SFD Promotion Initiative

Nonthaburi
Thailand

Final Report

This SFD Report was created through desk-based research by Sandec (the Department of Sanitation, Water and Solid Waste for Development) at Eawag (the Swiss Federal Institute of Aquatic Science and Technology) as part of the SFD Promotion Initiative.

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SFD Promotion Initiative

SFD Report Nonthaburi, Thailand, 2015

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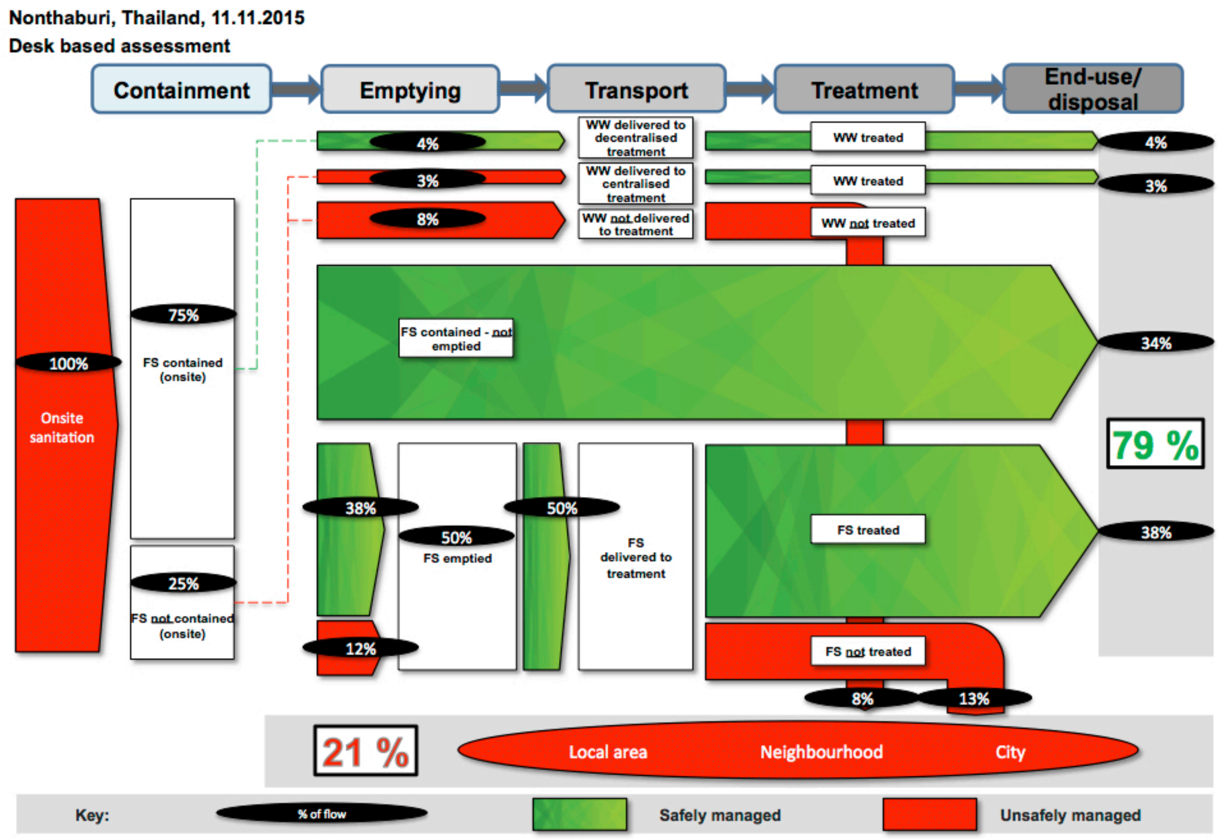
1. The Diagram



Note: Percentages do not add up to 100 due to rounding

2. Diagram information

The Shit Flow Diagram (SFD) was created through desk-based research by Sandec (Sanitation, Water and Solid Waste for Development) of Eawag (the Swiss Federal Institute of Aquatic Science and Technology)

Collaborating partners:

Kyoto University, Japan
Asian Institute of Technology, Thailand
Mahidol University, Thailand

Accreditation status:

Final SFD. Not yet reviewed by external committee.

Date of production:

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3. General city information

Nonthaburi City Municipality is the principal city of Nonthaburi province, located to the north of Bangkok. The city has a registered population of 256,457 in the area of 38.9 km^2 (NCM 2015a). Most of the city is urban and its population density is the second highest in Thailand after Bangkok (Wikipedia 2015).

As the city is located in the downstream area of the Chao Phraya River, the topography is relatively flat. The city has tropical monsoon climate with three seasons: summer, rainy and winter seasons. Annual average temperature and rainfall at Nonthaburi province are, respectively, 28.1^{o}C and 1,441 mm (Climate-Data.Org 2015)

4. Service delivery context

At a national level, approximately 100 centralized wastewater treatment plants are operated in Thailand and about 27% of wastewater generated in the country is treated (Boontanon & Buathong 2013). All houses are required to include onsite treatment systems such as septic tanks and cesspools according to the Building Control Act 1979.

