable nitrogen)

Recalling that 1 mg-N of biodegradable nitrogen required 4.57 mg-O_2/L for nitrification, the overall oxygen demand concentration (= (S_B+XC_B) + 4.57(S_{NHx}+$XC_{B\_org,N}$)) were also roughly calculated. Assuming that the sinusoidal curves of the 4 state variables were synchronised with each other in a day (from Figure 6.2E-H) and the peak of the overall oxygen demand concentration was expressed as the mean of the daily maximum, Site #1 had about 278 mg-O_2/L of the oxygen demand whilst Site #2 and Site #3 had 402 mgO_2/L and 592 mg-O_2/L respectively. Since these concentrations were scattered over the 3 sites, use of default values for oxygen demand might not be an attractive option to perform precise plant design, unlike the research by Schraa *et al.* (2017). Indeed, the ratio of the maximum value of the daily maximum to the mean value of the daily average were also distinct over the three sites. The ratios were 1.64 for Site #1, 1.37 Site #2 and 1.38 for Site #3, and not consistent with each other. Similarly, the ratio of nitrogenous oxygen demand fraction to the carbonaceous oxygen demand fraction in the mean of daily maximum were also inconsistent with each other (0.65 for Site #1, 0.76 for Site #2 and 0.54 for Site #3). These scatted results might affect the plant design for nitrification/denitrification processes as well as determination of blower capacity.

As summarised in Table 6.4**,** traditional water quality indices of $CBOD_5$ (soluble), $CBOD_5$ (total), ammonium-N and biodegradable Kjeldahl-N were interpreted from the influent state variables of S_B, XC_B, S_{NHx} and $XC_{B\_org,N}$ [28]. These concentrations measured in Site #1 and Site #2 were consistent with the literature which were obtained from surveys of a couple of WWTPs in Vietnam [6]. For Site #3, the mean daily average concentrations were also similar to those reported by Kumokawa *et al.* (2019) [69].

Table 6.4 Influent characterisation of the three experimental sites

Unit: S_B, XC_B, Soluble $CBOD_5$, Total $CBOD_5$: mg-COD/L; S_{NHx}, $XC_{B\_org,N}$, Ammonium-N, Biodegradable Kjeldahl-N: mg-N/L

	S_B	S_{NHx}	XC_B	$XC_{B\_org,N}$	Soluble $CBOD_5$	Total $CBOD_5$	Ammonium-N	Biodegradable Kjeldahl-N
				Site #1				
Daily maximum (Mean value)	18~190 (91)	5.4~20.5 (12.7)	25~211 (85)	3.1~17.7 (9.6)	13~136 (65)	29~168 (94)	5.4~20.5 (12.7)	10.4~32.3 (20.5)
Daily average (Mean value)	7~120 (42)	4.0~19.2 (9.7)	5~69 (32)	2.3~11.5 (5.7)	5~86 (30)	15~109 (49)	4.0~19.2 (9.7)	8.1~26.8 (15.5)
				Site #2				
Daily maximum (Mean value)	75~153 (110)	16.9~31.6 (24.0)	64~176 (124)	5.8~17.7 (10.7)	54~110 (79)	80~157 (125)	16.9~31.6 (24.0)	28.3~38.7 (32.5)
Daily average (Mean value)	33~87 (56)	14.5~28.0 (20.6)	33~97 (68)	3.2~13.2 (7.1)	24~63 (40)	47~113 (79)	14.5~28.0 (20.6)	23.9~32.6 (27.7)
				Site #3				
Daily maximum (Mean value)	99~408 (211)	20.2~38.0 (27.5)	56~318 (181)	10.2~23.4 (16.3)	71~293 (151)	134~352 (224)	20.2~38.0 (27.5)	30.2~51.7 (40.7)
Daily average (Mean value)	45~312 (130)	18.2~33.3 (22.8)	21~233 (98)	6.7~18.6 (11.0)	32~224 (93)	77~252 (150)	18.2~33.3 (22.8)	27.5~43.8 (33.9)

Where, soluble $CBOD_5 = 0.717S_B$; total $CBOD_5 = 0.717S_B + 0.58XC_B$ [12]

6.3.2. Statistical analysis to estimate required blower capacity

The calculated influent datasets collected from each site were further classified into 2 kinds of sub-groups for dry weather and wet weather respectively. Except for the wet weather of Site #2 where the number of datasets was only four, each sub-group dataset was combined in each site to create artificial consecutive days of operation. From this, total 5 artificial consecutive datasets were made (= A1, A2, B1, C1 and C2). Using these artificial influent loadings, blower power to maintain 1 mg-O_2/L in the aeration tank of the virtual WWTP was dynamically calculated in each day as shown in Figure 6.5. By extracting the maximum blower power in each day, the values of the maximum blower power were analysed using EVD type I.

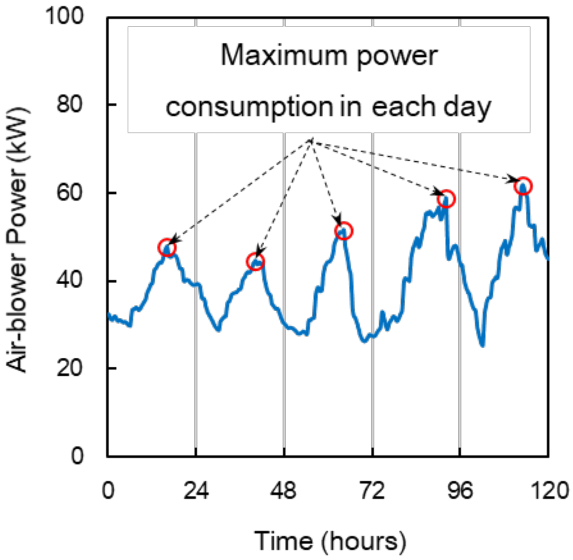

Figure 6.5 Example of blower power during the artificial consecutive days in the virtual WWTP

As shown in Figure 6.6, the data over the five artificial datasets were almost linearly plotted with EVD type I. The Y1-axis was the cumulative density function of EVD, $F_{(x)}$ (probability of successful operation) whist the Y2-axis was its inverse (= probability of operational failure (once per days of the plant operation = DO maintaining failure for 1 hour per days of the plant operation). During the data plotting, some data were supposed to be the outliners in the order statistic of the median-rank estimator (e.g. Y1-coordinate = 0.96 in Figure 6.6A1). Nevertheless, in overall, the required blower capacity to meet the daily maximum influent concentration was thought to be expressed as EVD.

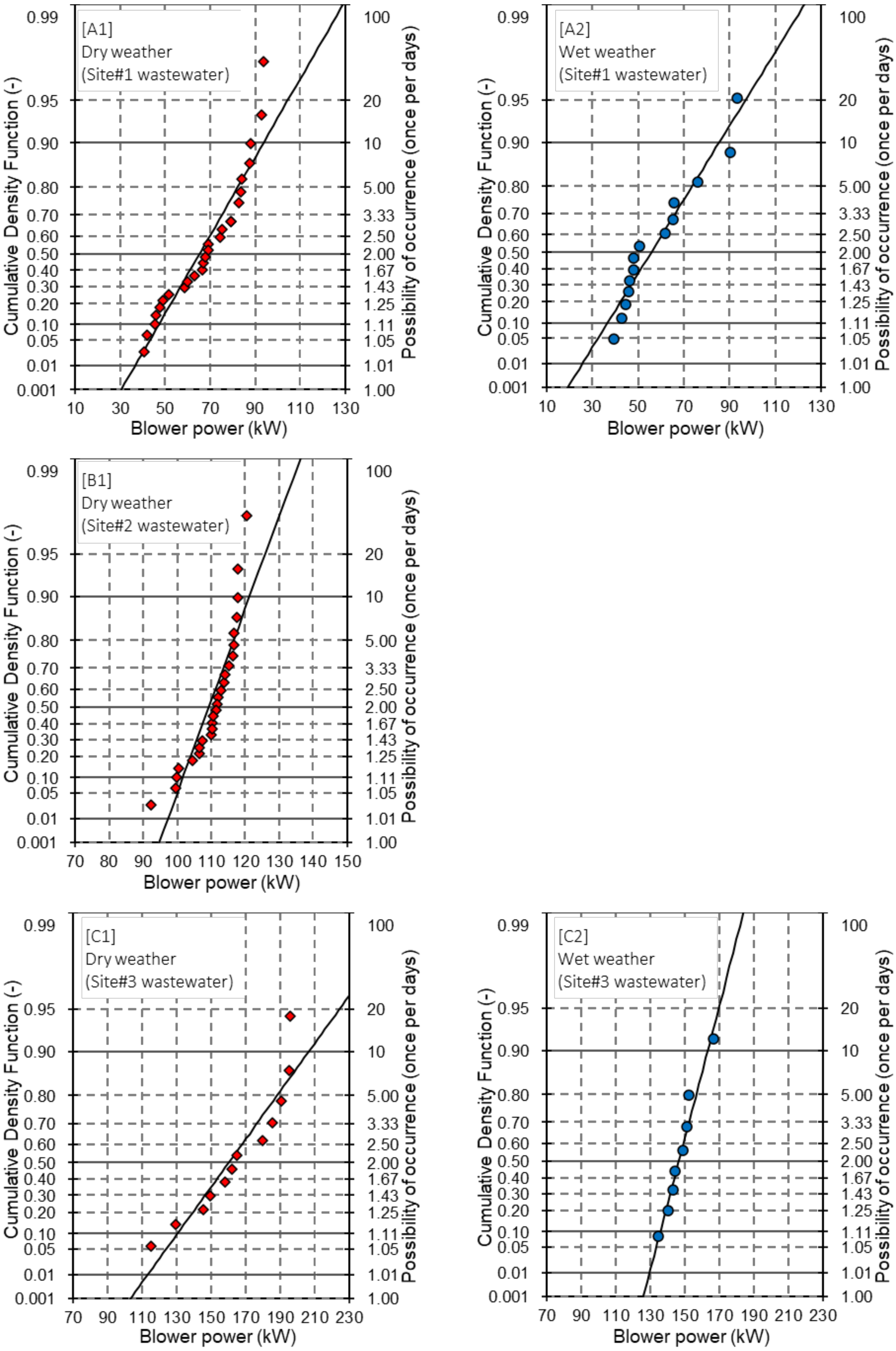

Figure 6.6 Prediction of the required air blower power to maintain 1 mg-O_2/L of DO in the aeration tank against the peak loading events (left: for dry weather; right: wet weather)

When the virtual WWTP received the Site #1 wastewater in dry weather (Figure 6.6A1), installation of blower having 127 kW of working power could maintain the aeration tank without 1-hour DO deficiency for 99 days out of 100 days of the plant operation (probability of successful operation = 0.99). In other word, the plant operator might face the aeration shortage once per 100 days of operation. On the other hand, when the plant designer placed 93 kW-blower in the aeration tank, the WWTP was supposed to face the DO deficiency almost every 10 days (probability of successful operation = 0.90). Even dry weather, the required blower capacity was distinct over the 3 kinds of wastewater. The virtual plant receiving the Site #2 wastewater required slightly higher blower capacity than that receiving the Site #1 wastewater (Figure 6.6B1). In case that the plant designer designed the blower capacity to meet the probability of successful operation = 0.99, the required blower power was estimated to be 136 kW. With respect to the Site #3 wastewater (Figure 6.6C1), about 265 kW of power was needed. The slopes of the EVD lines (EVD scale parameter) were also distinct over the wastewaters. The highest slope was found in Figure 6.6B1 and the lowest slope was recognised in Figure 6.6C1, respectively. Since high slope indicated low fluctuation of the daily maximum oxygen demand concentration in the wastewater treatment, the constituents of the Site #2 wastewater were supposed to be rather stable comparing to the others whereas the oxygen demand concentrations of the Site #3 wastewater highly varied. In fact, the range between 75-percentile and 25%-percentile for Site #2 previously shown in Figure 6.4 was the narrowest among the 3 sites for both daily average and daily maximum, and for both organic and nitrogen. These suggested that the plant designer should consider highly controllable blower (e.g. inverter driven induction motor) for the Site #3 wastewater treatment that might receive highly fluctuated oxygen demand from the influent.

Comparing the EVD lines of dry weather to those of wet weather, it appeared that the 2 weather conditions provided almost identical oxygen demand concentration in the Site #1 wastewater (Figure 6.6A1 vs. Figure 6.6A2). This indicated that the sudden elevation of oxygen demand concentration from the first flush in the sewer was comparable to that occurring in dry weather. Because of the combined sewer system, the elevation of wastewater flow rate was expected during wet weather for Site #1. In this case the plant designer might simply design the blower capacity in proportion to the design-daily-average flow rate. For the Site #3 wastewater, the required blower capacity during wet weather was estimated to be 184 kW which was lowered by about 30% comparing to that during dry weather (Figure 6.6C1 vs. Figure 6.6C2). This low blower power per influent volume suggested that the first flush of Site #3 sewer was considerably diluted by the runoff. In this case, first of all, the plant designer should calculate the product of the oxygen demand concentration of the influent and the inflow rate for both dry weather and wet weather conditions. Based on this, proper blower capacity could be selected by a bigger one of the two.

From the above experimental results and mathematical analysis, the required blower power to maintain 1 mgO$_2$/L of DO in the aeration tank of the virtual WWTP was summarised in Table 6.5. In general, the required blower powers under the daily maximum oxygen demand concentration were as high as about twice of those of daily dry weather (= 1.4~2.5 times). Apart from the increment of oxygen demand loading from the increased inflow rate due to runoff, the blower power per influent flow rate could be the basis to determine the blower capacity. In addition, the blower power under daily average concentration provided a technical information to the plant designer for the mean electricity cost of aeration over the year. Furthermore, the increment of the blower power between the daily average concentration and the daily maximum concentration could be the design basis to determine the number of motors and installation of inverter controls, which allowed a flexibility of aeration intensity. For instance, when a project was given to the plant designer to design the WWTP treating the Site #1 wastewater with fixed inflow rate, he might install primary blowers having total 58-kW working power to meet the daily average load and a couple of secondary small blowers having total 70-kW working power to treat the increment from the daily maximum.

Table 6.5 Required blower power to maintain 1 mgO_2/L of DO in the aeration tank of the virtual WWTP

Wastewater type	Flow rate: 36,000 m^3/d	Daily average concentration	Daily maximum concentration (Successful operation of 99 days out of 100 days)
Site #1	Dry weather	58 kW	127 kW
	Wet weather	50 kW	123 kW
Site #2	Dry weather	100 kW	136 kW
	Wet weather	Not calculated	Not calculated
Site #3	Dry weather	146 kW	265 kW
	Wet weather	135 kW	184 kW

6.4. Discussion

The back-calculation method integrated with the statistical analysis using EVD was thought to be a powerful tool to characterise influent biodegradable substance concentrations and to estimate the blower capacity of WWTPs. The calculated influent oxygen demand concentration could be one of the attractive databases for the plant design. When the flow pattern of wastewater to the WWTP was measured together with the influent characterisation, the product of the influent flow rate and the influent oxygen demand concentration could be further analysed in such way that the study demonstrated.

In practice, the plant designer might prefer to know the probability of occurrence per prolonged days of plant operation rather than per lowered days. For instance, risk of aeration shortage at every 100 days rather than every 20 days. To attain the task, more dense statistical analysis was necessary to improve the prediction accuracy at around 0.95~0.99 of probability on the EVD plot. Specifically, the number of data plot for the daily maximum should be increased according to the median-rank estimator, $MR_{(i)}$. In case of using the median-estimator shown in Equation (6.2), the required number of the field data was at least 14 to plot $F(x_i)$ on 0.95 of Y-coordinate and 69 to plot $F(x_i)$ on 0.99 of Y-coordinate respectively. This meant that the field test should be operated for more than 2 months to obtain the EVD plot having the $F(x_i)$ on 0.99 of Y-coordinate. On the other hand, the plant designer was also supposed to identify design-daily-average in the project, which was defined as the value throughout a year. Hence the operation and analysis should last for a year in the project anyway. As the conventional campaign to conduct numerous sampling and analysis of the influent was clearly infeasible because of huge manpower, the method developed in this study was supposed to be the only way to obtain exact value of design-daily-maximum loadings. Since the study successfully demonstrated to continue the continuous analysis for a couple of months, extension of the duration to 1 year would be technically feasible.

With respect to the first flush phenomena, the impact of the pollutant loading on WWTPs was supposed to be highly site specific [70]. Indeed, the daily maximum oxygen demand concentrations noticeably varied over the 3 sites in this study. Therefore, precise evaluation and analysis of the influent was essential to design WWTPs. According to Chow and Yusop (2014) [71], when they investigated the first flush phenomena, they were obliged to squeeze the sites to those neighbouring their laboratory because the fresh sample had to be analysed no sooner than the initiation of storm. On the other hand, the developed method in this study was free from the limitation of site selections. This was because the method did not require to analyse such readily biodegradable influent substances which could be collapsed within a couple of days of delivering time. Although they could monitor total 52 storm events with each 12-grab sample, such data volume and site selection would be the utmost for any laboratories as long as the conventional method was taken.

6.5. Conclusions

From the analysis of biodegradable substance concentration of the wastewater at three sites, the following conclusions were obtained in this study.

(1) The data density for optimization when configuring DPE somewhat affected the calculation results of the influent biodegradable substance concentrations. To estimate the hourly concentration of the influent with reasonable accuracy, the logging interval of DO and nitrate concentrations in the aeration tank of the field experimental unit was recommended to set at 10 minutes with the time step fixed at 1 hour (data density for optimization = 6 data/time step).

(2) The biodegradable organics and nitrogen concentrations of the wastewaters were successfully estimated as 1-hour discrete concentrations in both dry and wet weather flows. From the datasets, daily maximum expressed as the highest 1-hour discrete concentration in each day as well as daily average. The study demonstrated that developed method was able to obtain the daily maximum concentration with minimum manpower, which was thought to be technically very difficult to be measured until present.

(3) Using EVD and the median-rank estimator, the blower power versus the probability of oxygenation shortage was simulated on the virtual wastewater treatment plant in the computer. Based on the ASM1, the required blower power per influent flow rate to meet the daily maximum influent oxygen demand was as high as 1.4~2.2 times than those of the blower calculated from the daily average.

(4) The blower capacity per influent volume in wet weather for Hiagari sewage (Japan) was lower than that in dry weather probably due to dilution of the wastewater by runoff. For Vinh Niem sewage (Vietnam), the increase of the influent oxygen demand in wet weather was supposed to be associated with the increased sewage flow rate.

CHAPTER 7. COMPARATIVE ANALYSIS FOR CONFIGURATION OF DYNAMIC PARAMETER ESTIMATION TO ESTIMATE HOURLY CONCENTRATION OF INFLUENT BIODEGRADABLE COMPOSITIONS

7.1. Introduction

Process optimization is the discipline of adjusting a process so as to optimize (make the best or most effective use of) some specified set of parameters without violating some constraint. The most common goals are minimizing cost and maximizing throughput and/or efficiency. When optimizing a process, the goal is to maximize one or more of the process specifications, while keeping all others within their constraints. In the field of water/wastewater treatment design, process optimization can reduce the occurrence of problems, protects the environment, ensures regulatory compliance, and saves the operational cost.

GPS-X is a powerful process simulator developed by Hydromantic Inc., and widely used for the mathematical modelling, simulation, and management of wastewater treatment plants. Besides, the software also provides an interesting module namely Optimizer to estimate the values of parameters from the process layout in order to obtain the calibration or verification of model. Model calibration, also known as parameter estimation, is defined as the process of adjusting model parameters such that the difference between observed and simulated results is minimized. With many of the dynamic models used in GPS-X, most of the model parameters are assumed to be constant over the entire calibration period. For example, the clarifier's flocculent zone settling parameter is normally set to one specific value for the entire simulation. One reason for doing so is that it is difficult to determine or identify the changes in this parameter over time since it is difficult to measure on-line. The best the modeler can do is assume that the parameter does not change over the simulation period, and therefore use only one value to fit the target or measured data. A more rigorous approach, however, might be to try to fit the measured data by varying the parameter over the simulation period. This has two advantages: a better agreement between the model and data, and an indicator of the dynamic response of the parameter. In this context, Optimizer is intentionally programmed to actualize the approach.

The optimizer can be used to fit a model to measured data or to optimize process performance. The procedure of fitting a model to measured data is called "parameter estimation" and involves adjusting selected model parameters to achieve the best possible fit between the model responses and the measured data, which is identified by a maximization or minimization of a specific objective function. In addition, the term of process optimization involves adjusting certain model parameters to maximize or minimize the value of a model variable. In this regard, the optimizer module was developed specifically to solve both parameter estimation and process optimization problems involving dynamic wastewater treatment models. It can be used for both steady-state and dynamic optimization. The optimizer module is equipped to handle three different types of process measurements: Time series measurements, Long term operational data that are averages of the original process measurements, and On-line measurements. Each type of measurement set leads to a different type of optimization problem. The optimization problem types available in GPS-X are Time Series and DPE.

∗ *Time Series Optimization*

This optimization type is the one normally used for both parameter estimation and process optimization. For parameter estimation involving a dynamic model, normally the measured data will be the values for each of the response variables desired to fit at a series of time values. The response variables are referred to as target variables. GPS-X using one of the five objective functions depending on user selection for fitting model response to the measured data. The five objective functions provided by GPS-X are Absolute Difference, Relative Difference, Sum of Squares, Relative Sum of Squares and Maximum Likelihood.

∗ *Dynamic Parameter Estimation (DPE)*

GPS-X has a sophisticated dynamic parameter estimation feature (DPE) designed for the estimation of time-varying parameters. It can be used with on-line data or off-line time series data. The motivation behind DPE is that parameters in process models are often not constant, but vary with time. In GPS-X dynamic parameter estimation is done by applying the time series optimization approach mentioned earlier to a moving time window (time step). Instead of estimating parameters from an entire set of data, GPS-X calculates a set of parameter estimates for each time window using the parameter estimates from the previous time step as a starting guess. The length of the time step controls how often the parameters are updated. The shorter the time window, the more often the parameters are updated.

The feasibility of DPE integrated with ASM-based back-calculation in characterizing the hourly concentration of influent biodegradable constituents was proved in Chapter 5 and Chapter 6. Nevertheless, it was realized from the above backgrounds that the estimated results might be affected by several setting parameters of optimization tool DPE including objective function and time step. Moreover, the influence of target variables density was also confirmed in Chapter 6. Thus, the interaction between these three factors and their impact to the optimization results are investigated and discussed thoroughly in this Chapter.

7.2. Materials and methods

∗ *The length of time step of numerical integration*

In definition, time step of numerical integration (TSNI) expresses how often output data is plotted as well as model responses are updated with the values of input data. According to Hydromantis (2017), in order to ensure proper termination of the back-calculation routine, the DPE time step and the TSNI were chosen such that the DPE time step was an integer multiple of the TSNI. Thus, to elaborate the hypothesis that the length of TSNI affects the quality of the estimated results of optimized variables, the DPE time step was fixed at 1 hour whilst the TSNI was variedly set at 1.5, 3.0, 6.0, 12, 30 and 60 minutes; whereby the estimated results of optimized variables in each setting up of TSNI were compared.

∗ *The types of objective function*

Because 10-minute interval of data logging (data density = 6 data per each hour) was recommended to estimate hourly concentration of influent biodegradable constituents in Chapter 6, the dataset of 1-day dynamic simulation of ASR#1 influent in the case study of 10-minute interval of data logging (Figure 6.1 in sub-section 6.3.1) was selected to firstly examine the influence of objective function to estimated results. The time step was still set at 1 hour while the communication interval was set at 5 minutes. The value of Parameter Tolerance (= 1.0×10^{-6}) and the maximum number of optimizer iterations (= 200) was set exactly same as the description in sub-section 5.2.4. The fitness between model response and measured datasets in each case of all five objective functions (Absolute Difference, Relative Difference, Sum of

Squares, Relative Sum of Squares and Maximum Likelihood) was compared to elucidate the influence of objective function to estimation quality.

Basically, the difference among these five objective functions is mainly the manner how predicted results from model and measured results from experiments are compared. In more detail, the equations of the five objective functions are expressed below.

Absolute Difference

$$F = \sum_{j=1}^{m} \sum_{i=1}^{n_j} \left| z_{i,j} - f_{i,j} \right| \tag{7.1}$$

Relative Difference

$$F = \sum_{j=1}^{m} \sum_{i=1}^{n_j} \left| \frac{z_{i,j} - f_{i,j}}{z_{i,j}} \right| \tag{7.2}$$

Sum of Squares

$$F = \sum_{j=1}^{m} \sum_{i=1}^{n_j} \left(z_{i,j} - f_{i,j} \right)^2 \tag{7.3}$$

Relative Sum of Squares

$$F = \sum_{j=1}^{m} \sum_{i=1}^{n_j} \left(\frac{z_{i,j} - f_{i,j}}{z_{i,j}} \right)^2 \tag{7.4}$$

Maximum Likelihood

$$F = \frac{1}{2} \sum_{j=1}^{m} \left[n_j \left(\ln\left(2\pi\right) + 1 \right) + n_j \ln \left(\frac{1}{n_j} \sum_{i=1}^{n_j} \frac{\left(z_{i,j} - f_{i,j} \right)^2}{f_{i,j}^{\gamma_j}} \right) + \gamma_j \sum_{i=1}^{n_j} \ln f_{i,j} \right] \tag{7.5}$$

where:

$z_{i,j}$ = the measured value of response variable *j* in experiment *i*

$f_{i,j}$ = the value of response variable *j* predicted by the model in experiment *i*

γ_j = the heteroscedasticity parameter for response variable *j*

m = the number of measured response variables

n_j = the number of experiments (i.e. observations) for response *j*

It might be somewhat confused that Maximum Likelihood or Maximum Likelihood Estimation is widely known as a method of estimating the parameters of an assumed probability distribution, given some observed data. The parameters estimation is achieved by maximizing a likelihood function so that, under the assumed statistical model, the observed data is most probable. In this context, the reason Hydromantis Inc. names one of the objective functions in GPS-X same as that statistical estimation method is because it uses the likelihood and log-likelihood function for the comparison between model predicted and measured results (experimental error). It must be noted that the form of the likelihood function depends on the structure of the assumed probability distribution of experimental error. In this regard, GPS-X assumes that the experimental errors are normally distributed random variables with a mean of zero. In addition, GPS-X also assumes that the measurement errors are independent from observation to observation and from response variable to response variable. Hence, the Equation (7.5) was slightly customized based on the log-likelihood function of normal distribution.

∗ *The length of time step versus data density*

The dataset of 1-day dynamic simulation of ASR#1 influent in the case study of 10-minute data-logging interval (Figure 6.1 in sub-section 6.3.1) is repeatedly used to examine the influence of DPE time step to estimated results. As mentioned previously, the data density for optimization when configuring DPE somewhat affected the calculation results of the influent biodegradable substance concentrations. In Chapter 6, the variation of data density for optimization was created by fixing the time step (1 hour) whilst the data logging interval of target variables gradually changed from 5 to 60 minutes. On the contrary, the alteration of data density for optimization also can be formed by fixing data logging interval of target variables whilst the time step varied correspondingly. Additionally, it is uncertain that whether changing the time step might affects the estimation results. In this regard, the DPE time step was varied from 10 minutes, 30 minutes, 1 hour, 2 hours and 3 hours for the comparison while the data logging interval was still fixed at 10 minutes. The TSNI was set at 10 minutes and the Maximum Likelihood objective function was selected for the setting parameter estimation. The value of Parameter Tolerance and the maximum number of optimizer iterations was still kept at 1.0×10^{-6} and 200, respectively. In both case of objective function and time step analysis, the goodness-of-fit statistics was used to assess the quality for each estimation.

7.3. Results and discussion

7.3.1. The effect of time step of numerical integration on estimated results of influent biodegradable concentrations

As shown in Figure 7.1, the obtained results indicated that there was mostly no significant difference of estimated results among the case of TSNI = 3.0 minutes, 6.0 minutes, 12 minutes, and 30 minutes. For the case of TSNI = 1.5 minutes, there was a very soon appearance of overestimation in the S_B concentration during the period from 6h00 to 12h00 followed by a series of fixed values (S_B = 45 mg-COD/L) during the later stage. Although the exact reason to explain for this response was not clear, it might be attributed to the too short calculation frequency in conjunction with no provision of data within each of the 1-hour interval. Despite the data of influent S_B concentration attained in the case of TSNI = 60 minutes demonstrated a slight difference comparing to measured data, this was acceptable due to the capability of matching the overall trend of the fluctuation in concentration. Similarly, in case of the S_{NHx} concentration, the result collected from the case of TSNI = 1.5 minutes again demonstrated an appearance of unchanged values (S_{NHx} = 13.3 mg-N/L) during the later period (from 13h00 to 24h00). Although this result revealed a reasonable matching of calculated concentrations to those measured during the initial stage (from 0h00 to 12h00), most of the calculated concentrations were overestimated. A slight difference of estimated S_{NHx} concentration obtained from the case of TSNI = 60 minutes to measured dataset was also recognized.

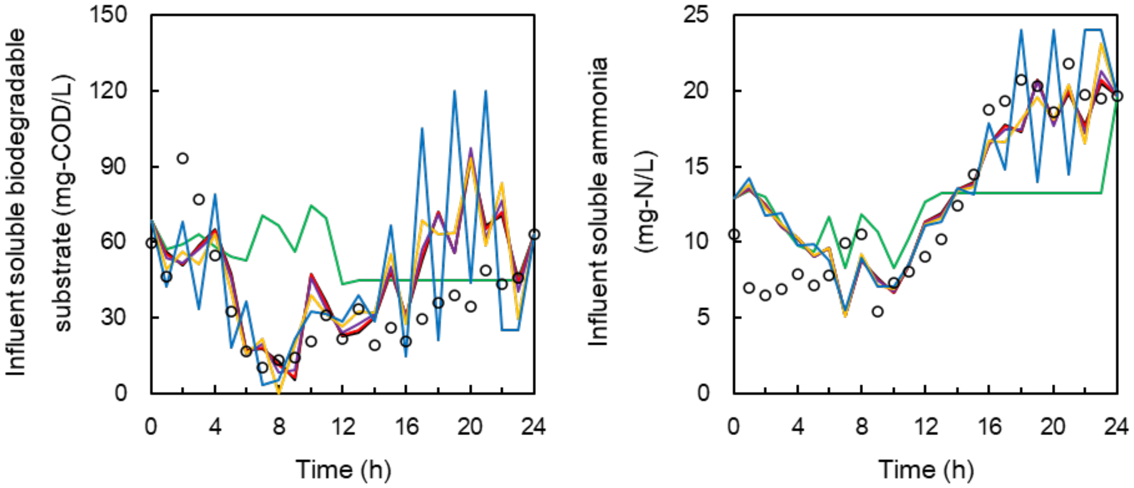

Figure 7.1 The comparable results obtained from each differentiated scenario of the estimation

To clarify the mismatch between estimated and measured results in each setting of TSNI, hourly calculated concentrations from each case of setting TSNI were respectively compared to measured data based on the mean difference percentage attained from each singular difference. As shown in Figure 7.2, the lowest TSNI (1.5 minutes) resulted in the highest difference for both S_B (106%) and S_{NHx} (37%) whilst there was no significant difference between calculated and measured concentrations data under the setting of TSNI = 3.0, 6.0 and 12 minute respectively (the difference percentage ranged from 47% to 49% for S_B and ranged from 23% to 24% for S_{NHx}). It was noted that when the low value of TSNI was set, the calculation speed was lowered consequently. For instance, in case of TSNI was set at 3.0 minutes with the time step fixed at 1 hour, it was obviously realized that 20 numerical integrations per each pair of data plot have to be performed. However, when the TSNI was half decreased (1.5 minutes) and the time step still was fixed (1 hour), the number of numerical integrations performed per each pair of data plot was double resulting in lowered calculation speed. It was obvious that the more frequency of data updating obtained from the decrement of TSNI reasonably deteriorated the calculation process in terms of both time consuming and accuracy. From this analysis, the TSNI should be set in the range of 5 - 10 times less than the time step but not lower than 3.0 minute.

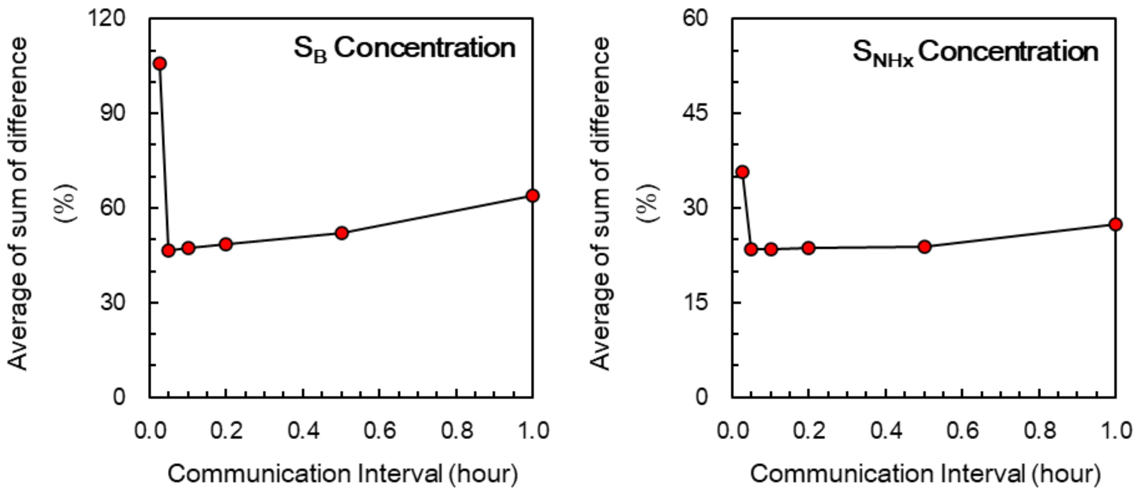

Figure 7.2 The difference between the results obtained from each scenario and from measurement

7.3.2. The influence of objective function to estimated results of influent biodegradable concentrations

As shown in Figure 7.3, the estimated hourly concentration of influent S_B and S_{NHx} in ASR#1, generated from most of objective functions except Relative Sum of Squares, were trendy with the measured results. In case of Relative Sum of Squares, the concentration of influent S_{NHx} was assumed to be constant at 25.8 mg-N/L during the first 13 hours followed by the remainder of 11 hours in which the S_{NHx} concentration of 20.6 mg-N/L was supposed to be unchanged. The slightly-similar tendency was also found for the estimated hourly concentration of influent S_B with constant values of 97 mgCOD/L during initial 19 hours and 78 mgCOD/L during later 5 hours, respectively. To make a clear comparison between the selected objective functions in the quality of back-calculation, the model fitness statistics was calculated for each case of selected objective function and demonstrated in Table 7.1.

Excepting Relative Sum of Squares, the quality of back-calculation from the remaining 4 objective functions are significantly similar. In particular, the best quality of model fitness for estimating hourly concentration of influent S_B is provided by Maximum Likelihood (highest NSE and lowest RMSR). In case of influent S_{NHx}, the best fit between estimated and measured results was obtained from Relative Difference.

The reason to explain for the model response when Relative Sum of Squares selected is attributed to the value of "scaled termination value for objective function" (STOF). As defined in Chapter 4, if the objective function value at a specific time of the optimization process is less than the user-specified STOF, the optimization process is terminated. In a simple comprehension, it can be supposed that the user-specified objective function value controls the variation scale of responded target variables that could be accepted for the optimization. The value of STOF was set at 0.1 by default in GPS-X. For example, considering that the DPE tried to adjust influent S_{NHx} to reproduce the responded effluent nitrate within a specific time step so that the responded value of effluent nitrate can closely fit to that measured value of 18 mgN/L. If the scaled termination value for objective function was set at 0.1, the acceptable range for responded value of effluent nitrate was calculated from 12.3 to 23.7 mgN/L. Consequently, the acceptable range for influent S_{NHx} to satisfy the optimization would be significantly large.

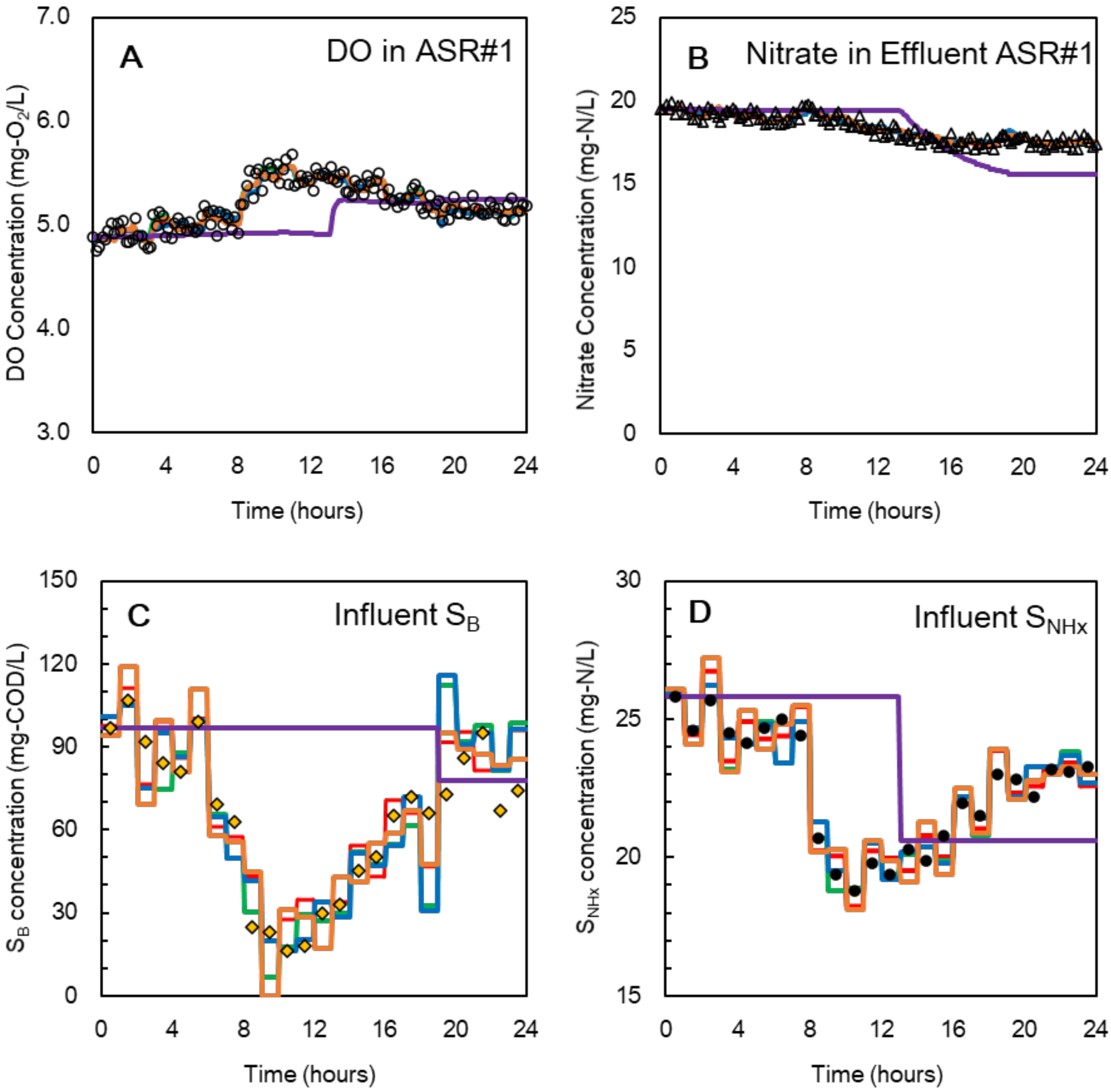

Figure 7.3 Estimation results of hourly concentration of influent S_B and S_{NHx} by different objective functions (plots: measured, curves: estimated; green: Absolute Difference, blue: Relative Difference, orange: Sum of Squares, violet: Relative Sum of Squares, red: Maximum Likelihood)

Recalling that GPS-X calculates parameter estimates for a specific time step using the parameter estimates from that previous as a starting guess, this leads to the unchanged value of DO and nitrate concentration during long period appeared when Relative Sum of Squares was selected. To cope with this issue, if the STOF is basically decreased, the estimated results from DPE when selecting Relative Sum of Squares might be comparable to that of other objective functions selected. In this study, when the STOF reduced to less than 0.0001, the quality of estimation results generated from Relative Sum of Squares are significantly identical to those in other cases of objective function (data not shown).

Table 7.1 Goodness-of-fit statistics versus the objective functions

	Nash-Sutcliff model Efficiency (NSE)				
	Absolute Difference	Relative Difference	Sum of Squares	Relative Sum of Squares	Maximum Likelihood
Influent S_B	0.724	0.716	0.764	-1.411	0.778
Influent S_{NHx}	0.901	0.924	0.834	-1.203	0.910
	Root of Mean Squared Residuals (RMSR)				
	Absolute Difference	Relative Difference	Sum of Squares	Relative Sum of Squares	Maximum Likelihood
Influent S_B	14.25	14.46	13.17	42.12	12.77
Influent S_{NHx}	0.667	0.584	0.864	3.149	0.638

Nevertheless, it is recommended by Hydromantis Inc. that the Maximum Likelihood or Sum of Squares objective functions should be used when conducting parameter estimation while the Absolute Difference objective function is the most suitable for process design or optimization. Specifically, the Maximum Likelihood objective function calculates statistically optimal parameter estimates based on assumptions on the nature of the measurement errors. The Sum of Squares objective function is a special case of the Maximum Likelihood objective function derived using further simplifying assumptions and can also be used. It is equivalent to the Maximum Likelihood objective function when there is only one response or target variable. The other objective functions can be used for curve fitting when calculating statistically optimal parameter estimates is not a concern. In this regard, the Maximum Likelihood was proved itself as the most suitable option for estimating hourly concentration of influent biodegradable compositions. This is because the relatively high fitness simultaneously obtained in both influent S_B and S_{NHx} estimation.

7.3.3. The impact of DPE time step versus data density to estimated results of the hourly concentration of influent biodegradable constituents

It must be noted that if the data logging interval of target variables was fixed at 10 minutes, the number of data utilized by DPE for each optimization would be 1, 3, 6, 12 and 18 when the time step was set at 10 minutes, 30 minutes, 1 hour, 2 hours and 3 hours, respectively. The estimated results of influent S_B and S_{NHx} concentration in case of data density for optimization = 18, 12 and 6 data/time step were compared and demonstrated in Figure 7.4. The quality of estimating influent S_B and S_{NHx} concentration when long time step selected was significantly high. This was demonstrated by the significant match between estimated and measured results in all three parameter estimations with different time step. Additionally, it seemed that there was no significant difference of estimated results among these three configurations of data density for optimization.

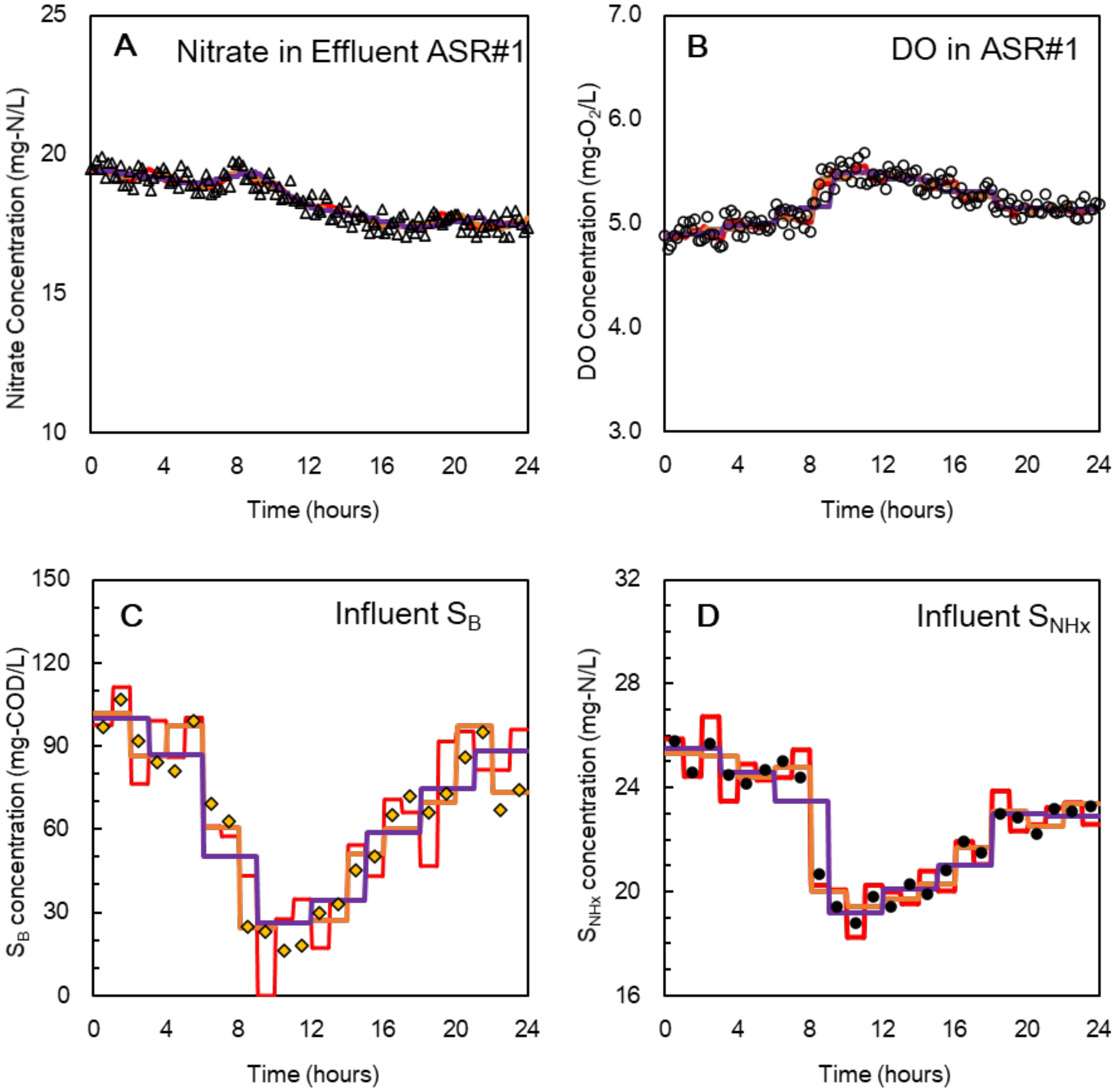

Figure 7.4 Estimation results of hourly concentration of influent S_B and S_{NHx} in three different setup of data density for optimization (plots: measured, curves: estimated; red: 6 data/time step, orange: 12 data/time step, violet: 18 data/time step)

The estimated results of concentration of influent S_B and S_{NHx} in case of 1 data/time step and 3 data/time step were demonstrated in Figure 7.5. Different to the three cases above, it can be recognized a significant fluctuation of estimated hourly concentration in both influent S_B and S_{NHx} when the data density for optimization was at 1 data/time step. In case of 3 data/time step, the intensity of oscillation seems to lower. In particular, it is noted that the range of oscillation is between the allowable minimum and maximum value of optimized variables (S_B and S_{NHx}) defined by user when setup DPE. To explain for this manner, it should be recalled firstly that the higher data density of target variables selected, the greater variation over time of target variables generated. In addition, the length of time step defines how frequent that the model responses of both optimized and target variables are updated. These leads to a consequence that DPE might accidentally generated the high oscillation in optimized variables during the attempt to catch the high variation of target variables if the short interval of data logging and short time step were simultaneously configured for the back-calculation. For example, assuming that DPE were trying to match the variation of both DO and nitrate concentration over two consecutive 10-minute interval of which they rapidly increased during the first 10-minute interval followed by a rapid decrease during that of second. The approach of DPE in this case is presumed that the influent S_{NHx} was adjusted to increase during the first 10-minute interval leading to an increment of DO consumption. However, the real tendency of DO concentration during this interval is decrease, resulting in a significant lowering of S_B to match that occurrence. During the second interval, influent S_{NHx} was accordingly decreased to meet the change of nitrate concentration, thus the influent S_B is forced to significantly increased during this interval to match the decrement of DO concentration. Because the concentration of S_B was significantly lowered during the first interval, DPE has to intensively increase the S_B concentration to compensate the gap of DO concentration caused by the decrement of influent S_{NHx}. By this manner, the oscillation of influent concentration might be prolonged if the high fluctuation of target variables still exists. In the relation to this regard, it is also suggested by Hydromantis Inc. that when using short time steps, it may be necessary to filter the data to eliminate noise, so GPS-X does not fit the noise.

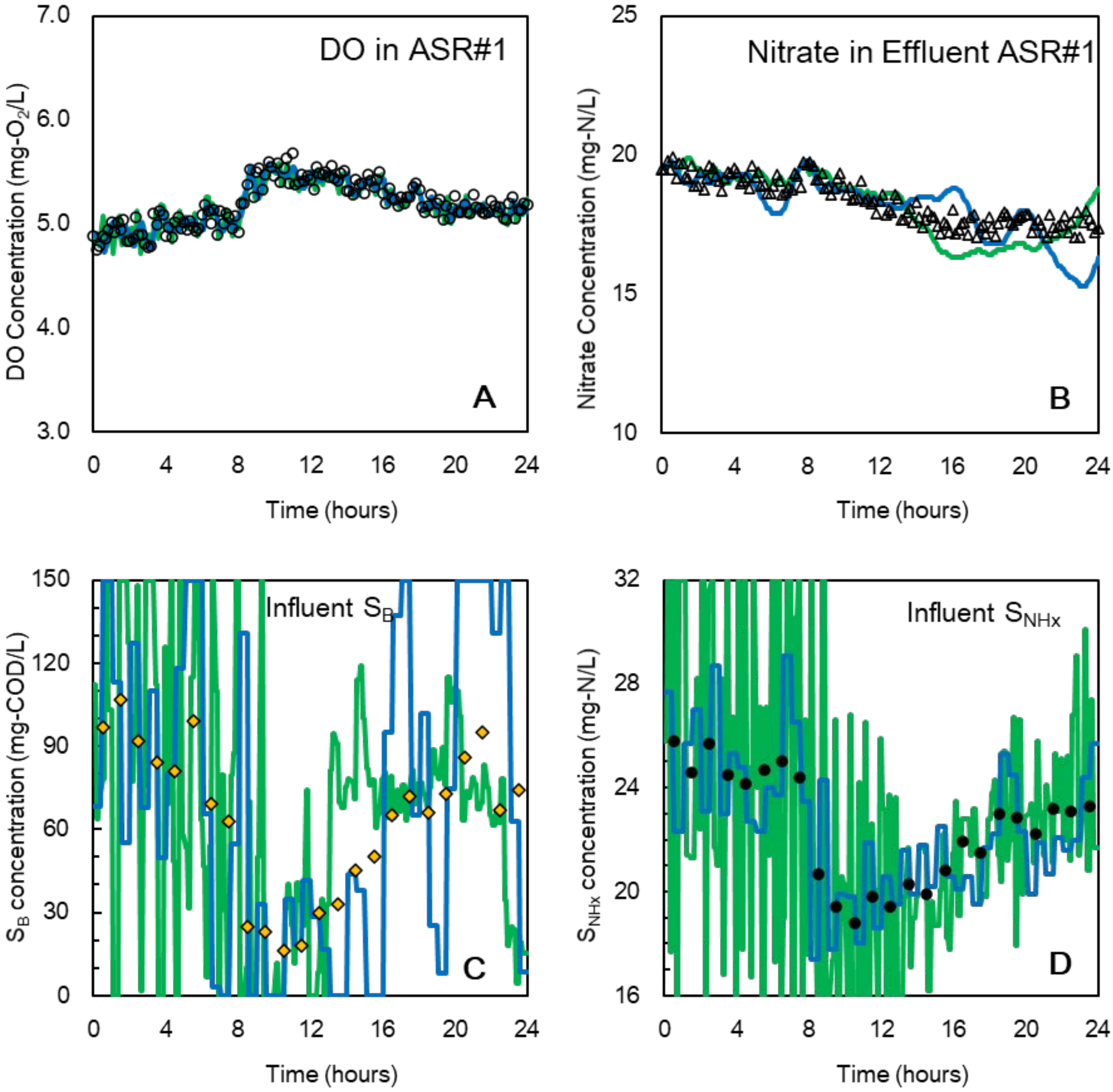

Figure 7.5 Estimation results of concentration of influent S_B and S_{NHx} by different DPE time step (plots: measured, curves: estimated; green: 1 data/time step, blue: 3 data/time step)

It is noted that when 1 data/time step and 3 data/time step were defined for back-calculation, the concentration of influent will vary in step wise manner at every 10 minutes and 30 minutes. Thus, average values within each hour (average of 6 estimated values of 10-minute concentration and average of 2 estimated values of 30-minute concentration) should be calculated for the purpose of estimating hourly concentration of influent S_B and S_{NHx}.

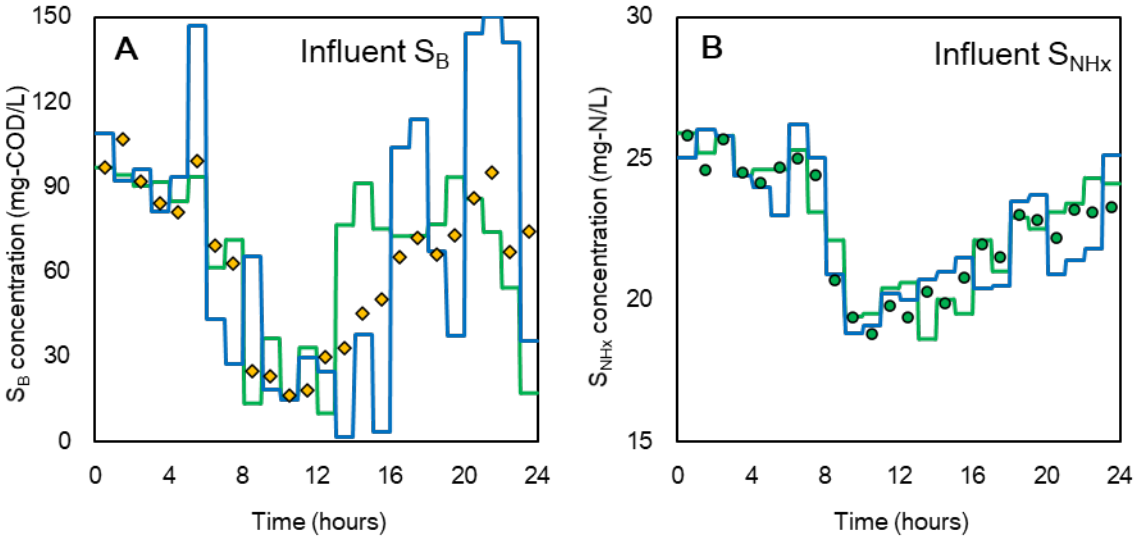

Figure 7.6 Average hourly concentration of influent S_B and S_{NHx} estimated from DPE with different selections of time step (plots: measured, curves: estimated; green: 1 data/time step, blue: 3 data/time step)

Although the estimated results of average hourly concentration of influent S_B and S_{NHx} obtained from the case of 1 data/time step and 3 data/time step reasonably fit to measured results, it is no doubt that the average hourly concentration is highly resulted by the range between minimum and maximum value defined for optimized variables. Obviously, choosing a proper range to obtain a good estimation is not an easy task, especially in case that the characterized influent wastewater is lack of information.

The comparison of NSE and RSMR value for both S_B and S_{NHx} estimation obtained from each configuration of data density for optimization were demonstrated in Table 7.2. Obviously, the high data density for optimization (greater than 6 data/time step) was found to yield better quality of estimation results of influent biodegradable substances compared to those of low data density for optimization. Particularly, the NSR value in S_B estimation was even negative when 3 data/time step of data density configured. Additionally, it was recognized that 6 data/time step of data density yields comparable results of model prediction to those by 12 data/time step and 18 data/time step.

Table 7.2 Model fitness versus the length of time step in estimating hourly concentration of influent S_B and S_{NHx}

	Nash-Sutcliff model Efficiency (NSE)				
	1 data/time step	3 data/time step	6 data/time step	12 data/time step	18 data/time step
Influent S_B	0.409	-0.574	0.778	0.94	0.83
Influent S_{NHx}	0.866	0.777	0.910	0.95	0.86
	Root of Mean Squared Residuals (RMSR)				

	1 data/time step	3 data/time step	6 data/time step	12 data/time step	18 data/time step
Influent S_B	20.85	34.04	12.77	6.60	11.13
Influent S_{NHx}	0.777	1.002	0.638	0.456	0.798

Moreover, it is shown that the data density of 12 data/time step can provide the best quality in estimating the hourly concentration of influent S_B and S_{NHx} (Table 7.2). This outcome is certainly in accordance with the results revealed in Chapter 6 (Table 6.3). However, it must be noted that 12 data/time step of data density in Chapter 6 was set up from 5-minute data logging interval of target variables in conjunction with 1-hour DPE time step. As mentioned in that chapter, duration of 5 minutes for a single measurement might be not long enough to guarantee a reliable result due to the limitation of sensor sensitivity in this study. In addition, in case that 12 data/time step of data density produced from 2-hour DPE time step and 10-minute logging interval of target variables, the estimated influent concentration would vary at every 2 hour is supposed to not provide information as closer for the purpose of hourly characterization than the dataset of influent concentration varied at every 1 hour (data density = 6 data/time step). Based on these consideration, 6 data/time step of data density was still recommended for DPE configuration to estimate hourly concentration of influent biodegradable substances. Moreover, once the quality of DO and nitrate sensor is upgraded so that the duration for a stable measurement is shortened (less than 5 minutes), 12 data/time step of data density is proposed for a better estimation result.

7.4. Conclusions

The comparative analysis was conducted for the optimization tool DPE focusing on the influence of several key parameters when setup DPE to the quality of estimated results of influent concentration. The main conclusions can be withdrawn from the main outcomes are listed as below:

(1) The appropriate time step of numerical integration using in the dynamic parameter estimation method was set to be 5 ~ 10 times less than the DPE time step but not lower than 0.05 hour. In case that the DPE time step was set at 1 hour, the 0.1-hour or 0.2-hour time step of numerical integration can be utilized without a huge difference (47% and 49% of difference for S_B and 24% of difference for S_{NHx} respectively).

(2) The obtained results of estimating hourly concentration of influent biodegradable compositions depend on the chosen objective function. Specifically, the Maximum Likelihood objective function is highly recommended for the purpose. When there is only one response or target variables selected, Sum of Squares objective function can be the alternation.

(3) The data density for optimization strongly affects the quality of estimating hourly concentration of influent S_B and S_{NHx}. When the data logging interval of target variables was fixed at 10 minutes, the long data density for optimization were proved to generate better quality of model fit between estimate and measured datasets. Moreover, the data density of 6 data/time step is generally recommended for determining the hourly variation of wastewater characteristic.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Main findings of the research

This study investigated ASM-based Dynamic Influent Characterization to design Biological Wastewater Treatment Plants. The key findings withdrawn from the outcomes throughout the research are listed as follows:

(1) The very low BOD concentration is typically found in the influent of municipal WWTPs in Vietnam. This is mainly due to the deterioration of organic during the path that effluent from septic tank conveyed to WWTP via the sewer system. In addition, the usage of CSS system as the most collection method of wastewater in Vietnamese urban areas also leads to an influence of surface runoff to the wastewater quality in both pollutants and volume. These backgrounds lead to the fact that the municipal wastewater characteristic in Vietnam significantly varied overtime. Consequently, the projection and design of new WWTPs in Vietnam is a real challenge due to the infeasibility of applying the recommended standards to estimate wastewater characteristics from several guidelines.

(2) To cope with the problem of ascertaining the variation of municipal wastewater concentration in Vietnam, a method of back-calculating the influent wastewater concentrations from the dynamic response of activated sludge process was developed, using IWA Activated Sludge Model integrated with optimization tool (DPE) from a process simulator (GPS-X). From the field experimental datasets of kinetic and biomass concentration of microorganism in activated sludge, the weekly average concentration of influent biodegradable organic and nitrogen were reasonably estimated in an automatically manner.

(3) The influent concentrations for readily biodegradable organics and ammonia could be estimated in a dynamic manner from the kinetic parameters of activated sludge, the operational conditions of the activated sludge process, and the DO and nitrate concentrations of activated sludge reactors. The hourly estimated concentrations of influent materials were comparable to those measured in the 1-day intensive sampling.

(4) The developed method only required 12 analytical items including OUR, b_{OHO}, μ_{max_ANO}, K_La, DO and nitrate per 1-day field test to estimate the hourly concentrations of influent biodegradable carbonaceous and nitrogenous materials, comparing to 96 analytical items including 48 items for each measurement of biodegradable organic and nitrogen of conventional method of on-site water sampling. Moreover, the cost for estimating the design-daily-average and design-daily-maximum BOD_5 and TKN of influent can be saved up to 70% and 90% respectively when applying the developed method instead of the conventional method. These indicating that the working load as well as the cost of the analysis could be significantly saved

(5) In the estimating hourly concentration of influent biodegradable constituents, the data density for optimization when configuring DPE somewhat affects the calculation results. When the data logging interval of DO and nitrate concentrations in the aeration tanks of the field experimental unit was fixed at 10 minutes, the long data density for optimization were proved to generate better quality of model fit between estimate and measured datasets. To estimate the hourly concentration of the influent with reasonable accuracy, the data density of 6 data/time step is generally recommended. Moreover, the obtained results of estimating hourly concentration of influent biodegradable compositions depend on the chosen objective function. Specifically, the Maximum Likelihood is highly

recommended for the purpose.

(6) A novel method to determine the blower capacity of wastewater treatment plants was also developed. Using EVD and the median-rank estimator, the blower power versus the probability of oxygenation shortage was simulated on the virtual wastewater treatment plant in the computer. Based on the ASM1, the required blower power per influent flow rate to meet the daily maximum influent oxygen demand was as high as 1.4~2.2 times than those of the blower calculated from the daily average.

(7) The time step of numerical integration was also suggested that it is an integer divisor of time step. In particular, when the time step was set at 1 hour, the time step of numerical integration is suggested to be 5 – 10 times less than the time step but not lower than 0.05 hour.

8.2. Recommendations for future studies

Based on these main findings, the following topics could be developed in the foreseeable future:

(1) In Chapter 1, the characteristic of municipal wastewater in Vietnam was stated that the concentration is highly fluctuated overtime and from region to region, leading to challenges in wastewater treatment and management. In this context, an intensive evaluation of typical characteristic of municipal wastewater in a broad scale over Vietnam could provide a valuable database for engineers in planning and design new WWTPs.

(2) The difficulties in the projection and design of new WWTPs in Vietnamese urban areas due to the impossibility of applying wastewater quality standard from available guidelines were mentioned in Chapter 2. In order to confront these challenges, together with an intensive characterization of municipal wastewater, the publication of a proper handbook/guideline for municipal wastewater treatment works in Vietnam is extremely desired.

(3) As mentioned in Chapter 3, the measurement of microorganism kinetic including specific decay rate of OHO and maximum specific growth rate of ANO are prerequisite criterions for the back calculation using mathematical activated sludge model concept. However, it is no doubt that the measurement of microorganism is somewhat not easy to be conducted. Also, the experiments hold a certain level in analytical errors. Based on these issues, the influence of analytical sensitivity in measuring/estimating kinetic and stoichiometry parameters to the quality of estimation results is supposed to be attractive research.

(4) As discussed in Chapter 4, the underestimation of influent soluble COD was recognized, and this was doubted of the ability to capture soluble materials of coagulant dosed into the primary settling tank. To cope with this issue, research seeking the types and proper dosage of flocculant/coagulant for primary settling tank of field-test activated sludge reactors module is surely essential.

(5) In relation to the dynamic hourly estimation of influent concentration, the HRT delay was doubted that might affects the quality of estimated results of influent biodegradable nitrogen from effluent nitrate. To improve the quality and reliability of the developed method, the study on the influence of HRT delay to back-calculation results is certainly needed.

(6) The ability of developed method to obtain daily maximum and average concentration of influent biodegradable organics and nitrogen from those of 1-hour discrete concentration was revealed in Chapter 6. To upgrade the applicability of the method, further application to examine extreme events of rapid changing influent concentration supposed to be another attractive research (e.g. duration of peak concentration, size of first flush…)

(7) In this study, it was stated that the regression process of optimization tool DPE to minimize or maximize the objective function in the task of parameter estimation will be terminated when one of the termination criteria (Parameter Tolerance, Objective function tolerance, Scaled termination value for objective function and Maximum number of optimizer iterations) was satisfied. Despite the fact that these terms are quite complicated to comprehend and explain, it still needs to be dug into for obtaining an insight of how the optimization tool work1k, thereby the quality of optimization can be improved.

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2. **Nguyen V H**, Le V T, Nguyen T H, Nguyen X H, Nguyen V A, Harada H, Terashima M, Yasui H: A Novel Method to Determine Blower Capacity of Wastewater Treatment Plants for Dry and Wet Weather Conditions. *Journal of Water and Environment Technology* (Accepted, In progress of publication)

PARTICIPATION TO INTERNATIONAL CONFERENCES

1. **Viet Hoang Nguyen**, Hidenori Harada, Van Tuan Le, Thi Ha Nguyen, Xuan Hai Nguyen, Mitsuharu Terashima, Hidenari Yasui: Dynamic Estimation of Hourly Fluctuation of Influent Biodegradable Carbonaceous and Nitrogenous Materials Using Activated Sludge System. *The Water and Environment Technology Conference 2018 (WET2018)*, Session 4C-04, p. 93, 14-15/July, Matsuyama, Japan, 2018.

2. **Viet Hoang Nguyen**, Nguyen Hoang Ho, Mitsuharu Terashima, Hidenari Yasui: Alternative Method to Determine Blower Capacity against Peak Pollutant Load in Wastewater Treatment System. *The Water and Environment Technology Conference 2019 (WET2019)*, Session 3C-20, p. 97, 13-14/July, Osaka, Japan, 2019.

3. **Viet Hoang Nguyen**, Thi Ha Nguyen, Huu Huan Nguyen, Xuan Hai Nguyen, Mitsuharu Terashima, Hidenari Yasui: Estimating Hourly Concentration of Influent Biodegradable Carbonaceous Substrate and Ammonia Nitrogen by using IWA Activated Sludge Model and Dynamic Parameter Estimation Function. *9th International Forum on Green Technology and Management (IFGTM 2019)*, Session 2-3, 27-28/Sep, Hanoi, Vietnam, 2019.

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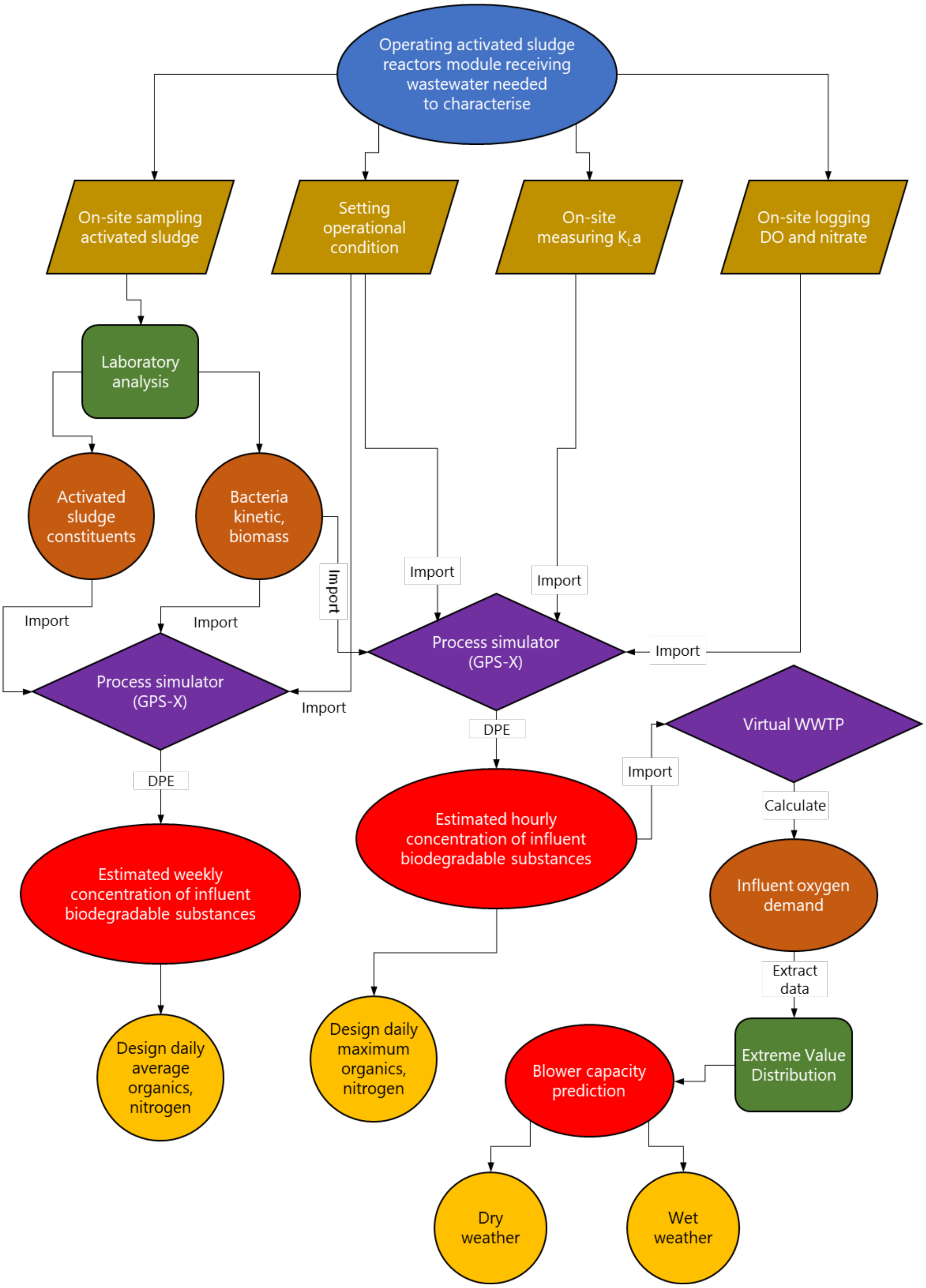
APPENDIX

1. Flowchart for obtaining weekly concentration, hourly concentration, and design basis of influent biodegradable substances



2. List of terminology in GPS-X and those correlated in this study

No	Terminology in GPS-X	Terminology in this study
1	Readily biodegradable substrate (ss)	Soluble biodegradable organics (S_B)
2	Slowly biodegradable substrate (xs)	Particulate biodegradable organics (XC_B)
3	Soluble biodegradable organic nitrogen (snd)	Soluble biodegradable nitrogen (S_{B_N})
4	Particulate biodegradable organic nitrogen (xnd)	Particulate biodegradable organic nitrogen ($XC_{B\_org,N}$)
5	Soluble inert organic material (si)	Soluble unbiodegradable organics (S_U)
6	Particulate inert organic material (xi)	Particulate unbiodegradable organic (X_U)
7	Inert inorganic suspended solids (xii)	Particulate inorganic (X_{Ig})
8	Time window	Time step
9	Communication interval	Time step of numerical integration
10	Dynamic Parameter Estimation (DPE)	-
11	Target variables	-
12	Optimized variables	-
13	Objective function	-
14	Parameter Tolerance	-
15	Objective function tolerance	-
16	Scaled termination value for objective function	-
17	Maximum number of optimizer iterations	-

3. Estimated results of influent concentration

3.1. Case study at Vinh Niem WWTP (Chapter 4)

Time (day)	S_B (mgCOD/L)	XC_B (mgCOD/L)	S_{B_N} (mgN/L)	$XC_{B\_org,N}$ (mgN/L)	Mea.Inf. COD (mgCOD/L)	Mea.Inf. S-COD (mgCOD/L)	Mea.Inf. STKN (mgN/L)	Mea.Inf. TKN (mgN/L)
0	63.0	25.3	43.4	2.3	104	64	28.4	31.9
1	63.0	25.3	43.4	2.3				
2	63.0	25.3	43.4	2.3				
3	63.0	25.3	43.4	2.3	168	100	41.9	42.8
4	63.0	25.3	43.4	2.3				
5	63.0	25.3	43.4	2.3				
6	63.0	25.3	43.4	2.3	154	88	33.37	35.08
7	81.4	15.3	38.8	3.1				
8	81.4	15.3	38.8	3.1				
9	81.4	15.3	38.8	3.1				
10	81.4	15.3	38.8	3.1	163	125	35	40.4
11	81.4	15.3	38.8	3.1				
12	81.4	15.3	38.8	3.1				
13	81.4	15.3	38.8	3.1				
14	72.9	43.9	36.0	0.0	168	116	32.7	35.8
15	72.9	43.9	36.0	0.0				
16	72.9	43.9	36.0	0.0				
17	72.9	43.9	36.0	0.0	189	118	52.1	56
18	72.9	43.9	36.0	0.0				
19	72.9	43.9	36.0	0.0				
20	72.9	43.9	36.0	0.0				
21	73.6	27.2	21.2	0.0	112	78	30	31.9
22	73.6	27.2	21.2	0.0				
23	73.6	27.2	21.2	0.0				
24	73.6	27.2	21.2	0.0	164	104	28	26.4
25	73.6	27.2	21.2	0.0				
26	73.6	27.2	21.2	0.0				
27	73.6	27.2	21.2	0.0				
28	100.0	38.7	29.6	0.0	156	84	35.8	38.1
29	100.0	38.7	29.6	0.0				
30	100.0	38.7	29.6	0.0				
31	100.0	38.7	29.6	0.0				
32	100.0	38.7	29.6	0.0				
33	100.0	38.7	29.6	0.0				
34	100.0	38.7	29.6	0.0				
35	73.7	17.2	26.0	0.0	100	52	31.1	28.8
36	73.7	17.2	26.0	0.0				
37	73.7	17.2	26.0	0.0				
38	73.7	17.2	26.0	0.0	216	165	40.4	42
39	73.7	17.2	26.0	0.0				
40	73.7	17.2	26.0	0.0				

41	73.7	17.2	26.0	0.0				
42	42.4	8.0	12.9	0.0	72	33	22.4	23
43	42.4	8.0	12.9	0.0				
44	42.4	8.0	12.9	0.0				
45	42.4	8.0	12.9	0.0				
46	42.4	8.0	12.9	0.0				
47	42.4	8.0	12.9	0.0				
48	42.4	8.0	12.9	0.0				
49	41.5	9.4	28.4	6.7				
50	41.5	9.4	28.4	6.7	52	36	18	19.1
51	41.5	9.4	28.4	6.7	58	32	24	27.2
52	41.5	9.4	28.4	6.7	72	38	33.6	36.4
53	41.5	9.4	28.4	6.7	73	42	35.8	38.9
54	41.5	9.4	28.4	6.7				
55	41.5	9.4	28.4	6.7	97	55	40.6	45.5
56	29.9	12.8	25.1	2.0	69	36	36.6	38.1
57	29.9	12.8	25.1	2.0	96	57	40.4	42
58	29.9	12.8	25.1	2.0	58	23	24.5	20.7
59	29.9	12.8	25.1	2.0	101	57	31.1	35.8
60	29.9	12.8	25.1	2.0				
61	29.9	12.8	25.1	2.0				
62	29.9	12.8	25.1	2.0	68	39	31.9	28
63	37.0	27.3	23.4	3.3	64	32	24.9	21.8
64	37.0	27.3	23.4	3.3	76	50	23	30.5
65	37.0	27.3	23.4	3.3	71	36	35.8	31.9
66	37.0	27.3	23.4	3.3	86	48	38	42.1
67	37.0	27.3	23.4	3.3				
68	37.0	27.3	23.4	3.3				
69	37.0	27.3	23.4	3.3	106	60	42.8	38.9
70	14.1	13.4	14.4	2.6	84	49	24.9	26.4
71	14.1	13.4	14.4	2.6	52	28	21	21.8
72	14.1	13.4	14.4	2.6	51	32	17.5	16.1
73	14.1	13.4	14.4	2.6	38	21	11.3	11.3
74	14.1	13.4	14.4	2.6				
75	14.1	13.4	14.4	2.6				
76	14.1	13.4	14.4	2.6	61	37	12.4	12.4
77	19.3	28.3	16.5	2.6	42	34	13.4	14.2
78	19.3	28.3	16.5	2.6	51	33	15.9	16.5
79	19.3	28.3	16.5	2.6	70	48	17.5	14.9
80	19.3	28.3	16.5	2.6	63	36	19.9	22.9
81	19.3	28.3	16.5	2.6				
82	19.3	28.3	16.5	2.6				
83	19.3	28.3	16.5	2.6	30	26	6	6.1
84	17.4	8.4	10.0	1.0	48	21	7.9	8.4
85	17.4	8.4	10.0	1.0	46	21	8.5	8.4
86	17.4	8.4	10.0	1.0	40	18	7.6	7.9
87	17.4	8.4	10.0	1.0	42	17	7.8	8.6

88	17.4	8.4	10.0	1.0				
89	17.4	8.4	10.0	1.0				
90	17.4	8.4	10.0	1.0	69	39	10.1	11.7
91	34.7	22.6	22.1	1.9	66	31	11.2	13.2
92	34.7	22.6	22.1	1.9	68	40	14.1	16.3
93	34.7	22.6	22.1	1.9				
94	34.7	22.6	22.1	1.9	72	45	21.9	21
95	34.7	22.6	22.1	1.9				
96	34.7	22.6	22.1	1.9				
97	34.7	22.6	22.1	1.9	69	52	25.2	24.3
98	14.4	4.3	10.5	1.3	80	46	14.3	17.2
99	14.4	4.3	10.5	1.3	36	18	10.8	11.9
100	14.4	4.3	10.5	1.3	46	37	7.6	8.4
101	14.4	4.3	10.5	1.3	60	30	6.5	7
102	14.4	4.3	10.5	1.3				
103	14.4	4.3	10.5	1.3				
104	14.4	4.3	10.5	1.3	65	60	11.5	12.1
105	29.0	16.0	20.7	5.5	63	29	15.2	15.3
106	29.0	16.0	20.7	5.5	92	62	18.7	21.7
107	29.0	16.0	20.7	5.5	86	61	19.1	18.5
108	29.0	16.0	20.7	5.5	98	56	23.3	24.5
109	29.0	16.0	20.7	5.5				
110	29.0	16.0	20.7	5.5				
111	29.0	16.0	20.7	5.5	100	68	24.7	24.7
112	10.7	0.0	10.6	0.3	72	53	21	21
113	10.7	0.0	10.6	0.3	53	26	14	15.9
114	10.7	0.0	10.6	0.3	42	34	8.3	11.1
115	10.7	0.0	10.6	0.3	50	31	6.1	7.3
116	10.7	0.0	10.6	0.3				
117	10.7	0.0	10.6	0.3				
118	10.7	0.0	10.6	0.3	38	12	4.9	4.5
119	24.7	6.9	10.5	6.0	98	48	14.8	18.2
120	24.7	6.9	10.5	6.0	111	69	21.8	26.3
121	24.7	6.9	10.5	6.0	78	45	14.7	16
122	24.7	6.9	10.5	6.0	70	43	11.7	14.5
123	24.7	6.9	10.5	6.0				
124	24.7	6.9	10.5	6.0				
125	24.7	6.9	10.5	6.0				
126	24.7	6.9	10.5	6.0				

3.2. Case study at Chua Cau WWTP (Chapter 4)

Time (day)	S_B (mgCOD/L)	XC_B (mgCOD/L)	S_{B_N} (mgN/L)	$XC_{B\_org,N}$ (mgN/L)	Mea.Inf. COD (mgCOD/L)	Mea.Inf. S-COD (mgCOD/L)	Mea.Inf. STKN (mgN/L)	Mea.Inf. TKN (mgN/L)
0	36.6	36.6	16.6	5.9	73	36		
1	36.6	36.6	16.6	5.9				
2	36.6	36.6	16.6	5.9	96	40	13	19
3	36.6	36.6	16.6	5.9				
4	36.6	36.6	16.6	5.9	98	27	13	17
5	36.6	36.6	16.6	5.9				
6	36.6	36.6	16.6	5.9	168	51	22	27
7	50.3	37.9	23.8	3.8				
8	50.3	37.9	23.8	3.8	141	47	23	27
9	50.3	37.9	23.8	3.8				
10	50.3	37.9	23.8	3.8				
11	50.3	37.9	23.8	3.8				
12	50.3	37.9	23.8	3.8				
13	50.3	37.9	23.8	3.8				
14	50.2	54.6	21.8	5.3				
15	50.2	54.6	21.8	5.3				
16	50.2	54.6	21.8	5.3	153	63	26	32
17	50.2	54.6	21.8	5.3				
18	50.2	54.6	21.8	5.3	159	68	25	31
19	50.2	54.6	21.8	5.3				
20	50.2	54.6	21.8	5.3				
21	65.1	51.7	22.9	4.6	172	70	23	30
22	65.1	51.7	22.9	4.6				
23	65.1	51.7	22.9	4.6	180	76	27	33
24	65.1	51.7	22.9	4.6				
25	65.1	51.7	22.9	4.6	168	73	23	30
26	65.1	51.7	22.9	4.6				
27	65.1	51.7	22.9	4.6				
28	48.0	64.4	20.3	5.6	176	98	24	31
29	48.0	64.4	20.3	5.6				
30	48.0	64.4	20.3	5.6	152	87	23	29
31	48.0	64.4	20.3	5.6				
32	48.0	64.4	20.3	5.6				
33	48.0	64.4	20.3	5.6	142	75	22	28
34	48.0	64.4	20.3	5.6				
35	44.5	70.3	16.0	11.4	190	77	23	30
36	44.5	70.3	16.0	11.4				
37	44.5	70.3	16.0	11.4	134	42	18	21
38	44.5	70.3	16.0	11.4				
39	44.5	70.3	16.0	11.4	172	70	24	29
40	44.5	70.3	16.0	11.4				
41	44.5	70.3	16.0	11.4				
42	44.5	70.3	16.0	11.4	84	36	20	22

3.3. At research field of Hue Citadel area, Vietnam (Chapter 5, sub-section 5.3.3)

Time (hours)		0	1	2	3	4	5	6	7	8	9	10	11	12
C-BOD$_{30}$ (mg/L)	Measured	59	46	93	77	55	33	16	10	13	14	21	31	22
	Calculated	59	49	44	51	57	41	15	15	11	5	41	32	20
Ammonia (mg-N/L)	Measured	10.6	7.0	6.5	6.9	7.9	7.2	7.8	10.0	10.6	5.4	7.3	8.0	9.1
	Calculated	12.9	13.5	12.5	11.0	10.2	9.0	9.6	5.2	8.8	7.6	6.7	8.5	11.4
Nitrate (mg-N/L)	Measured	0.07	0.06	0.08	0.06	0.06	0.06	0.05	0.05	0.04	0.05	0.05	0.05	0.06

Time (hours)		13	14	15	16	17	18	19	20	21	22	23	24	Avg.
C-BOD$_{30}$ (mg/L)	Measured	33	19	26	20	30	36	39	35	49	43	46	63	37
	Calculated	21	26	42	26	46	63	48	81	58	61	39	73	41
Ammonia (mg-N/L)	Measured	10.2	12.4	14.5	18.8	19.4	20.8	20.3	18.6	21.8	19.8	19.5	19.5	12.8
	Calculated	11.9	13.5	14.0	16.4	17.8	17.3	20.7	18.0	19.8	17.8	20.5	20.5	13.4
Nitrate (mg-N/L)	Measured	0.06	0.06	0.05	0.06	0.07	0.06	0.06	0.04	0.07	0.05	0.06	0.06	0.06