The legal framework on sanitation services is clearly distinguished between faecal sludge management and wastewater management (AECOM & Eawag/Sandec 2010). In addition to the Building Control Act 1979, the most important laws on the sanitation services are the Public Health Act 1992 and the National Environmental Quality Act 1992. The former classifies faecal sludge as solid waste, and tasks local governments to address faecal sludge collection, transportation, and treatment, whereas the latter requests local governments to address wastewater treatments.

A key policy is the 1997-2016 Pollution Prevention and Mitigation Policy that orders each province to undertake faecal sludge management in terms of storage, collection, treatment and disposal, and to make a master plan of faecal sludge disposal (PCD 2015). Although MOPH published the Manual on Integrated Septage Management in 2001, 22% of local government authorities have not drafted local regulations on septage management (AECOM & Eawag/Sandec 2010).

At a city level, the responsibility of faecal sludge collection, transportation and treatment is allocated to the city municipality by the Public Health Act 1992 (Boontanon & Buathong 2013). Although the collection of local policy and legislation of Nonthaburi City Municipality was not feasible during research of this desk-based study, NCM (2015b) and NCM (n.d.) indicate the implementation of faecal sludge collection and treatment, resource recovery from the sludge, and wastewater collection and treatment in the city.

5. Service outcomes

Overview

Due to the Building Control Act of 1979, most houses have onsite sanitation systems such as septic tanks or cesspools, which typically do not receive greywater and only black water from toilets (AECOM & Eawag/Sandec 2010; Boontanon & Buathong 2013). It is notable that in Thailand, a small proportion of onsite sanitation systems employ anaerobic filters or activated sludge at the individual household level, which typically have improved treatment performance over conventional septic tanks (Boontanon & Buathong 2013).

Regarding offsite sanitation, Nonthaburi City Municipality has a centralized wastewater treatment plant, which covers 29% of the city area (NCM 2015b). Since the containment systems are mostly connected to an infiltration tank, the treatment plant mostly receives greywater as well as storm water through open drain and storm sewer.

For the collection and transport of faecal sludge in the city, an official request must be submitted to the city office of Public Health and Environment (Boontanon & Buathong 2013). Faecal sludge is collected and transported by vacuum trucks. One of places where trucks transport faecal sludge is the Bio-fertilizer Plant, which is one of the best operated faecal sludge treatment plants in Thailand (AECOM & Eawag/Sandec 2010, Nonthaburi Municipality, n.d.) (Fig.1). This plant treats roughly a half volume of the faecal sludge emptied in the city (AECOM & Eawag/Sandec 2010). There is no available information on the transportation and treatment of the other half.

Figure 1: A faecal sludge treatment plant of Nonthaburi city, called the bio-fertilizer plant (Source: AECOM & Eawag/Sandec 2010)

Shit-flow diagram of Nonthaburi

Seventy-nine percent (79%) of the excreta flow was classified as safely managed, and the remaining 21% was classified as unsafely managed. The details are discussed along the sanitation service chain below.

Containment

The city has several types of containment systems and they are categorized into six types to fit the SFD calculation, as listed in Table 1.

Table 1: Sanitation containment systems in Nonthaburi

Description of systems (% coverage in the city)
Septic tank connected to a soak pit without significant

risk from groundwater pollution (17%)
Septic tank connected to a soak pit at significant risk from groundwater pollution (<1%)
Septic tank connected to open drain or storm sewer (6%)
Fully lined tank (sealed) connected to a decentralized treatment (8.0%)
Lined tank with impermeable walls and open bottom connected to an open drain or storm sewer (18%)
Lined pit with semi-permeable walls and open bottom without discharging any effluent, without significant risk from groundwater pollution (51%)
Lined pit with semi-permeable walls and open bottom without discharging any effluent at significant risk from groundwater pollution (1%)

At the stage of containment, 75% of the excreta is safely managed, i.e., contained by septic tanks with soak pits (17%) and lined pits with semi-permeable walls and open bottom (51%), and by fully lined tanks connected to decentralized treatment (8%). On the other hand, 25% of the excreta is not safely managed, which is caused by septic tanks with soak pits (<1%), septic tanks connected to open drain or storm sewer (6%), lined pits with impermeable walls and open bottom connected to open drain or storm sewer (18%), and lined pits with semi-permeable walls and open bottom (1%). Following the groundwater pollution risk decision matrix of the SFD calculation tool, this study focused on the risk on drinking water. Although the containment systems in the city mostly employ an infiltration mechanism, most of the risk from groundwater pollution is mitigated since 99% of the city was served by the public water supply network (MWA, 2015), where people do not use groundwater for drinking.

Emptying

Fifty percent (50%) of the excreta collected in onsite sanitation technologies are emptied; this is composed of safe containment with emptying (38%), and unsafe containment with emptying (12%). It was assumed that 100% of the population uses systems with emptying services, based on the fact that no households abandon their containment systems after they malfunction and have them emptied. Another assumption is that 50% of the excreta received at onsite sanitation systems is accumulated in the system and emptied, and the remaining 50% is infiltrated and/or overflowed.

Transport

All emptied faecal sludge (50%) is transported to the Bio-fertilizer Plant (Nonthaburi Municipality n.d.) or other designated place(s). This result is based on the assumption that since all faecal sludge emptying services are provided by an official request to the city authority, they are not illegally dumped but transported to designated places. Out of the emptied faecal sludge, only half is transported to the Bio-fertilizer Plant (AECOM & Eawag/Sandec 2010), and the others are transported to other designated place(s), which were not able to be identified during this desk based study.

Four percent (4%) of the excreta is transported to decentralized treatment in the SFD but it is actually treated at onsite treatment systems by commercial package systems. The effluent from other onsite sanitation which is drained to open drain or storm sewer was partly transported to a centralized treatment plant and contributes to delivered 3% wastewater delivered. The remaining effluent 8% are discharged to the environment.

Treatment

Out of 50% of faecal sludge being delivered to treatment, 38% of the excreta was considered treated at the Bio-fertilizer Plant. The plant has a unique system (AECOM & Eawag/Sandec 2010; Nakano 2011; NCM n.d.) as follows. The plant has 30 separate anaerobic tanks, each of which has an inlet for faecal sludge from vacuum trucks, and does not have any mechanical equipment (Figure 1). Each tank receives sludge one day a month so that the faecal sludge will be stabilized in the tank for four weeks, and then the sludge will be discharged into one of 30 drying beds connected to each tank. The liquid from drying beds drains into a stabilization pond. The dried sludge is composted and sold as fertilizer. The gas generated from the tanks is released through a pipe by natural ventilation. The treatment and resource recovery at the Bio-fertilizer Plant is a good model of faecal sludge management; the challenge is required to expand this model to the whole municipality.

Out of 50% of faecal sludge being delivered to treatment, 13% are considered as not treated. However, there is no quantitative information on the treatment at the designated place(s). Further instigation is required to decrease the uncertainty on this flow.

Three percent (3%) of the excreta is treated at a centralized wastewater treatment plant, which is effluent from containment systems. Another 4% percent of the excreta is treated at decentralized treatment systems, which are actually commercial package systems employing anaerobic filter and/or activated sludge. They have a superior treatment performance compared to conventional septic tanks (Boontanon & Buathong 2013; Sinsupan 2004; Dulyakasem et al. 2013), complementing centralized wastewater treatment in the city.

End-use and disposal

End-use of faecal sludge is identified at the bio-fertilizer plant as mentioned above. Information of the end-use and disposal of the sludge that is not delivered to the plant is not available, or at the centralized wastewater treatment plant during the research of this study.

6. Overview of stakeholders

Table 2 summarizes stakeholders identified during research of this study. According to the Public Health Act of 1992, the city is responsible for faecal sludge collection and treatment.

Table 2: Overview of Danang stakeholders.

Key Stakeholder	Institutions / Organizations
Public Institutions	Ministry of Public Health Ministry of Natural Resource and Environment Office of Public Health and Environment, Nonthaburi city
Private Sector	Not confirmed in this report
Development Partners, Donors	ADB, EC, JICA
Others	Academia such as Asian Institute of Technology, Mahidol University, and Kasetsert University

7. Credibility of data

Detailed information on sanitation services does not exist for Nonthaburi except for the Bio-fertilizer plant, and therefore data of neighbouring municipalities and key informant interviews complemented local data to develop the SFD. There were two major challenges to develop the SFD. One is no quantitative data of emptying practices from containment systems, although the transported volume to the Bio-fertilizer Plant was available. Another is no available data on the treatment of faecal sludge transported to designated faecal sludge disposal sites other than the bio-fertilizer plant. Excreta flow for these parts were estimated based on several assumptions, and they would be the most uncertain parts of the SFD, requiring further investigation to develop a more accurate SFD.

8. Process of SFD development

The SFD was developed based on secondary data and key informant interviews with two local academics working in the sector. The author firstly collected secondary data, and then interviewed a key informant, who supported the secondary data collection. After a preliminary SFD was developed, two key informants reviewed it. By revising the preliminary SFD based on the reviewers' comments and additional secondary information, the final SFD was created.

9. List of data sources

AECOM & Eawag/Sandec, 2010. *A Rapid Assessment of Septage Management in Asia*, Washington DC: USAID.

Boontanon, S.K. & Buathong, T., 2013. *Onsite management for domestic wastewater in Thailand*, Hayama: IGES.

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Pollution Control Department, 2015. "Pollution Prevention and Mitigation Policy 1997-2016".

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Nonthaburi City Municipality, 2015a. "General environment and basic information".

Nonthaburi City Municipality, 2015b. "Information of wastewater treatment".

Nonthaburi City Municipality, "Sustainable Environmental Management".

Wikipedia, 2015. "Nonthaburi (city)".

Danang, Vietnam, 2015

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Abbreviations

MOPH	Ministry of Public Health
MONRE	Ministry of Natural Resources and Environment
SFD	Shit Flow Diagram

1 City context

Nonthaburi city municipality is the principal city of Nonthaburi province, located to the north of Bangkok. The city is under Mueang Nonthaburi district and composed of five sub-districts: Suan Yai, Talat Khwan, Bang Khen, Bang Kraso and Tha Sai. The city has a registered population of 256,457 (129,579 households) in the area of 38.9 km^2 (Nonthaburi City Municipality 2015a). Most of the city is urban and its population density is the second highest in Thailand after Bangkok (Wikipedia 2015).

As the city is located in a downstream area of the Chao Phraya River (Figure 2 and Figure 3), the topography is relatively flat. The city has tropical monsoon climate with three seasons: summer, rainy and winter seasons. The annual average temperature and rainfall at the province are, respectively, 28.1°C and 1,441 mm (Climate-Data.Org 2015).