3.4. Estimated results of influent concentration at site #1 (Chapter 6, sub-section 6.3.1)

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
1	0	7	4.7	12	7.6	6.57	6.36	4.0	9.5
	1	6	4.6	10	7.7	6.42	6.44	4.0	9.5
	2	0	4.0	0	7.0	6.56	6.32	4.0	9.5
	3	0	3.9	0	6.7	6.56	6.34	3.9	9.6
	4	31	5.4	40	11.7	6.46	6.45	3.9	9.5
	5	33	5.3	42	11.3	6.57	6.34	3.9	9.3
	6	34	6.1	71	11.4	6.57	6.16	3.9	9.3
	7	36	6.0	67	11.6	6.56	6.21	3.9	9.5
	8	35	6.1	8	4.3	6.36	6.16	3.9	9.5
	9	33	6.0	9	4.5	6.40	6.34	3.9	9.6
	10	36	6.1	0	10.0	6.42	6.33	3.9	9.4
	11	38	6.2	0	9.1	6.51	6.25	3.9	9.4
	12	36	7.3	95	8.8	6.43	6.30	3.9	9.6
	13	38	7.1	100	9.8	6.39	6.09	3.9	9.5
	14	51	9.9	0	2.4	6.43	6.06	4.3	9.4
	15	54	10.1	0	2.3	6.12	6.13	4.7	9.6
	16	34	8.7	19	9.8	6.17	6.25	5.1	9.6
	17	32	8.5	20	8.8	6.26	6.05	5.5	10.6
	18	62	8.4	67	9.2	6.19	6.02	5.5	10.2
	19	65	8.5	64	9.4	6.09	5.86	5.5	10.4
	20	56	9.4	55	9.3	6.23	5.81	5.4	10.1
	21	53	9.3	52	10.2	6.14	5.86	5.5	10.1
	22	14	6.9	108	10.5	6.16	5.93	5.4	10.6
	23	13	7.0	106	11.6	6.32	6.04	5.4	10.3
2	0	11	6.8	121	11.8	6.42	6.02	5.5	10.3
	1	10	6.6	135	12.1	6.29	5.88	5.5	10.0
	2	3	6.3	34	12.4	6.43	5.90	5.5	9.9
	3	2	6.5	31	11.7	6.32	6.00	5.5	10.7
	4	0	6.5	146	9.9	6.31	5.93	5.5	11.3
	5	0	6.7	131	10.4	6.46	5.99	5.6	11.2
	6	10	8.7	86	6.0	6.37	5.99	5.7	10.7
	7	12	8.9	77	5.7	6.38	6.06	6.0	10.3
	8	9	9.1	67	5.1	6.43	6.04	6.3	9.8
	9	8	9.6	74	5.4	6.32	6.20	6.5	9.3
	10	55	11.2	31	4.1	6.25	6.08	6.9	9.8
	11	61	12.4	34	3.9	6.22	6.19	7.1	9.7
	12	71	13.3	25	4.5	6.01	6.03	7.4	9.8
	13	78	13.5	26	4.7	6.02	5.94	7.7	10.2
	14	77	12.2	54	8.6	5.93	5.89	7.9	10.5
	15	85	12.4	59	7.8	6.04	5.78	7.9	10.7
	16	80	14.7	62	6.4	5.88	5.70	7.8	10.8
	17	88	13.0	65	6.7	5.84	5.67	8.1	11.1
	18	130	13.5	110	13.7	5.76	5.61	8.0	11.4
	19	137	14.9	121	13.0	5.78	5.28	7.8	11.1
	20	154	16.3	54	7.1	5.78	5.17	7.7	11.3
	21	162	15.5	59	7.5	5.64	5.46	7.6	11.4
	22	181	18.6	32	6.8	5.56	5.34	7.3	11.5
	23	190	17.4	35	7.1	5.52	5.39	7.3	11.4

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
3	0	101	14.5	35	6.7	5.56	5.34	7.2	11.4
	1	93	13.1	35	7.1	5.81	5.57	7.1	11.4
	2	103	12.2	111	14.3	5.81	5.56	7.0	11.5
	3	110	12.8	117	12.8	5.83	5.32	6.9	11.5
	4	26	9.1	200	16.1	5.91	5.32	6.8	11.5
	5	23	8.7	211	17.7	6.10	5.34	6.8	11.4
	6	16	7.7	0	4.8	6.23	5.42	6.7	11.5
	7	14	7.9	0	5.4	6.11	6.10	6.7	11.5
	8	0	7.5	0	8.1	6.31	5.99	6.6	11.5
	9	0	7.6	0	8.2	6.33	6.07	6.6	12.0
	10	59	7.5	57	10.4	6.29	6.00	6.7	12.5
	11	65	7.4	60	10.9	6.29	5.73	6.3	12.1
	12	75	10.1	42	9.3	6.22	5.71	5.8	11.8
	13	83	9.6	40	9.1	5.99	5.65	5.6	11.8
	14	88	10.5	0	7.5	6.02	5.76	5.5	11.7
	15	93	11.0	0	6.1	6.02	5.84	5.4	11.8
	16	89	10.8	51	9.5	5.83	5.69	5.4	11.7
	17	98	11.4	49	10.7	5.80	5.56	5.3	11.5
	18	113	11.7	0	9.5	5.81	5.56	5.3	11.9
	19	119	11.6	0	8.7	5.84	5.46	5.2	12.1
	20	134	13.4	0	7.4	5.80	5.62	5.1	12.2
	21	141	13.5	0	8.7	5.68	5.63	5.1	12.4
	22	114	12.2	0	10.1	5.67	5.59	5.1	12.5
	23	120	12.3	0	9.8	5.90	5.62	5.1	12.8
4	0	120	12.3	0	9.8	5.85	5.65	5.1	13.1
	1	84	10.5	0	12.1	5.94	5.66	5.1	13.4
	2	149	13.9	0	10.2	6.05	5.64	5.2	13.9
	3	142	14.1	1	10.7	5.77	5.59	5.2	14.1
	4	103	12.2	1	9.7	5.76	5.52	5.3	14.4
	5	98	12.0	1	10.4	6.02	5.74	5.3	14.5
	6	63	10.2	0	11.5	6.00	5.66	5.4	14.6
	7	60	10.3	0	10.0	6.13	5.81	5.5	15.1
	8	57	11.0	0	8.6	6.14	5.93	5.7	15.2
	9	60	10.9	0	9.1	6.20	5.87	5.9	15.2
	10	0	8.6	0	8.5	6.19	5.88	6.1	15.3
	11	0	9.2	0	7.8	6.25	6.07	6.3	15.4
	12	0	8.4	0	8.7	6.31	6.20	6.8	15.5
	13	0	8.5	0	8.9	6.27	6.24	7.0	15.6
	14	23	10.5	0	8.1	6.36	6.04	7.2	15.6
	15	22	10.4	0	8.4	6.26	6.04	7.4	15.7
	16	87	14.5	89	14.3	6.31	6.05	7.6	15.8
	17	91	14.7	80	12.0	6.00	5.50	7.8	15.9
	18	124	14.6	78	16.7	5.95	5.54	8.1	15.9
	19	130	14.5	86	15.9	5.98	5.46	7.7	15.9
	20	45	15.1	182	12.5	5.88	5.45	7.8	16.1
	21	47	15.9	173	16.4	6.03	5.49	7.9	16.0
	22	0	10.7	191	16.2	5.97	5.28	8.8	16.1
	23	0	11.3	189	17.1	6.14	5.60	9.1	15.9

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
5	0	5	9.3	91	13.2	6.35	5.54	9.3	16.2
	1	7	9.8	95	11.4	6.32	5.87	9.3	15.9
	2	34	11.4	23	10.3	6.29	5.88	9.1	15.5
	3	39	12.0	21	11.3	6.26	5.93	8.9	15.6
	4	37	13.4	74	9.2	6.31	5.88	9.1	16.2
	5	40	11.0	78	10.3	6.17	5.79	9.5	16.2
	6	18	8.6	65	13.5	6.19	5.84	8.8	15.9
	7	16	8.2	68	12.8	6.36	5.95	8.8	15.6
	8	49	14.0	57	7.1	6.50	6.03	8.2	15.1
	9	52	13.3	60	7.5	6.11	5.81	8.8	15.2
	10	43	11.1	45	13.2	6.16	6.01	8.6	15.4
	11	40	11.7	47	11.9	6.18	5.94	8.6	15.7
	12	61	9.0	53	9.0	6.31	5.79	8.7	15.2
	13	64	10.0	50	9.7	6.24	5.90	8.0	14.9
	14	63	12.0	42	4.0	6.22	5.86	7.7	14.4
	15	70	12.7	44	4.4	6.18	5.94	7.6	13.6
	16	114	13.8	15	8.7	6.03	5.99	7.7	13.0
	17	120	12.5	17	8.2	5.93	5.63	7.7	12.8
	18	86	12.4	53	9.9	5.94	5.79	7.3	12.4
	19	91	12.6	56	10.4	5.93	5.67	7.1	12.6
	20	108	13.3	70	8.4	5.94	5.58	7.1	13.0
	21	103	13.9	66	8.8	5.85	5.56	6.8	12.3
	22	99	12.9	34	8.9	5.82	5.66	7.1	12.5
	23	104	12.2	32	9.2	5.99	5.70	7.0	12.2
6	0	5	9.3	91	13.2	5.89	5.67	6.7	12.5
	1	24	9.2	75	11.0	6.05	5.76	6.9	12.7
	2	45	9.8	80	11.3	6.14	5.78	6.9	12.7
	3	50	10.3	45	9.5	6.05	5.69	6.9	12.9
	4	43	11.0	50	9.1	6.04	5.82	7.0	13.1
	5	48	10.5	44	8.7	6.08	5.72	7.3	13.2
	6	86	11.0	8	5.7	6.12	5.77	7.1	13.2
	7	88	10.8	10	6.0	6.06	5.94	7.3	12.9
	8	48	11.6	8	5.4	6.12	5.99	6.6	12.4
	9	44	11.0	14	7.6	6.14	5.93	7.2	12.3
	10	78	9.2	16	8.6	6.11	5.99	7.0	12.6
	11	73	10.0	20	8.4	6.25	5.89	6.6	12.5
	12	53	9.5	29	9.0	6.19	5.90	6.4	12.5
	13	50	9.2	25	8.5	6.11	5.95	6.1	12.6
	14	78	10.2	28	8.8	6.13	5.89	6.1	12.4
	15	82	10.4	20	8.6	6.08	5.83	5.9	12.5
	16	91	10.9	23	8.1	6.02	5.74	5.9	12.6
	17	96	11.1	25	7.8	5.96	5.79	5.7	12.3
	18	0	6.6	78	11.0	5.96	5.60	5.7	12.1
	19	0	6.2	80	11.5	6.29	5.85	5.9	12.0
	20	59	9.1	82	11.3	6.31	5.69	5.7	12.2
	21	64	9.3	75	11.6	6.08	5.59	5.7	12.0
	22	35	8.3	73	11.2	6.10	5.63	5.7	12.0
	23	32	8.2	71	11.4	6.18	5.71	5.7	12.0

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
7	0	38	8.4	75	10.8	6.12	5.63	5.7	12.1
	1	43	8.6	79	10.9	6.12	5.72	5.8	12.1
	2	40	8.4	80	11.3	6.07	5.78	5.7	12.0
	3	45	8.7	83	11.6	6.13	5.66	5.7	11.9
	4	43	8.8	29	9.8	6.16	5.70	5.8	12.0
	5	45	8.7	32	10.1	6.10	5.86	5.8	12.0
	6	32	8.0	40	7.9	6.25	5.93	5.8	12.5
	7	28	8.1	43	8.0	6.27	5.95	5.9	12.1
	8	78	10.7	14	7.6	6.21	5.90	5.8	12.2
	9	81	10.5	20	7.7	5.95	5.79	5.8	12.0
	10	45	8.7	74	11.5	5.98	5.98	5.8	12.0
	11	49	8.6	79	11.8	6.21	5.90	5.8	11.9
	12	50	6.9	32	14.1	6.18	5.66	5.8	12.0
	13	54	6.5	28	13.8	6.20	5.76	5.3	12.3
	14	97	11.0	39	11.0	6.12	5.80	5.0	12.7
	15	103	10.8	43	11.5	5.96	5.62	4.9	13.2
	16	0	5.1	30	6.9	5.89	5.58	4.9	13.2
	17	1	5.0	33	7.4	6.16	5.93	4.8	12.6
	18	7	5.2	6	5.8	6.29	6.11	4.8	12.1
	19	8	5.1	8	6.1	6.11	6.11	4.7	11.5
	20	0	4.5	11	5.7	6.20	5.96	4.7	11.1
	21	0	4.4	14	6.0	6.21	6.07	4.6	10.6
	22	0	4.3	0	7.2	6.21	6.08	4.4	10.3
	23	0	4.2	0	6.8	6.25	6.05	4.3	10.2
8	0	5	4.1	0	6.4	6.28	6.21	4.2	10.2
	1	13	4.3	1	6.0	6.24	6.19	4.1	10.2
	2	95	8.7	37	7.5	6.25	6.20	4.0	9.8
	3	100	9.3	35	7.8	6.12	5.96	3.9	9.5
	4	86	8.6	49	9.3	5.91	5.90	3.8	9.3
	5	91	8.9	52	9.2	6.09	5.79	3.7	9.2
	6	50	6.9	91	9.9	6.12	5.89	3.7	9.2
	7	43	6.6	96	10.1	6.12	5.90	3.7	9.0
	8	44	6.4	52	9.1	6.16	5.87	3.7	8.8
	9	42	6.2	50	9.3	6.17	6.06	3.7	8.8
	10	83	8.5	20	8.1	6.10	6.00	3.7	9.0
	11	87	8.7	22	7.7	6.02	5.84	3.7	9.3
	12	96	9.4	18	10.6	6.00	5.80	3.7	9.3
	13	102	9.7	21	9.8	5.93	5.79	3.7	9.8
	14	99	9.3	44	9.2	5.87	5.65	3.7	10.2
	15	94	9.6	47	9.5	5.76	5.69	3.6	10.3
	16	86	8.3	7	7.9	5.75	5.58	3.7	10.4
	17	82	8.5	6	7.4	5.79	5.70	3.5	10.6
	18	69	7.6	5	7.5	5.91	5.80	3.6	10.2
	19	64	7.9	4	7.3	5.88	5.72	3.6	10.3
	20	61	7.3	15	6.8	5.82	5.87	3.7	10.4
	21	57	7.0	13	6.0	5.87	5.82	3.6	10.3
	22	0	3.5	14	6.9	5.97	5.84	3.6	9.8
	23	0	3.6	12	6.6	6.11	6.03	3.5	9.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
9	0	4	3.7	31	5.7	6.28	6.05	3.5	9.3
	1	8	3.8	34	5.7	6.12	6.20	3.4	8.8
	2	4	3.5	18	5.0	6.29	6.14	3.4	8.5
	3	3	3.6	16	5.3	6.22	6.12	3.3	8.0
	4	10	3.7	8	4.1	6.30	6.26	3.3	7.8
	5	7	3.6	7	4.3	6.38	6.28	3.2	7.6
	6	6	3.5	0	4.2	6.22	6.29	3.2	7.4
	7	8	3.9	0	4.3	6.31	6.38	3.1	7.2
	8	50	6.5	0	3.9	6.31	6.35	3.2	7.2
	9	55	6.7	0	4.0	6.28	6.16	3.2	7.1
	10	97	9.6	17	5.4	6.25	6.15	3.3	7.2
	11	106	9.3	19	5.5	5.90	6.02	3.4	7.3
	12	143	12.2	37	6.2	6.10	5.93	3.4	7.3
	13	151	12.5	34	6.1	5.71	5.79	3.5	7.4
	14	139	11.9	72	8.0	5.82	5.75	3.6	7.4
	15	132	12.0	79	7.8	5.71	5.56	3.6	7.3
	16	119	11.2	130	11.7	5.84	5.49	3.7	7.3
	17	113	10.5	117	11.4	5.72	5.42	3.8	7.6
	18	73	7.2	106	8.4	5.79	5.40	3.7	7.4
	19	68	7.5	97	8.3	5.96	5.79	3.6	7.0
	20	16	5.2	67	7.6	5.94	5.62	3.6	6.8
	21	14	5.1	74	7.7	6.06	5.84	3.5	6.9
	22	0	4.3	45	5.6	6.29	5.98	3.7	7.0
	23	0	4.0	41	5.3	6.29	6.18	3.8	7.1
10	0	4	4.0	36	5.3	6.31	6.11	3.7	6.9
	1	6	4.1	31	5.0	6.37	6.11	3.7	6.8
	2	12	3.7	28	5.4	6.33	6.23	3.6	6.7
	3	10	3.9	30	5.5	6.36	6.18	3.5	6.6
	4	17	4.3	17	4.4	6.26	6.24	3.4	6.6
	5	15	3.9	15	4.5	6.40	6.25	3.4	6.5
	6	11	3.8	0	3.7	6.31	6.23	3.2	6.5
	7	10	3.6	0	3.5	6.34	6.35	3.2	6.5
	8	0	3.2	0	3.1	6.44	6.46	3.1	6.4
	9	0	3.0	0	3.3	6.44	6.63	3.1	6.3
	10	0	3.7	0	3.0	6.55	6.50	3.0	6.2
	11	0	4.1	0	3.1	6.34	6.53	3.0	6.2
	12	0	4.0	16	3.7	6.43	6.48	3.2	6.3
	13	0	4.1	19	3.8	6.45	6.54	3.3	6.3
	14	3	4.9	38	4.1	6.38	6.44	3.4	6.3
	15	4	4.5	42	4.3	6.32	6.51	3.6	6.2
	16	5	4.8	44	4.8	6.35	6.41	3.7	6.2
	17	6	5.4	48	4.5	6.44	6.30	3.8	6.2
	18	17	4.0	49	5.7	6.34	6.39	4.0	6.2
	19	15	4.8	54	5.6	6.35	6.40	3.8	5.9
	20	18	4.6	17	3.2	6.30	6.39	3.8	6.0
	21	16	4.3	14	3.5	6.29	6.39	3.7	5.7
	22	3	3.9	0	2.2	6.39	6.52	3.6	5.9
	23	2	3.6	0	2.9	6.39	6.43	3.5	5.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
11	0	1	3.0	2	2.9	6.41	6.54	3.4	5.8
	1	0	3.5	3	2.5	6.51	6.52	3.4	5.7
	2	0	3.2	0	3.1	6.35	6.60	3.3	5.6
	3	0	3.0	0	2.9	6.35	6.55	3.3	5.6
	4	0	3.2	0	2.6	6.40	6.53	3.2	5.6
	5	0	3.1	0	2.8	6.42	6.61	3.1	5.6
	6	22	4.3	0	3.0	6.54	6.58	3.1	5.6
	7	24	4.6	0	2.5	6.51	6.66	3.0	5.6
	8	21	4.3	23	4.0	6.48	6.69	3.0	5.5
	9	23	4.2	25	4.4	6.53	6.52	3.0	5.4
	10	29	4.5	32	5.3	6.49	6.47	2.9	5.4
	11	32	4.7	35	5.1	6.38	6.49	2.9	5.4
	12	49	5.8	38	5.4	6.39	6.34	2.9	5.4
	13	54	5.9	42	5.9	6.34	6.35	2.9	5.5
	14	48	5.8	43	7.4	6.21	6.32	2.9	5.5
	15	53	6.0	47	7.3	6.17	6.14	2.9	5.8
	16	38	5.4	25	6.8	6.09	6.04	2.9	6.0
	17	42	5.6	22	7.0	6.22	6.23	2.9	6.4
	18	41	5.4	33	5.4	6.18	6.18	2.9	6.8
	19	37	5.3	36	6.0	6.10	6.17	2.9	6.7
	20	18	4.4	24	6.3	6.19	6.18	2.9	6.8
	21	16	4.3	21	5.8	6.27	6.27	2.9	6.9
	22	14	4.0	36	5.9	6.26	6.32	3.0	7.0
	23	15	4.1	32	6.1	6.33	6.18	3.0	6.9
12	0	16	4.0	35	5.1	6.23	6.27	3.0	6.9
	1	0	3.5	31	5.4	6.39	6.27	3.0	6.7
	2	0	3.2	0	3.6	6.38	6.31	3.0	6.6
	3	0	3.3	0	3.4	6.44	6.53	3.0	6.6
	4	0	3.3	0	2.8	6.43	6.40	3.0	6.5
	5	0	3.3	0	2.8	6.40	6.59	3.0	6.4
	6	15	3.9	0	3.7	6.34	6.63	3.0	6.2
	7	17	4.0	0	3.6	6.45	6.46	3.0	6.1
	8	38	4.8	7	4.2	6.36	6.60	3.0	6.1
	9	41	5.4	8	4.2	6.32	6.53	2.9	6.0
	10	44	5.3	10	4.6	6.28	6.35	2.9	6.1
	11	48	5.4	11	4.6	6.24	6.48	2.8	6.1
	12	51	6.0	33	5.3	6.29	6.28	2.8	6.1
	13	56	6.1	36	5.6	6.24	6.32	2.8	6.1
	14	49	6.0	32	6.2	6.24	6.28	2.8	6.1
	15	54	6.2	35	6.6	6.19	6.17	2.9	6.1
	16	43	5.6	45	7.4	6.04	6.11	2.9	6.3
	17	39	5.2	42	7.6	6.08	6.09	2.9	6.5
	18	14	4.0	41	4.6	6.24	6.18	2.9	6.6
	19	13	4.1	37	5.3	6.33	6.16	2.9	6.4
	20	0	3.5	33	4.7	6.31	6.18	2.9	6.4
	21	0	3.3	30	5.2	6.21	6.26	3.0	6.2
	22	0	3.3	8	3.4	6.31	6.25	3.0	6.2
	23	0	3.3	7	3.7	6.42	6.33	3.0	6.1

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO$_2$/L)	DO in ASR#2 (mgO$_2$/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
13	0	0	3.2	2	3.4	6.24	6.40	3.0	6.1
	1	1	3.3	3	3.6	6.28	6.56	3.0	6.1
	2	0	3.3	0	3.1	6.42	6.40	3.0	6.1
	3	0	3.2	0	3.4	6.37	6.54	3.0	6.1
	4	2	3.2	0	4.0	6.39	6.54	3.0	6.1
	5	2	3.0	0	3.4	6.37	6.59	3.0	6.1
	6	20	4.3	0	3.2	6.31	6.56	2.9	6.0
	7	22	4.7	0	3.6	6.42	6.54	2.9	6.0
	8	44	6.5	28	4.8	6.38	6.37	3.0	6.1
	9	40	6.0	26	4.6	6.19	6.32	3.2	6.2
	10	54	7.6	41	6.0	6.19	6.42	3.2	6.2
	11	50	7.7	45	5.1	6.10	6.14	3.4	6.4
	12	59	7.5	51	7.6	6.07	6.27	3.6	6.5
	13	63	8.3	57	6.1	5.93	6.03	3.6	6.7
	14	66	8.7	71	7.4	5.90	5.99	3.8	6.8
	15	70	8.0	79	8.4	5.98	5.96	4.0	6.8
	16	26	7.0	43	3.7	5.86	5.90	4.0	6.9
	17	23	6.5	39	4.5	6.07	6.20	4.2	7.0
	18	0	3.9	0	3.7	6.01	6.20	4.3	7.0
	19	0	3.5	0	2.5	6.17	6.29	4.2	7.0
	20	0	3.2	0	2.4	6.07	6.33	4.0	6.7
	21	0	3.1	0	2.8	6.25	6.31	3.8	6.3
	22	0	3.3	0	3.7	6.16	6.30	3.6	6.2
	23	0	3.0	0	3.5	6.26	6.30	3.5	6.2
14	0	0	2.9	3	4.6	6.26	6.43	3.3	6.1
	1	0	2.9	3	5.0	6.33	6.31	3.2	6.1
	2	28	4.3	0	1.7	6.33	6.33	3.1	6.3
	3	30	4.5	0	2.1	6.15	6.38	3.0	6.1
	4	43	5.0	0	3.4	6.21	6.38	2.9	5.8
	5	46	5.1	0	2.6	6.19	6.41	2.8	5.6
	6	45	4.5	18	4.2	6.15	6.41	2.7	5.4
	7	50	4.4	20	4.8	6.15	6.48	2.5	5.0
	8	76	7.4	12	2.7	6.26	6.43	2.3	5.0
	9	85	7.8	13	2.6	6.06	6.30	2.3	5.1
	10	132	9.5	19	5.7	5.97	6.34	2.5	5.0
	11	120	9.7	21	5.1	5.76	6.07	2.5	5.0
	12	90	8.3	74	7.8	5.81	5.96	2.5	5.2
	13	99	8.5	82	7.4	5.92	6.09	2.5	5.5
	14	123	10.0	22	4.8	5.94	5.84	2.6	5.4
	15	136	10.5	24	4.3	5.65	6.06	2.6	5.7
	16	129	10.7	64	5.7	5.78	6.05	2.7	5.6
	17	117	11.1	71	5.5	5.64	5.86	2.8	5.5
	18	100	9.1	90	8.3	5.62	5.87	3.0	5.4
	19	111	9.3	81	8.2	5.79	5.72	3.0	5.4
	20	18	4.0	74	9.0	5.85	5.85	3.0	5.5
	21	16	4.3	67	9.4	6.07	6.02	2.8	5.6
	22	0	5.5	47	4.5	6.22	6.09	3.0	6.1
	23	0	5.7	53	5.2	6.01	6.14	3.0	6.6

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
15	0	22	5.8	12	2.4	6.01	6.22	3.7	6.8
	1	24	6.0	12	2.4	6.01	6.25	3.9	6.7
	2	39	5.2	0	2.3	6.23	6.32	4.0	6.5
	3	35	5.0	0	1.8	6.22	6.49	3.8	6.1
	4	24	3.7	3	0.0	6.31	6.41	3.6	5.7
	5	22	3.5	2	0.0	6.34	6.58	3.3	5.1
	6	72	5.8	0	3.1	6.26	6.74	3.0	4.5
	7	80	5.4	0	2.6	6.23	6.40	2.8	4.2
	8	96	6.8	0	2.5	6.20	6.39	2.4	4.0
	9	106	7.0	0	2.3	6.01	6.46	2.1	3.9
	10	114	8.3	42	5.1	6.12	6.44	1.9	3.8
	11	103	8.2	46	4.8	5.92	6.16	1.9	3.7
	12	68	6.2	97	8.6	6.04	6.23	1.9	3.8
	13	61	5.8	107	8.7	6.09	6.19	1.9	3.8
	14	90	8.1	79	6.0	6.13	6.16	2.0	3.9
	15	99	7.7	87	7.5	5.87	5.98	2.1	4.0
	16	137	10.2	46	5.4	5.84	6.02	2.1	4.1
	17	124	10.1	42	4.8	5.82	5.94	2.3	4.3
	18	64	8.1	94	5.6	5.74	5.92	2.3	4.4
	19	58	7.8	104	5.9	5.81	5.95	2.6	4.5
	20	6	5.5	122	7.1	5.94	6.04	2.9	4.5
	21	5	5.3	110	7.8	6.20	6.14	3.2	4.3
	22	0	4.6	38	5.0	6.18	6.06	3.5	4.7
	23	0	4.8	34	6.0	6.25	6.21	3.5	4.9
16	0	41	14.8	90	14.8	5.79	5.35	13.3	22.5
	1	37	14.5	90	15.3	5.73	5.55	13.1	22.3
	2	0	13.3	51	12.2	5.83	5.55	12.8	21.9
	3	0	13.3	51	12.2	5.87	5.67	12.9	22.1
	4	14	12.9	14	11.1	5.83	5.94	12.6	21.8
	5	14	12.9	14	11.1	5.94	6.00	12.5	21.6
	6	0	13.4	30	11.6	5.89	5.98	12.3	21.4
	7	0	13.4	30	11.6	5.88	5.75	12.6	21.8
	8	87	16.0	0	10.6	5.93	6.01	12.5	21.6
	9	87	16.0	0	10.6	5.55	5.85	12.3	21.4
	10	75	16.1	0	9.5	5.76	5.85	11.8	21.1
	11	75	16.1	0	9.5	5.64	5.91	11.7	20.9
	12	93	16.1	9	10.4	5.64	5.90	11.6	20.8
	13	93	16.1	9	10.4	5.54	5.70	11.3	20.7
	14	92	16.2	49	12.7	5.61	5.83	11.2	20.2
	15	92	16.2	49	12.7	5.59	5.64	11.0	20.0
	16	84	16.6	35	11.5	5.63	5.59	10.9	19.9
	17	84	16.6	35	11.5	5.54	5.58	11.0	20.0
	18	45	15.4	52	13.0	5.48	5.59	11.1	20.1
	19	45	15.4	52	13.0	5.68	5.63	11.4	20.4
	20	47	14.8	63	13.9	5.63	5.60	11.5	20.6
	21	47	14.8	63	13.9	5.58	5.63	11.5	20.6
	22	72	17.0	3	9.5	5.60	5.49	11.7	20.8
	23	72	17.0	3	9.5	5.64	5.66	11.7	20.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
17	0	48	17.0	3	9.5	5.46	5.75	12.0	21.1
	1	44	16.9	3	9.5	5.52	5.76	12.2	21.3
	2	2	15.4	42	12.5	5.55	5.72	12.6	21.8
	3	2	15.4	42	12.5	5.65	5.80	12.5	21.6
	4	0	14.3	61	14.5	5.73	5.67	13.4	22.6
	5	0	14.3	61	14.5	5.93	5.80	13.4	22.6
	6	0	14.2	43	12.6	5.75	5.74	13.5	22.8
	7	0	14.2	43	12.6	5.94	5.87	14.0	23.3
	8	8	17.4	24	10.0	5.92	5.93	13.5	22.8
	9	8	17.4	24	10.0	5.62	5.75	14.1	23.5
	10	0	14.7	0	11.9	5.82	5.94	14.5	23.6
	11	0	14.7	0	11.9	5.81	5.90	14.5	23.8
	12	0	15.3	38	11.2	5.86	5.87	14.4	23.8
	13	0	15.3	38	11.2	5.84	5.97	14.5	23.5
	14	70	12.8	0	11.4	5.92	5.95	14.5	23.8
	15	70	12.8	0	11.4	5.89	6.05	13.3	22.6
	16	40	14.3	23	10.5	5.83	5.98	12.3	21.4
	17	40	14.3	23	10.5	5.81	5.82	12.5	21.6
	18	0	10.7	0	10.2	5.86	5.81	11.8	20.9
	19	0	10.7	0	10.2	6.01	5.99	11.8	20.9
	20	0	8.4	44	12.1	6.06	6.19	11.2	20.2
	21	0	8.4	44	12.1	6.13	6.13	10.3	19.2
	22	35	8.8	0	9.7	6.20	6.01	10.0	18.9
	23	35	8.8	0	9.7	6.10	6.08	9.5	18.4
18	0	27	8.5	1	10.0	6.19	6.12	8.6	17.4
	1	19	8.3	3	10.2	6.19	6.23	8.6	17.4
	2	34	7.5	0	9.1	6.26	6.32	7.9	16.5
	3	34	7.5	0	9.1	6.17	6.22	7.6	16.2
	4	0	11.2	80	4.3	6.32	6.21	6.9	15.5
	5	0	11.2	80	4.3	6.00	6.36	7.6	15.0
	6	14	12.9	93	5.7	6.14	6.16	8.3	14.3
	7	14	12.9	93	5.7	5.90	6.22	9.0	13.6
	8	44	14.3	16	6.2	5.91	6.04	9.7	13.0
	9	44	14.3	16	6.2	5.94	6.10	9.9	13.4
	10	44	16.6	81	4.9	5.93	6.02	10.5	13.9
	11	44	16.6	81	4.9	5.72	5.95	11.0	14.1
	12	54	17.9	53	6.6	5.73	5.90	11.6	14.4
	13	54	17.9	53	6.6	5.67	5.90	12.1	14.9
	14	76	18.1	79	6.3	5.70	5.86	12.7	15.2
	15	76	18.1	79	6.3	5.58	5.79	12.8	15.4
	16	99	18.3	101	6.3	5.48	5.76	13.0	15.2
	17	99	18.3	101	6.3	5.39	5.69	12.9	14.5
	18	143	18.8	57	7.4	5.37	5.49	12.7	14.4
	19	143	18.8	57	7.4	5.33	5.47	11.8	13.7
	20	92	17.7	138	7.4	5.18	5.44	12.1	14.0
	21	92	17.7	138	7.4	5.48	5.37	11.9	13.5
	22	92	17.1	63	6.4	5.41	5.38	11.7	13.3
	23	92	17.1	63	6.4	5.41	5.65	11.7	13.3

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
19	0	119	18.1	63	5.1	5.44	5.63	11.7	13.2
	1	133	19.1	64	4.7	5.40	5.67	11.6	13.2
	2	128	20.0	51	4.7	5.22	5.53	11.5	13.2
	3	128	20.0	51	4.7	5.19	5.45	11.7	13.1
	4	95	17.4	48	2.8	5.19	5.51	11.8	13.4
	5	95	17.4	48	2.8	5.38	5.66	11.7	12.8
	6	102	18.0	0	1.3	5.41	5.75	11.7	12.8
	7	102	18.0	0	1.3	5.48	5.92	11.4	12.8
	8	98	19.8	32	1.7	5.45	5.83	11.7	12.8
	9	98	19.8	32	1.7	5.39	5.68	12.0	13.0
	10	143	20.1	56	6.5	5.40	5.76	12.4	13.2
	11	143	20.1	56	6.5	5.25	5.36	12.5	13.5
	12	139	20.5	68	7.2	5.25	5.43	12.2	13.5
	13	139	20.5	68	7.2	5.12	5.42	12.4	13.9
	14	139	20.0	86	7.5	5.05	5.21	12.1	14.2
	15	139	20.0	86	7.5	5.09	5.25	12.0	14.4
	16	147	19.8	43	5.8	5.03	5.29	11.9	14.2
	17	147	19.8	43	5.8	4.97	5.22	11.7	13.6
	18	129	20.1	20	2.3	5.05	5.23	11.6	14.2
	19	129	20.1	20	2.3	4.92	5.37	11.8	14.1
	20	104	18.4	3	3.6	5.08	5.47	11.8	14.0
	21	104	18.4	3	3.6	5.15	5.44	11.7	14.0
	22	90	17.7	11	4.3	5.19	5.46	11.9	14.3
	23	90	17.7	11	4.3	5.29	5.45	12.0	14.5
20	0	96	18.6	50	4.4	5.32	5.39	11.9	14.8
	1	107	19.6	55	4.4	5.25	5.54	12.2	14.4
	2	59	17.4	17	3.7	5.23	5.48	12.3	14.7
	3	59	17.4	17	3.7	5.24	5.59	12.9	14.5
	4	57	15.6	12	4.0	5.37	5.54	12.8	15.2
	5	57	15.6	12	4.0	5.37	5.68	12.4	14.9
	6	44	15.1	35	5.9	5.44	5.66	12.4	15.0
	7	44	15.1	35	5.9	5.48	5.60	12.6	15.3
	8	1	11.4	57	7.5	5.52	5.71	12.3	15.2
	9	1	11.4	57	7.5	5.73	5.91	11.9	15.2
	10	4	12.9	102	8.3	5.78	5.82	11.7	15.0
	11	4	12.9	102	8.3	5.76	5.69	11.6	15.0
	12	85	16.4	86	6.0	5.70	5.69	11.8	14.9
	13	85	16.4	86	6.0	5.40	5.58	11.9	14.2
	14	73	16.1	91	7.6	5.46	5.55	11.6	13.8
	15	73	16.1	91	7.6	5.46	5.44	11.6	13.7
	16	85	16.8	114	7.7	5.46	5.45	11.6	13.6
	17	85	16.8	114	7.7	5.35	5.37	11.7	13.7
	18	57	17.1	78	5.7	5.36	5.33	11.6	13.3
	19	57	17.1	78	5.7	5.22	5.48	11.9	14.0
	20	59	18.2	88	5.8	5.30	5.36	12.2	13.8
	21	59	18.2	88	5.8	5.22	5.29	12.5	14.9
	22	83	18.1	47	9.7	5.33	5.32	13.0	14.3
	23	83	18.1	47	9.7	5.31	5.29	12.8	14.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
21	0	75	18.3	56	5.7	5.15	5.22	13.0	15.9
	1	79	18.5	62	5.3	5.32	5.50	13.3	16.9
	2	42	17.0	48	5.5	5.28	5.38	13.1	15.9
	3	42	17.0	48	5.5	5.35	5.49	13.3	16.1
	4	21	15.8	33	4.7	5.33	5.51	13.5	16.2
	5	21	15.8	33	4.7	5.42	5.64	13.6	16.3
	6	11	15.5	10	3.7	5.44	5.76	13.7	16.4
	7	11	15.5	10	3.7	5.62	5.88	13.8	16.6
	8	17	15.5	3	0.0	5.65	5.72	13.9	16.8
	9	17	15.5	3	0.0	5.51	6.02	14.6	16.2
	10	18	17.4	53	0.7	5.62	6.00	13.9	15.9
	11	18	17.4	53	0.7	5.45	5.90	14.8	15.7
	12	23	12.9	40	9.4	5.46	5.85	14.6	14.9
	13	23	12.9	40	9.4	5.75	5.84	13.5	14.6
	14	11	14.1	49	0.0	5.76	5.75	13.4	15.3
	15	11	14.1	49	0.0	5.71	5.99	13.5	14.9
	16	0	13.5	0	2.5	5.58	5.87	13.1	14.3
	17	0	13.5	0	2.5	5.64	5.96	12.6	14.2
	18	0	11.1	21	0.4	5.71	5.83	13.0	14.2
	19	0	11.1	21	0.4	5.71	6.06	12.8	13.3
	20	0	10.3	0	2.6	5.84	6.03	12.2	12.8
	21	0	10.3	0	2.6	5.89	5.98	11.8	12.7
	22	0	8.1	12	0.0	5.96	6.14	11.2	12.1
	23	0	8.1	12	0.0	5.82	6.18	10.8	11.4
22	0	21	7.6	9	3.4	5.93	6.38	9.9	10.4
	1	23	7.3	9	3.6	6.02	6.11	9.3	9.9
	2	14	6.9	20	0.0	6.05	6.26	8.3	9.6
	3	14	6.9	20	0.0	5.94	6.26	8.0	8.8
	4	67	10.1	0	0.0	6.14	6.38	7.3	8.0
	5	67	10.1	0	0.0	6.03	6.36	6.8	7.4
	6	57	11.0	0	2.9	5.89	6.21	6.8	7.6
	7	57	11.0	0	2.9	6.00	6.18	6.8	7.8
	8	70	10.7	52	5.0	5.93	6.19	7.0	7.8
	9	70	10.7	52	5.0	5.84	6.03	6.9	8.0
	10	18	10.3	99	6.0	5.86	6.03	6.8	8.2
	11	18	10.3	99	6.0	5.93	5.97	7.2	8.4
	12	35	11.0	111	7.3	5.98	5.96	7.5	8.6
	13	35	11.0	111	7.3	5.87	5.94	7.7	8.6
	14	59	11.5	104	7.2	5.80	5.95	8.0	8.8
	15	59	11.5	104	7.2	5.77	5.71	8.3	8.9
	16	52	11.4	111	6.9	5.82	5.87	8.0	8.8
	17	52	11.4	111	6.9	5.88	5.91	8.1	8.8
	18	50	11.0	55	3.4	5.86	5.87	8.0	8.7
	19	50	11.0	55	3.4	5.82	6.03	8.0	8.5
	20	1	8.1	53	3.9	5.93	5.94	8.0	8.5
	21	1	8.1	53	3.9	6.10	6.10	7.9	8.5
	22	0	8.0	50	4.1	6.12	6.20	7.8	8.4
	23	0	8.0	50	4.1	6.10	6.20	7.8	8.5

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
23	0	3	8.4	0	1.7	6.04	6.12	7.8	8.5
	1	3	8.8	0	1.7	6.07	6.42	7.8	8.5
	2	24	8.1	0	0.3	6.15	6.38	7.9	8.7
	3	0	8.7	0	0.3	6.12	6.41	7.6	8.5
	4	4	8.4	0	0.2	6.13	6.50	7.7	8.4
	5	66	11.8	0	0.2	6.20	6.53	7.8	8.2
	6	76	12.6	0	0.6	5.89	6.19	7.8	8.0
	7	98	12.6	0	0.6	5.95	6.21	7.8	7.8
	8	44	10.7	64	4.8	5.89	6.23	7.7	8.0
	9	27	9.4	64	4.8	5.94	6.15	7.6	7.9
	10	93	11.8	84	7.4	6.00	6.09	7.6	8.4
	11	100	13.9	84	7.4	5.85	5.92	7.4	8.6
	12	91	14.6	114	10.9	5.79	5.87	7.4	8.5
	13	116	15.2	114	10.9	5.57	5.63	7.8	9.9
	14	117	16.5	77	6.3	5.47	5.41	8.0	10.0
	15	79	15.9	77	6.3	5.49	5.62	8.2	10.5
	16	65	12.2	16	7.1	5.52	5.64	8.9	11.1
	17	1	9.6	16	7.1	5.70	5.90	8.9	11.4
	18	1	9.9	0	2.7	5.97	5.89	8.9	12.1
	19	0	11.1	0	2.7	5.91	6.12	9.0	12.7
	20	5	11.5	0	0.6	5.73	6.12	9.3	12.7
	21	0	11.8	0	0.6	5.80	6.06	9.7	12.8
	22	0	12.5	0	2.2	5.85	6.06	10.1	12.4
	23	0	10.5	0	2.2	5.77	6.10	10.5	12.5
24	0	6	14.2	17	0.6	5.83	6.24	10.5	12.5
	1	22	11.2	15	4.0	5.83	5.99	10.8	12.5
	2	4	10.8	0	0.4	5.86	5.98	10.8	12.5
	3	1	10.3	0	0.4	5.97	6.32	10.6	12.5
	4	23	10.3	0	1.3	5.95	6.39	10.4	11.9
	5	0	8.3	0	1.3	5.87	6.21	10.0	11.3
	6	31	9.9	18	0.8	6.19	6.32	9.5	10.8
	7	53	11.1	18	0.8	6.01	6.40	9.1	10.0
	8	81	9.4	42	7.1	5.93	6.37	8.8	9.6
	9	77	11.1	42	7.1	5.98	6.06	7.9	9.4
	10	73	11.5	47	2.4	6.01	6.10	7.4	9.1
	11	94	12.9	47	2.4	5.97	6.13	7.3	8.8
	12	107	15.0	38	4.8	5.92	6.20	7.3	8.7
	13	92	14.3	38	4.8	5.79	6.05	7.6	9.4
	14	56	14.5	53	4.4	5.89	6.12	7.8	9.3
	15	32	12.1	53	4.4	5.85	6.03	8.4	10.0
	16	5	12.3	43	3.9	5.98	6.27	8.8	10.3
	17	27	12.0	43	3.9	6.01	6.30	9.3	10.4
	18	33	14.0	42	1.3	6.10	6.32	9.6	11.0
	19	42	12.7	42	1.3	5.96	6.31	10.0	10.7
	20	0	12.1	14	0.8	6.00	6.34	10.1	10.7
	21	0	10.3	14	0.8	6.03	6.48	10.3	10.6
	22	0	10.8	0	0.8	6.23	6.50	10.3	10.6
	23	0	9.6	0	0.8	6.14	6.64	10.2	10.5