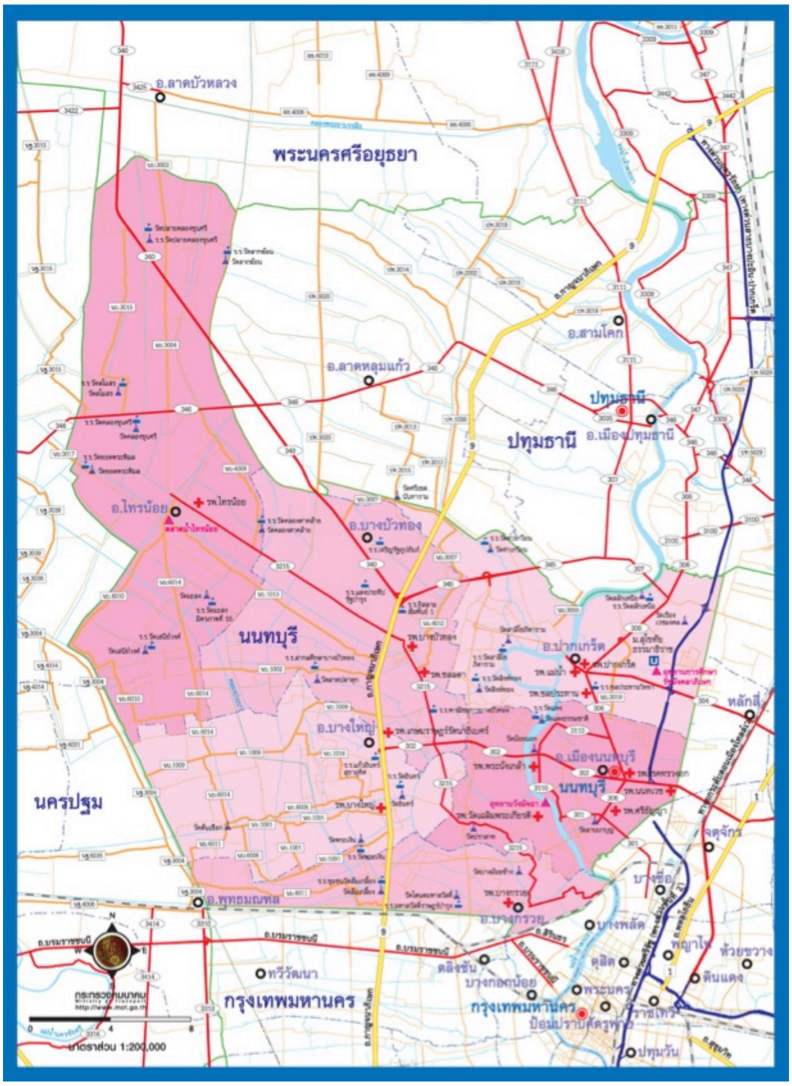

Figure 2: Map of Nonthaburi Province (Mappery, 2015)

Figure 3: Map of Nonthaburi municipality (Maps of Thailand, 2015)

2 Service delivery context description

2.1 Policy, legislation and regulation

National level

Policy and legislation are summarized in AECOM & Eawag/Sandec (2010) and Boontanon & Buathong (2013). Approximately 100 centralized wastewater treatment plants are operated in in Thailand and about 27% of wastewater generated in the country is treated (Boontanon & Buathong 2013). All houses are required to include onsite treatment systems such as septic tanks and cesspools according to the Building Control Act 1979.

The legal framework on sanitation services is clearly distinguished between faecal sludge management and wastewater management (AECOM & Eawag/Sandec 2010). In addition to the Building Control Act 1979, the most important legislation on the sanitation services are the Public Health Act 1992, which the Ministry of Public Health (MOPH) is in charge of, and the National Environmental Quality Act 1992, which the Ministry of Natural Resources and Environment (MONRE) is in charge of. The former classifies faecal sludge as solid waste, and tasks local governments to address faecal sludge collection, transportation, and treatment, whereas the latter requests local governments to address wastewater treatments. This division of responsibilities between MOPH and MONRE prevent either of them from dealing with faecal sludge and wastewater management holistically.

A key policy of faecal sludge management is the 1997-2016 Pollution Prevention and Mitigation Policy that orders each province to undertake faecal sludge management in terms of storage, collection, treatment and disposal, and to make a master plan of faecal sludge disposal (Pollution Control Department 2015). Although MOPH published the Manual on Integrated Septage Management in 2001, 22% of local government authorities did not draft local regulations on septage management (AECOM & Eawag/Sandec 2010).

City level

According to the Public Health Act 1992, the responsibility of faecal sludge collection, transportation and treatment was allocated to the city municipality (Boontanon & Buathong 2013). Although the collection of local policy and legislation of Nonthaburi city municipality was not feasible during research of this study due to time limitation and difficulties of understanding the local language, Nonthaburi City Municipality (2015b) and Nonthaburi Municipality, (n.d.) indicated the implementation of faecal sludge collection, treatment and resource recovery, and wastewater collection and treatment in the city. The structure of environmental management in the city is summarized in Figure 4.