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
25	0	0	8.5	0	3.8	6.30	6.58	10.0	10.5
	1	0	8.5	0	3.8	6.37	6.62	9.6	10.3
	2	37	9.2	0	0.3	6.42	6.64	9.3	10.4
	3	37	9.2	0	0.3	6.17	6.53	8.8	10.1
	4	41	8.7	0	1.7	6.28	6.57	8.3	9.4
	5	41	8.7	0	1.7	6.25	6.65	7.9	8.7
	6	55	9.6	0	2.5	6.25	6.63	7.4	8.5
	7	55	9.6	0	2.5	6.15	6.53	7.1	8.4
	8	68	10.7	19	5.7	6.27	6.61	6.9	8.4
	9	68	10.7	19	5.7	6.10	6.26	6.7	8.7
	10	94	12.5	62	5.8	6.12	6.22	6.7	9.1
	11	94	12.5	62	5.8	5.85	6.24	6.8	9.4
	12	88	13.4	87	4.7	5.84	6.09	6.8	9.1
	13	88	13.4	87	4.7	5.81	6.10	7.2	9.0
	14	68	11.9	55	4.9	5.79	6.15	7.2	8.7
	15	68	11.9	55	4.9	5.82	6.09	7.4	8.6
	16	20	8.7	75	5.8	5.90	6.08	7.4	8.7
	17	20	8.7	75	5.8	6.15	6.20	7.4	8.7
	18	3	8.1	44	3.9	6.07	6.34	7.3	8.6
	19	3	8.1	44	3.9	6.26	6.47	7.4	8.6
	20	0	8.2	0	1.6	6.20	6.37	7.4	8.7
	21	0	8.2	0	1.6	6.24	6.49	7.6	8.9
	22	0	7.8	0	1.8	6.16	6.61	7.6	9.0
	23	0	7.8	0	1.8	6.20	6.58	7.5	9.1
26	0	2	7.0	0	2.5	6.27	6.73	7.5	9.0
	1	3	6.4	0	1.8	6.39	6.68	7.2	8.9
	2	32	6.8	0	2.7	6.34	6.63	6.9	8.8
	3	32	6.8	0	0.8	6.25	6.58	6.6	8.3
	4	85	9.0	33	2.7	6.34	6.77	6.1	7.7
	5	85	9.0	33	2.7	6.15	6.57	5.7	7.0
	6	45	6.1	62	6.2	6.11	6.48	5.3	6.6
	7	45	6.1	62	6.2	6.33	6.41	4.8	6.3
	8	33	6.2	86	7.1	6.38	6.60	4.5	5.9
	9	33	6.2	86	7.1	6.35	6.41	4.4	5.9
	10	11	4.5	48	5.7	6.37	6.42	4.3	5.9
	11	11	4.5	48	5.7	6.62	6.64	4.2	5.9
	12	19	4.7	41	4.3	6.53	6.61	4.0	6.0
	13	19	4.7	41	4.3	6.54	6.75	4.1	5.9
	14	25	5.1	44	3.7	6.56	6.79	3.8	5.7
	15	25	5.1	44	3.7	6.50	6.84	3.7	5.3
	16	34	5.8	34	3.0	6.57	6.62	3.7	5.3
	17	34	5.8	34	3.0	6.43	6.77	3.7	5.1
	18	44	6.4	32	3.0	6.39	6.64	3.7	5.0
	19	44	6.4	32	3.0	6.34	6.77	3.7	4.9
	20	44	6.4	38	3.0	6.43	6.61	3.7	4.9
	21	44	6.4	38	3.0	6.42	6.60	3.7	4.8
	22	51	6.7	22	3.0	6.33	6.61	3.7	4.7
	23	51	6.7	22	3.0	6.44	6.61	3.7	4.7

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
27	0	59	7.5	21	1.5	6.34	6.58	3.7	4.8
	1	59	7.5	21	1.5	6.41	6.72	3.8	4.8
	2	59	7.5	2	1.0	6.37	6.76	3.8	4.7
	3	59	7.5	2	1.0	6.32	6.69	3.9	4.7
	4	79	8.4	0	0.3	6.36	6.66	3.9	4.7
	5	79	8.4	0	0.3	6.21	6.60	3.9	4.6
	6	47	6.6	27	1.5	6.12	6.71	3.9	4.5
	7	47	6.6	27	1.5	6.27	6.63	3.8	4.3
	8	4	4.0	39	3.3	6.26	6.75	3.8	4.1
	9	4	4.0	39	3.3	6.41	6.68	3.7	4.0
	10	66	7.1	0	1.1	6.44	6.71	3.7	4.1
	11	66	7.1	0	1.1	6.35	6.63	3.6	4.3
	12	75	8.2	0	3.5	6.32	6.68	3.6	4.2
	13	75	8.2	0	3.5	6.21	6.57	3.6	4.5
	14	31	5.9	27	4.5	6.10	6.57	3.6	5.0
	15	31	5.9	27	4.5	6.31	6.54	3.7	5.5
	16	0	4.9	25	2.7	6.20	6.55	3.7	5.7
	17	0	4.9	25	2.7	6.30	6.75	3.9	5.7
	18	16	5.0	6	3.3	6.46	6.55	4.1	5.9
	19	16	5.0	6	3.3	6.33	6.57	4.1	5.9
	20	0	4.3	53	5.8	6.37	6.63	4.0	6.0
	21	0	4.3	53	5.8	6.48	6.52	3.8	6.0
	22	0	4.2	9	3.0	6.39	6.58	4.1	6.1
	23	0	4.2	9	3.0	6.44	6.76	4.0	6.2
28	0	1	4.5	0	1.9	6.47	6.77	4.0	6.3
	1	1	4.5	0	1.9	6.49	6.67	4.1	6.3
	2	1	4.5	0	2.3	6.55	6.86	4.1	6.2
	3	1	4.5	0	2.3	6.44	6.83	4.1	6.2
	4	0	4.5	0	1.7	6.39	6.70	4.1	6.2
	5	0	4.5	0	1.7	6.50	6.86	4.2	6.2
	6	0	4.5	0	1.1	6.41	6.75	4.2	6.1
	7	0	4.5	0	1.1	6.52	6.92	4.2	6.0
	8	72	8.3	33	3.8	6.46	6.93	4.2	5.8
	9	72	8.3	33	3.8	6.14	6.61	4.4	5.7
	10	75	8.4	45	8.8	6.26	6.58	4.2	5.6
	11	75	8.4	45	8.8	6.23	6.29	4.3	6.1
	12	72	8.1	84	9.8	6.29	6.31	4.1	6.6
	13	72	8.1	84	9.8	6.32	6.18	4.0	7.0
	14	58	8.3	130	12.5	6.14	6.09	4.0	7.3
	15	58	8.3	130	12.5	6.20	6.04	4.1	7.6
	16	62	8.7	125	10.0	6.21	5.96	4.3	7.9
	17	62	8.7	125	10.0	6.11	6.01	4.3	8.1
	18	70	9.1	56	6.2	6.04	6.03	4.5	7.9
	19	70	9.1	56	6.2	5.94	6.15	4.7	7.9
	20	0	5.3	21	5.7	6.10	6.09	4.7	7.8
	21	0	5.3	21	5.7	6.38	6.48	4.6	8.0
	22	0	5.4	0	0.0	6.24	6.51	4.8	8.2
	23	0	5.4	0	0.0	6.23	6.62	4.9	8.2

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
29	0	16	4.8	3	0.0	6.47	6.65	4.9	7.5
	1	16	4.8	2	0.0	6.31	6.79	4.7	6.7
	2	14	4.3	0	0.0	6.35	6.77	4.5	5.9
	3	14	4.3	0	0.0	6.36	6.87	4.2	5.2
	4	9	3.9	0	0.0	6.46	6.73	4.0	4.8
	5	9	3.9	0	0.0	6.50	6.89	3.8	4.5
	6	31	4.9	0	2.7	6.58	6.81	3.6	4.3
	7	31	4.9	0	2.7	6.40	6.81	3.5	4.0
	8	31	5.3	0	1.7	6.38	6.73	3.4	4.3
	9	31	5.3	0	1.7	6.42	6.81	3.4	4.5
	10	80	10.6	12	0.5	6.32	6.72	3.4	4.7
	11	80	10.6	12	0.5	6.00	6.49	4.0	4.9
	12	85	9.3	30	3.4	6.01	6.52	4.3	5.3
	13	85	9.3	30	3.4	6.10	6.27	4.3	5.2
	14	85	10.6	83	3.3	5.83	6.22	4.4	5.3
	15	85	10.6	83	3.3	5.95	6.23	4.7	5.1
	16	96	11.2	100	8.2	5.90	6.16	4.8	5.1
	17	96	11.2	100	8.2	5.73	5.89	4.8	5.1
	18	97	8.1	92	8.8	5.83	5.90	5.1	5.6
	19	97	8.1	92	8.8	5.84	5.90	4.9	5.8
	20	85	8.7	85	7.3	5.96	5.97	4.2	5.5
	21	85	8.7	85	7.3	5.95	6.05	4.0	5.3
	22	85	8.7	21	8.3	5.99	6.00	3.9	5.7
	23	85	8.7	21	8.3	5.86	5.91	3.8	6.3
30	0	86	9.4	38	4.7	5.89	6.04	3.8	7.1
	1	88	10.1	35	5.0	5.77	6.10	4.0	7.1
	2	103	9.9	48	7.2	5.75	6.11	4.2	7.4
	3	103	9.9	48	7.2	5.89	6.11	3.7	7.2
	4	103	10.7	1	5.2	5.82	6.05	4.1	7.4
	5	103	10.7	1	5.2	5.87	6.13	4.3	7.9
	6	77	10.7	15	6.5	5.74	6.14	4.3	8.2
	7	77	10.7	15	6.5	5.84	6.18	3.9	8.3
	8	26	9.9	67	4.7	5.87	5.99	4.9	9.3
	9	26	9.9	67	4.7	5.95	6.18	5.3	9.3
	10	55	9.4	0	5.5	5.90	6.04	6.0	9.4
	11	55	9.4	0	5.5	6.00	6.11	6.4	9.8
	12	46	10.8	5	2.5	5.91	6.12	6.1	9.7
	13	46	10.8	5	2.5	5.72	6.20	6.9	9.8
	14	69	11.8	0	5.4	5.77	6.17	6.7	10.1
	15	69	11.8	0	5.4	5.62	5.96	6.8	10.3
	16	95	9.3	0	10.4	5.66	5.98	7.0	10.7
	17	95	9.3	0	10.4	5.72	5.74	6.5	11.2
	18	95	10.6	34	5.5	5.74	5.80	5.9	11.3
	19	95	10.6	34	5.5	5.63	5.88	5.6	10.8
	20	61	9.0	9	8.4	5.58	5.68	5.4	10.6
	21	61	9.0	9	8.4	5.78	5.82	5.3	10.8
	22	35	8.6	30	6.3	5.82	5.91	5.3	10.9
	23	35	8.6	30	6.3	5.73	5.90	5.5	11.0

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
31	0	32	8.2	29	6.8	5.73	6.02	5.6	11.0
	1	28	8.6	26	7.0	5.94	6.05	5.7	11.2
	2	44	9.5	13	5.0	5.79	6.05	6.1	11.2
	3	44	9.5	13	5.0	5.76	6.02	6.2	11.2
	4	49	10.1	0	6.2	5.81	6.09	6.3	11.0
	5	49	10.1	0	6.2	5.86	6.10	6.5	11.0
	6	55	10.2	18	6.4	5.70	5.97	6.5	11.4
	7	55	10.2	18	6.4	5.80	6.01	6.5	11.6
	8	68	11.2	21	6.6	5.70	6.05	6.6	11.6
	9	68	11.2	21	6.6	5.73	6.01	6.6	11.6
	10	62	10.6	50	9.9	5.74	5.84	6.7	11.7
	11	62	10.6	50	9.9	5.73	5.88	6.7	11.7
	12	21	8.1	61	13.4	5.65	5.86	6.7	12.0
	13	21	8.1	61	13.4	5.86	5.75	6.5	12.3
	14	30	8.0	47	11.0	5.85	5.75	6.6	13.1
	15	30	8.0	47	11.0	5.92	5.81	6.4	13.7
	16	34	8.2	30	12.1	5.75	5.78	6.4	13.5
	17	34	8.2	30	12.1	5.82	5.69	6.3	13.7
	18	0	6.9	38	9.0	5.87	5.75	6.2	14.1
	19	0	6.9	38	9.0	5.91	5.90	6.2	14.0
	20	10	7.6	0	6.8	5.83	5.93	6.3	13.9
	21	10	7.6	0	6.8	5.96	6.05	6.4	13.7
	22	9	7.8	0	5.7	6.00	6.09	6.4	13.5
	23	9	7.8	0	5.7	5.99	6.07	6.4	13.2
32	0	4	7.9	11	7.5	6.00	6.15	6.6	13.0
	1	3	8.1	13	7.0	5.95	6.04	6.8	13.2
	2	19	9.2	5	4.1	5.90	6.08	6.9	13.0
	3	19	9.2	5	4.1	5.78	6.04	7.4	12.8
	4	29	9.5	0	6.2	5.81	6.18	7.2	12.5
	5	29	9.5	0	6.2	5.80	6.12	7.2	12.4
	6	2	11.0	27	3.4	5.90	6.13	7.3	12.5
	7	2	11.0	27	3.4	5.90	6.08	7.9	12.4
	8	10	8.7	18	5.8	5.88	6.30	8.3	12.7
	9	10	8.7	18	5.8	6.10	6.29	8.1	12.0
	10	18	9.2	9	5.7	6.16	6.24	8.2	12.1
	11	18	9.2	9	5.7	6.21	6.29	8.4	12.1
	12	46	11.9	7	5.5	6.04	6.20	8.0	12.2
	13	46	11.9	7	5.5	5.87	6.11	8.1	12.8
	14	60	12.9	0	5.0	5.78	5.98	8.3	12.7
	15	60	12.9	0	5.0	5.86	6.03	8.4	12.7
	16	80	12.8	36	5.5	5.83	5.91	8.0	13.1
	17	80	12.8	36	5.5	5.91	5.89	8.6	12.5
	18	5	9.1	58	7.8	5.93	5.94	8.0	12.3
	19	5	9.1	58	7.8	6.24	6.01	8.4	12.5
	20	23	11.8	32	2.8	6.10	6.18	8.2	12.1
	21	23	11.8	32	2.8	6.02	6.23	8.6	11.8
	22	12	9.7	0	4.7	6.00	6.27	8.8	12.0
	23	12	9.7	0	4.7	6.09	6.41	8.7	12.1

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
33	0	5	5.2	12	3.1	5.61	5.79	4.7	7.4
	1	7	5.2	12	3.3	5.57	5.86	4.7	6.9
	2	24	5.4	11	4.0	5.64	5.83	4.5	6.7
	3	24	5.4	11	4.0	5.38	5.69	4.2	6.6
	4	26	5.7	29	5.0	5.37	5.81	4.1	6.5
	5	26	5.7	29	5.0	5.44	5.50	4.0	6.6
	6	32	6.0	27	4.7	5.32	5.64	4.0	6.6
	7	32	6.0	27	4.7	5.27	5.47	4.0	6.6
	8	42	6.3	22	5.7	5.25	5.47	4.0	6.6
	9	42	6.3	22	5.7	5.27	5.43	3.9	6.6
	10	41	6.6	23	6.4	5.14	5.32	3.9	7.1
	11	41	6.6	23	6.4	5.17	5.33	3.9	7.3
	12	32	6.6	29	6.2	4.98	5.19	4.1	8.0
	13	32	6.6	29	6.2	5.18	5.28	4.2	8.2
	14	76	9.1	31	6.7	5.14	5.16	4.5	8.3
	15	76	9.1	31	6.7	4.58	4.84	4.5	8.9
	16	64	8.7	64	9.6	4.55	4.77	4.7	8.6
	17	64	8.7	64	9.6	4.48	4.52	4.7	8.7
	18	18	6.1	76	11.3	4.52	4.40	4.8	9.4
	19	18	6.1	76	11.3	5.00	4.60	4.8	9.8
	20	16	5.9	35	8.0	5.25	4.51	4.7	10.2
	21	16	5.9	35	8.0	5.14	5.05	4.7	9.8
	22	4	5.4	2	3.3	5.13	4.98	4.8	10.2
	23	4	5.4	2	3.3	5.21	5.60	4.8	9.9
34	0	5	5.9	13	2.3	5.23	5.64	4.8	8.7
	1	10	6.1	15	2.5	5.14	5.59	5.0	7.9
	2	16	6.6	18	3.0	5.17	5.63	5.1	7.3
	3	16	6.6	18	3.0	5.08	5.52	5.3	7.1
	4	17	7.0	27	2.8	5.02	5.57	5.3	7.1
	5	13	7.1	27	2.8	5.01	5.49	5.5	7.1
	6	10	7.3	34	3.0	4.99	5.37	5.8	7.1
	7	10	7.3	34	3.0	4.99	5.50	6.1	7.1
	8	13	7.6	36	3.2	5.02	5.43	6.3	7.2
	9	19	7.7	36	3.2	5.06	5.44	6.4	7.2
	10	17	9.0	37	2.7	4.99	5.19	6.4	7.3
	11	24	8.6	37	2.7	4.72	5.30	7.0	7.8
	12	34	9.9	32	1.9	4.67	5.12	7.0	7.6
	13	35	11.4	32	1.9	4.54	5.03	7.3	8.0
	14	29	11.9	31	2.3	4.32	5.08	8.1	8.3
	15	30	11.4	31	2.3	4.14	4.87	8.9	9.3
	16	16	10.3	29	3.4	4.25	4.94	9.1	9.4
	17	2	10.3	29	3.4	4.55	4.98	9.0	9.7
	18	1	10.3	13	3.5	4.53	4.91	9.3	10.5
	19	0	10.0	13	3.5	4.56	5.10	9.0	11.9
	20	1	10.5	14	3.4	4.70	5.18	9.5	11.6
	21	0	10.7	14	3.4	4.63	5.14	9.6	11.8
	22	7	10.2	0	3.7	4.54	5.06	9.8	12.1
	23	11	10.4	0	3.7	4.67	5.20	9.6	12.4

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
35	0	18	11.2	8	3.1	4.59	5.18	9.4	12.3
	1	20	11.4	9	3.5	4.56	5.17	9.6	11.9
	2	33	11.2	10	4.3	4.54	5.13	9.6	12.1
	3	33	11.2	10	4.3	4.40	4.91	9.5	12.0
	4	40	12.2	18	4.1	4.38	5.00	9.0	12.0
	5	40	12.2	18	4.1	4.21	4.78	9.3	11.8
	6	35	11.6	19	4.4	4.28	4.78	9.3	12.1
	7	35	11.6	19	4.4	4.40	4.93	9.2	11.9
	8	24	12.4	36	3.7	4.23	4.90	9.1	11.9
	9	24	12.4	36	3.7	4.31	4.92	9.8	12.0
	10	30	12.2	25	4.1	4.24	4.70	10.1	12.0
	11	30	12.2	25	4.1	4.22	4.82	10.2	12.0
	12	27	12.4	33	4.2	4.19	4.76	10.0	12.1
	13	27	12.4	33	4.2	4.04	4.76	10.3	12.2
	14	32	12.2	6	3.7	4.16	4.61	10.2	12.3
	15	32	12.2	6	3.7	4.17	4.81	10.3	12.6
	16	39	12.5	13	3.5	4.19	4.75	10.0	12.7
	17	39	12.5	13	3.5	4.12	4.88	9.4	12.4
	18	42	12.9	13	4.0	4.10	4.65	9.8	12.4
	19	42	12.9	13	4.0	3.93	4.63	9.8	12.5
	20	26	12.7	21	3.3	3.89	4.66	10.0	12.8
	21	26	12.7	21	3.3	3.98	4.64	10.3	12.8
	22	21	12.4	18	3.9	4.06	4.82	10.5	12.7
	23	21	12.4	18	3.9	4.13	4.77	10.5	12.7
36	0	20	12.5	21	3.2	4.28	4.70	10.6	13.0
	1	13	12.3	23	3.4	4.10	4.85	10.7	13.0
	2	17	12.3	17	3.0	4.24	5.00	10.8	12.7
	3	17	12.9	17	3.0	4.23	4.83	10.8	12.6
	4	31	14.0	0	1.4	4.02	4.89	11.0	12.9
	5	32	14.2	0	1.4	3.81	4.90	11.3	13.1
	6	23	13.2	1	2.8	3.85	4.97	11.5	13.0
	7	19	12.0	1	2.8	3.98	4.87	11.4	13.1
	8	7	12.1	16	3.3	4.34	5.04	10.9	13.0
	9	26	11.5	16	3.3	4.30	4.96	10.9	12.8
	10	20	12.2	16	3.5	4.37	5.05	10.3	12.6
	11	36	11.4	16	3.5	4.16	4.99	10.3	12.2
	12	28	11.9	12	3.7	4.32	4.83	9.7	12.1
	13	45	11.4	12	3.7	4.26	4.94	9.7	11.9
	14	39	11.8	7	3.8	4.23	4.75	9.1	11.8
	15	39	11.8	7	3.8	4.08	4.75	9.1	11.9
	16	27	10.4	15	5.3	4.19	4.72	9.1	12.0
	17	26	9.9	15	5.3	4.38	4.92	8.8	12.0
	18	14	9.1	31	5.2	4.49	4.75	8.4	12.0
	19	13	9.3	31	5.2	4.66	5.00	8.2	11.6
	20	22	9.1	40	4.9	4.48	4.88	8.2	11.4
	21	11	9.5	40	4.9	4.55	4.89	7.8	10.9
	22	37	8.8	12	4.9	4.65	4.83	8.1	10.6
	23	25	9.2	12	4.9	4.58	4.89	7.4	10.6

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
37	0	22	9.1	24	4.4	5.16	5.34	7.4	10.6
	1	31	8.8	16	5.2	5.06	5.40	7.6	10.5
	2	27	9.0	32	4.2	5.01	5.24	7.2	10.7
	3	30	9.3	29	4.5	5.12	5.43	7.2	10.4
	4	28	9.0	10	5.9	4.93	5.37	7.3	10.1
	5	25	8.8	11	5.2	5.04	5.31	7.2	10.7
	6	14	9.0	40	5.2	4.99	5.28	7.2	10.8
	7	15	9.8	44	5.3	5.05	5.43	7.4	10.8
	8	32	10.4	16	4.5	5.07	5.22	7.9	11.0
	9	35	11.4	18	4.3	4.98	5.37	8.0	11.2
	10	54	12.4	15	4.6	4.76	5.22	8.4	11.5
	11	60	12.0	17	4.3	4.66	5.03	8.7	11.8
	12	48	11.6	19	4.1	4.63	5.05	8.5	11.6
	13	44	11.4	21	3.8	4.72	5.09	8.6	11.6
	14	10	9.9	17	4.0	4.63	5.28	8.5	11.3
	15	9	10.1	19	4.2	5.05	5.44	8.7	11.4
	16	0	9.3	18	4.7	4.99	5.32	8.9	11.7
	17	0	9.2	16	5.0	5.00	5.35	8.9	11.8
	18	3	9.9	8	3.2	5.19	5.37	8.9	12.1
	19	4	10.1	7	3.8	5.08	5.49	9.1	12.2
	20	0	10.9	12	3.3	4.99	5.36	9.3	12.4
	21	0	11.2	11	3.1	4.87	5.42	9.7	12.6
	22	0	11.3	28	3.7	4.86	5.40	10.2	12.7
	23	0	11.5	25	4.0	4.80	5.26	10.4	12.7
38	0	11	11.5	14	3.4	4.80	5.21	10.7	13.0
	1	9	12.0	16	3.1	4.77	5.26	10.6	12.9
	2	7	11.9	25	4.1	4.84	5.37	10.7	13.0
	3	8	11.9	25	4.1	4.73	5.17	10.9	13.1
	4	15	12.1	31	4.5	4.75	5.23	11.0	13.4
	5	14	12.1	31	4.5	4.81	5.17	11.0	13.2
	6	17	11.8	21	5.2	4.86	5.30	10.9	13.4
	7	19	11.8	21	5.2	4.85	5.12	10.7	13.5
	8	13	12.3	26	3.5	4.79	5.19	10.6	13.6
	9	14	12.3	26	3.5	4.88	5.34	10.8	13.5
	10	13	12.6	27	3.4	5.09	5.42	10.9	13.3
	11	15	12.6	27	3.4	5.01	5.38	11.1	13.2
	12	6	13.1	40	3.2	4.94	5.27	11.2	13.1
	13	7	13.1	40	3.2	5.01	5.33	11.6	13.2
	14	5	11.7	23	2.9	4.96	5.35	11.9	13.3
	15	4	11.7	23	2.9	5.00	5.54	11.6	12.9
	16	11	12.3	11	1.7	5.17	5.53	11.4	12.7
	17	12	12.3	11	1.7	4.98	5.47	11.4	12.7
	18	21	13.3	0	1.5	5.09	5.51	11.2	12.4
	19	23	13.3	0	1.5	4.95	5.45	11.5	12.8
	20	22	12.4	0	1.9	4.86	5.50	11.5	12.8
	21	20	12.4	0	1.9	5.02	5.62	11.3	12.6
	22	15	11.7	0	3.5	4.92	5.46	11.1	12.7
	23	14	11.7	0	3.5	5.19	5.44	10.9	12.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
39	0	15	11.7	0	3.5	5.20	5.55	10.7	13.2
	1	14	11.8	0	3.0	5.15	5.47	10.6	13.4
	2	10	11.5	0	4.0	5.07	5.53	10.6	13.4
	3	11	11.5	0	3.7	5.14	5.51	10.6	13.6
	4	7	11.4	14	4.3	5.28	5.51	10.5	13.7
	5	6	11.2	13	3.8	5.30	5.65	10.6	13.7
	6	5	10.7	25	3.6	5.20	5.57	10.5	13.5
	7	4	10.8	23	3.3	5.37	5.68	10.3	13.1
	8	3	10.4	21	2.7	5.35	5.74	10.3	12.7
	9	4	10.8	19	2.4	5.34	5.78	10.1	12.2
	10	2	10.6	3	1.6	5.27	5.72	10.2	11.9
	11	3	10.7	4	1.5	5.28	5.80	10.1	11.8
	12	26	10.7	0	1.3	5.33	5.87	10.2	11.6
	13	29	10.8	0	1.2	5.27	5.84	9.7	11.1
	14	75	11.2	0	3.3	5.06	5.65	9.4	10.5
	15	68	10.7	0	3.4	5.06	5.51	8.4	10.0
	16	35	10.8	7	2.3	4.99	5.50	7.7	9.9
	17	39	10.8	6	2.5	5.12	5.58	8.0	10.1
	18	0	9.0	0	3.3	5.19	5.63	8.1	10.2
	19	0	8.8	0	3.6	5.38	5.72	8.3	10.6
	20	1	8.0	16	2.3	5.42	5.84	8.4	11.1
	21	1	7.6	15	2.4	5.57	5.99	8.1	10.4
	22	7	7.2	0	2.8	5.70	5.98	7.8	9.7
	23	6	7.3	0	2.5	5.66	6.13	7.3	9.4
40	0	10	7.2	0	2.8	5.72	6.15	7.1	9.2
	1	8	7.1	0	3.1	5.79	6.12	6.8	9.2
	2	0	7.7	6	1.9	5.73	6.12	6.6	9.0
	3	0	7.7	5	1.7	5.70	6.20	6.9	9.2
	4	3	7.8	2	2.2	5.66	6.16	7.1	9.0
	5	3	7.6	2	2.6	5.73	6.13	7.2	9.0
	6	0	7.8	9	2.4	5.66	6.11	7.2	9.2
	7	0	7.6	8	2.5	5.84	6.13	7.3	9.2
	8	6	8.2	23	2.4	5.91	6.17	7.3	9.2
	9	6	8.1	25	2.7	5.65	6.05	7.4	8.9
	10	43	10.2	0	2.1	5.70	5.98	7.4	8.7
	11	48	10.5	0	2.3	5.29	5.88	7.5	9.0
	12	63	11.5	0	2.2	5.17	5.81	7.5	9.1
	13	57	11.1	0	2.0	5.08	5.67	7.6	9.3
	14	63	11.1	0	2.7	5.15	5.61	7.6	9.4
	15	70	11.6	0	2.4	4.98	5.61	7.5	9.5
	16	63	12.2	6	1.7	5.07	5.58	7.5	9.6
	17	57	11.4	7	1.9	4.89	5.50	7.9	9.7
	18	56	10.8	3	3.0	4.97	5.52	7.9	9.5
	19	51	10.6	3	2.7	5.04	5.56	7.7	9.5
	20	43	10.5	4	2.1	5.10	5.60	7.6	9.6
	21	47	11.0	4	2.3	4.98	5.55	7.7	9.7
	22	36	11.2	13	1.9	5.02	5.68	7.9	9.7
	23	40	11.1	14	2.1	5.00	5.60	8.2	9.9

3.5. Estimated results of influent concentration at site #2 (Chapter 6, sub-section 6.3.1)

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO2/L)	DO in ASR#2 (mgO2/L)	Nitrate in ASR#1 (mgN/L)	Nitrate in ASR#2 (mgN/L)
1	0	50	18.3	95	7.5	5.69	4.85	15.0	16.4
	1	55	19.2	105	7.2	5.66	4.81	14.8	16.3
	2	45	17.7	153	9.9	5.62	4.84	14.9	16.2
	3	41	18.7	139	9.4	5.69	4.78	14.8	16.2
	4	78	16.0	24	6.1	5.63	4.65	15.0	16.1
	5	85	16.8	22	5.7	5.81	5.02	14.1	15.9
	6	17	16.0	69	4.7	5.75	5.11	13.8	15.7
	7	15	15.3	63	5.0	5.84	5.22	13.8	15.7
	8	13	13.5	11	3.9	6.01	5.29	13.6	15.6
	9	12	13.8	10	3.6	6.09	5.53	13.3	15.4
	10	17	14.3	2	1.0	6.09	5.61	13.2	15.3
	11	19	13.8	3	1.6	5.99	5.62	13.1	14.9
	12	56	18.9	50	5.6	6.06	5.65	12.9	14.9
	13	62	18.0	55	5.8	5.73	5.08	13.3	15.0
	14	88	21.4	108	7.8	5.75	5.14	13.4	15.3
	15	97	20.4	118	8.2	5.37	4.70	14.3	15.3
	16	82	20.2	94	7.8	5.41	4.60	14.0	15.8
	17	74	19.7	104	8.4	5.57	4.68	14.1	15.8
	18	99	21.2	91	7.7	5.55	4.64	14.3	16.0
	19	109	20.4	95	8.3	5.35	4.57	14.4	16.1
	20	93	20.6	110	10.4	5.44	4.60	14.3	16.3
	21	103	21.7	120	9.8	5.39	4.49	14.3	16.5
	22	87	20.7	86	8.5	5.33	4.34	14.5	16.8
	23	96	21.2	78	7.8	5.43	4.56	14.6	17.1
2	0	107	21.9	58	9.1	5.35	4.60	14.7	17.2
	1	118	20.9	64	9.3	5.32	4.50	14.9	17.6
	2	69	21.0	148	10.2	5.43	4.56	14.5	17.9
	3	63	20.0	162	11.0	5.39	4.47	15.0	18.0
	4	95	20.5	26	7.2	5.45	4.44	14.9	17.9
	5	86	19.6	24	6.7	5.38	4.75	14.9	18.0
	6	55	19.7	50	6.0	5.44	4.82	14.7	18.1
	7	50	18.6	55	6.6	5.51	4.95	14.9	18.2
	8	0	18.4	52	2.1	5.58	4.99	14.8	18.4
	9	1	17.5	47	2.3	5.83	5.21	15.4	18.1
	10	30	15.9	2	4.8	5.78	5.32	15.5	18.0
	11	33	16.3	3	4.0	5.83	5.41	15.3	17.6
	12	28	16.6	94	6.7	5.76	5.33	15.0	17.3
	13	31	17.3	104	7.4	5.77	5.05	14.7	17.0
	14	60	15.7	63	11.6	5.82	5.04	14.8	17.0
	15	66	16.5	70	11.0	5.73	4.84	14.2	16.8
	16	50	15.9	155	12.1	5.76	4.75	13.8	16.9
	17	55	16.7	171	13.3	5.85	4.69	13.2	16.9
	18	56	19.0	159	11.5	5.64	4.46	13.4	16.8
	19	61	18.8	175	12.5	5.54	4.47	13.6	16.6
	20	62	19.6	116	13.4	5.55	4.46	13.9	16.9
	21	69	20.5	105	12.2	5.50	4.36	14.1	17.5
	22	92	21.4	127	9.1	5.42	4.34	14.5	17.9
	23	83	21.9	115	10.0	5.30	4.35	14.7	18.2

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
3	0	98	22.0	73	9.6	5.33	4.34	15.1	18.6
	1	89	21.7	80	9.0	5.30	4.49	15.2	18.7
	2	100	22.3	92	9.3	5.28	4.46	15.3	18.7
	3	91	22.5	84	8.9	5.32	4.46	15.4	19.1
	4	70	22.7	113	6.3	5.36	4.43	15.6	19.2
	5	63	21.6	103	6.9	5.36	4.49	16.1	19.1
	6	67	20.6	48	6.3	5.37	4.62	16.2	19.0
	7	60	21.6	53	5.7	5.47	4.86	16.3	19.0
	8	36	17.7	43	4.3	5.36	4.73	16.5	18.7
	9	33	18.6	39	4.7	5.74	5.13	16.1	18.5
	10	1	15.0	45	6.5	5.71	5.11	16.1	18.4
	11	1	15.7	50	5.6	5.90	5.22	15.5	18.1
	12	0	16.2	130	10.6	5.97	5.22	15.6	17.9
	13	0	15.4	143	11.7	5.85	4.95	15.6	17.7
	14	40	18.3	86	9.3	5.85	4.79	15.2	17.9
	15	44	17.4	78	9.9	5.64	4.76	15.5	18.0
	16	62	20.2	114	9.7	5.68	4.83	15.0	18.2
	17	68	20.5	126	10.4	5.45	4.61	15.2	18.4
	18	78	21.2	94	8.9	5.38	4.54	15.4	18.5
	19	86	20.4	104	9.6	5.34	4.45	15.5	18.5
	20	113	21.2	49	9.7	5.40	4.58	15.4	18.5
	21	124	22.3	54	9.0	5.34	4.55	15.1	18.7
	22	89	23.5	110	8.5	5.27	4.37	15.2	18.9
	23	98	22.7	120	9.0	5.26	4.32	15.4	19.1
4	0	110	21.4	38	11.3	5.23	4.40	15.7	19.2
	1	100	22.3	42	10.3	5.38	4.47	15.5	19.6
	2	84	20.7	118	9.9	5.26	4.43	15.6	19.8
	3	76	21.2	107	10.6	5.45	4.49	15.5	20.0
	4	39	21.9	116	8.0	5.45	4.48	15.6	20.0
	5	43	21.0	105	8.8	5.45	4.47	16.3	20.0
	6	45	20.5	75	7.7	5.49	4.60	16.3	20.0
	7	41	19.5	68	7.2	5.58	4.66	16.7	19.9
	8	0	20.6	76	3.4	5.60	4.88	16.5	19.7
	9	1	20.3	69	3.1	5.52	5.00	17.0	19.7
	10	1	21.2	40	5.2	5.52	5.07	17.5	19.7
	11	1	21.3	44	5.7	5.57	5.12	18.0	19.7
	12	28	22.3	160	5.0	5.57	5.04	18.5	20.5
	13	31	21.2	176	4.7	5.38	4.72	18.8	20.2
	14	81	22.9	64	6.6	5.46	4.82	18.7	18.9
	15	89	23.1	58	6.2	5.23	4.68	18.5	18.5
	16	84	24.3	97	4.2	5.19	4.61	18.3	18.5
	17	92	24.6	107	4.6	5.08	4.61	18.3	18.5
	18	109	24.3	82	8.3	5.07	4.55	18.4	18.5
	19	99	24.8	74	7.6	5.11	4.45	18.2	18.6
	20	71	23.9	147	6.3	5.06	4.42	18.2	18.7
	21	64	23.2	133	6.9	5.09	4.42	18.3	18.7
	22	103	25.3	43	4.7	5.25	4.57	18.3	18.8
	23	114	26.0	47	4.3	5.01	4.52	18.4	18.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
5	0	115	25.4	110	6.5	4.92	4.61	18.5	19.0
	1	104	26.4	100	5.9	4.92	4.44	18.3	19.0
	2	106	25.9	80	5.6	4.98	4.31	18.6	19.0
	3	116	26.5	88	6.2	4.97	4.44	18.6	19.0
	4	99	24.9	48	5.0	4.93	4.42	18.7	19.3
	5	90	25.6	44	5.2	5.01	4.57	18.6	19.4
	6	52	23.2	101	5.7	5.07	4.61	18.7	19.8
	7	47	23.5	92	6.3	5.20	4.70	18.8	19.8
	8	0	22.3	69	0.0	5.29	4.74	18.9	20.0
	9	1	21.4	63	0.0	5.46	5.18	19.3	19.6
	10	43	21.1	1	2.2	5.56	5.23	19.5	19.4
	11	47	21.9	0	2.0	5.37	5.24	19.3	19.2
	12	12	20.5	88	4.2	5.32	5.12	19.1	19.0
	13	13	19.5	97	4.6	5.52	4.99	19.0	18.9
	14	52	21.0	60	4.2	5.53	5.04	18.7	18.7
	15	47	22.0	66	4.6	5.35	5.03	18.4	18.3
	16	56	21.5	107	7.4	5.28	4.95	18.5	18.5
	17	51	20.3	97	7.9	5.41	4.65	18.3	18.4
	18	14	18.6	116	8.4	5.38	4.70	17.9	18.4
	19	13	18.8	105	8.2	5.64	4.80	17.7	18.4
	20	59	20.8	52	4.9	5.60	4.82	17.6	18.5
	21	65	22.0	57	5.4	5.37	4.82	17.3	18.6
	22	39	21.7	112	8.4	5.33	4.76	17.5	18.7
	23	36	21.0	102	7.8	5.33	4.59	17.6	18.9
6	0	33	21.6	110	6.6	5.42	4.73	17.7	19.1
	1	39	22.7	100	7.0	5.47	4.70	17.8	19.2
	2	36	24.1	97	4.7	5.38	4.75	18.4	19.4
	3	40	23.0	88	5.1	5.21	4.79	18.8	19.6
	4	35	23.3	94	4.2	5.28	4.81	18.9	19.6
	5	39	24.5	85	3.8	5.39	4.87	19.2	19.7
	6	36	23.4	39	1.8	5.24	4.86	19.7	19.6
	7	33	22.3	35	2.0	5.36	5.04	19.9	19.4
	8	15	21.1	21	1.2	5.46	5.22	19.7	19.6
	9	14	21.8	19	0.8	5.62	5.27	19.6	19.6
	10	23	18.9	30	4.3	5.53	5.30	19.9	19.7
	11	25	18.6	33	3.8	5.74	5.38	19.0	19.3
	12	21	19.0	66	4.7	5.75	5.39	18.7	19.0
	13	23	19.7	73	4.5	5.77	5.19	18.2	18.8
	14	34	20.2	111	8.7	5.66	5.18	18.0	18.6
	15	37	20.6	122	7.9	5.54	4.93	17.9	18.6
	16	63	21.3	136	9.0	5.52	4.86	17.8	18.5
	17	57	20.3	150	10.0	5.39	4.69	17.7	18.2
	18	69	23.4	124	5.2	5.52	4.67	17.4	18.2
	19	76	24.4	137	5.7	5.32	4.60	17.5	18.1
	20	70	25.8	134	5.9	5.14	4.62	17.9	18.0
	21	77	25.2	148	6.0	5.18	4.48	18.4	18.0
	22	109	24.8	123	8.4	5.16	4.47	18.8	18.0
	23	99	25.7	136	8.1	5.13	4.48	18.7	17.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
7	0	97	25.8	109	5.3	5.03	4.33	18.8	18.1
	1	107	24.6	120	5.9	5.12	4.49	18.8	18.0
	2	92	25.7	121	6.1	5.10	4.53	18.5	18.2
	3	84	24.5	110	6.6	5.02	4.49	18.9	18.1
	4	81	24.2	109	5.6	5.16	4.46	18.7	18.2
	5	99	24.7	99	6.0	5.23	4.56	18.8	18.2
	6	69	25.0	84	2.1	5.04	4.57	18.6	18.2
	7	63	24.4	76	3.0	5.08	4.70	18.9	18.2
	8	25	20.7	53	3.9	5.14	4.76	19.1	18.2
	9	23	19.4	48	3.0	5.50	5.07	19.1	18.2
	10	16	18.8	70	2.9	5.57	5.25	18.4	17.9
	11	18	19.8	77	3.3	5.67	5.31	18.2	17.7
	12	30	19.4	44	3.9	5.60	5.10	18.2	17.6
	13	33	20.3	48	3.1	5.67	5.21	17.8	17.5
	14	45	19.9	74	4.7	5.61	5.19	17.8	17.5
	15	50	20.8	82	5.0	5.55	5.02	17.6	17.4
	16	65	22.0	63	4.3	5.46	4.89	17.5	17.4
	17	72	21.5	69	5.2	5.38	4.91	17.5	17.4
	18	66	23.0	84	4.3	5.35	4.90	17.3	17.6
	19	73	22.8	93	4.7	5.21	4.86	17.5	17.6
	20	86	22.2	57	6.2	5.33	4.72	17.6	17.6
	21	95	23.2	63	5.6	5.27	4.77	17.4	17.6
	22	67	23.1	126	6.5	5.25	4.63	17.4	17.8
	23	74	23.3	114	7.2	5.31	4.59	17.5	18.0
8	0	61	21.6	102	7.2	5.22	4.54	17.7	18.1
	1	55	22.7	92	6.5	5.35	4.64	17.5	18.1
	2	46	21.4	95	6.4	5.33	4.69	18.0	18.3
	3	51	22.5	105	6.1	5.35	4.81	17.6	18.4
	4	39	21.4	88	5.8	5.25	4.75	18.2	18.5
	5	43	21.6	97	5.3	5.35	4.87	18.1	18.5
	6	22	22.1	110	4.2	5.40	4.84	18.1	18.5
	7	20	21.1	100	4.6	5.34	4.90	18.4	18.3
	8	23	21.3	32	0.0	5.48	4.86	18.5	18.4
	9	21	21.1	29	0.0	5.41	5.29	18.7	18.2
	10	42	20.0	39	2.2	5.48	5.32	18.7	18.0
	11	46	21.0	43	2.0	5.59	5.30	18.3	17.7
	12	49	22.0	108	4.9	5.38	5.23	18.3	17.4
	13	44	21.7	119	5.5	5.33	4.83	18.2	17.3
	14	74	21.9	76	5.2	5.37	4.78	18.2	17.3
	15	82	23.0	69	4.9	5.38	4.87	18.0	17.2
	16	81	24.5	77	4.0	5.17	4.78	17.9	17.3
	17	89	23.3	85	4.4	5.10	4.66	18.1	17.5
	18	84	24.1	110	7.4	5.25	4.72	17.9	17.6
	19	93	23.8	121	7.0	5.17	4.55	18.1	17.7
	20	96	25.1	95	5.2	5.13	4.46	18.0	17.8
	21	106	24.3	105	5.7	5.08	4.47	18.2	17.8
	22	100	24.7	90	5.4	5.13	4.49	18.1	17.9
	23	91	24.2	82	4.9	5.08	4.57	18.1	17.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
9	0	90	18.5	80	7.4	5.84	4.46	14.4	15.5
	1	82	18.9	88	7.0	6.04	4.74	14.0	15.4
	2	73	17.9	86	7.8	5.98	4.70	13.9	15.4
	3	80	17.4	78	7.2	6.05	4.67	13.7	15.4
	4	86	17.8	62	5.6	6.01	4.73	13.4	15.3
	5	78	16.4	56	6.2	6.04	4.88	13.2	15.1
	6	43	14.5	69	6.4	6.08	5.01	12.8	14.8
	7	39	14.3	62	6.3	6.22	5.10	12.5	14.6
	8	1	12.1	91	6.1	6.24	5.04	12.3	14.4
	9	0	11.7	82	6.8	6.45	5.25	12.1	13.9
	10	26	14.4	87	8.8	6.52	5.29	11.9	13.9
	11	31	14.6	96	8.3	6.23	4.96	12.0	13.9
	12	45	15.8	94	8.0	6.34	4.94	12.0	14.2
	13	50	14.6	104	8.8	6.17	4.95	12.2	14.1
	14	44	14.5	103	11.8	6.19	4.96	12.0	14.4
	15	49	15.7	114	11.0	6.29	4.79	11.9	14.5
	16	75	15.5	127	11.3	6.27	4.81	12.0	14.9
	17	68	16.2	140	10.3	6.21	4.69	11.7	14.9
	18	82	18.7	123	9.6	6.16	4.66	11.7	14.7
	19	91	17.6	112	9.8	6.06	4.52	12.1	14.8
	20	95	18.8	116	9.0	6.11	4.58	12.0	14.8
	21	86	17.3	105	9.9	6.04	4.55	12.3	14.6
	22	116	19.0	125	9.1	6.11	4.74	12.1	15.0
	23	105	17.8	138	10.1	5.99	4.53	12.1	14.6
10	0	96	18.2	96	10.0	6.03	4.61	11.9	14.4
	1	106	19.5	106	9.0	6.07	4.63	11.9	14.6
	2	129	19.0	112	8.8	5.96	4.59	12.1	14.7
	3	117	19.8	101	8.6	5.88	4.62	12.0	14.7
	4	118	19.7	38	4.4	5.88	4.49	12.1	14.6
	5	130	20.7	34	4.6	5.91	4.79	12.1	14.7
	6	101	18.8	10	2.4	5.78	4.82	12.3	14.7
	7	111	20.2	9	2.7	5.93	5.04	12.2	14.5
	8	87	17.8	59	5.3	5.95	5.01	12.5	14.9
	9	79	18.0	53	5.9	6.10	4.93	12.5	14.5
	10	9	18.2	62	4.9	6.12	5.02	12.5	14.8
	11	10	17.7	69	4.8	6.07	5.09	13.2	15.3
	12	19	14.4	86	10.0	6.19	5.04	13.9	15.8
	13	17	15.9	95	9.0	6.35	5.01	13.7	15.9
	14	24	14.8	117	10.2	6.27	4.91	13.9	16.0
	15	26	16.2	129	10.0	6.29	4.87	13.5	16.2
	16	49	18.4	103	10.0	6.24	4.82	13.8	16.2
	17	54	17.0	114	10.3	6.05	4.70	13.9	16.5
	18	77	19.9	95	8.1	6.24	4.73	13.8	16.6
	19	85	19.0	105	8.3	5.97	4.61	14.0	16.8
	20	94	20.1	127	7.0	6.04	4.75	13.9	16.6
	21	104	20.3	140	7.7	5.95	4.65	13.9	15.9
	22	126	23.8	77	6.3	5.91	4.54	13.9	15.7
	23	139	22.5	70	6.9	5.82	4.52	14.3	15.6