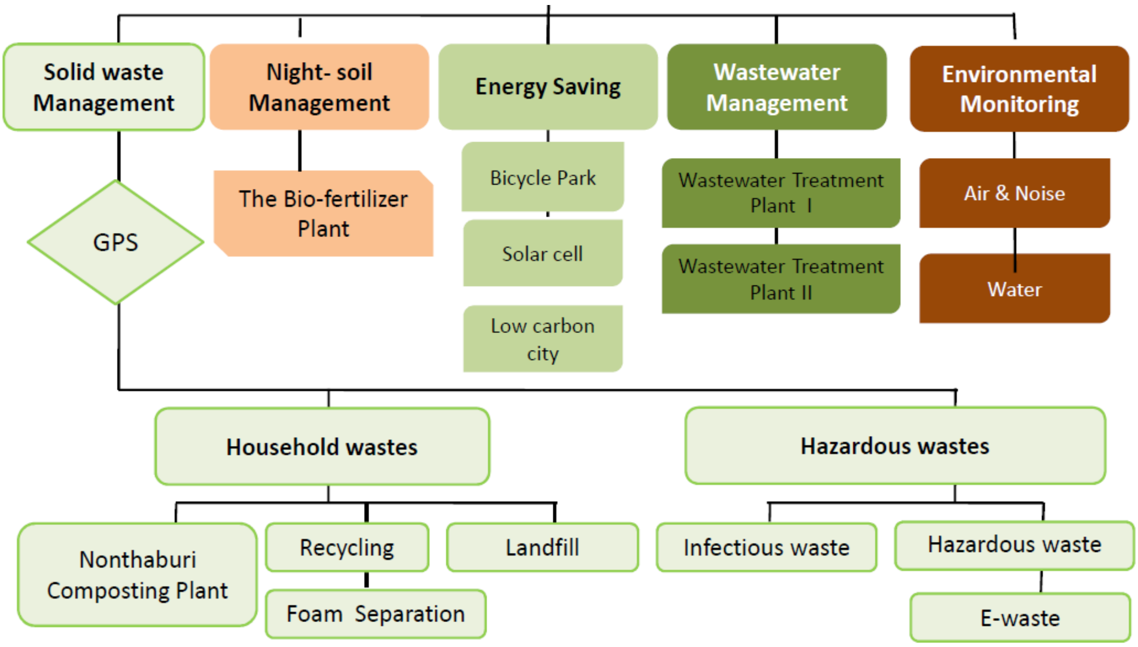

Figure 4: The structure of environmental management in Nonthaburi City Municipality (Nonthaburi City Municipality n.d.).

3 Service Outcomes

3.1 Overview

Because of the Building Control Act of 1979, most houses have onsite sanitation systems such as septic tanks or cesspools, which typically do not receive greywater and only black water from toilets (AECOM & Eawag/Sandec 2010; Boontanon & Buathong 2013). Although there is no detailed data about onsite sanitation systems in Nonthaburi City Municipality, in neighbouring municipalities, onsite sanitation systems are mostly connected to an infiltration system such as a soak pit, and effluents are not discharged to the surface as long as infiltration is possible (Dulyakasem et al. 2013; Sinsupan 2004). It is notable that in Thailand, a small proportion of onsite sanitation systems employ anaerobic filters or activated sludge at individual housing scale, which typically have superior performance of removing pollutants to conventional septic tanks (Boontanon & Buathong 2013).

Regarding offsite sanitation, Nonthaburi City Municipality has a centralized wastewater treatment plant, which covers 29% of the city area (Nonthaburi City Municipality 2015b). Since all houses need to equip an onsite sanitation system according to the Building Control Act of 1979 and onsite facilities are mostly connected to an infiltration tank as mentioned above, combined sewers in the city mostly collect greywater, with a small fraction of effluent from onsite sanitation systems.

For the collection and transport of faecal sludge in the city, an official request must be submitted to the city office of Public Health and Environment (Koottatep et al. 2012). Faecal sludge is collected and transported by vacuum trucks. One of the places where trucks transport faecal sludge is the Bio-fertilizer Plant, which is one of the best operating faecal sludge treatment plants in Thailand (Figure 5 and Figure 6) as reported as follows:

> *“Nonthaburi Municipality, a city of 270,000 people just north of Bangkok, has established the best example of septage treatment in the country with the support of the King, the mayor, and key technical staff. Twenty-five years ago, a public health professor from Mahidol University began testing and developing septage treatment facilities in Nonthaburi, and his project came to the King’s attention. With royal support, Nonthaburi eventually constructed a treatment facility that uses anaerobic digestion tanks (called “bio-tanks”), sludge drying beds, and an oxidation pond to transform septage into fertilizer”* (AECOM & Eawag/Sandec 2010)

This bio-fertilizer plant treats roughly a half of the faecal sludge emptied in the city (AECOM & Eawag/Sandec 2010). There is no available information on the transportation and treatment of the other half.

Figure 5: The bio-fertilizer plant, a faecal sludge treatment plant of Nonthaburi City Municipality (1). AECOM & Eawag/Sandec (2010)

Figure 6: The bio-fertilizer plant, a faecal sludge treatment plant of Nonthaburi City Municipality (2). Photo: Hidenori Harada

3.2 SFD Matrix

3.2.1 Technologies and methods used for different sanitation systems through the sanitation service chain

Key informant interviews confirmed that available quantitative data about faecal sludge management is limited in Nonthaburi City Municipality. In addition, most data obtained through this study was not suitable to be used directly in the production of the Shit Flow Diagram (SFD). It was therefore necessary to make assumptions to convert these limited data into a usable format the SFD calculation tool. Following is an explanation of all assumptions.