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
11	0	150	24.4	62	4.9	5.79	4.56	14.2	15.9
	1	136	23.8	69	5.4	5.71	4.58	14.5	16.0
	2	139	23.0	74	6.3	5.70	4.52	14.6	16.2
	3	153	25.0	67	5.7	5.77	4.54	14.5	16.2
	4	151	25.3	62	3.3	5.69	4.39	14.9	16.3
	5	137	24.3	56	3.7	5.63	4.52	15.0	16.3
	6	134	22.7	1	2.9	5.70	4.63	15.1	16.3
	7	122	22.6	0	3.2	5.73	4.80	15.0	16.2
	8	73	21.9	16	3.7	5.84	4.89	15.0	16.7
	9	66	21.5	14	3.4	5.93	4.92	15.3	17.4
	10	27	16.6	59	7.9	5.92	5.00	15.6	17.4
	11	24	17.3	53	7.1	6.19	4.99	15.4	17.7
	12	7	15.9	88	6.6	6.21	5.02	15.3	17.7
	13	6	15.4	80	7.3	6.28	5.09	15.2	17.6
	14	15	16.9	46	6.0	6.34	5.11	15.0	17.5
	15	17	17.2	51	5.4	6.21	5.05	15.0	17.5
	16	31	18.2	77	7.1	6.26	5.11	15.1	17.5
	17	34	17.9	85	7.8	6.15	5.01	15.2	17.6
	18	43	18.1	115	10.8	6.19	4.97	15.2	17.7
	19	48	19.3	127	9.8	6.18	4.76	15.1	17.7
	20	94	20.8	118	10.5	6.13	4.62	15.3	17.7
	21	85	21.6	130	9.7	5.96	4.42	15.2	17.8
	22	106	22.3	119	8.6	5.91	4.44	15.3	17.9
	23	96	22.1	131	9.4	5.98	4.48	15.4	17.8
12	0	100	22.3	120	10.4	5.98	4.47	15.4	17.7
	1	95	21.9	129	10.2	5.94	4.32	15.5	17.7
	2	113	22.7	118	9.1	5.97	4.36	15.5	17.7
	3	107	22.5	110	9.2	5.93	4.38	15.5	17.8
	4	121	23.5	77	6.3	6.00	4.39	15.5	17.8
	5	127	23.6	70	6.4	5.90	4.60	15.5	17.8
	6	113	22.6	25	4.3	5.86	4.50	15.6	17.8
	7	107	22.4	23	4.2	6.01	4.73	15.6	17.8
	8	36	19.4	43	4.1	5.89	4.86	15.4	17.8
	9	40	19.1	39	4.2	6.26	5.16	15.7	17.9
	10	63	19.1	43	6.2	6.17	5.10	15.6	17.9
	11	57	19.2	47	5.9	6.16	4.99	15.5	17.8
	12	79	20.6	71	6.8	6.26	5.03	15.5	17.8
	13	71	20.4	78	7.0	6.08	4.80	15.5	17.7
	14	99	20.5	86	9.5	6.15	4.77	15.4	17.8
	15	92	20.8	78	9.3	5.99	4.57	15.2	17.8
	16	96	22.6	110	7.4	6.04	4.57	15.1	17.9
	17	90	22.3	118	7.7	5.88	4.56	15.4	17.9
	18	75	21.6	120	9.8	5.93	4.58	15.4	17.9
	19	83	22.1	129	9.5	5.95	4.49	15.7	18.0
	20	88	22.3	122	8.6	5.98	4.37	16.0	18.0
	21	80	22.1	114	8.5	5.86	4.38	16.1	18.0
	22	83	20.7	104	10.0	5.95	4.46	16.1	18.0
	23	77	21.0	111	9.4	6.08	4.50	15.9	18.1

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
13	0	78	22.6	124	6.8	6.01	4.47	16.0	18.1
	1	71	23.7	118	7.5	6.01	4.47	16.1	18.1
	2	112	22.1	34	5.6	5.91	4.54	16.6	18.3
	3	101	23.6	31	5.1	5.93	4.74	16.4	18.3
	4	69	20.7	50	4.8	5.91	4.77	16.5	18.3
	5	62	21.4	45	5.3	6.01	4.91	16.3	18.4
	6	30	18.6	70	6.7	6.01	4.90	16.4	18.5
	7	27	20.4	77	6.1	6.33	4.95	16.3	18.5
	8	0	19.4	67	3.7	6.21	4.90	16.6	18.6
	9	0	18.0	61	4.1	6.30	5.21	16.9	18.6
	10	0	16.1	0	4.2	6.44	5.35	16.9	18.5
	11	0	16.7	0	3.8	6.50	5.42	16.7	18.5
	12	0	18.7	68	5.0	6.40	5.50	16.5	18.5
	13	0	17.1	75	5.6	6.35	5.20	16.7	18.5
	14	36	17.7	66	8.8	6.43	5.33	16.6	18.5
	15	40	19.5	60	8.0	6.25	5.01	16.3	18.6
	16	18	18.4	100	7.0	6.27	4.97	16.4	18.6
	17	16	19.0	110	7.8	6.22	5.00	16.3	18.7
	18	37	18.7	94	10.6	6.26	4.94	16.5	18.7
	19	33	19.1	104	9.6	6.24	4.76	16.4	18.8
	20	73	20.8	70	6.5	6.16	4.86	16.4	18.8
	21	66	22.0	77	7.0	6.01	4.86	16.3	19.0
	22	84	22.7	51	5.7	6.03	4.85	16.5	19.0
	23	76	22.3	56	5.8	5.97	4.76	16.6	19.1
14	0	63	21.4	99	9.2	6.01	4.92	16.7	19.2
	1	57	21.6	90	8.4	6.03	4.79	16.7	19.3
	2	43	20.1	104	9.0	6.13	4.73	16.9	19.4
	3	39	20.9	115	9.4	6.21	4.88	16.9	19.4
	4	35	19.8	76	7.4	6.26	4.71	17.0	19.5
	5	32	20.4	69	6.7	6.19	4.96	17.0	19.6
	6	22	19.4	83	7.4	6.26	5.00	17.1	19.7
	7	20	19.7	75	7.7	6.25	5.06	17.1	19.7
	8	3	18.3	35	4.4	6.34	5.02	17.2	19.8
	9	2	17.5	32	4.6	6.40	5.26	17.2	19.8
	10	0	17.9	23	3.9	6.40	5.46	17.1	19.6
	11	0	17.1	21	4.3	6.40	5.51	17.1	19.5
	12	10	17.9	75	8.0	6.45	5.50	16.9	19.5
	13	9	18.7	83	7.2	6.40	5.15	16.8	19.4
	14	22	19.0	108	10.0	6.28	5.16	16.9	19.4
	15	24	18.6	119	10.4	6.25	4.86	16.9	19.4
	16	45	21.7	91	7.5	6.37	4.84	16.8	19.5
	17	50	21.5	101	8.3	6.16	4.76	17.1	19.6
	18	83	22.6	70	7.7	6.05	4.76	17.2	19.8
	19	75	22.8	77	7.0	6.03	4.74	17.3	19.8
	20	81	23.1	78	8.0	6.06	4.76	17.3	19.9
	21	73	23.0	86	7.7	6.02	4.77	17.4	20.0
	22	95	24.2	60	6.5	6.02	4.68	17.5	20.1
	23	86	23.7	54	5.9	5.98	4.66	17.6	20.2

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
15	0	98	24.5	53	6.8	5.98	4.81	17.7	20.3
	1	89	24.3	59	6.2	5.90	4.73	17.8	20.4
	2	108	25.5	48	5.7	5.98	4.67	17.9	20.5
	3	98	24.5	43	5.2	5.84	4.75	18.0	20.7
	4	118	26.0	24	3.9	5.92	4.84	18.0	20.6
	5	130	26.1	22	4.3	5.75	4.71	18.1	20.7
	6	105	25.0	3	3.1	5.75	4.68	18.1	20.7
	7	95	23.2	2	3.4	5.89	4.93	18.1	20.6
	8	0	20.0	34	4.6	5.99	5.12	17.9	20.6
	9	0	18.5	38	5.1	6.31	5.26	17.9	20.6
	10	0	18.6	42	6.0	6.36	5.33	17.9	20.5
	11	0	18.9	46	5.4	6.36	5.28	17.9	20.5
	12	31	19.9	71	7.5	6.27	5.34	17.9	20.5
	13	28	19.8	79	7.1	6.18	5.01	17.8	20.4
	14	58	21.4	66	7.2	6.28	5.03	17.7	20.3
	15	52	21.0	73	6.5	6.04	4.95	17.6	20.3
	16	48	20.2	112	11.1	6.10	4.95	17.5	20.1
	17	53	20.3	124	10.1	6.13	4.85	17.4	20.0
	18	60	22.0	148	9.7	6.14	4.70	17.2	19.8
	19	54	21.3	134	10.7	6.10	4.65	17.3	19.7
	20	68	20.5	118	11.3	6.08	4.64	17.3	19.7
	21	61	21.8	130	10.2	6.04	4.66	17.1	19.7
	22	71	22.8	165	10.1	6.08	4.56	17.1	19.6
	23	64	22.0	149	11.2	5.96	4.52	17.2	19.6
16	0	100	24.0	90	8.0	5.99	4.47	17.3	19.5
	1	90	22.0	100	8.8	5.95	4.55	17.4	19.4
	2	89	22.2	107	9.6	6.02	4.60	17.1	19.5
	3	80	23.7	118	8.7	5.92	4.58	16.9	19.5
	4	66	21.4	83	7.3	5.99	4.52	17.3	19.5
	5	60	22.3	75	6.6	6.02	4.82	17.1	19.5
	6	38	20.0	55	6.0	6.09	4.77	17.3	19.5
	7	34	19.8	50	5.9	6.19	5.11	17.2	19.5
	8	18	19.3	36	3.8	6.17	5.02	17.2	19.5
	9	16	18.7	33	4.2	6.30	5.46	17.2	19.5
	10	0	17.7	9	2.8	6.40	5.51	17.1	19.4
	11	0	18.5	8	2.5	6.48	5.60	17.1	19.4
	12	0	17.0	2	2.8	6.35	5.60	17.2	19.3
	13	0	15.5	3	3.3	6.50	5.77	17.0	19.2
	14	0	18.0	30	3.2	6.51	5.72	16.5	19.0
	15	0	18.3	33	2.8	6.35	5.66	16.5	19.0
	16	6	19.3	78	5.7	6.41	5.58	16.7	18.8
	17	7	18.4	86	5.5	6.34	5.41	17.1	18.6
	18	28	19.0	100	7.9	6.43	5.41	17.1	18.4
	19	25	17.8	110	8.3	6.31	5.28	17.0	18.3
	20	32	18.8	145	8.7	6.42	5.19	16.8	18.1
	21	35	19.8	131	9.6	6.25	5.14	16.6	17.7
	22	58	20.8	68	9.3	6.25	4.95	16.7	17.9
	23	64	19.7	75	9.9	6.22	4.98	16.7	18.2

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
17	0	50	21.0	77	11.0	6.16	4.97	16.4	18.7
	1	55	19.0	85	12.2	6.25	4.99	16.7	19.4
	2	101	18.9	63	11.4	6.24	5.01	16.3	20.1
	3	112	19.4	57	10.3	6.25	4.94	15.7	20.2
	4	81	19.2	85	7.5	6.25	5.01	15.1	19.7
	5	73	18.7	77	8.3	6.25	5.12	14.7	19.3
	6	83	17.4	44	8.5	6.23	5.18	14.5	19.0
	7	92	18.1	49	7.7	6.35	5.29	14.1	18.5
	8	0	12.9	60	6.6	6.31	5.26	13.7	18.0
	9	0	11.7	54	7.3	6.67	5.65	13.5	17.5
	10	30	12.2	0	11.8	6.81	5.67	12.8	17.0
	11	33	13.4	1	10.7	6.64	5.55	12.3	17.4
	12	84	15.8	60	10.2	6.56	5.46	12.1	17.7
	13	93	14.3	66	11.3	6.39	5.29	11.8	17.8
	14	71	14.8	138	12.9	6.53	5.27	11.1	17.6
	15	64	15.9	125	14.2	6.44	5.11	10.9	16.7
	16	52	15.1	82	12.5	6.36	4.93	11.0	16.9
	17	47	16.1	90	11.3	6.40	5.08	11.1	17.3
	18	91	16.9	86	11.9	6.40	5.14	11.5	17.3
	19	101	16.8	77	10.7	6.37	4.96	11.6	17.7
	20	80	15.6	105	10.9	6.28	5.05	11.4	17.2
	21	72	17.0	95	12.0	6.39	5.04	11.1	16.9
	22	51	16.3	102	10.3	6.32	4.93	11.4	17.0
	23	46	15.0	92	11.4	6.33	5.17	11.7	16.8
18	0	43	14.3	95	13.9	6.53	5.11	11.7	16.9
	1	48	15.8	86	12.6	6.53	5.10	11.6	17.1
	2	33	16.9	72	12.7	6.52	4.99	11.9	17.4
	3	37	15.3	65	12.4	6.40	5.00	12.4	18.3
	4	32	14.6	139	8.6	6.47	5.20	12.2	18.8
	5	35	15.5	126	9.1	6.61	5.24	12.4	18.3
	6	0	14.8	28	8.5	6.47	5.20	12.5	17.4
	7	1	14.2	25	7.7	6.66	5.44	12.7	17.6
	8	1	11.4	58	7.9	6.64	5.60	12.9	17.7
	9	0	12.5	64	8.8	6.85	5.76	12.6	17.4
	10	14	12.5	31	8.4	6.81	5.67	12.4	17.2
	11	15	11.9	34	9.3	6.68	5.66	12.2	16.8
	12	38	13.8	52	10.9	6.75	5.60	11.8	17.2
	13	42	12.8	55	9.9	6.55	5.38	11.7	17.4
	14	76	13.8	77	10.9	6.70	5.44	11.4	16.8
	15	69	14.1	70	12.0	6.59	5.37	10.9	16.5
	16	61	14.5	110	10.0	6.57	5.28	10.6	16.5
	17	67	13.5	100	11.1	6.55	5.23	10.6	16.1
	18	88	16.7	110	10.9	6.53	5.31	10.3	15.8
	19	80	15.1	121	12.0	6.36	4.96	10.5	15.4
	20	104	15.9	90	14.7	6.35	5.10	10.4	15.4
	21	94	15.3	100	13.3	6.37	4.91	10.4	15.5
	22	100	16.2	89	12.9	6.40	4.93	10.1	15.6
	23	110	16.0	80	14.2	6.26	4.92	10.2	15.8

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
19	0	104	16.3	111	17.3	6.28	4.90	10.0	16.5
	1	94	15.1	100	15.7	6.27	4.71	10.1	17.0
	2	99	16.0	140	14.5	6.46	4.84	9.9	16.9
	3	90	16.5	127	15.9	6.39	4.82	9.9	17.1
	4	80	15.3	88	14.2	6.42	4.70	10.1	17.3
	5	89	16.7	79	12.8	6.40	4.91	10.0	17.5
	6	115	17.1	76	12.0	6.41	4.84	10.4	17.6
	7	104	16.1	69	13.0	6.23	4.98	10.4	17.7
	8	86	16.6	10	2.7	6.36	4.98	10.2	17.6
	9	95	15.2	11	3.0	6.33	5.39	10.4	16.9
	10	59	14.2	3	11.4	6.36	5.64	10.2	16.4
	11	65	13.2	4	10.3	6.56	5.39	10.2	16.3
	12	26	13.7	77	8.1	6.56	5.43	10.0	16.5
	13	29	14.2	85	9.0	6.65	5.39	10.3	16.6
	14	43	14.1	58	14.0	6.49	5.33	10.6	16.8
	15	48	15.5	64	12.7	6.58	5.16	10.7	17.3
	16	64	14.6	45	15.5	6.38	5.00	11.2	17.3
	17	71	14.3	41	14.0	6.44	4.96	11.0	18.3
	18	66	14.4	116	14.1	6.48	5.00	10.8	18.7
	19	60	14.8	105	15.5	6.50	4.95	10.6	18.7
	20	49	14.2	89	14.8	6.43	4.83	10.7	18.7
	21	44	15.6	80	13.4	6.43	4.96	10.7	18.8
	22	55	14.8	67	14.5	6.43	4.97	11.1	19.1
	23	50	16.3	61	13.1	6.48	5.01	11.0	19.7
20	0	38	14.4	113	15.6	6.42	5.04	11.5	19.8
	1	34	15.2	102	17.2	6.53	4.95	11.5	19.7
	2	30	15.5	71	13.6	6.49	4.86	11.7	20.4
	3	33	15.2	64	14.9	6.43	4.97	12.0	20.4
	4	42	15.3	54	13.2	6.57	5.11	12.1	21.1
	5	46	16.3	49	14.0	6.47	5.12	12.2	21.2
	6	32	14.8	56	12.8	6.44	4.99	12.4	21.5
	7	35	15.4	50	13.6	6.61	5.15	12.4	21.5
	8	19	15.9	92	9.1	6.57	5.17	12.5	21.6
	9	21	15.3	83	10.1	6.61	5.27	12.8	21.2
	10	13	12.2	102	16.6	6.59	5.41	12.9	20.7
	11	12	13.4	113	16.0	6.66	5.16	12.5	19.9
	12	0	13.2	60	13.0	6.72	5.14	12.5	20.0
	13	1	12.9	54	11.8	6.71	5.24	12.5	20.5
	14	30	12.2	38	17.7	6.68	5.38	12.4	20.4
	15	27	13.4	42	16.1	6.68	5.20	11.9	20.7
	16	58	15.9	53	10.4	6.64	5.17	11.9	21.2
	17	52	16.1	48	11.5	6.41	5.18	11.8	21.3
	18	55	16.4	52	11.1	6.34	5.19	12.0	21.3
	19	61	15.9	57	11.9	6.40	5.22	12.2	20.9
	20	77	16.8	59	13.6	6.42	5.20	12.1	20.6
	21	85	17.6	54	12.3	6.33	4.93	12.0	20.6
	22	72	18.4	41	9.3	6.28	4.99	12.2	20.5
	23	80	17.0	37	10.3	6.22	5.06	12.5	20.4

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
21	0	83	20.3	14	10.6	6.33	5.22	12.3	20.4
	1	92	18.5	15	10.3	6.13	4.99	12.9	20.8
	2	88	19.0	37	12.8	6.20	5.08	12.9	21.0
	3	97	18.0	41	12.5	6.22	4.99	13.1	21.2
	4	73	20.6	14	7.9	6.22	5.02	12.8	21.2
	5	81	18.6	13	8.7	6.18	5.14	13.3	21.4
	6	63	16.9	8	8.1	6.21	5.30	13.4	21.6
	7	70	18.6	7	7.3	6.40	5.33	13.2	21.2
	8	36	17.7	32	4.1	6.29	5.30	13.5	20.8
	9	33	16.1	29	4.6	6.45	5.48	13.8	20.3
	10	2	12.6	1	7.5	6.50	5.58	13.4	19.5
	11	1	12.1	0	6.8	6.70	5.82	13.3	19.0
	12	0	12.1	44	8.4	6.72	5.88	12.9	18.6
	13	0	12.8	49	7.6	6.80	5.82	12.6	18.3
	14	18	10.7	62	9.5	6.72	5.66	12.5	17.9
	15	16	11.9	56	8.6	6.72	5.72	11.9	17.3
	16	13	12.2	82	9.3	6.69	5.61	11.6	16.6
	17	14	11.0	74	10.2	6.74	5.62	11.4	16.3
	18	14	13.3	96	9.8	6.78	5.57	11.0	16.0
	19	15	12.2	106	10.8	6.68	5.43	11.2	15.9
	20	24	15.2	66	6.0	6.76	5.56	11.1	15.7
	21	27	16.7	73	6.6	6.54	5.49	11.4	15.8
	22	39	15.0	46	7.9	6.41	5.50	12.1	15.9
	23	43	16.6	51	8.7	6.56	5.49	12.0	15.9
22	0	34	18.4	74	7.3	6.50	5.33	12.5	16.4
	1	31	16.8	67	8.0	6.41	5.36	13.0	16.9
	2	39	17.2	43	6.2	6.53	5.41	13.3	17.2
	3	35	17.7	39	6.8	6.42	5.54	13.6	17.3
	4	65	19.1	18	4.3	6.45	5.57	13.8	17.6
	5	72	19.4	16	4.8	6.37	5.51	14.1	17.7
	6	44	18.4	38	5.5	6.32	5.58	14.2	17.9
	7	40	18.6	34	5.7	6.41	5.62	14.3	17.8
	8	1	16.1	46	9.9	6.41	5.51	14.5	18.0
	9	0	15.2	51	9.0	6.63	5.65	14.7	18.3
	10	33	17.1	59	9.6	6.67	5.54	14.6	18.6
	11	37	17.3	65	10.6	6.58	5.44	14.6	18.9
	12	42	17.3	82	9.5	6.50	5.32	14.6	19.3
	13	47	17.6	91	10.7	6.50	5.29	14.5	19.2
	14	58	18.4	73	9.2	6.53	5.25	14.4	19.2
	15	64	18.1	66	9.9	6.33	5.29	14.5	19.1
	16	56	17.9	83	10.1	6.37	5.22	14.4	19.1
	17	62	18.6	92	9.1	6.36	5.24	14.2	19.0
	18	29	16.3	82	12.8	6.26	5.09	14.3	18.8
	19	32	17.0	74	11.6	6.40	5.23	14.2	19.1
	20	50	18.5	81	7.0	6.37	5.13	14.2	19.2
	21	45	17.8	89	7.8	6.27	5.22	14.4	19.1
	22	75	18.6	53	12.6	6.41	5.36	14.4	19.1
	23	68	19.0	58	11.4	6.35	5.05	14.3	19.3

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
23	0	27	17.2	125	10.9	6.33	5.03	14.4	19.4
	1	24	17.0	113	12.0	6.41	5.12	14.3	19.5
	2	42	17.2	63	11.6	6.42	5.08	14.5	19.6
	3	47	18.9	57	10.6	6.46	5.17	14.4	19.8
	4	76	19.2	46	9.8	6.36	5.06	14.6	20.1
	5	69	19.4	51	10.8	6.36	5.06	14.6	20.3
	6	17	17.3	35	9.4	6.33	5.06	14.6	20.6
	7	15	17.4	32	8.5	6.51	5.33	14.7	20.9
	8	0	15.3	10	5.9	6.45	5.50	14.9	21.1
	9	0	15.2	9	6.5	6.72	5.80	14.8	20.6
	10	26	16.8	10	5.6	6.69	5.83	14.7	20.7
	11	29	16.7	11	6.2	6.50	5.67	14.7	20.4
	12	40	17.3	22	9.8	6.48	5.62	14.6	20.1
	13	44	18.0	24	8.9	6.50	5.39	14.5	20.3
	14	52	17.5	43	9.3	6.42	5.29	14.6	20.4
	15	57	19.3	39	8.4	6.40	5.34	14.4	20.5
	16	75	19.0	29	9.4	6.36	5.23	14.6	20.5
	17	68	19.5	32	8.5	6.23	5.16	14.6	20.6
	18	84	20.4	40	8.0	6.19	5.23	14.6	20.6
	19	76	19.8	44	8.9	6.21	5.22	14.7	20.6
	20	91	19.5	53	10.7	6.27	5.09	14.7	20.6
	21	82	20.2	48	9.3	6.17	5.10	14.5	20.5
	22	73	19.9	43	12.9	6.24	5.09	14.6	20.5
	23	66	19.5	48	11.7	6.23	4.99	14.6	21.0
24	0	93	25.3	0	2.7	5.74	5.25	19.0	20.9
	1	84	25.0	0	3.0	5.98	5.38	19.1	21.1
	2	100	25.6	11	3.5	6.04	5.38	19.1	21.3
	3	90	25.7	10	3.7	6.00	5.40	19.1	21.4
	4	81	24.2	12	5.7	6.01	5.29	19.2	21.5
	5	73	24.6	13	5.2	6.19	5.41	19.1	21.9
	6	41	22.8	41	5.1	6.14	5.44	19.2	21.9
	7	37	22.9	45	5.6	6.35	5.47	19.2	21.9
	8	0	20.7	33	5.7	6.28	5.55	19.3	22.1
	9	0	20.1	30	6.3	6.39	5.66	19.4	22.2
	10	0	20.6	50	6.6	6.53	5.66	19.3	22.6
	11	0	20.4	55	6.0	6.42	5.60	19.4	22.5
	12	35	22.3	68	6.7	6.39	5.58	19.4	22.3
	13	32	22.2	75	7.4	6.33	5.41	19.4	22.2
	14	62	25.7	66	4.2	6.30	5.39	19.5	22.2
	15	69	25.9	73	4.7	6.00	5.14	19.8	22.0
	16	79	25.4	68	7.6	6.03	5.23	20.1	22.2
	17	72	26.4	75	6.9	6.00	5.06	20.1	22.2
	18	126	28.4	45	5.0	5.96	4.95	20.4	22.3
	19	114	28.1	50	5.6	5.77	4.88	20.5	22.3
	20	116	28.8	35	8.1	5.78	4.93	20.5	22.6
	21	105	28.0	32	7.4	5.75	4.77	20.7	23.1
	22	115	29.0	43	6.2	5.78	4.83	20.7	23.7
	23	101	27.9	39	6.8	5.69	4.81	20.9	23.9

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
25	0	117	29.7	29	9.0	5.76	4.94	21.0	24.3
	1	106	29.2	32	8.2	5.62	4.68	21.2	24.9
	2	108	29.3	44	8.6	5.73	4.67	21.4	25.4
	3	98	28.3	40	9.5	5.73	4.63	21.6	25.9
	4	79	28.5	17	8.1	5.77	4.76	21.6	26.3
	5	71	27.5	15	7.8	5.80	4.74	21.8	26.8
	6	88	28.8	13	7.4	5.94	4.93	21.9	27.2
	7	80	27.4	12	8.1	5.78	4.79	22.2	27.5
	8	0	24.1	42	5.0	5.93	4.99	22.1	27.7
	9	0	22.5	38	5.5	6.13	5.27	22.2	27.0
	10	0	22.7	21	5.3	6.32	5.45	22.0	26.9
	11	0	23.3	23	4.8	6.26	5.39	21.9	26.9
	12	12	23.4	69	6.3	6.23	5.45	22.0	26.2
	13	11	24.4	76	5.7	6.11	5.34	21.9	25.8
	14	10	24.5	91	6.0	6.12	5.24	22.1	25.3
	15	9	24.3	101	5.6	6.07	5.08	22.2	25.0
	16	26	24.3	83	5.4	6.05	5.17	22.4	24.5
	17	24	25.0	92	5.0	6.11	5.13	22.3	24.0
	18	60	27.6	64	4.5	6.01	5.14	22.4	23.7
	19	54	27.3	58	5.0	5.80	5.03	22.5	23.3
	20	99	28.4	0	4.8	5.83	4.95	22.6	23.8
	21	90	29.1	0	4.4	5.70	4.98	22.5	24.2
	22	54	27.8	52	3.4	5.72	4.88	22.6	24.7
	23	49	28.3	57	3.1	5.79	5.07	22.8	25.1
26	0	83	27.5	59	4.3	5.87	5.04	23.1	24.8
	1	75	28.9	53	3.9	5.76	4.91	22.9	24.5
	2	63	28.4	34	3.0	5.72	4.90	23.0	24.1
	3	57	28.5	31	3.3	5.85	5.04	23.1	24.1
	4	65	27.6	0	1.9	5.81	5.11	23.3	24.5
	5	59	28.4	0	2.4	5.86	5.25	23.2	24.7
	6	42	27.6	24	3.8	5.83	5.12	23.4	24.9
	7	38	27.4	22	3.2	5.94	5.16	23.5	25.1
	8	0	26.4	30	0.4	5.95	5.14	23.6	25.2
	9	0	25.1	27	1.4	6.06	5.46	24.0	24.8
	10	18	23.5	45	5.8	6.10	5.46	23.8	24.7
	11	16	25.0	50	5.2	6.12	5.37	23.5	24.7
	12	10	24.0	61	5.6	6.09	5.19	23.4	24.4
	13	9	24.8	68	6.2	6.21	5.32	23.1	24.4
	14	19	25.1	50	5.6	6.10	5.14	23.1	24.5
	15	17	25.0	55	5.1	6.09	5.21	23.1	24.7
	16	37	27.4	69	5.7	6.07	5.20	23.1	24.7
	17	41	26.8	76	6.3	5.96	5.02	23.3	24.8
	18	60	27.4	101	8.6	5.89	5.01	23.4	25.0
	19	54	27.9	91	7.8	5.92	4.72	23.3	24.9
	20	93	29.7	57	3.8	5.89	4.80	23.4	25.1
	21	84	30.3	52	4.2	5.71	4.74	23.5	25.0
	22	105	31.3	49	2.7	5.63	4.77	23.6	25.2
	23	95	30.6	54	3.0	5.53	4.79	23.8	24.9

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
27	0	82	30.4	103	6.1	5.69	4.88	23.8	24.9
	1	74	29.9	93	5.5	5.73	4.66	24.0	24.9
	2	97	31.6	55	3.2	5.72	4.76	24.1	24.5
	3	88	31.3	61	3.5	5.55	4.66	24.3	24.6
	4	64	29.1	67	4.8	5.73	4.75	24.5	24.8
	5	58	29.9	61	5.3	5.88	4.86	24.4	24.5
	6	51	29.4	60	3.6	5.78	4.87	24.6	25.1
	7	46	27.9	54	4.0	5.83	4.89	24.8	25.0
	8	7	26.4	24	0.8	5.90	5.02	24.6	25.2
	9	6	25.4	22	0.9	6.09	5.43	24.6	24.9
	10	23	26.4	19	2.7	6.13	5.48	24.5	24.9
	11	26	26.8	21	2.5	6.10	5.39	24.4	24.9
	12	39	26.9	33	2.0	6.03	5.30	24.4	24.9
	13	35	27.0	30	1.8	6.00	5.23	24.2	24.9
	14	9	25.0	75	5.1	5.95	5.23	24.2	24.6
	15	8	25.6	68	5.7	6.14	5.21	24.0	24.2
	16	39	26.5	27	1.3	5.98	5.01	24.0	24.5
	17	43	26.7	24	1.4	5.97	5.24	23.9	24.4
	18	56	27.2	6	3.4	5.97	5.18	23.8	24.3
	19	51	27.4	7	3.1	5.92	5.15	23.6	24.4
	20	84	27.9	18	2.7	5.80	5.06	23.6	24.6
	21	76	29.4	20	3.0	5.73	4.99	23.3	24.6
	22	74	29.0	15	2.8	5.78	5.02	23.4	24.7
	23	67	28.5	14	2.5	5.79	5.06	23.5	24.9
28	0	71	29.3	39	3.9	5.79	5.07	23.5	25.0
	1	64	27.8	43	4.3	5.75	4.93	23.7	24.9
	2	62	27.5	67	4.1	5.89	5.05	23.6	25.0
	3	56	29.6	61	3.7	5.87	5.02	23.4	24.9
	4	87	27.1	6	2.3	5.79	4.87	23.8	24.8
	5	79	29.1	5	2.1	5.89	5.11	23.4	24.7
	6	69	25.3	47	3.3	5.83	5.12	23.3	24.5
	7	62	27.0	54	3.7	6.05	5.14	22.8	23.8
	8	55	24.8	51	5.4	5.97	5.12	22.7	23.6
	9	61	25.7	56	5.8	6.01	5.21	22.3	23.3
	10	44	26.1	35	3.5	6.07	5.12	22.1	23.3
	11	49	25.9	32	3.9	6.04	5.20	22.1	23.4
	12	31	25.0	48	4.8	5.98	5.09	22.2	23.6
	13	34	26.6	53	4.4	6.05	5.13	22.2	23.9
	14	0	24.4	65	4.6	5.89	5.01	22.5	23.8
	15	0	23.2	72	5.1	6.03	5.19	22.6	23.7
	16	21	24.3	57	5.3	6.09	5.19	22.6	23.8
	17	19	23.9	63	4.8	6.04	5.11	22.5	23.8
	18	43	26.7	33	4.6	6.02	5.21	22.4	23.6
	19	48	24.5	37	5.1	5.91	4.96	22.6	23.8
	20	62	27.2	47	2.7	5.92	5.05	22.3	23.9
	21	56	26.3	42	3.0	5.79	5.04	22.4	23.8
	22	87	27.7	15	2.1	5.79	5.13	22.3	23.6
	23	79	26.1	14	1.9	5.79	5.02	22.4	23.5

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO$_2$/L)	DO in ASR#2 (mgO$_2$/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
29	0	64	25.9	49	3.1	5.88	5.25	22.0	23.1
	1	58	25.0	54	2.9	5.83	5.18	21.9	22.8
	2	77	25.3	42	5.4	5.88	5.23	21.6	22.4
	3	70	23.3	38	5.0	5.89	5.13	21.4	22.2
	4	75	23.5	34	2.4	6.09	5.12	20.8	21.9
	5	68	25.3	38	2.7	6.04	5.29	20.3	21.5
	6	59	24.6	29	1.9	5.91	5.16	20.3	21.4
	7	53	22.3	32	2.1	5.97	5.27	20.5	21.0
	8	30	19.2	7	3.0	6.13	5.44	20.0	20.7
	9	27	21.3	6	3.3	6.36	5.67	19.3	20.2
	10	18	21.6	9	0.8	6.28	5.49	19.2	20.6
	11	16	23.2	10	0.9	6.20	5.67	19.2	20.6
	12	26	20.1	22	3.0	6.16	5.56	19.7	20.8
	13	29	22.1	24	2.7	6.33	5.56	19.4	20.7
	14	18	23.0	14	3.1	6.19	5.45	19.4	20.3
	15	20	21.0	13	2.8	6.06	5.51	19.8	21.0
	16	4	23.7	33	1.0	6.22	5.61	19.6	20.9
	17	5	22.3	37	1.1	6.13	5.45	20.1	21.1
	18	0	20.5	48	6.6	6.18	5.65	20.4	21.2
	19	0	21.5	53	6.0	6.27	5.53	20.3	21.3
	20	43	21.4	64	3.7	6.14	5.39	20.3	21.3
	21	39	23.0	58	4.1	6.21	5.44	20.0	21.1
	22	69	21.1	37	4.7	6.08	5.33	19.9	20.9
	23	62	23.1	41	4.3	6.15	5.36	19.1	20.5
30	0	85	24.8	78	4.2	6.10	5.34	19.1	20.3
	1	77	24.2	86	4.6	5.98	5.07	19.1	20.1
	2	90	23.6	50	4.5	6.04	5.07	19.1	19.8
	3	81	25.4	45	4.2	5.97	5.23	18.9	19.8
	4	110	24.1	0	1.6	5.94	5.16	19.1	19.8
	5	121	24.7	0	1.8	5.93	5.22	18.8	19.6
	6	83	24.8	31	2.4	5.87	5.24	18.4	19.6
	7	75	23.4	28	2.7	6.00	5.19	18.5	19.6
	8	0	22.1	0	2.3	5.97	5.34	18.5	19.5
	9	0	20.0	0	2.6	6.18	5.48	19.0	20.0
	10	16	23.4	11	1.4	6.33	5.71	19.1	20.5
	11	14	21.2	12	1.6	6.07	5.57	19.6	20.7
	12	0	22.4	30	3.9	6.14	5.58	19.7	21.0
	13	0	21.0	33	3.5	6.22	5.48	20.0	21.3
	14	25	20.9	73	6.0	6.17	5.48	20.1	21.3
	15	23	22.5	81	5.4	6.19	5.32	19.8	21.2
	16	48	23.0	68	6.3	6.07	5.22	19.9	21.0
	17	43	20.8	75	6.5	6.09	5.17	19.9	21.0
	18	51	23.1	73	5.0	6.26	5.25	19.4	20.7
	19	46	23.6	66	4.5	6.02	5.24	19.4	20.7
	20	74	23.1	61	6.7	6.05	5.15	19.5	20.6
	21	67	22.9	67	6.1	5.98	5.06	19.4	20.6
	22	73	23.3	100	4.1	6.00	5.06	19.1	20.4
	23	66	23.0	90	4.6	5.95	5.19	19.0	19.9

3.6. Estimated results of influent concentration at site #3 (Chapter 6, sub-section 6.3.1)

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO$_2$/L)	DO in ASR#2 (mgO$_2$/L)	Nitrate in ASR#1 (mgN/L)	Nitrate in ASR#2 (mgN/L)
1	0	71	23.7	184	12.7	6.09	3.71	15.3	20.8
	1	64	22.5	166	14.0	6.35	4.08	15.5	21.0
	2	43	19.5	124	17.6	6.41	4.17	15.7	21.2
	3	39	21.0	112	16.0	6.61	4.39	15.9	21.4
	4	0	22.0	173	8.0	6.51	4.53	16.0	21.6
	5	0	20.9	157	8.9	6.72	4.53	16.4	21.7
	6	0	17.7	103	18.8	6.83	4.77	16.6	21.9
	7	0	18.6	114	17.0	6.76	4.90	16.8	22.0
	8	43	20.5	191	15.1	6.89	4.64	17.0	22.2
	9	39	19.5	211	16.7	6.72	4.22	17.1	22.4
	10	96	18.3	208	20.0	6.66	4.35	16.8	22.5
	11	106	19.2	230	18.1	6.60	4.07	16.4	22.0
	12	139	22.1	228	15.8	6.46	3.92	16.0	21.4
	13	153	22.6	252	17.5	6.20	3.67	15.6	20.8
	14	181	23.0	248	20.7	5.88	3.47	15.3	20.3
	15	200	23.8	274	18.7	5.72	3.33	14.9	19.7
	16	226	26.6	184	20.9	5.59	3.15	14.5	19.1
	17	250	27.9	166	19.0	5.43	3.03	14.1	19.3
	18	219	29.7	197	12.9	5.15	2.87	14.2	19.5
	19	199	28.3	178	14.3	5.26	3.21	14.4	19.7
	20	226	28.8	65	11.7	5.25	3.36	14.5	19.8
	21	250	30.3	59	10.6	5.35	3.47	14.7	20.0
	22	222	29.5	45	7.2	5.36	3.52	14.8	20.2
	23	201	29.2	41	7.5	5.42	3.91	14.9	20.4
2	0	189	28.1	20	7.0	5.58	4.00	15.1	20.5
	1	171	26.7	19	6.3	5.66	4.16	15.3	20.6
	2	141	26.0	31	7.6	5.73	4.29	15.3	20.7
	3	128	23.5	28	8.4	5.87	4.39	15.6	20.8
	4	131	25.4	24	6.0	6.06	4.68	15.5	20.9
	5	144	25.8	26	6.7	5.96	4.60	15.6	20.8
	6	114	24.9	54	8.5	6.12	4.58	15.7	21.1
	7	103	22.7	60	9.4	6.17	4.67	15.9	21.1
	8	105	24.8	73	9.4	6.21	4.68	15.9	21.2
	9	115	22.6	66	10.4	6.31	4.70	16.0	21.2
	10	129	20.5	37	7.0	6.16	4.56	16.0	21.4
	11	117	21.5	33	6.3	6.36	4.84	15.7	21.0
	12	88	19.5	24	5.3	6.17	4.84	15.4	20.6
	13	80	18.5	22	6.3	6.30	5.06	15.2	20.2
	14	53	15.7	47	8.1	6.27	5.05	14.9	19.8
	15	48	15.2	42	7.1	6.49	5.07	14.5	19.5
	16	47	15.9	11	7.1	6.56	5.25	14.1	19.1
	17	43	14.4	10	8.5	6.48	5.11	14.0	18.7
	18	14	16.6	11	4.7	6.54	5.25	13.5	18.7
	19	13	17.1	10	5.2	6.67	5.38	13.6	18.8
	20	0	13.8	0	8.5	6.66	5.35	13.8	18.9
	21	0	15.3	0	7.0	6.84	5.67	13.7	19.1
	22	0	16.8	43	7.6	6.69	5.59	13.8	19.3
	23	0	15.2	48	8.4	6.81	5.48	14.0	19.4

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
3	0	0	16.4	33	8.6	6.80	5.68	14.1	19.5
	1	0	17.5	36	7.8	6.80	5.51	14.2	19.7
	2	73	22.2	23	6.5	6.89	5.64	14.5	19.9
	3	81	21.0	21	7.2	6.47	5.43	14.8	20.0
	4	39	20.2	27	6.5	6.48	5.48	15.0	20.4
	5	35	21.1	24	5.9	6.65	5.60	15.1	20.5
	6	0	17.3	29	8.9	6.73	5.52	15.4	20.5
	7	0	19.1	32	8.1	6.89	5.79	15.4	20.9
	8	11	20.0	25	5.0	7.04	5.74	15.8	21.1
	9	12	18.0	28	5.5	6.86	5.78	16.0	21.1
	10	56	16.0	30	9.9	7.03	5.92	16.1	21.2
	11	51	17.5	27	9.0	6.90	5.86	15.8	21.0
	12	45	16.1	101	10.6	6.92	5.70	15.5	20.7
	13	50	16.9	112	11.8	6.89	5.56	15.2	20.3
	14	44	15.4	173	17.4	6.72	5.36	14.9	20.1
	15	49	17.0	191	15.8	6.75	4.98	14.5	19.9
	16	117	19.3	100	15.6	6.72	4.87	14.4	19.5
	17	129	21.3	111	14.2	6.30	4.82	14.0	19.7
	18	81	22.5	193	15.1	6.24	4.61	14.0	19.7
	19	89	20.4	213	16.7	6.29	4.55	14.2	19.8
	20	188	28.5	76	9.5	6.34	4.58	14.3	19.9
	21	208	26.1	84	10.5	5.86	4.38	14.6	19.9
	22	158	27.0	162	15.6	6.03	4.62	14.6	20.0
	23	143	24.5	147	14.2	6.03	4.34	14.8	20.2
4	0	134	24.1	148	13.7	6.75	4.62	15.3	20.1
	1	121	24.5	134	12.4	6.55	4.82	15.3	20.1
	2	84	21.4	117	11.4	6.61	5.08	15.4	20.1
	3	76	21.7	106	11.2	6.91	5.35	15.4	20.1
	4	54	20.1	59	7.3	7.05	5.53	15.4	20.1
	5	49	21.0	53	6.6	7.06	5.83	15.4	20.1
	6	28	19.5	71	8.5	7.10	5.85	15.5	20.0
	7	25	18.1	64	8.9	7.26	6.03	15.6	20.0
	8	56	18.1	120	12.1	7.46	6.02	15.6	20.0
	9	51	17.6	109	11.0	7.33	5.76	15.5	19.9
	10	35	18.9	91	8.6	7.45	5.89	15.2	19.7
	11	39	17.1	82	8.2	7.44	6.03	15.1	19.5
	12	34	16.0	38	8.0	7.41	6.08	15.0	19.2
	13	38	17.6	42	7.3	7.38	6.29	14.9	19.1
	14	52	19.2	49	10.2	7.30	5.96	14.8	19.2
	15	57	19.0	54	9.2	7.04	5.72	14.8	19.3
	16	62	19.6	86	6.9	7.02	5.64	14.9	19.5
	17	68	20.5	95	7.6	6.84	5.65	14.9	19.4
	18	0	17.2	101	14.0	6.89	5.61	15.0	19.4
	19	0	16.0	91	12.7	7.14	5.66	15.1	19.4
	20	18	17.2	147	8.4	7.25	5.75	15.1	19.5
	21	16	18.0	133	9.2	7.12	5.72	15.1	19.4
	22	0	15.1	82	10.6	7.07	5.81	15.2	19.3
	23	0	16.6	74	10.6	7.22	5.94	15.1	19.1

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
5	0	33	18.5	90	16.0	7.27	6.10	15.1	19.1
	1	36	18.7	99	14.5	7.17	5.72	15.1	19.2
	2	47	19.3	183	12.5	7.32	5.65	15.1	19.5
	3	52	19.5	202	13.8	7.26	5.67	15.2	19.7
	4	0	17.6	164	16.1	7.31	5.73	15.2	19.6
	5	0	17.0	148	14.6	7.38	5.86	15.2	19.5
	6	76	20.6	99	7.6	7.52	5.90	15.3	19.6
	7	84	21.1	109	8.4	7.20	5.83	15.3	19.6
	8	127	21.5	96	15.7	7.22	5.89	15.3	19.5
	9	115	21.7	106	14.2	7.13	5.50	15.2	19.4
	10	56	19.9	282	16.7	7.02	5.48	15.0	19.5
	11	51	18.0	256	18.5	7.18	5.26	15.0	19.4
	12	49	19.1	126	13.1	7.21	5.19	14.9	19.3
	13	65	19.7	139	11.9	7.28	5.47	14.9	19.2
	14	53	18.8	179	14.2	7.03	5.60	14.9	19.1
	15	48	18.2	162	15.2	7.08	5.58	14.9	19.1
	16	48	18.6	195	16.7	7.12	5.57	14.9	19.1
	17	43	19.8	215	15.2	7.13	5.38	14.8	19.1
	18	11	16.3	269	23.4	7.13	5.23	15.0	19.1
	19	10	16.7	297	22.4	7.36	5.27	15.0	19.1
	20	52	19.0	270	21.6	7.32	5.11	15.0	19.2
	21	58	19.2	298	21.1	7.21	5.04	15.0	19.3
	22	103	21.8	257	21.6	7.15	5.00	14.9	19.3
	23	93	21.7	284	20.0	6.98	4.95	14.9	19.3
6	0	138	24.0	207	17.5	7.15	4.95	14.9	19.3
	1	153	24.4	229	17.8	7.01	4.87	15.0	19.3
	2	101	22.6	298	23.1	6.89	4.87	15.0	19.3
	3	91	21.4	270	22.1	7.17	4.96	14.9	19.4
	4	129	23.0	241	16.6	7.21	4.99	15.0	19.4
	5	143	24.2	218	18.3	7.10	5.00	14.9	19.4
	6	132	23.2	207	17.8	7.02	5.03	15.0	19.4
	7	119	23.7	187	16.2	6.98	5.06	14.9	19.4
	8	157	24.2	170	13.0	7.07	5.16	15.0	19.4
	9	174	25.1	188	14.4	6.93	5.19	14.9	19.4
	10	143	23.6	254	22.1	6.90	5.00	14.9	19.3
	11	129	23.1	230	20.1	6.92	4.80	14.8	19.3
	12	168	25.0	213	14.3	6.90	4.65	14.8	19.2
	13	186	25.5	235	15.9	6.60	4.65	14.8	19.1
	14	179	25.5	246	23.3	6.61	4.54	14.7	19.1
	15	198	26.4	272	21.1	6.51	4.27	14.7	19.1
	16	211	28.3	288	20.6	6.50	4.10	14.7	19.0
	17	233	28.5	318	22.8	6.20	4.13	14.7	19.1
	18	207	28.6	283	23.2	6.26	3.80	14.7	19.1
	19	187	26.5	256	21.1	6.21	3.90	14.8	19.2
	20	166	26.0	258	18.2	6.48	4.31	14.8	19.3
	21	184	26.6	233	20.1	6.48	4.41	14.8	19.3
	22	191	27.8	158	13.6	6.50	4.37	14.8	19.4
	23	173	26.5	143	13.4	6.57	4.73	14.9	19.4

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
7	0	184	27.7	125	12.0	6.66	4.98	14.9	19.5
	1	166	26.7	113	11.8	6.78	5.04	15.0	19.6
	2	104	23.2	129	12.5	6.81	5.19	15.0	19.6
	3	94	22.8	117	12.3	7.18	5.62	15.1	19.7
	4	67	21.4	74	7.7	7.39	5.58	15.1	19.7
	5	74	21.6	67	8.0	7.47	5.96	15.1	19.7
	6	55	21.5	53	6.9	7.52	6.18	15.2	19.8
	7	50	20.9	48	6.2	7.66	6.36	15.2	19.8
	8	61	17.4	33	5.9	7.71	6.34	15.3	19.7
	9	67	19.0	37	6.5	7.69	6.54	15.2	19.5
	10	116	21.6	117	12.3	7.62	6.25	15.1	19.3
	11	128	20.8	129	12.5	7.18	5.61	15.0	19.2
	12	184	25.9	205	15.7	7.08	5.48	14.9	19.0
	13	203	26.2	227	17.0	6.57	4.67	14.9	18.9
	14	205	26.6	220	18.5	6.48	4.38	14.8	18.8
	15	226	27.8	243	17.9	6.35	4.26	14.7	18.7
	16	243	29.1	227	18.2	5.99	4.11	14.7	18.7
	17	220	28.2	251	18.4	6.03	4.03	14.7	18.7
	18	248	29.9	223	17.3	5.95	3.89	14.7	18.7
	19	224	28.8	201	16.0	5.95	3.88	14.7	18.7
	20	264	30.9	154	12.9	5.93	4.10	14.7	18.7
	21	239	30.0	139	12.6	5.96	4.22	14.8	18.8
	22	244	29.9	90	9.1	5.93	4.46	14.8	18.8
	23	269	31.0	99	10.0	5.97	4.57	14.9	18.8
8	0	311	32.4	21	6.3	6.06	4.60	14.9	18.8
	1	281	32.7	19	5.7	5.92	4.71	14.8	18.8
	2	297	32.7	8	4.0	5.88	4.82	14.8	18.9
	3	269	32.2	7	4.4	5.97	4.85	14.8	18.9
	4	281	31.8	0	5.1	6.14	4.91	14.9	18.9
	5	254	31.5	0	4.6	6.09	4.96	14.9	19.0
	6	260	30.6	0	5.3	6.20	5.13	14.9	19.1
	7	287	31.0	0	5.9	6.08	5.01	15.0	19.1
	8	289	32.9	21	4.1	6.20	5.10	14.9	19.2
	9	319	32.7	23	4.3	6.10	4.89	14.8	19.1
	10	316	33.5	0	6.3	5.94	4.85	14.8	19.0
	11	349	33.8	0	5.7	5.87	4.70	14.8	18.9
	12	332	33.9	40	5.0	5.65	4.45	14.7	18.9
	13	367	35.5	44	5.6	5.45	4.44	14.6	18.8
	14	356	35.7	71	9.6	5.25	4.14	14.5	18.6
	15	393	37.0	79	8.7	5.21	3.95	14.5	18.6
	16	408	38.0	97	9.4	5.13	3.76	14.5	18.5
	17	369	36.6	88	9.5	4.97	3.59	14.5	18.5
	18	358	35.8	92	9.4	4.93	3.69	14.5	18.5
	19	324	34.5	83	9.2	5.10	3.73	14.5	18.5
	20	298	32.2	92	10.2	5.19	4.01	14.6	18.5
	21	270	31.2	83	9.4	5.35	4.16	14.6	18.6
	22	264	30.6	55	6.7	5.62	4.30	14.6	18.6
	23	239	30.1	50	7.1	5.60	4.43	14.6	18.6

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
9	0	283	32.2	26	5.5	5.78	4.72	14.6	18.7
	1	256	30.8	23	5.8	5.69	4.63	14.7	18.7
	2	228	28.8	46	7.5	5.81	4.88	14.7	18.7
	3	206	27.9	42	7.1	5.95	4.95	14.7	18.7
	4	210	27.5	16	5.3	6.14	4.93	14.7	18.7
	5	190	27.4	15	5.4	6.15	5.17	14.7	18.8
	6	198	27.2	5	5.3	6.18	5.29	14.7	18.9
	7	219	27.8	6	5.8	6.28	5.33	14.7	18.9
	8	268	30.1	3	5.0	6.14	5.25	14.7	19.0
	9	242	29.8	4	4.6	5.97	5.03	14.7	19.0
	10	257	29.8	0	6.9	6.12	5.13	14.6	19.0
	11	284	30.7	0	7.6	6.00	4.96	14.6	19.0
	12	260	30.0	53	3.1	5.70	4.73	14.6	19.3
	13	287	30.8	59	3.4	5.79	4.91	14.5	19.0
	14	277	31.3	0	10.5	5.66	4.74	14.5	18.6
	15	306	32.3	0	9.5	5.61	4.54	14.5	18.7
	16	314	33.5	58	5.2	5.34	4.30	14.5	19.1
	17	284	32.8	64	5.8	5.40	4.22	14.5	19.3
	18	282	31.2	91	9.1	5.31	4.33	14.6	19.1
	19	255	30.5	82	8.2	5.55	4.31	14.6	18.9
	20	254	29.8	66	12.8	5.49	4.46	14.6	18.7
	21	230	29.4	73	11.6	5.58	4.38	14.6	18.9
	22	235	29.0	127	10.2	5.56	4.41	14.7	19.3
	23	213	28.0	140	11.3	5.66	4.29	14.7	19.4
10	0	107	23.5	95	8.6	6.79	5.99	14.1	18.1
	1	97	21.3	89	9.2	6.52	6.12	14.1	18.0
	2	67	19.7	82	9.6	6.62	6.25	14.0	18.1
	3	61	18.5	68	11.7	6.77	6.57	14.1	18.1
	4	60	22.1	63	10.4	6.95	6.49	14.0	18.2
	5	54	20.0	73	10.9	6.86	6.45	14.2	18.3
	6	50	17.1	95	11.1	6.92	6.54	14.2	18.6
	7	55	18.9	90	10.9	7.16	6.52	14.2	18.8
	8	75	20.2	80	10.2	7.07	6.54	14.2	18.8
	9	68	18.3	77	7.5	7.09	6.66	14.1	18.8
	10	64	19.9	86	7.8	7.12	6.74	14.0	18.7
	11	71	17.9	80	8.4	7.17	6.75	14.0	18.4
	12	99	19.2	55	8.5	7.11	6.75	13.9	18.3
	13	109	19.8	49	7.8	6.99	6.75	13.7	18.0
	14	127	23.2	53	7.6	6.97	6.52	13.6	17.9
	15	140	21.0	61	6.4	6.65	6.48	13.6	17.8
	16	161	24.9	65	7.4	6.72	6.44	13.4	17.7
	17	146	22.5	69	7.0	6.60	6.31	13.5	17.5
	18	135	22.8	111	13.0	6.58	6.35	13.4	17.5
	19	149	23.7	121	12.1	6.60	6.17	13.4	17.4
	20	176	25.5	125	11.3	6.53	6.20	13.4	17.3
	21	195	24.4	108	8.2	6.41	6.00	13.4	17.3
	22	187	26.2	110	9.5	6.49	6.01	13.4	17.2
	23	207	25.1	92	10.4	6.48	6.11	13.4	17.2

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
11	0	190	27.9	79	9.4	6.38	6.10	13.3	17.0
	1	172	25.1	87	8.5	6.35	6.06	13.4	17.1
	2	185	24.5	84	9.5	6.45	6.12	13.4	16.9
	3	167	23.3	93	10.5	6.53	6.32	13.4	16.9
	4	189	28.7	21	6.5	6.71	6.21	13.3	16.9
	5	209	26.3	19	6.0	6.40	6.25	13.4	17.1
	6	174	23.8	49	13.4	6.30	6.27	13.4	17.3
	7	182	24.8	54	12.7	6.62	6.42	13.4	17.5
	8	201	26.5	53	7.9	6.51	6.19	13.3	17.7
	9	203	24.0	48	8.7	6.36	6.19	13.3	17.9
	10	183	23.9	39	5.9	6.39	6.25	13.1	18.1
	11	192	26.4	35	5.4	6.47	6.51	13.0	18.3
	12	204	27.3	7	2.9	6.35	6.34	13.1	18.0
	13	225	24.7	8	3.2	6.35	6.43	13.1	17.7
	14	220	26.8	10	4.1	6.27	6.40	12.9	17.4
	15	243	26.1	11	4.5	6.13	6.41	12.9	17.1
	16	245	29.4	94	6.3	6.04	6.26	12.8	16.9
	17	222	26.7	114	6.9	6.00	5.91	12.9	16.6
	18	200	27.1	195	13.0	6.09	5.84	12.8	16.3
	19	181	24.7	176	11.8	6.16	5.58	12.9	16.0
	20	164	26.0	157	14.5	6.24	5.83	12.9	15.7
	21	148	23.6	173	13.1	6.36	5.72	13.1	15.8
	22	171	24.0	151	9.8	6.38	5.90	13.1	15.9
	23	189	25.9	127	10.8	6.41	5.82	13.2	16.0
12	0	200	29.5	97	9.3	6.29	6.00	13.2	16.1
	1	181	26.7	92	8.4	6.13	5.83	13.4	16.3
	2	157	26.6	102	9.0	6.32	6.04	13.5	16.4
	3	142	24.1	148	8.7	6.51	6.09	13.7	16.6
	4	121	27.5	141	8.4	6.55	6.09	13.8	16.8
	5	110	25.6	134	8.1	6.61	5.99	14.0	16.9
	6	130	21.3	87	12.5	6.65	6.25	14.2	16.9
	7	118	23.5	83	12.1	6.53	6.23	14.3	17.1
	8	94	23.3	79	11.3	6.76	6.30	14.4	17.2
	9	85	21.1	159	12.0	6.85	6.27	14.6	17.4
	10	127	16.5	168	13.0	6.78	6.03	14.4	17.7
	11	140	18.3	175	13.3	6.82	6.12	14.1	17.6
	12	151	23.9	152	13.1	6.77	5.98	13.9	17.3
	13	167	22.0	160	11.9	6.54	5.71	13.6	17.0
	14	192	22.7	168	12.1	6.26	5.68	13.4	16.7
	15	212	23.4	174	16.0	6.14	5.42	13.2	16.4
	16	232	25.6	183	14.0	5.89	5.35	12.9	16.2
	17	254	25.2	192	15.0	5.78	5.03	12.7	15.9
	18	167	25.7	232	15.8	5.74	5.03	12.4	15.6
	19	151	23.5	221	16.8	5.79	4.94	12.6	15.7
	20	110	20.0	218	17.3	5.95	5.09	12.7	15.9
	21	100	21.0	148	12.9	6.20	5.44	12.7	16.0
	22	72	19.5	142	11.6	6.29	5.65	12.8	16.1
	23	65	19.0	135	11.7	6.44	5.90	12.9	16.3

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
13	0	46	21.7	123	12.6	6.67	6.12	13.1	16.5
	1	42	19.6	111	11.4	6.75	6.16	13.3	16.9
	2	31	17.4	189	13.9	6.67	6.13	13.5	17.3
	3	28	19.1	209	12.6	6.94	6.09	13.7	17.6
	4	9	20.4	218	12.1	6.95	6.04	13.9	17.5
	5	10	18.4	240	13.4	6.92	6.12	14.1	17.4
	6	36	18.0	193	20.0	6.94	6.01	14.3	17.5
	7	40	19.8	213	18.1	6.89	6.05	14.5	17.6
	8	64	17.9	172	11.0	6.85	5.72	14.7	17.7
	9	58	19.9	156	12.2	6.83	5.92	14.6	17.8
	10	61	16.6	84	13.8	6.79	6.10	14.7	18.0
	11	55	18.0	76	12.6	6.82	6.31	14.5	17.9
	12	70	18.1	125	6.9	6.86	6.32	14.3	18.0
	13	77	16.9	113	7.6	6.92	6.35	14.1	17.9
	14	75	18.4	66	9.4	7.01	6.52	13.8	17.6
	15	68	17.6	60	8.6	6.83	6.64	13.6	17.3
	16	90	18.0	57	4.8	7.05	6.73	13.4	16.9
	17	99	16.5	51	5.3	7.02	6.67	13.2	16.6
	18	80	23.8	3	3.6	6.96	6.81	12.9	16.3
	19	72	21.5	2	3.3	6.80	6.82	13.0	16.4
	20	81	17.7	33	7.0	6.85	6.94	13.1	16.5
	21	90	19.5	36	7.7	6.90	6.90	13.2	16.6
	22	79	22.9	91	6.1	6.80	6.72	13.3	16.7
	23	87	20.7	111	6.7	6.87	6.43	13.4	16.8
14	0	73	19.9	89	12.9	4.64	4.17	14.2	20.6
	1	66	20.8	80	11.7	4.50	4.23	14.3	20.7
	2	82	20.1	82	10.1	4.50	4.20	14.5	20.9
	3	91	20.6	74	11.2	4.49	4.30	14.6	20.8
	4	128	22.7	25	7.0	4.36	4.36	14.6	21.0
	5	116	23.0	23	6.3	4.21	4.38	14.6	20.9
	6	108	21.3	14	9.4	4.29	4.31	14.7	20.8
	7	98	20.1	15	8.5	4.29	4.43	14.7	20.9
	8	147	20.1	88	10.7	4.53	4.59	14.5	20.8
	9	133	21.5	97	11.5	4.41	4.33	14.2	20.4
	10	125	20.9	87	12.9	4.38	4.05	14.0	20.1
	11	138	21.3	96	13.9	4.35	3.97	13.9	19.9
	12	142	21.5	119	14.8	4.31	3.94	13.7	20.1
	13	157	23.7	131	13.4	4.16	3.86	13.6	20.1
	14	132	22.8	162	16.8	4.00	3.71	13.7	20.0
	15	146	23.1	179	17.4	4.13	3.59	13.7	20.1
	16	154	25.3	174	14.4	4.03	3.56	13.8	20.2
	17	139	26.1	192	13.0	3.77	3.50	14.0	20.3
	18	159	25.8	130	15.3	3.74	3.39	14.4	20.3
	19	144	26.4	118	13.9	3.68	3.41	14.6	20.7
	20	186	26.7	71	8.8	3.84	3.42	14.9	20.7
	21	168	29.3	64	7.9	3.62	3.80	15.1	21.1
	22	143	26.0	132	9.7	3.46	3.76	15.4	21.1
	23	129	25.4	120	10.7	3.69	3.81	15.6	21.0

Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
15	0	111	24.5	113	8.2	3.97	3.83	15.8	20.9
	1	100	26.7	102	9.0	4.12	3.98	16.0	20.6
	2	103	23.5	70	10.3	4.03	3.96	16.3	20.8
	3	93	24.8	63	9.3	4.15	4.25	16.5	21.0
	4	98	22.3	98	8.4	4.13	4.08	16.6	21.0
	5	88	24.4	89	9.3	4.36	4.31	16.6	21.0
	6	110	23.8	124	8.5	4.26	4.27	16.7	21.1
	7	121	21.5	137	9.4	4.16	4.25	16.7	20.6
	8	193	20.8	124	13.1	4.25	4.30	16.4	20.1
	9	175	21.8	137	11.8	4.13	4.01	15.7	19.2
	10	187	21.1	120	10.0	4.13	4.01	15.0	18.4
	11	207	23.4	133	11.0	4.03	4.04	14.3	17.8
	12	176	25.0	94	10.9	3.90	3.67	13.9	17.5
	13	194	27.6	104	9.9	3.79	3.56	13.7	17.5
	14	169	29.4	103	9.4	3.55	3.42	14.1	17.8
	15	153	26.7	93	10.4	3.33	3.50	14.6	18.2
	16	156	24.1	107	11.2	3.52	3.62	14.8	18.8
	17	141	26.7	97	10.2	3.73	3.69	14.8	19.1
	18	147	28.4	98	4.7	3.70	3.52	15.3	19.3
	19	133	25.7	89	5.2	3.41	3.68	15.9	19.4
	20	167	24.7	30	5.2	3.76	4.02	15.9	19.3
	21	151	27.3	33	4.7	3.80	4.05	15.8	19.1
	22	112	26.7	148	4.8	3.71	4.12	16.0	18.9
	23	101	24.2	134	5.3	3.76	4.05	16.3	18.7
16	0	64	23.7	25	5.2	4.00	4.13	16.4	18.4
	1	58	24.2	23	4.7	4.04	4.30	16.6	18.8
	2	90	20.5	81	6.1	4.12	4.32	17.0	19.0
	3	82	22.7	89	6.8	4.22	4.44	16.9	18.8
	4	69	23.1	88	7.6	4.27	4.40	16.8	18.7
	5	62	20.9	80	8.4	4.16	4.22	17.0	18.9
	6	106	21.2	137	8.5	4.46	4.37	16.8	19.0
	7	117	22.1	151	9.3	4.17	4.34	16.6	18.6
	8	91	23.2	203	5.6	4.12	4.12	16.3	18.1
	9	82	25.6	184	6.2	4.26	4.18	16.2	17.6
	10	164	21.9	62	11.4	4.04	4.00	16.6	17.2
	11	181	24.2	68	10.3	3.97	4.07	16.2	17.0
	12	173	23.2	84	9.0	3.82	3.88	15.9	17.0
	13	191	25.6	93	9.9	3.89	3.98	15.3	17.1
	14	98	23.9	164	7.8	3.55	3.75	15.2	17.5
	15	89	24.3	181	8.6	3.99	3.98	15.3	17.4
	16	97	22.8	156	12.6	3.95	3.79	15.6	17.5
	17	88	25.2	172	11.4	3.96	3.63	15.7	17.5
	18	58	26.3	192	11.6	3.75	3.60	16.3	17.7
	19	53	23.8	174	12.8	3.94	3.61	16.9	18.4
	20	131	25.7	122	8.9	4.03	3.74	17.1	19.0
	21	119	26.2	135	8.5	3.68	3.79	17.4	19.1
	22	146	25.5	91	6.6	3.74	3.78	17.5	19.2
	23	161	28.1	82	6.0	3.74	3.87	17.3	19.1

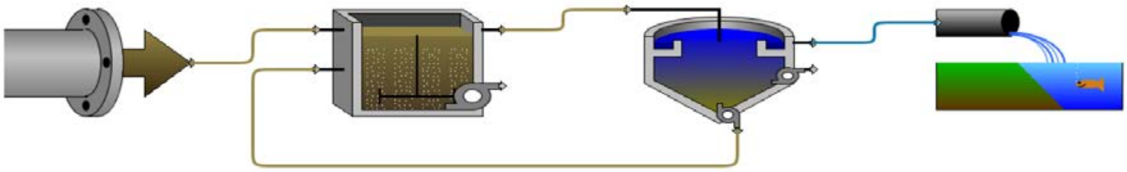
Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
17	0	64	18.3	144	17.8	3.75	2.94	16.5	24.2
	1	71	19.6	130	16.1	4.07	3.07	16.2	24.0
	2	96	19.1	86	13.6	4.08	3.16	16.0	23.7
	3	106	20.3	95	14.8	4.03	3.26	15.6	23.5
	4	82	18.9	115	15.1	3.97	3.25	15.3	23.3
	5	91	18.3	127	16.7	4.05	3.14	15.0	23.0
	6	107	19.2	96	14.0	4.09	3.17	14.7	22.8
	7	118	20.1	87	14.3	3.99	3.30	14.4	22.5
	8	110	18.2	86	14.5	3.91	3.17	14.2	22.3
	9	121	19.7	78	13.1	4.13	3.26	13.8	22.1
	10	135	21.5	21	13.9	3.94	3.28	13.5	21.8
	11	149	22.4	23	13.6	3.59	3.38	13.5	22.0
	12	91	22.9	133	14.0	3.62	3.31	13.5	22.4
	13	101	21.7	147	15.4	3.56	3.05	13.8	22.6
	14	120	22.9	104	17.2	3.67	3.11	14.1	22.6
	15	133	23.7	115	15.5	3.49	2.92	14.3	22.7
	16	47	21.6	157	17.6	3.43	2.85	14.5	22.8
	17	52	21.0	173	16.0	3.82	3.11	14.8	23.3
	18	51	22.4	110	17.2	3.81	3.09	15.2	23.3
	19	56	20.3	99	15.6	3.79	3.07	15.7	23.8
	20	63	20.1	140	14.1	3.97	3.31	15.7	24.0
	21	57	21.5	127	15.5	4.07	3.34	15.8	23.8
	22	72	21.4	74	12.6	3.78	3.40	16.0	23.9
	23	80	20.1	82	13.9	3.80	3.53	16.1	23.8
18	0	31	20.8	177	11.4	3.98	3.52	15.8	23.9
	1	34	18.8	160	12.6	4.13	3.63	16.1	23.5
	2	90	20.9	5	14.4	4.11	3.66	16.1	23.1
	3	100	18.9	5	13.2	3.83	3.66	16.1	23.0
	4	72	21.6	31	10.9	4.06	3.88	15.7	23.2
	5	80	19.6	28	12.0	4.00	3.72	15.7	23.6
	6	127	21.2	11	11.5	4.10	3.98	15.5	23.9
	7	140	20.3	10	10.5	3.73	3.87	15.3	23.7
	8	76	20.5	63	12.8	3.77	3.90	14.8	23.4
	9	84	19.1	57	11.6	4.06	3.81	14.8	23.5
	10	152	20.9	17	10.6	4.07	3.95	14.7	23.2
	11	168	18.9	19	11.7	3.72	3.75	14.4	22.8
	12	115	22.1	81	11.2	3.90	3.88	13.6	22.4
	13	127	20.0	90	12.2	3.79	3.52	13.6	22.1
	14	143	22.3	18	12.0	3.90	3.59	13.5	21.8
	15	158	21.6	20	10.8	3.50	3.64	13.5	21.8
	16	72	20.8	73	17.1	3.54	3.63	13.3	21.6
	17	80	20.4	66	15.5	3.86	3.48	13.5	22.3
	18	89	21.3	29	12.8	3.95	3.58	13.8	22.7
	19	98	19.2	26	13.4	3.75	3.72	14.1	23.3
	20	74	21.6	86	13.0	4.02	3.85	13.9	23.4
	21	67	19.6	95	14.3	3.84	3.58	14.3	23.4
	22	118	20.1	49	10.8	4.05	3.84	14.3	23.5
	23	130	20.3	44	11.9	3.85	3.92	14.2	23.1

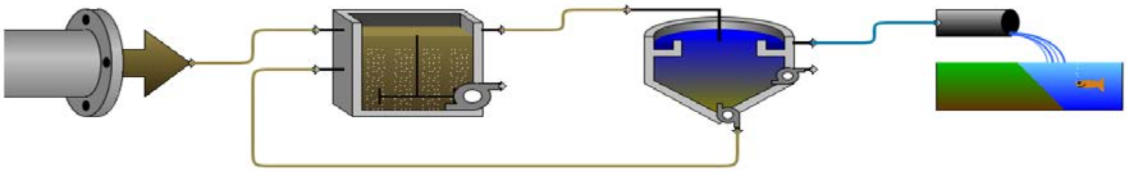
Day	Time	S_B (mgCOD/L)	S_{NHx} (mgN/L)	XC_B (mgCOD/L)	$XC_{B\_org,N}$ (mgN/L)	DO in ASR#1 (mgO_2/L)	DO in ASR#2 (mgO_2/L)	Nitrate in ASR #1 (mgN/L)	Nitrate in ASR #2 (mgN/L)
19	0	62	21.4	45	12.0	3.83	3.79	14.0	22.8
	1	69	19.4	50	10.9	3.88	3.81	14.2	23.0
	2	135	21.0	2	10.6	4.05	4.03	14.3	23.0
	3	149	20.3	2	9.6	3.81	3.90	14.2	22.9
	4	95	20.5	23	8.5	3.71	3.99	13.8	22.5
	5	105	20.0	21	9.4	4.02	4.10	13.8	22.3
	6	142	21.0	0	11.7	3.98	4.18	13.8	22.2
	7	157	19.0	0	11.9	3.73	3.87	13.6	22.0
	8	131	20.7	60	9.1	3.81	4.03	13.1	21.8
	9	145	19.0	66	10.0	3.85	4.01	12.9	21.6
	10	188	19.9	9	12.5	3.91	4.02	12.6	20.9
	11	208	21.9	10	11.4	3.61	3.82	12.1	20.4
	12	160	20.5	62	9.5	3.43	3.62	11.8	20.2
	13	177	21.6	69	9.2	3.70	3.80	11.6	20.0
	14	189	22.1	15	11.8	3.39	3.71	11.5	19.5
	15	209	22.0	16	10.7	3.33	3.50	11.4	19.4
	16	142	21.7	18	13.5	3.28	3.65	11.2	19.3
	17	128	20.1	16	12.3	3.51	3.59	11.4	19.9
	18	114	22.0	56	10.5	3.66	3.71	11.5	20.3
	19	126	19.9	51	11.6	3.60	3.62	11.9	20.6
	20	117	19.6	48	13.0	3.77	3.86	12.0	20.7
	21	106	19.3	43	11.7	3.88	3.93	12.0	20.6
	22	134	20.1	17	7.9	3.88	3.94	12.1	20.6
	23	148	19.3	16	8.7	3.84	4.17	12.1	20.5
20	0	83	19.1	18	9.6	3.77	4.08	11.9	20.2
	1	92	17.9	16	9.9	4.08	4.33	12.1	20.2
	2	133	19.5	1	7.6	4.02	4.41	12.1	20.3
	3	147	18.9	1	8.4	3.85	4.34	12.1	20.1
	4	96	18.9	20	8.6	3.81	4.40	11.8	19.8
	5	87	18.2	18	7.8	3.98	4.29	11.9	19.7
	6	149	17.7	2	7.6	4.04	4.50	11.9	19.6
	7	165	16.0	2	8.4	3.96	4.43	11.7	19.0
	8	115	17.7	51	10.7	4.16	4.61	10.9	18.4
	9	127	17.3	56	11.2	4.11	4.17	10.8	18.1
	10	143	18.6	33	8.5	3.96	4.15	10.6	18.0
	11	158	18.2	36	8.0	3.85	4.18	10.5	17.8
	12	129	18.0	27	9.4	3.88	4.14	10.3	17.4
	13	143	18.4	30	8.6	3.96	4.22	10.2	17.3
	14	146	19.4	0	7.5	3.70	4.22	10.2	17.1
	15	161	20.2	0	8.2	3.76	4.15	10.3	17.2
	16	77	18.0	28	9.8	3.64	4.11	10.3	17.4
	17	85	16.3	31	10.6	3.99	4.19	10.6	17.6
	18	118	18.9	0	10.1	4.13	4.28	10.7	17.9
	19	130	17.9	0	11.1	3.86	4.04	10.8	18.2
	20	89	18.5	47	11.7	3.88	4.22	10.8	18.5
	21	80	16.8	42	12.2	3.87	4.02	11.0	18.8
	22	115	17.3	19	9.0	4.18	4.15	11.1	19.0
	23	104	18.1	17	9.9	3.89	4.42	11.0	19.0