- Containment

Two literature sources were found on the containment systems in the neighbouring municipalities of Nonthaburi City Municipality (Dulyakasem et al. 2013; Sinsupan 2004). Based on a key informant interview (Key Informant Interview Aug. 4, 2015), this study assumed the proportion of containment systems in Nonthaburi City Municipality are the same in that of neighbouring municipalities.

Three types of containment systems were reported in the neighbouring municipalities in Nonthaburi province as follows (Dulyakasem et al. 2013):

- Concrete-ring single cesspool system (69%),
- Concrete-ring double cesspool system (23%), and
- Commercial package system made of polyethylene (8%).

Out of these containment systems, 76% drain no effluent but infiltrate, and 24% drain effluent to open drain / storm sewer (Dulyakasem et al. 2013).

There are a variety of commercial package systems. Most of them are made of polyethylene, and some of them employ anaerobic filter material to support biofilm growth and or others employ activated sludge processes (Dulyakasem et al. 2013; Boontanon & Buathong 2013). They are superior to conventional septic tanks in terms of pollutant removal. The average effluent BOD concentration of commercial package systems with anaerobic filters was 31.2 mg/L whereas that of conventional septic tanks was 90-380 mg/L (Sinsupan 2004). The treated effluent of these systems is discharged to open drains or storm sewers (Dulyakasem et al. 2013), and accumulated faecal sludge in the tank needs to be emptied regularly. These systems cannot be simply classified into the six categories defined in the Shit-Flow Diagram (SFD) calculation tools: no onsite container; septic tank; fully lined tank; lined tank with impermeable walls and open bottom; lined pit with semi-permeable walls and open bottom; unlined pit. Therefore, this study categorized these systems into a fully lined tank, which is connected to decentralized treatment.

Regarding concrete-ring single / double cesspool systems, the cesspool systems in Thailand were conventionally constructed by brick walls and recently by cement rings with lower permeability although the lining of the bottom is not clear (Boontanon & Buathong 2013). Due to its similarity of the structure and function, some of them are regarded as septic tanks (Boontanon & Buathong 2013). For the SFD development, double cesspool systems without any effluent was regarded as septic tanks with a soak pit, double cesspool systems draining effluent was regarded as septic tanks connected to open drain / storm sewer. Single cesspool systems without any effluent was classified as lined pits with semi-permeable walls and open bottom, and single cesspool systems draining effluent was classified as lined pits with impermeable walls and open bottom, with effluent discharge to open drain or storm sewer.

Thus, each proportion of containment systems are estimated with assumptions as follows:

$$FLT_{dst} = CST \quad \text{(Eq. 1)}$$

$$R = R'/(1 - FLT_{dst}) \quad \text{(Eq. 2)}$$

$$ST_{eff} = DCP \times R \quad \text{(Eq. 3)}$$

$$ST_{sp} = DCP \times (1 - R) \quad \text{(Eq. 4)}$$

$$LPSP_{eff} = SCP \times R \quad \text{(Eq. 5)}$$

$$LPIP_{no-eff} = SCP \times (1 - R) \quad \text{(Eq. 6)}$$

where FLT_{dst} = proportion of fully-lined tanks connected to a decentralized treatment system draining effluent to open drain or storm sewer (8%),

CST = proportion of commercial package systems (0.08, based on Dulyakasem et al. (2013)),

R = proportion of cement-ring single / double cesspool which drain effluent to open drain or storm sewer (0.26),

R' = proportion of onsite sanitation which drain effluent to open drain or storm sewer (0.24, Dulyakasem et al. (2013))

ST_{eff} = proportion of septic tanks which drain effluent to open drain or storm sewer (6%),

ST_{sp} = proportion of septic tanks connected to soak pits (17%),

DCP = proportion of cement-ring double cesspool systems (23%, based on Dulyakasem et al. (2013)),

$LPIP_{eff}$ = proportion of lined pits with impermeable walls and open bottom which drain effluent to open drain or storm sewer (18%),

SCP = proportion of cement-ring single cesspool systems (69% based on Dulyakasem et al. (2013)), and

$LPSP_{no-eff}$ = proportion of lined pits with semi-permeable walls and open bottom without any discharge of effluent (51%).

At risk due to improper excreta management, are fisheries and tourism, both important economic activities (Key informatn interview Oct. 14, 2015). However, following the groundwater pollution risk decision matrix of the SFD calculation tool, this study did not include them, and took into account the risk from groundwater pollution when faecal sludge is infiltrated from containment systems under the conditions that residents use groundwater for drinking purposes.