4. Information of GPS-X for estimation

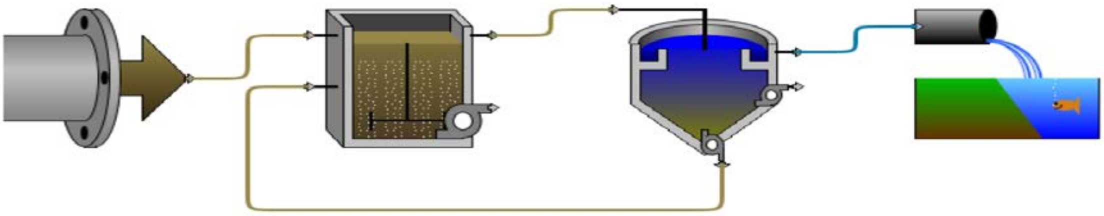
4.1. Model layout

∗ *In Chapter 4*

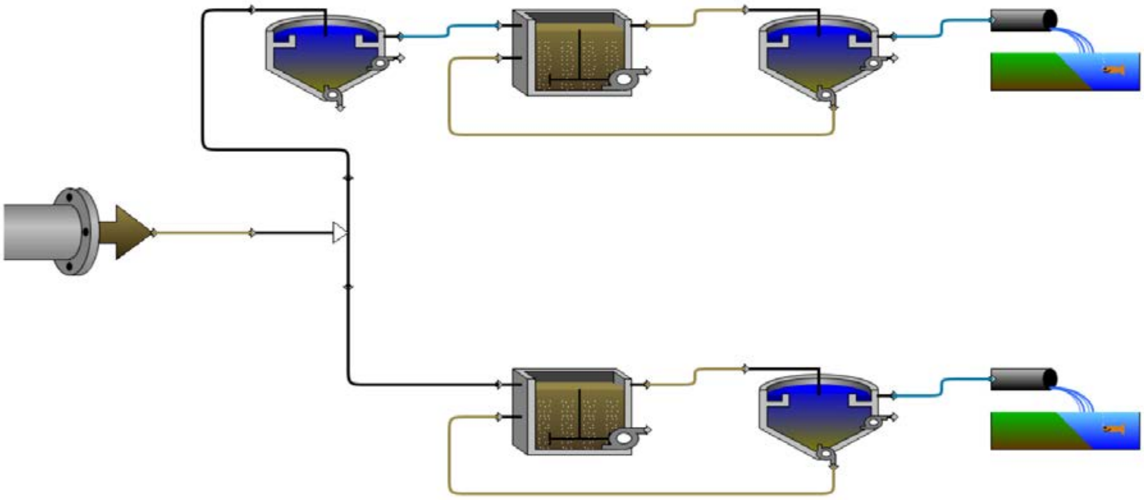




∗ *In Chapter 5 and 7*



∗ *In Chapter 6*

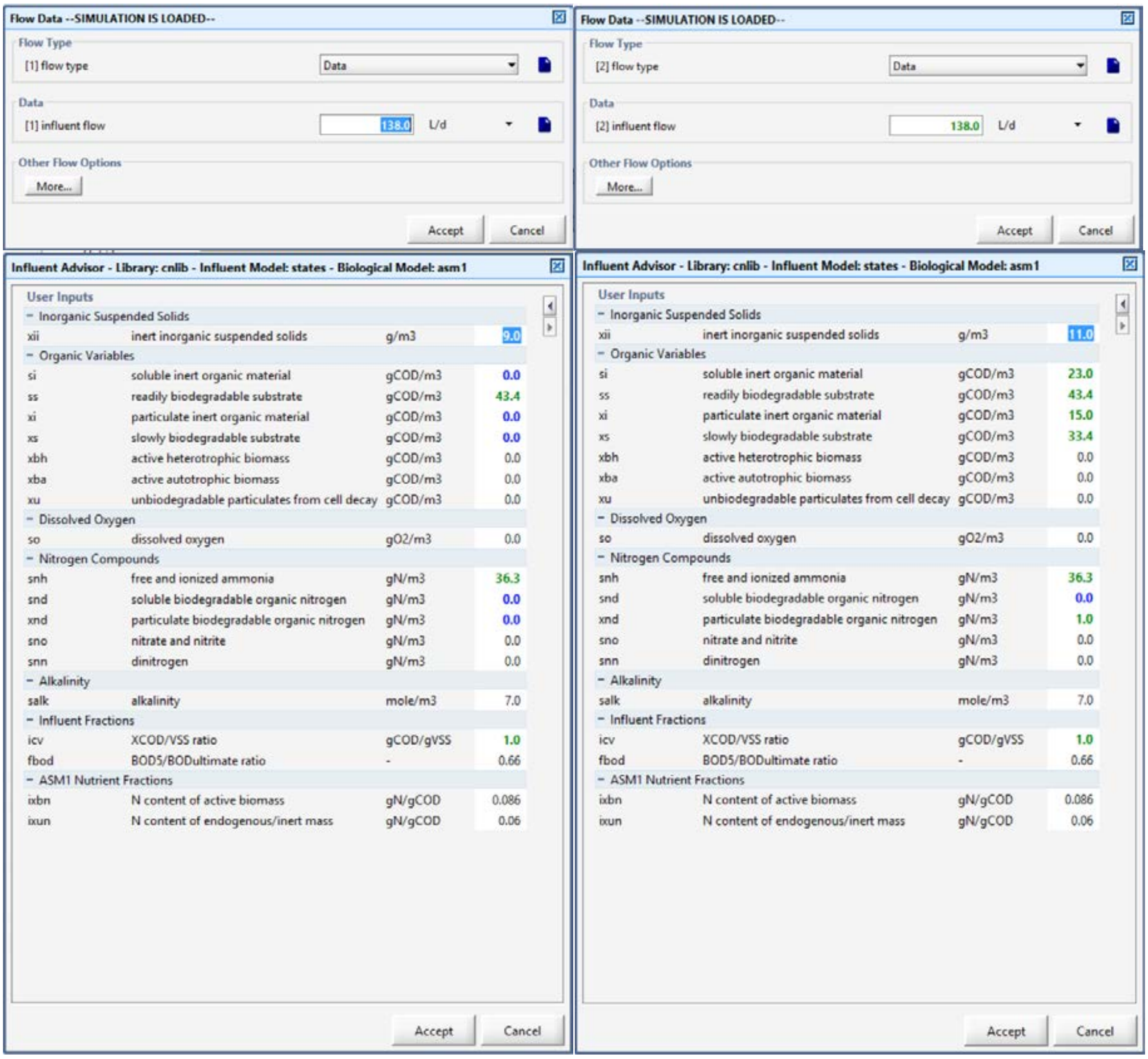


4.2. Unit configuration

a) In Chapter 4

∗ *Case study of Vinh Niem WWTP*

Influent flow and characteristic



Flow Data --SIMULATION IS LOADED--

Flow Type
[1] flow type: Data

Data
[1] influent flow: 138.0 L/d

Other Flow Options

Flow Data --SIMULATION IS LOADED--

Flow Type
[2] flow type: Data

Data
[2] influent flow: 138.0 L/d

Other Flow Options

Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

User Inputs

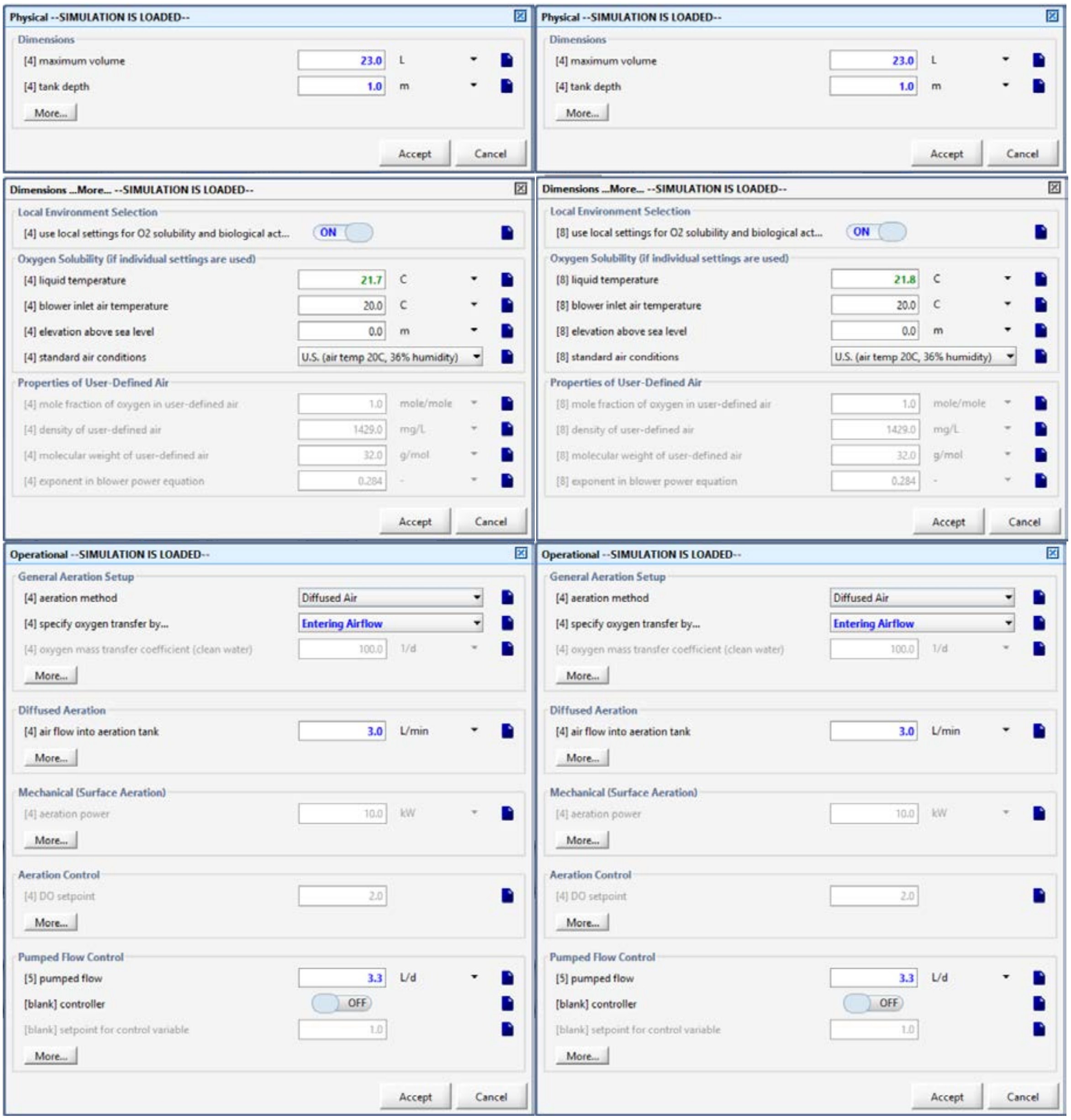
− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	9.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	0.0
ss	readily biodegradable substrate	gCOD/m3	43.4
xi	particulate inert organic material	gCOD/m3	0.0
xs	slowly biodegradable substrate	gCOD/m3	0.0
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	36.3
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	0.0
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.0
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

User Inputs

− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	11.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	23.0
ss	readily biodegradable substrate	gCOD/m3	43.4
xi	particulate inert organic material	gCOD/m3	15.0
xs	slowly biodegradable substrate	gCOD/m3	33.4
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	36.3
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	1.0
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.0
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

Physical and Operational conditions of reactors



Physical --SIMULATION IS LOADED--

Dimensions
[4] maximum volume 23.0 L
[4] tank depth 1.0 m

Physical --SIMULATION IS LOADED--

Dimensions
[4] maximum volume 23.0 L
[4] tank depth 1.0 m

Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection
[4] use local settings for O2 solubility and biological act... ON

Oxygen Solubility (if individual settings are used)
[4] liquid temperature 21.7 C
[4] blower inlet air temperature 20.0 C
[4] elevation above sea level 0.0 m
[4] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air
[4] mole fraction of oxygen in user-defined air 1.0 mole/mole
[4] density of user-defined air 1429.0 mg/L
[4] molecular weight of user-defined air 32.0 g/mol
[4] exponent in blower power equation 0.284 -

Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection
[8] use local settings for O2 solubility and biological act... ON

Oxygen Solubility (if individual settings are used)
[8] liquid temperature 21.8 C
[8] blower inlet air temperature 20.0 C
[8] elevation above sea level 0.0 m
[8] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air
[8] mole fraction of oxygen in user-defined air 1.0 mole/mole
[8] density of user-defined air 1429.0 mg/L
[8] molecular weight of user-defined air 32.0 g/mol
[8] exponent in blower power equation 0.284 -

Operational --SIMULATION IS LOADED--

General Aeration Setup
[4] aeration method Diffused Air
[4] specify oxygen transfer by... Entering Airflow
[4] oxygen mass transfer coefficient (clean water) 100.0 1/d

Diffused Aeration
[4] air flow into aeration tank 3.0 L/min

Mechanical (Surface Aeration)
[4] aeration power 10.0 kW

Aeration Control
[4] DO setpoint 2.0

Pumped Flow Control
[5] pumped flow 3.3 L/d
[blank] controller OFF
[blank] setpoint for control variable 1.0

Operational --SIMULATION IS LOADED--

General Aeration Setup
[4] aeration method Diffused Air
[4] specify oxygen transfer by... Entering Airflow
[4] oxygen mass transfer coefficient (clean water) 100.0 1/d

Diffused Aeration
[4] air flow into aeration tank 3.0 L/min

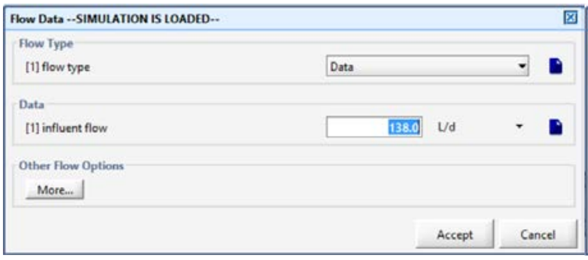
Mechanical (Surface Aeration)
[4] aeration power 10.0 kW

Aeration Control
[4] DO setpoint 2.0

Pumped Flow Control
[5] pumped flow 3.3 L/d
[blank] controller OFF
[blank] setpoint for control variable 1.0

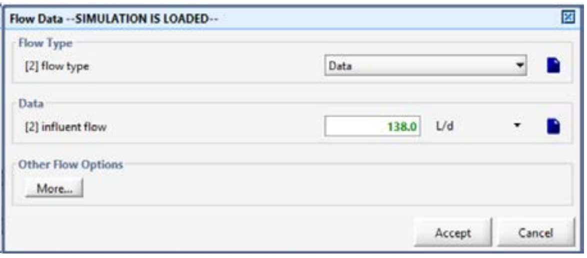
∗ *Case study of Chua Cau WWTP*

Influent flow and characteristic



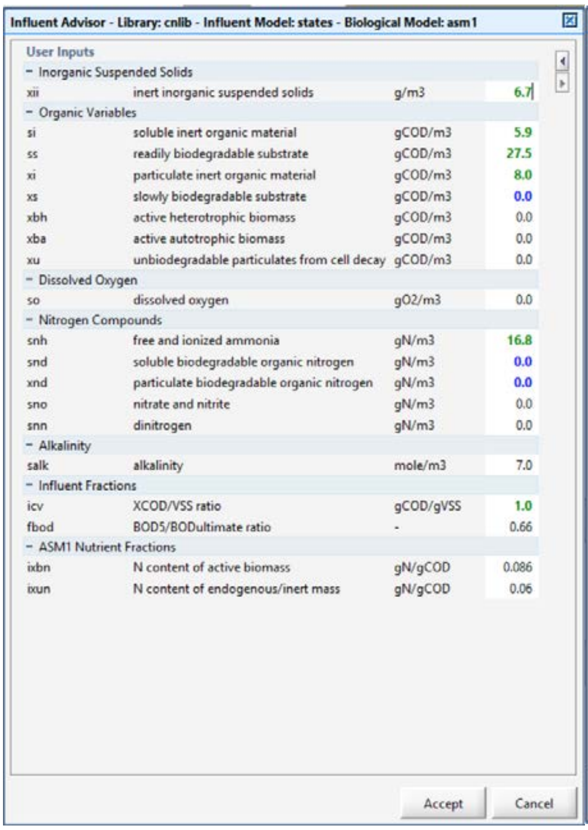
[1] flow type: Data

[1] influent flow: 138.0 L/d

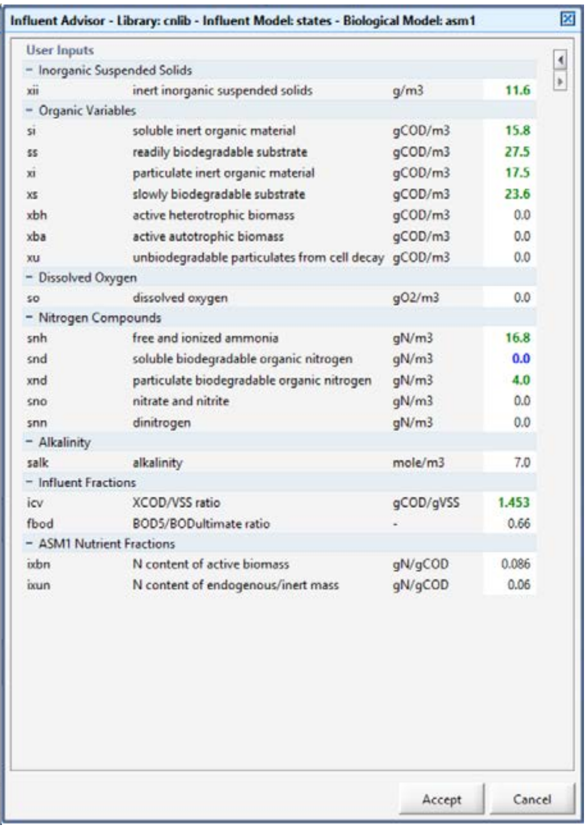


[2] flow type: Data

[2] influent flow: 138.0 L/d

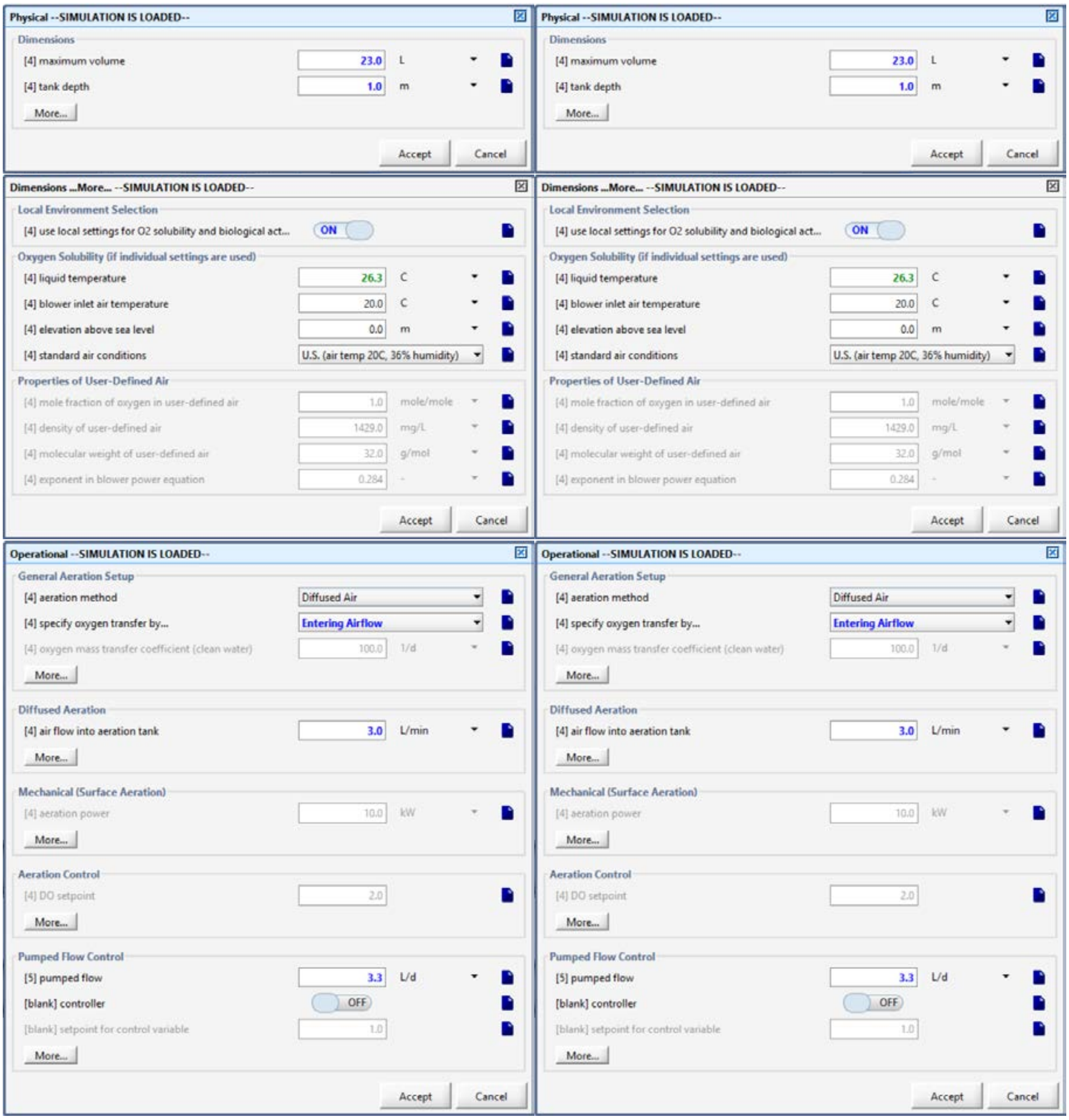


− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	6.7
− Organic Variables			
si	soluble inert organic material	gCOD/m3	5.9
ss	readily biodegradable substrate	gCOD/m3	27.5
xi	particulate inert organic material	gCOD/m3	8.0
xs	slowly biodegradable substrate	gCOD/m3	0.0
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	16.8
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	0.0
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.0
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06



− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	11.6
− Organic Variables			
si	soluble inert organic material	gCOD/m3	15.8
ss	readily biodegradable substrate	gCOD/m3	27.5
xi	particulate inert organic material	gCOD/m3	17.5
xs	slowly biodegradable substrate	gCOD/m3	23.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	16.8
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	4.0
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.453
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

Physical and Operational conditions of reactors



Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume 23.0 L

[4] tank depth 1.0 m

Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

[4] use local settings for O2 solubility and biological act... ON

Oxygen Solubility (if individual settings are used)

[4] liquid temperature 26.3 C

[4] blower inlet air temperature 20.0 C

[4] elevation above sea level 0.0 m

[4] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air

[4] mole fraction of oxygen in user-defined air 1.0 mole/mole

[4] density of user-defined air 1429.0 mg/L

[4] molecular weight of user-defined air 32.0 g/mol

[4] exponent in blower power equation 0.284 -

Operational --SIMULATION IS LOADED--

General Aeration Setup

[4] aeration method Diffused Air

[4] specify oxygen transfer by... Entering Airflow

[4] oxygen mass transfer coefficient (clean water) 100.0 1/d

Diffused Aeration

[4] air flow into aeration tank 3.0 L/min

Mechanical (Surface Aeration)

[4] aeration power 10.0 kW

Aeration Control

[4] DO setpoint 2.0

Pumped Flow Control

[5] pumped flow 3.3 L/d

[blank] controller OFF

[blank] setpoint for control variable 1.0

Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume 23.0 L

[4] tank depth 1.0 m

Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

[4] use local settings for O2 solubility and biological act... ON

Oxygen Solubility (if individual settings are used)

[4] liquid temperature 26.3 C

[4] blower inlet air temperature 20.0 C

[4] elevation above sea level 0.0 m

[4] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air

[4] mole fraction of oxygen in user-defined air 1.0 mole/mole

[4] density of user-defined air 1429.0 mg/L

[4] molecular weight of user-defined air 32.0 g/mol

[4] exponent in blower power equation 0.284 -

Operational --SIMULATION IS LOADED--

General Aeration Setup

[4] aeration method Diffused Air

[4] specify oxygen transfer by... Entering Airflow

[4] oxygen mass transfer coefficient (clean water) 100.0 1/d

Diffused Aeration

[4] air flow into aeration tank 3.0 L/min

Mechanical (Surface Aeration)

[4] aeration power 10.0 kW

Aeration Control

[4] DO setpoint 2.0

Pumped Flow Control

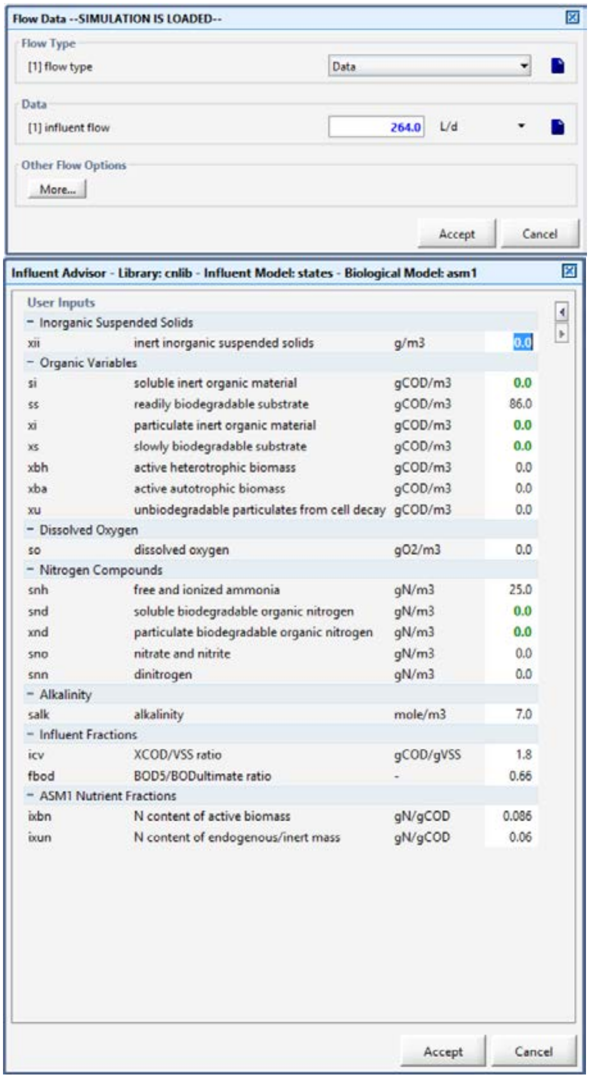
[5] pumped flow 3.3 L/d

[blank] controller OFF

[blank] setpoint for control variable 1.0

b) In Chapter 5

Influent flow and characteristic



Flow Data --SIMULATION IS LOADED--

Flow Type

[1] flow type: Data

Data

[1] influent flow: 264.0 L/d

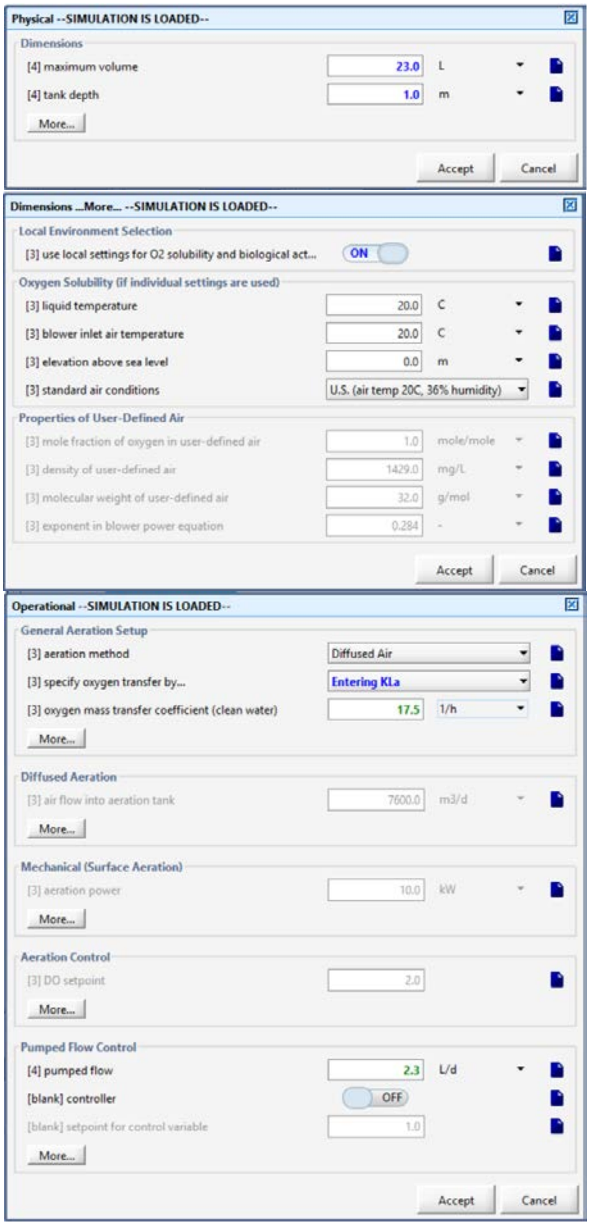
Other Flow Options

Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

User Inputs

− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	0.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	0.0
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	0.0
xs	slowly biodegradable substrate	gCOD/m3	0.0
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	0.0
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

Physical and Operational conditions of reactors



Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume	23.0	L
[4] tank depth	1.0	m

Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

[3] use local settings for O2 solubility and biological act...	ON

Oxygen Solubility (if individual settings are used)

[3] liquid temperature	20.0	C
[3] blower inlet air temperature	20.0	C
[3] elevation above sea level	0.0	m
[3] standard air conditions	U.S. (air temp 20C, 36% humidity)	

Properties of User-Defined Air

[3] mole fraction of oxygen in user-defined air	1.0	mole/mole
[3] density of user-defined air	1429.0	mg/L
[3] molecular weight of user-defined air	32.0	g/mol
[3] exponent in blower power equation	0.284	-

Operational --SIMULATION IS LOADED--

General Aeration Setup

[3] aeration method	Diffused Air	
[3] specify oxygen transfer by...	Entering KLa	
[3] oxygen mass transfer coefficient (clean water)	17.5	1/h

Diffused Aeration

[3] air flow into aeration tank	7600.0	m3/d

Mechanical (Surface Aeration)

[3] aeration power	10.0	kW

Aeration Control

[3] DO setpoint	2.0

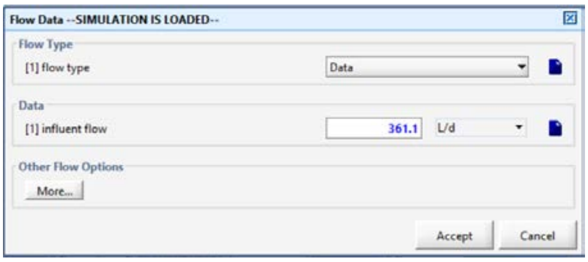
Pumped Flow Control

[4] pumped flow	2.3	L/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

c) In Chapter 6 and 7

∗ Case study at Site #1

Influent flow and characteristic

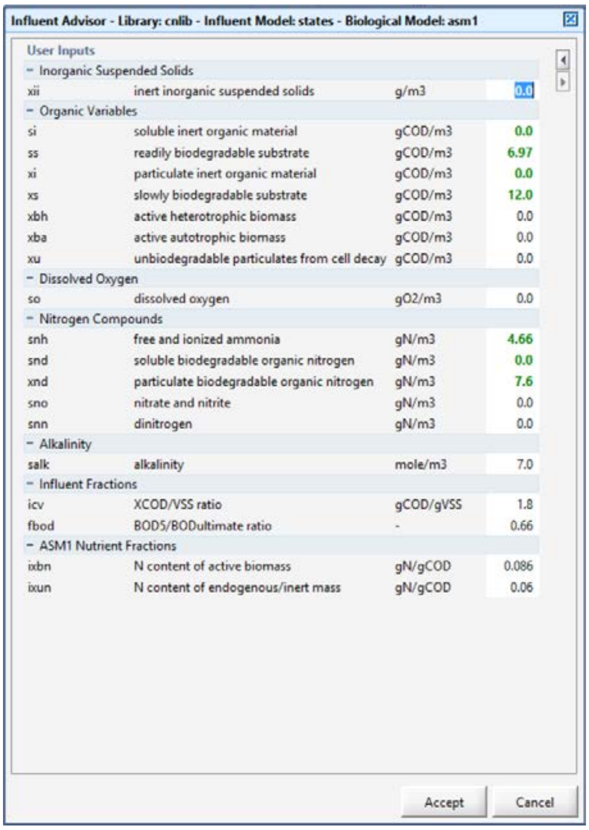

Flow Data --SIMULATION IS LOADED--

Flow Type

[1] flow type: Data

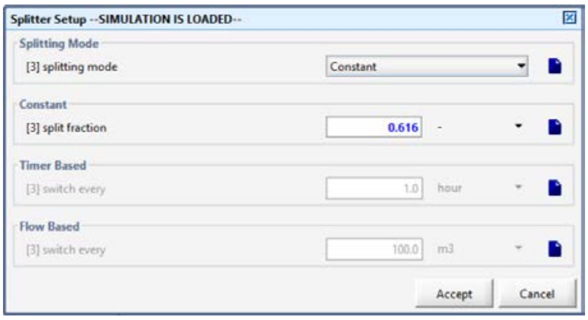
Data

[1] influent flow: 361.1 L/d


Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

User Inputs

− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	0.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	0.0
ss	readily biodegradable substrate	gCOD/m3	6.97
xi	particulate inert organic material	gCOD/m3	0.0
xs	slowly biodegradable substrate	gCOD/m3	12.0
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	4.66
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	7.6
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06


Splitter Setup --SIMULATION IS LOADED--

Splitting Mode

[3] splitting mode: Constant

Constant

[3] split fraction: 0.616 -

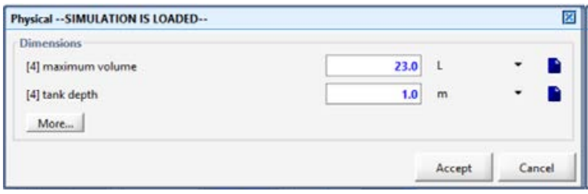
Timer Based

[3] switch every: 1.0 hour

Flow Based

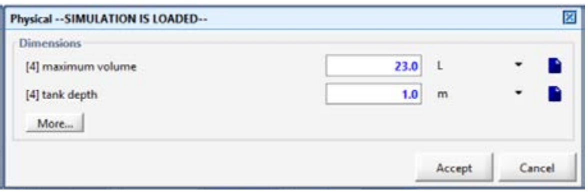
[3] switch every: 100.0 m3

Physical and Operational conditions of reactors


Physical --SIMULATION IS LOADED--

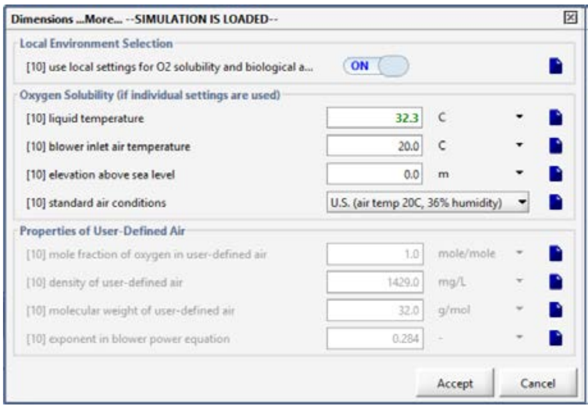
Dimensions

[4] maximum volume	23.0	L
[4] tank depth	1.0	m


Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume	23.0	L
[4] tank depth	1.0	m


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

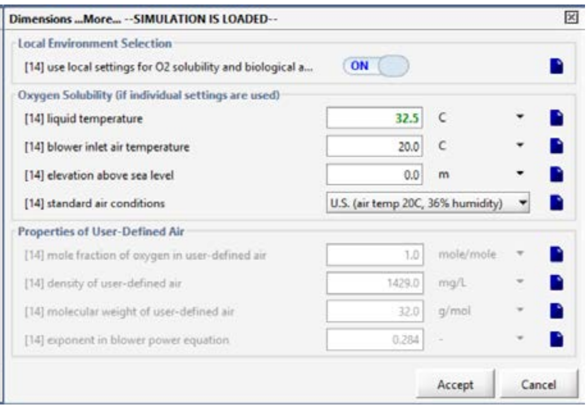
[10] use local settings for O2 solubility and biological a...	ON	

Oxygen Solubility (if individual settings are used)

[10] liquid temperature	32.3	C
[10] blower inlet air temperature	20.0	C
[10] elevation above sea level	0.0	m
[10] standard air conditions	U.S. (air temp 20C, 36% humidity)	

Properties of User-Defined Air

[10] mole fraction of oxygen in user-defined air	1.0	mole/mole
[10] density of user-defined air	1429.0	mg/L
[10] molecular weight of user-defined air	32.0	g/mol
[10] exponent in blower power equation	0.284	-


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

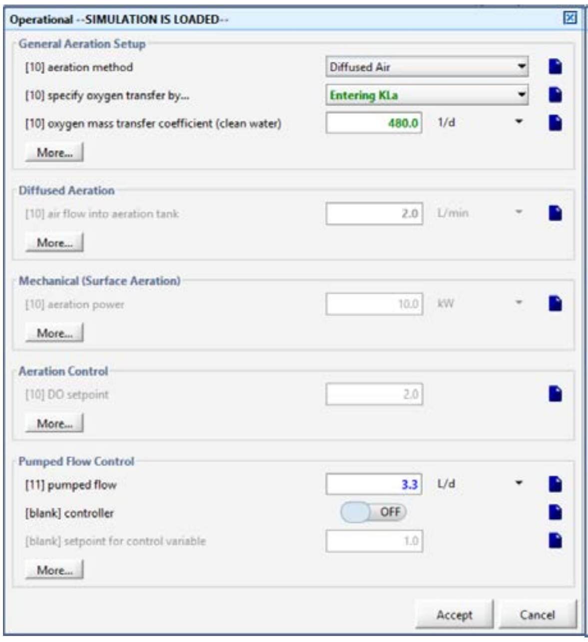
[14] use local settings for O2 solubility and biological a...	ON	

Oxygen Solubility (if individual settings are used)

[14] liquid temperature	32.5	C
[14] blower inlet air temperature	20.0	C
[14] elevation above sea level	0.0	m
[14] standard air conditions	U.S. (air temp 20C, 36% humidity)	

Properties of User-Defined Air

[14] mole fraction of oxygen in user-defined air	1.0	mole/mole
[14] density of user-defined air	1429.0	mg/L
[14] molecular weight of user-defined air	32.0	g/mol
[14] exponent in blower power equation	0.284	-


Operational --SIMULATION IS LOADED--

General Aeration Setup

[10] aeration method	Diffused Air	
[10] specify oxygen transfer by...	Entering KLa	
[10] oxygen mass transfer coefficient (clean water)	480.0	1/d

Diffused Aeration

[10] air flow into aeration tank	2.0	L/min

Mechanical (Surface Aeration)

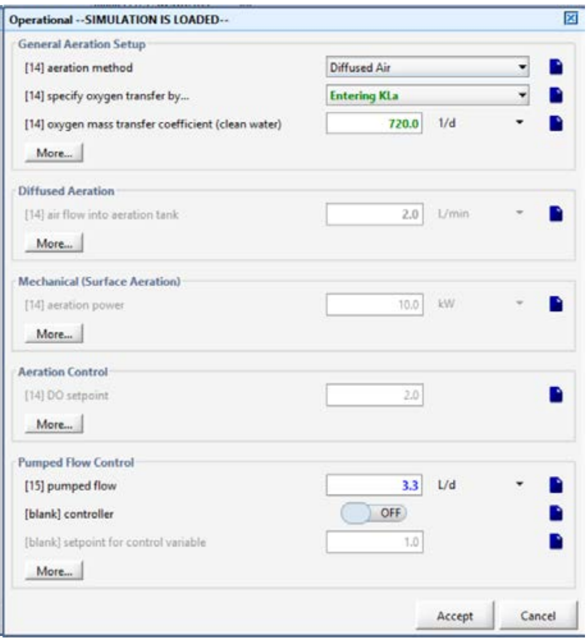
[10] aeration power	10.0	kW

Aeration Control

[10] DO setpoint	2.0	

Pumped Flow Control

[11] pumped flow	3.3	L/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	


Operational --SIMULATION IS LOADED--

General Aeration Setup

[14] aeration method	Diffused Air	
[14] specify oxygen transfer by...	Entering KLa	
[14] oxygen mass transfer coefficient (clean water)	720.0	1/d

Diffused Aeration

[14] air flow into aeration tank	2.0	L/min

Mechanical (Surface Aeration)

[14] aeration power	10.0	kW

Aeration Control

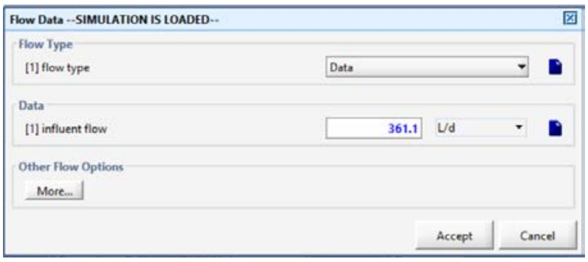
[14] DO setpoint	2.0	

Pumped Flow Control

[15] pumped flow	3.3	L/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

∗ *Case study at Site #2*

Influent flow and characteristic



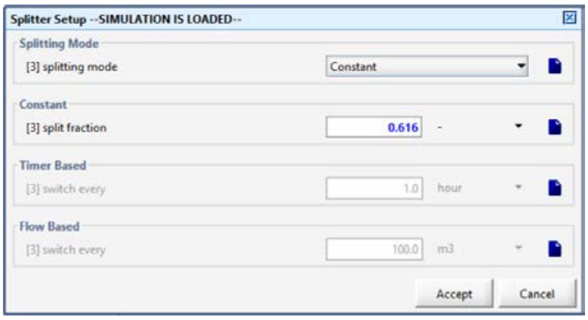
Flow Data --SIMULATION IS LOADED--

Flow Type

[1] flow type: Data

Data

[1] influent flow: 361.1 L/d



Splitter Setup --SIMULATION IS LOADED--

Splitting Mode

[3] splitting mode: Constant

Constant

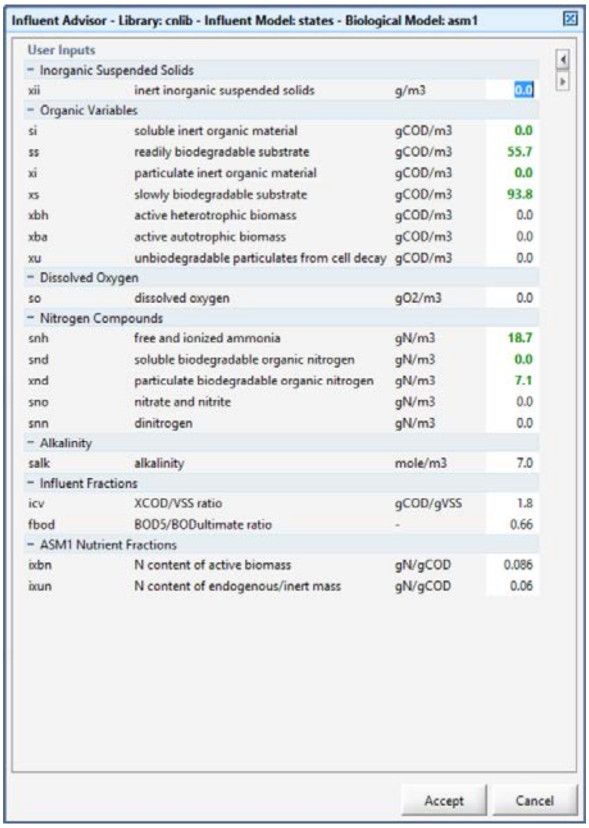
[3] split fraction: 0.616 -

Timer Based

[3] switch every: 1.0 hour

Flow Based

[3] switch every: 100.0 m3

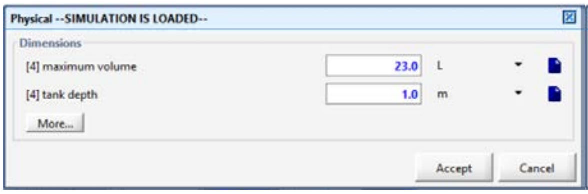


Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

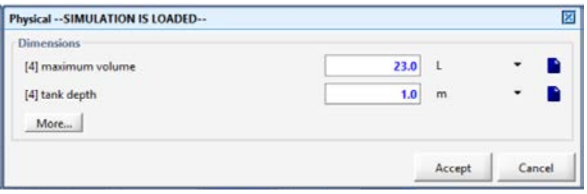
User Inputs

− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	0.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	0.0
ss	readily biodegradable substrate	gCOD/m3	55.7
xi	particulate inert organic material	gCOD/m3	0.0
xs	slowly biodegradable substrate	gCOD/m3	93.8
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	18.7
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	7.1
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