The Nonthaburi Waterworks operates public water supply in Nonthaburi City Municipality, which is included in the Metropolitan Waterworks Authority together with surrounding municipalities' waterworks including the Bangkok Waterworks. According to Metropolitan Waterworks Authority (2015), its water supply service covers up to 99% of population in the area, and the source water come from Chao Phraya River or Mae Klong River. Then, this report assumed that 99% of the population in Nonthaburi City Municipality has an access to public water supply and 1% of them rely on their own groundwater sources for drinking. Although information on the rock type of the ground and proximity of a well and a containment systems are not available, this study assumed that the population of this 1% is at a significant risk of groundwater pollution if they use containment systems with infiltration: septic tanks with a soak pit, and lined tanks with semi-permeable walls and open bottom without any discharge of effluent. Thus, each proportion of containment systems was calculated as follows:

$$ST_{sp-r} = ST_{sp} \times 0.99 \quad \text{(Eq. 7)}$$

$$ST_{sp+r} = ST_{sp} \times 0.01 \quad \text{(Eq. 8)}$$

$$LPSP_{no-eff-r} = LPSP_{no-eff} \times 0.99 \quad \text{(Eq. 9)}$$

$$LPSP_{no-eff+r} = LPSP_{no-eff} \times 0.01 \quad \text{(Eq. 10)}$$

where ST_{sp-r} = proportion of septic tanks connected to soak pits without significant risk from groundwater pollution (17%),

ST_{sp+r} = proportion of septic tanks connected to soak pits at significant risk from groundwater pollution (0%),

$LPSP_{no-eff-r}$ = proportion of lined pits with semi-permeable walls and open bottoms, without discharging any effluent, without significant risk from groundwater pollution (51%), and

$LPSP_{no-eff+r}$ = proportion of lined pits with semi-permeable walls and open bottoms, without discharging any effluent, at significant risk from groundwater pollution (1%).

Finally, this report estimated the proportions of the six containment systems as summarized in Table 3. Among six systems, ST_{sp-r}, FLT_{dst} and $LPSP_{no-eff-r}$ are classified into safely contained systems, and the remaining into unsafely contained systems.

$$SC = ST_{sp-r} + FLT_{dst} + LPSP_{no-eff-r}$$

$$USC = ST_{sp+r} + ST_{eff} + LPIP_{eff} + LPSP_{no-eff+r}$$

Where SC = proportion of the excreta safely contained (75%, F2 in SFD), and

USC = proportion of the excreta unsafely contained (25%, F10 in SFD).

Table 3: Sanitation containment systems of Nonthaburi City Municipality

Tab1 ref	Description of sanitation containment system	Estimated proportion
T1A2C5	Septic tank connected to a soak pit without significant risk from groundwater pollution	ST_{sp-r} (17%)
T2A2C5	Septic tank connected to a soak pit at significant risk from groundwater pollution	ST_{sp+r} (0%)
T1A2C6	Septic tank connected to an open drain or storm sewer	ST_{eff} (6%)
T1A3C4	Fully lined tank (sealed) connected to decentralized treatment	FLT_{dst} (8%)
T1A4C6	Lined tank with impermeable walls and open bottom, connected to an open drain or storm sewer	$LPIP_{eff}$ (18%)
T1A5C10	Lined pit with semi-permeable walls and open bottom, without discharging any effluent without significant risk from groundwater pollution	$LPSP_{no-eff-r}$ (51%)
T2A5C10	Lined pit with semi-permeable walls and open bottom without discharging any effluent at significant risk from groundwater pollution	$LPSP_{no-eff+r}$ (1%)

- Emptying

All the containment systems above have a container / chamber, where faecal sludge accumulates, and eventually needs to be emptied. In Nonthaburi City Municipality, vacuum trucks empty faecal sludge based on an official request submitted to the city office of Public Health and Environment (Koottatep et al. 2012). However, data on volumes emptied could not be identified during the research of the study.

Since the proportion of the content of each septic tank / lined tank which is faecal sludge could not be determined, this report used the default value of 50% in the *SFD calculation tool* so that 50% of the faecal sludge from a tank is emptied by emptying services, whereas the remaining 50% is not emptied but treated, infiltrate, and/or overflow. In addition, this study assumed that since Nonthaburi City Municipality is located in urban areas, no households abandon their containment systems after they malfunction but have them emptied so they can continue using them, meaning all containment systems are potentially emptied from a long term perspective. Thus, proportions of faecal sludge emptied were calculated as follows:

$$Esc = ST_{sp-r}\times 0.5 + FLT_{dst}\times 0.5 + LPSP_{no-eff-r}\times 0.5$$

$$Ensc = ST_{sp+r}\times 0.5 + ST_{eff}\times 0.5 + LPIP_{eff}\times 0.5 + LPSP_{no-eff+r}\times 0.5$$

$$NEsc = ST_{sp-r}\times 0.5 + LPSP_{no-eff-r}\times 0.5$$

Where Esc = proportion of faecal sludge safely contained and emptied (38%, F3a in SFD),

$Ensc$ = proportion of faecal sludge not safely contained but emptied (12%, F3b in SFD), and

$NEsc$ = proportion of faecal sludge safely contained but not emptied (34%, F8 in SFD).

- Transport

Vacuum trucks transport emptied faecal sludge. In 2012, 9,839 m^3 of faecal sludge from 3,575 households was transported to the bio-fertilizer plant of the city (Nonthaburi City Municipality n.d.). According to AECOM & Eawag/Sandec (2010), this amount is roughly a half of the volume emptied in the municipality. The information of the transportation of the remaining half was not available while conducting research of this study. Based on that fact that emptying and transportation services are conducted by an official request to the authority (Koottatep et al. 2012), this paper assumed 100% of emptied sludge is transported to the bio-fertilizer plant or other designated place(s).