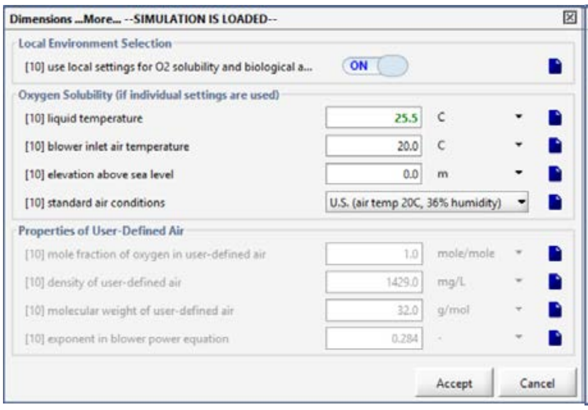
Physical and Operational conditions of reactors


Physical --SIMULATION IS LOADED--

Dimensions
[4] maximum volume 23.0 L
[4] tank depth 1.0 m


Physical --SIMULATION IS LOADED--

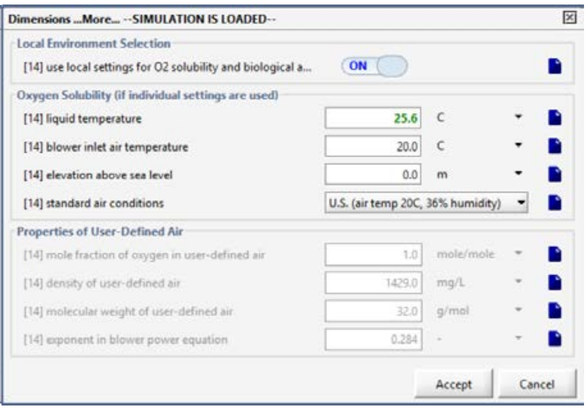
Dimensions
[4] maximum volume 23.0 L
[4] tank depth 1.0 m


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection
[10] use local settings for O2 solubility and biological a... ON

Oxygen Solubility (if individual settings are used)
[10] liquid temperature 25.5 C
[10] blower inlet air temperature 20.0 C
[10] elevation above sea level 0.0 m
[10] standard air conditions U.S. (air temp 20C, 36% humidity)

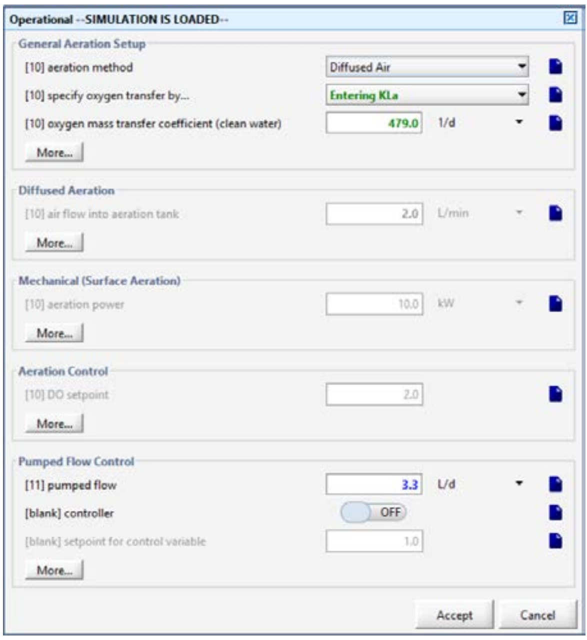
Properties of User-Defined Air
[10] mole fraction of oxygen in user-defined air 1.0 mole/mole
[10] density of user-defined air 1429.0 mg/L
[10] molecular weight of user-defined air 32.0 g/mol
[10] exponent in blower power equation 0.284 -


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection
[14] use local settings for O2 solubility and biological a... ON

Oxygen Solubility (if individual settings are used)
[14] liquid temperature 25.6 C
[14] blower inlet air temperature 20.0 C
[14] elevation above sea level 0.0 m
[14] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air
[14] mole fraction of oxygen in user-defined air 1.0 mole/mole
[14] density of user-defined air 1429.0 mg/L
[14] molecular weight of user-defined air 32.0 g/mol
[14] exponent in blower power equation 0.284 -


Operational --SIMULATION IS LOADED--

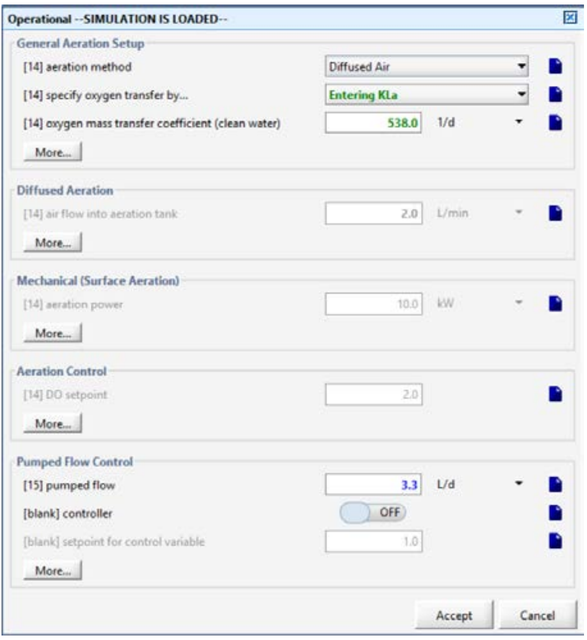
General Aeration Setup
[10] aeration method Diffused Air
[10] specify oxygen transfer by... Entering KLa
[10] oxygen mass transfer coefficient (clean water) 479.0 1/d

Diffused Aeration
[10] air flow into aeration tank 2.0 L/min

Mechanical (Surface Aeration)
[10] aeration power 10.0 kW

Aeration Control
[10] DO setpoint 2.0

Pumped Flow Control
[11] pumped flow 3.3 L/d
[blank] controller OFF
[blank] setpoint for control variable 1.0


Operational --SIMULATION IS LOADED--

General Aeration Setup
[14] aeration method Diffused Air
[14] specify oxygen transfer by... Entering KLa
[14] oxygen mass transfer coefficient (clean water) 538.0 1/d

Diffused Aeration
[14] air flow into aeration tank 2.0 L/min

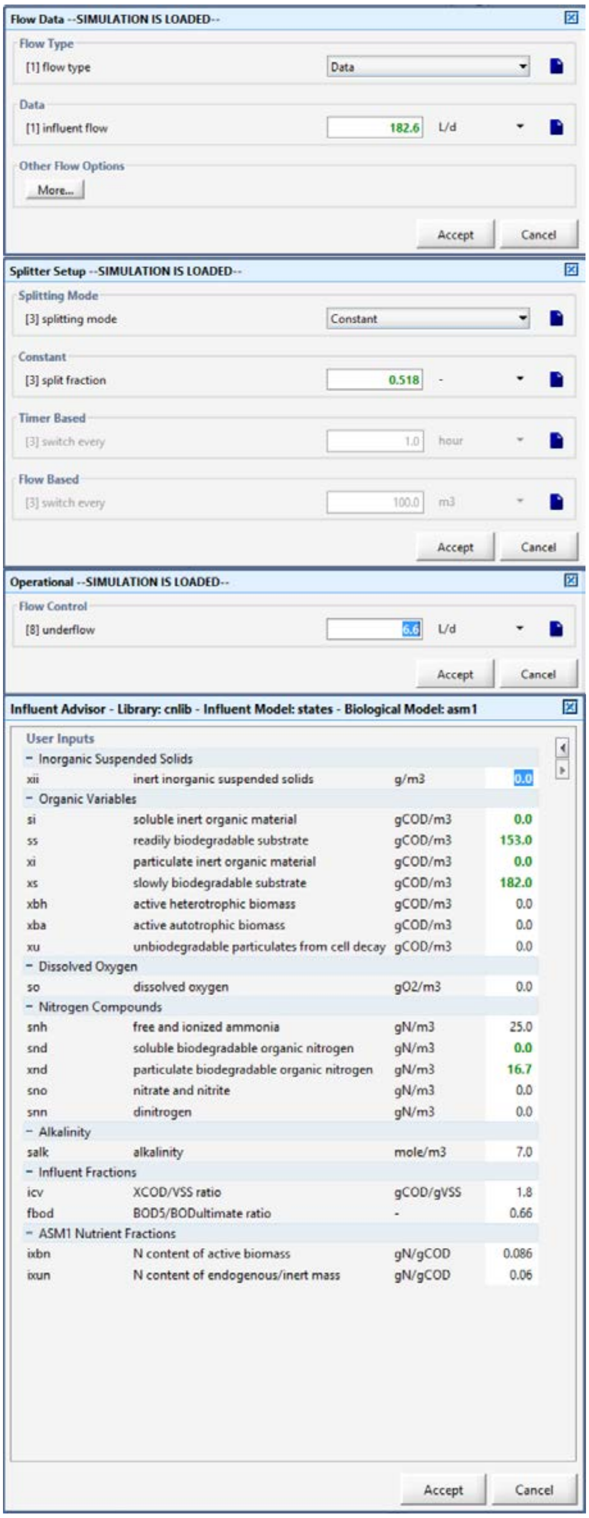
Mechanical (Surface Aeration)
[14] aeration power 10.0 kW

Aeration Control
[14] DO setpoint 2.0

Pumped Flow Control
[15] pumped flow 3.3 L/d
[blank] controller OFF
[blank] setpoint for control variable 1.0

∗ *Case study at Site #3*

Influent flow and characteristic



Flow Data --SIMULATION IS LOADED--

Flow Type

[1] flow type: Data

Data

[1] influent flow: 182.6 L/d

Other Flow Options

Splitter Setup --SIMULATION IS LOADED--

Splitting Mode

[3] splitting mode: Constant

Constant

[3] split fraction: 0.518 -

Timer Based

[3] switch every: 1.0 hour

Flow Based

[3] switch every: 100.0 m3

Operational --SIMULATION IS LOADED--

Flow Control

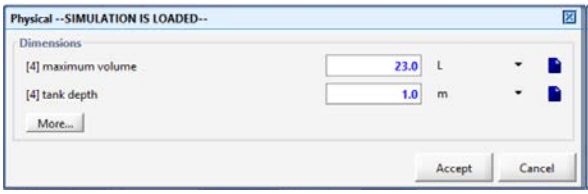
[8] underflow: 6.6 L/d

Influent Advisor - Library: cnlib - Influent Model: states - Biological Model: asm1

User Inputs

− Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	0.0
− Organic Variables			
si	soluble inert organic material	gCOD/m3	0.0
ss	readily biodegradable substrate	gCOD/m3	153.0
xi	particulate inert organic material	gCOD/m3	0.0
xs	slowly biodegradable substrate	gCOD/m3	182.0
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
− Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
− Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	0.0
xnd	particulate biodegradable organic nitrogen	gN/m3	16.7
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
− Alkalinity			
salk	alkalinity	mole/m3	7.0
− Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
− ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

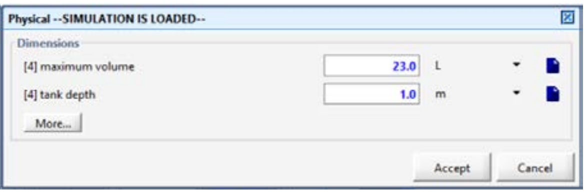
Physical and Operational conditions of reactors


Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume 23.0 L

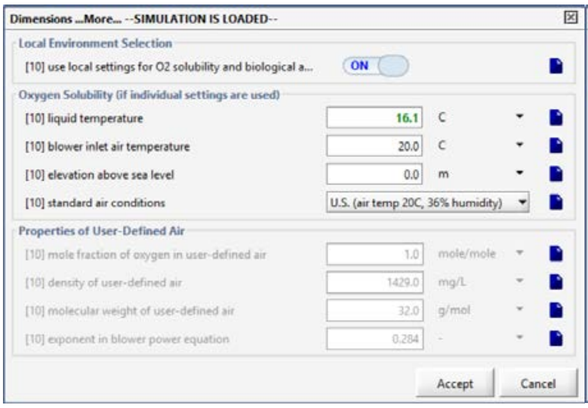
[4] tank depth 1.0 m


Physical --SIMULATION IS LOADED--

Dimensions

[4] maximum volume 23.0 L

[4] tank depth 1.0 m


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

[10] use local settings for O2 solubility and biological a... ON

Oxygen Solubility (if individual settings are used)

[10] liquid temperature 16.1 C

[10] blower inlet air temperature 20.0 C

[10] elevation above sea level 0.0 m

[10] standard air conditions U.S. (air temp 20C, 36% humidity)

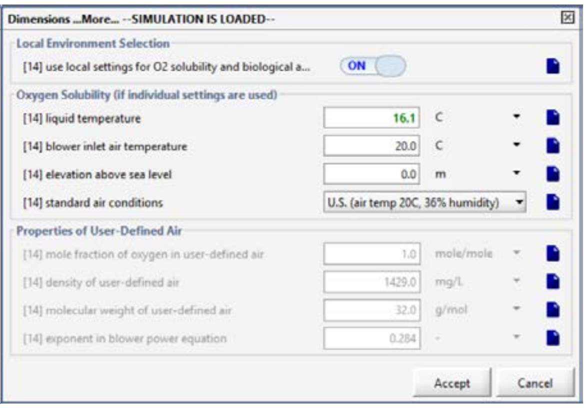
Properties of User-Defined Air

[10] mole fraction of oxygen in user-defined air 1.0 mole/mole

[10] density of user-defined air 1429.0 mg/L

[10] molecular weight of user-defined air 32.0 g/mol

[10] exponent in blower power equation 0.284 -


Dimensions ...More... --SIMULATION IS LOADED--

Local Environment Selection

[14] use local settings for O2 solubility and biological a... ON

Oxygen Solubility (if individual settings are used)

[14] liquid temperature 16.1 C

[14] blower inlet air temperature 20.0 C

[14] elevation above sea level 0.0 m

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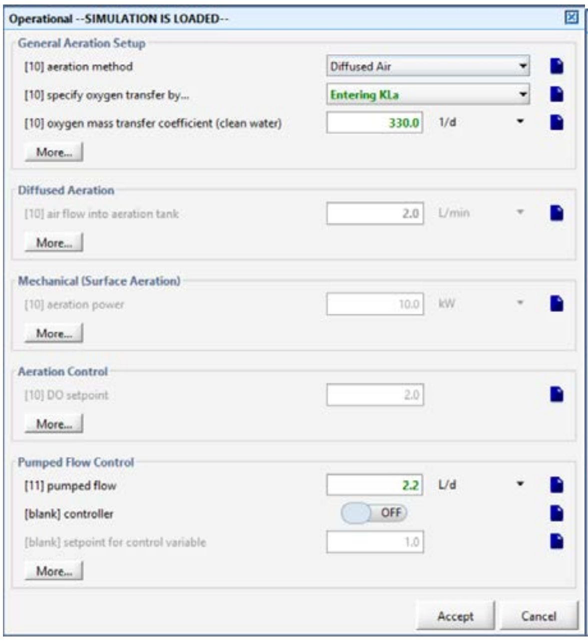
[14] density of user-defined air 1429.0 mg/L

[14] molecular weight of user-defined air 32.0 g/mol

[14] exponent in blower power equation 0.284 -


Operational --SIMULATION IS LOADED--

General Aeration Setup

[10] aeration method Diffused Air

[10] specify oxygen transfer by... Entering KLa

[10] oxygen mass transfer coefficient (clean water) 330.0 1/d

Diffused Aeration

[10] air flow into aeration tank 2.0 L/min

Mechanical (Surface Aeration)

[10] aeration power 10.0 kW

Aeration Control

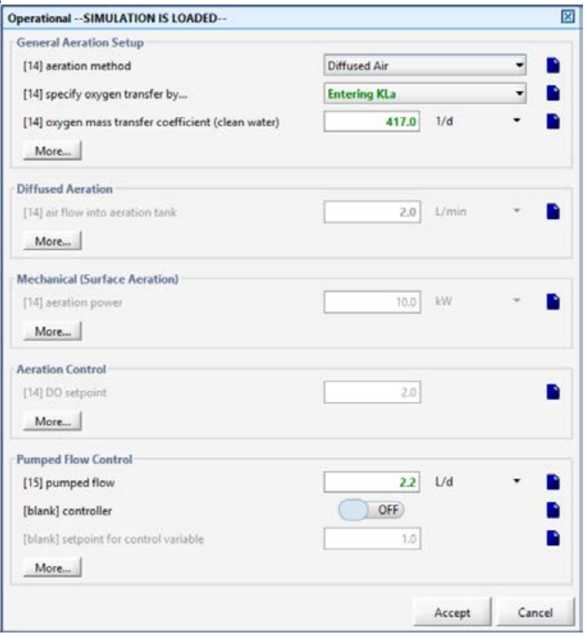
[10] DO setpoint 2.0

Pumped Flow Control

[11] pumped flow 2.2 L/d

[blank] controller OFF

[blank] setpoint for control variable 1.0


Operational --SIMULATION IS LOADED--

General Aeration Setup

[14] aeration method Diffused Air

[14] specify oxygen transfer by... Entering KLa

[14] oxygen mass transfer coefficient (clean water) 417.0 1/d

Diffused Aeration

[14] air flow into aeration tank 2.0 L/min

Mechanical (Surface Aeration)

[14] aeration power 10.0 kW

Aeration Control

[14] DO setpoint 2.0

Pumped Flow Control

[15] pumped flow 2.2 L/d

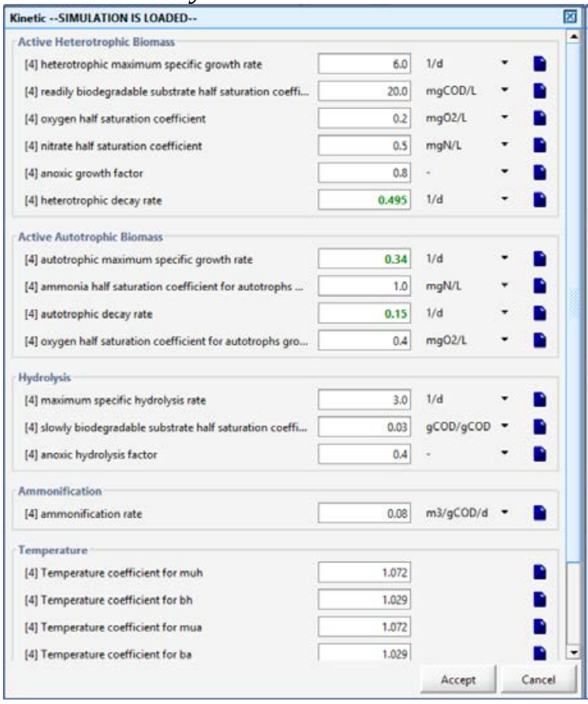
[blank] controller OFF

[blank] setpoint for control variable 1.0

4.3. Kinetic and stoichiometry parameters

a) In Chapter 4

∗ Case study at Vinh Niem WWTP


Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[4] heterotrophic maximum specific growth rate	6.0	1/d
[4] readily biodegradable substrate half saturation coeffi...	20.0	mgCOD/L
[4] oxygen half saturation coefficient	0.2	mgO2/L
[4] nitrate half saturation coefficient	0.5	mgN/L
[4] anoxic growth factor	0.8	-
[4] heterotrophic decay rate	0.495	1/d

Active Autotrophic Biomass

[4] autotrophic maximum specific growth rate	0.34	1/d
[4] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[4] autotrophic decay rate	0.15	1/d
[4] oxygen half saturation coefficient for autotrophs gro...	0.4	mgO2/L

Hydrolysis

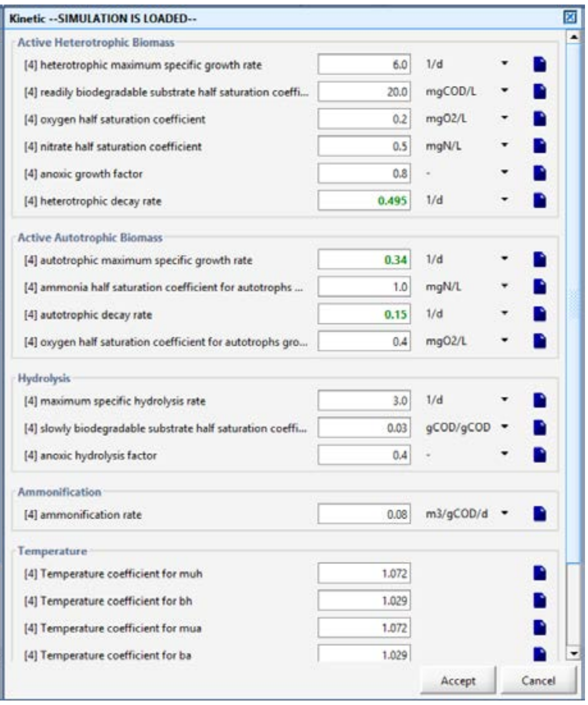
[4] maximum specific hydrolysis rate	3.0	1/d
[4] slowly biodegradable substrate half saturation coeffi...	0.03	gCOD/gCOD
[4] anoxic hydrolysis factor	0.4	-

Ammonification

[4] ammonification rate	0.08	m3/gCOD/d

Temperature

[4] Temperature coefficient for muh	1.072
[4] Temperature coefficient for bh	1.029
[4] Temperature coefficient for mua	1.072
[4] Temperature coefficient for ba	1.029


Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[4] heterotrophic maximum specific growth rate	6.0	1/d
[4] readily biodegradable substrate half saturation coeffi...	20.0	mgCOD/L
[4] oxygen half saturation coefficient	0.2	mgO2/L
[4] nitrate half saturation coefficient	0.5	mgN/L
[4] anoxic growth factor	0.8	-
[4] heterotrophic decay rate	0.495	1/d

Active Autotrophic Biomass

[4] autotrophic maximum specific growth rate	0.34	1/d
[4] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[4] autotrophic decay rate	0.15	1/d
[4] oxygen half saturation coefficient for autotrophs gro...	0.4	mgO2/L

Hydrolysis

[4] maximum specific hydrolysis rate	3.0	1/d
[4] slowly biodegradable substrate half saturation coeffi...	0.03	gCOD/gCOD
[4] anoxic hydrolysis factor	0.4	-

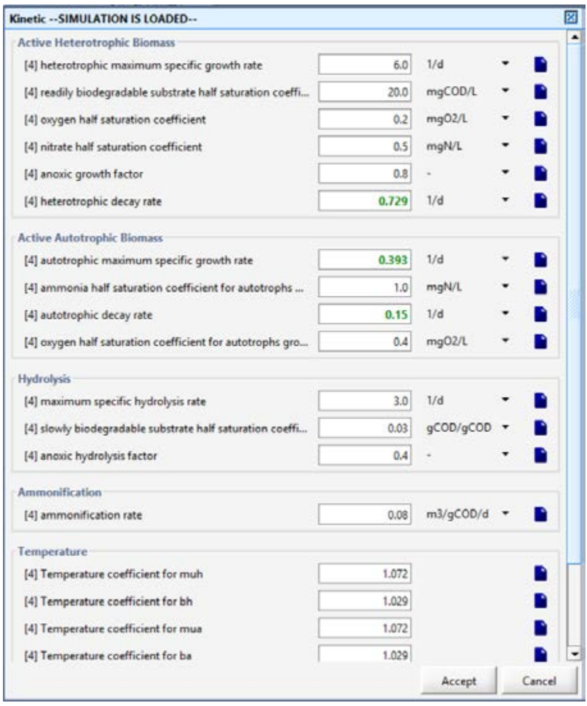
Ammonification

[4] ammonification rate	0.08	m3/gCOD/d

Temperature

[4] Temperature coefficient for muh	1.072
[4] Temperature coefficient for bh	1.029
[4] Temperature coefficient for mua	1.072
[4] Temperature coefficient for ba	1.029

∗ Case study at Chua Cau WWTP


Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[4] heterotrophic maximum specific growth rate	6.0	1/d
[4] readily biodegradable substrate half saturation coeffi...	20.0	mgCOD/L
[4] oxygen half saturation coefficient	0.2	mgO2/L
[4] nitrate half saturation coefficient	0.5	mgN/L
[4] anoxic growth factor	0.8	-
[4] heterotrophic decay rate	0.729	1/d

Active Autotrophic Biomass

[4] autotrophic maximum specific growth rate	0.393	1/d
[4] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[4] autotrophic decay rate	0.15	1/d
[4] oxygen half saturation coefficient for autotrophs gro...	0.4	mgO2/L

Hydrolysis

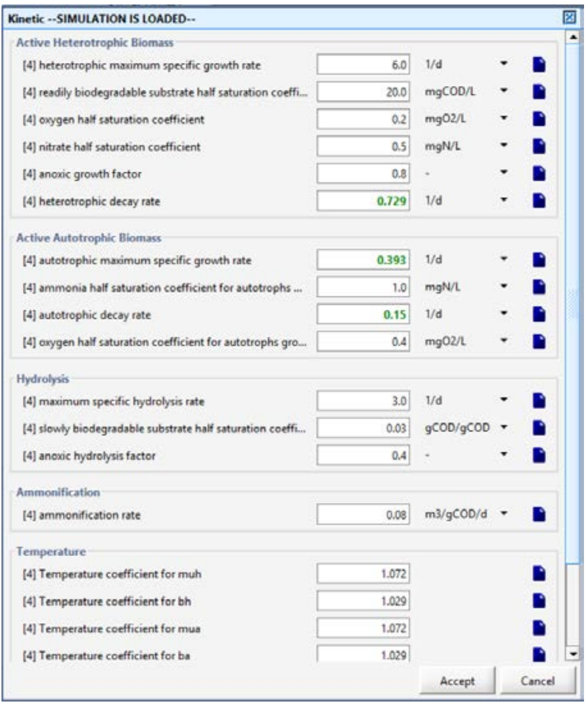
[4] maximum specific hydrolysis rate	3.0	1/d
[4] slowly biodegradable substrate half saturation coeffi...	0.03	gCOD/gCOD
[4] anoxic hydrolysis factor	0.4	-

Ammonification

[4] ammonification rate	0.08	m3/gCOD/d

Temperature

[4] Temperature coefficient for muh	1.072
[4] Temperature coefficient for bh	1.029
[4] Temperature coefficient for mua	1.072
[4] Temperature coefficient for ba	1.029


Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[4] heterotrophic maximum specific growth rate	6.0	1/d
[4] readily biodegradable substrate half saturation coeffi...	20.0	mgCOD/L
[4] oxygen half saturation coefficient	0.2	mgO2/L
[4] nitrate half saturation coefficient	0.5	mgN/L
[4] anoxic growth factor	0.8	-
[4] heterotrophic decay rate	0.729	1/d

Active Autotrophic Biomass

[4] autotrophic maximum specific growth rate	0.393	1/d
[4] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[4] autotrophic decay rate	0.15	1/d
[4] oxygen half saturation coefficient for autotrophs gro...	0.4	mgO2/L

Hydrolysis

[4] maximum specific hydrolysis rate	3.0	1/d
[4] slowly biodegradable substrate half saturation coeffi...	0.03	gCOD/gCOD
[4] anoxic hydrolysis factor	0.4	-

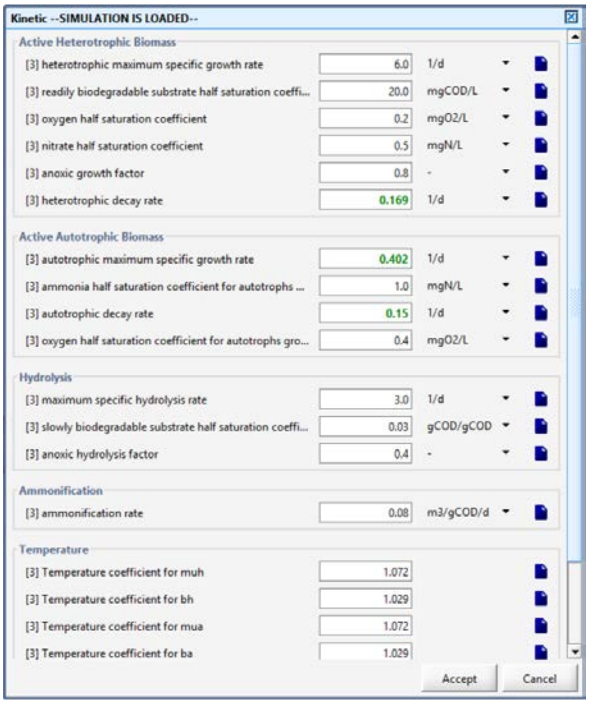
Ammonification

[4] ammonification rate	0.08	m3/gCOD/d

Temperature

[4] Temperature coefficient for muh	1.072
[4] Temperature coefficient for bh	1.029
[4] Temperature coefficient for mua	1.072
[4] Temperature coefficient for ba	1.029

b) In Chapter 5



Active Heterotrophic Biomass

[3] heterotrophic maximum specific growth rate	6.0	1/d
[3] readily biodegradable substrate half saturation coeffi...	20.0	mgCOD/L
[3] oxygen half saturation coefficient	0.2	mgO2/L
[3] nitrate half saturation coefficient	0.5	mgN/L
[3] anoxic growth factor	0.8	-
[3] heterotrophic decay rate	0.169	1/d

Active Autotrophic Biomass

[3] autotrophic maximum specific growth rate	0.402	1/d
[3] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[3] autotrophic decay rate	0.15	1/d
[3] oxygen half saturation coefficient for autotrophs gro...	0.4	mgO2/L

Hydrolysis

[3] maximum specific hydrolysis rate	3.0	1/d
[3] slowly biodegradable substrate half saturation coeffi...	0.03	gCOD/gCOD
[3] anoxic hydrolysis factor	0.4	-

Ammonification

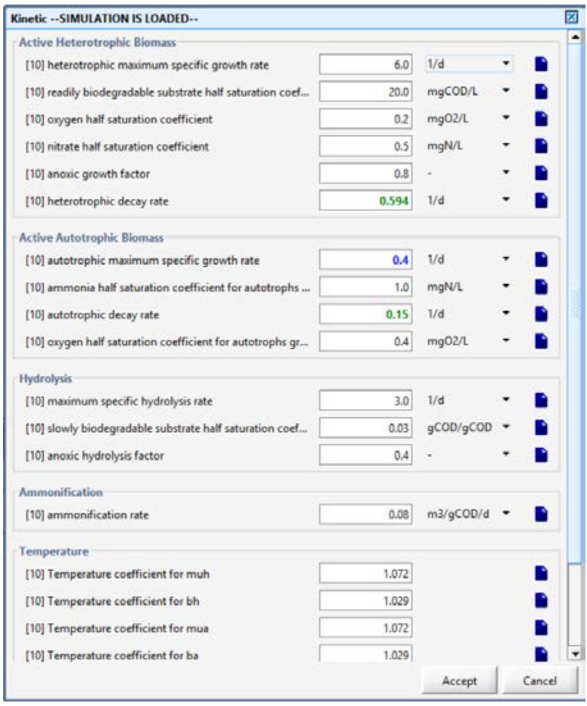
[3] ammonification rate	0.08	m3/gCOD/d

Temperature

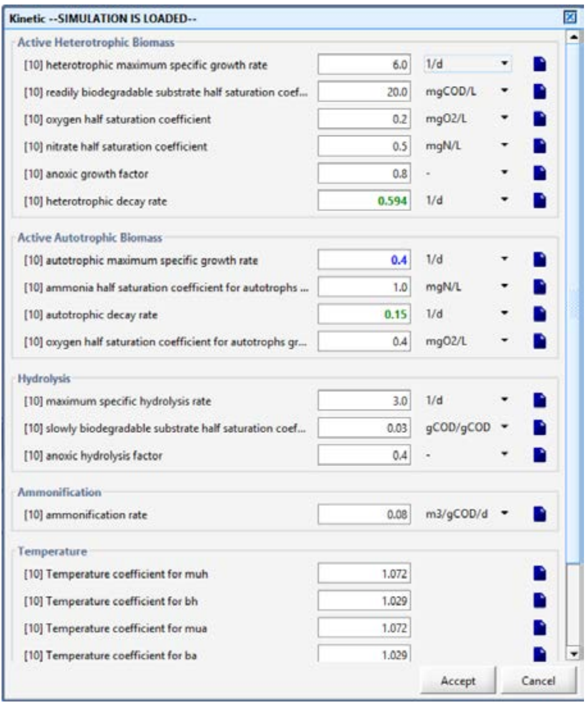
[3] Temperature coefficient for muh	1.072
[3] Temperature coefficient for bh	1.029
[3] Temperature coefficient for mua	1.072
[3] Temperature coefficient for ba	1.029

c) In Chapter 6 and 7

∗ *Case study at Site #1*

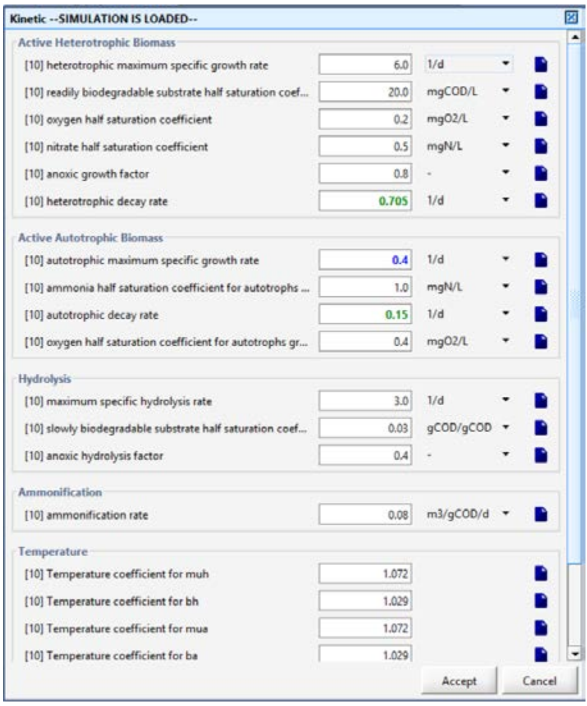


Active Heterotrophic Biomass		
[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.594	1/d
Active Autotrophic Biomass		
[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L
Hydrolysis		
[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-
Ammonification		
[10] ammonification rate	0.08	m3/gCOD/d
Temperature		
[10] Temperature coefficient for muh	1.072	
[10] Temperature coefficient for bh	1.029	
[10] Temperature coefficient for mua	1.072	
[10] Temperature coefficient for ba	1.029	

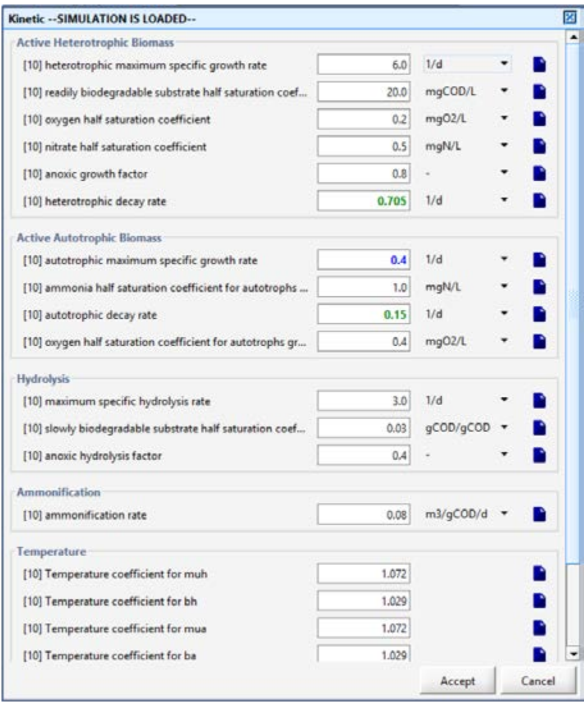


Active Heterotrophic Biomass		
[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.594	1/d
Active Autotrophic Biomass		
[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L
Hydrolysis		
[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-
Ammonification		
[10] ammonification rate	0.08	m3/gCOD/d
Temperature		
[10] Temperature coefficient for muh	1.072	
[10] Temperature coefficient for bh	1.029	
[10] Temperature coefficient for mua	1.072	
[10] Temperature coefficient for ba	1.029	

Case study at Site #2

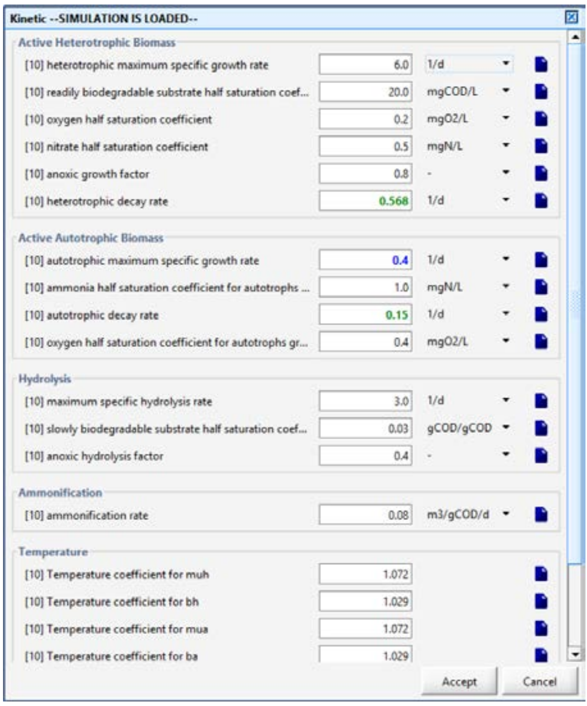


Active Heterotrophic Biomass		
[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.705	1/d
Active Autotrophic Biomass		
[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L
Hydrolysis		
[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-
Ammonification		
[10] ammonification rate	0.08	m3/gCOD/d
Temperature		
[10] Temperature coefficient for muh	1.072	
[10] Temperature coefficient for bh	1.029	
[10] Temperature coefficient for mua	1.072	
[10] Temperature coefficient for ba	1.029	



Active Heterotrophic Biomass		
[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.705	1/d
Active Autotrophic Biomass		
[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L
Hydrolysis		
[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-
Ammonification		
[10] ammonification rate	0.08	m3/gCOD/d
Temperature		
[10] Temperature coefficient for muh	1.072	
[10] Temperature coefficient for bh	1.029	
[10] Temperature coefficient for mua	1.072	
[10] Temperature coefficient for ba	1.029	

∗ *Case study at Site #3*



Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.568	1/d

Active Autotrophic Biomass

[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L

Hydrolysis

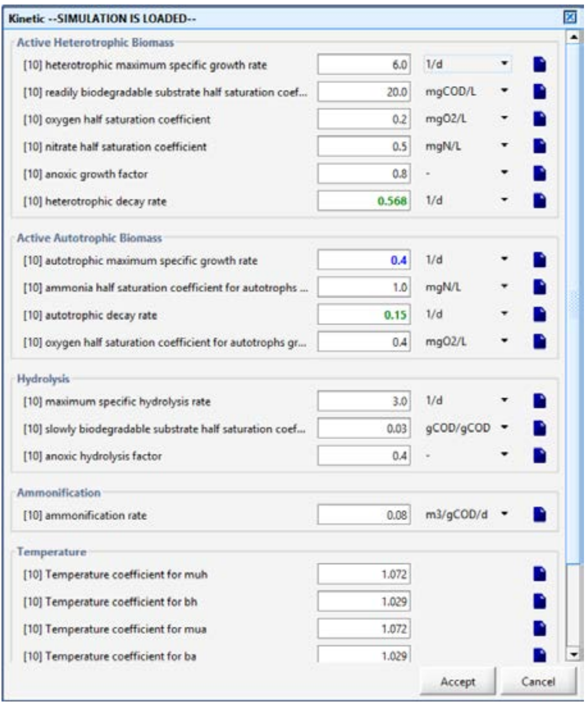
[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-

Ammonification

[10] ammonification rate	0.08	m3/gCOD/d

Temperature

[10] Temperature coefficient for muh	1.072
[10] Temperature coefficient for bh	1.029
[10] Temperature coefficient for mua	1.072
[10] Temperature coefficient for ba	1.029



Kinetic --SIMULATION IS LOADED--

Active Heterotrophic Biomass

[10] heterotrophic maximum specific growth rate	6.0	1/d
[10] readily biodegradable substrate half saturation coef...	20.0	mgCOD/L
[10] oxygen half saturation coefficient	0.2	mgO2/L
[10] nitrate half saturation coefficient	0.5	mgN/L
[10] anoxic growth factor	0.8	-
[10] heterotrophic decay rate	0.568	1/d

Active Autotrophic Biomass

[10] autotrophic maximum specific growth rate	0.4	1/d
[10] ammonia half saturation coefficient for autotrophs ...	1.0	mgN/L
[10] autotrophic decay rate	0.15	1/d
[10] oxygen half saturation coefficient for autotrophs gr...	0.4	mgO2/L

Hydrolysis

[10] maximum specific hydrolysis rate	3.0	1/d
[10] slowly biodegradable substrate half saturation coef...	0.03	gCOD/gCOD
[10] anoxic hydrolysis factor	0.4	-

Ammonification

[10] ammonification rate	0.08	m3/gCOD/d

Temperature

[10] Temperature coefficient for muh	1.072
[10] Temperature coefficient for bh	1.029
[10] Temperature coefficient for mua	1.072
[10] Temperature coefficient for ba	1.029