$Trans\_fs = Esc + Ensc$

Where $Trans\_fs$ = proportion of faecal sludge transported to the bio-fertilizer plant or other designated place(s) (50%, F4 in SFD).

Three containment systems of this study produce effluent: septic tanks, lined tanks with impermeable walls and open bottom, fully lined tank connected to decentralized treatment. Since the proportion of the content of a septic tank / lined tank which is faecal sludge was assumed 50%, a half of the excreta are accumulated in the tank and another half are drained as effluent. As the city has a centralized wastewater treatment plant, which cover 29% of the area of the city (Nonthaburi City Municipality 2015b), this report assumed that the same proportion of the effluent from septic tanks and from lined tanks with impermeable walls and open bottom is transported to the treatment plant. The remaining proportion of these systems reaches the environment without any further treatment. All effluent from fully lined tanks is transported to decentralized treatment as it is actually treated onsite by commercial package systems. Thus, the proportions of transport of effluent from containment systems are estimated as follows:

$Trans\_ct = ST_{eff} \times 0.5 \times 0.29 + LPIP_{eff} \times 0.5 \times 0.29$

$Trans\_nt = ST_{eff} \times 0.5 \times 0.71 + LPIP_{eff} \times 0.5 \times 0.71$

$Trans\_dt = FLT_{dst} \times 0.5$

Where $Trans\_ct$ = proportion of the excreta as wastewater transported to centralized treatment (3%, W4c in SFD),

$Trans\_nt$ = proportion of the excreta as wastewater not transported to treatment (8%, W11c in SFD), and

$Trans\_dt$ = proportion of the excreta as wastewater not transported to decentralized treatment (4%, W4b in SFD).

- Treatment

The city has one of the best faecal sludge treatment plants in Thailand, called the bio-fertilizer plant. All faecal sludge transported to the bio-fertilizer plant is adequately treated (Nonthaburi Municipality n.d.; AECOM & Eawag/Sandec 2010; Harada 2011).

The plant has a unique system (AECOM & Eawag/Sandec 2010; Nakano 2011; Nonthaburi Municipality n.d.) that has 30 separate anaerobic tanks, each of which has an inlet for faecal sludge from vacuum trucks, and does not have any mechanical equipment (Figure 5 and Figure 6). Each tank receives sludge one day a month, so that the faecal sludge will be stabilized in the tank for four weeks, and then the sludge will be discharged into one of 30 drying beds connected to each tank. The drained anaerobic tank is used on the same day in the next month. The liquid from drying beds drains into a pond. The dried sludge is composted and sold as fertilizer. The gas generated from the tanks is released through a pipe by natural ventilation.

According to AECOM & Eawag/Sandec (2010), out of the faecal sludge emptied in the study, around half is treated at this plant. There is no available information of treatment of the faecal sludge transported to other designated place(s), and observations and interviews with local authorities were not feasible while conducting this desk-based study. To minimize the error, this study assumed that half the faecal sludge transported to the bio-fertilizer plant is treated, but the other half is not. Based on this assumption, out of the total amount transported, 75% is treated, and 25% is not.

$Treat\_fs$ = $Trans\_fs \times 0.75$

$NTreat\_fs$ = $Trans\_fs \times 0.25$

Where $Treat\_fs$ = proportion of the excreta as faecal sludge transported and treated (38%, F5 in SFD), and

$NTreat\_fs$ = proportion of the excreta as faecal sludge transported but treated (13%, F12 in SFD).

As mentioned above, the treatment performance of commercial package systems is much better than conventional septic tanks (Sinsupan 2004). Hence, in this study, this treatment is regarded as decentralized treatment, and 100% of the excreta transported to decentralized treatment are treated.

Twenty-nine percent (29%) of the effluent from lined tanks with impermeable walls and open bottom is transported to a modern centralized wastewater treatment plant, employing activated sludge processes (Nonthaburi City Municipality n.d.). Detailed information of the operation at the plant is not available but it is operated continuously according to Nonthaburi Municipality (n.d.). This study assumed that 100% of the effluent transported to the centralized treatment plants is treated.

$Treat\_ct$ = $Trans\_ct$

$Treat\_ds$ = $Trans\_ds$

Where $Treat\_cs$ = proportion of the excreta as wastewater transported to decentralized treatment and treated (3%, W5a in SFD), and

$Treat\_ds$ = proportion of the excreta as wastewater transported to centralized treatment and treated (4%, W5b in SFD).

- End-use and disposal

End-use of faecal sludge takes place at the bio-fertilizer plant, where the dried sludge from drying beds is composted and sold as fertilizer (Nonthaburi Municipality n.d.; AECOM & Eawag/Sandec 2010; Nakano 2011). The leachate is stabilized in a pond. The final disposal of the effluent from the pond was not identified during the research of this study. Information on end-use and disposal of the sludge that is not delivered to the plant is not available, or at the centralized wastewater treatment plant. Due to a lack of documentation, a field-based study and interviews would be required to determine this.

Results and Discussion on the SFD for Nonthaburi City Municipality

The SFD of Nonthaburi City Municipality is shown in the executive summary of this study. Seventy-nine percent (79%) of the excreta flow was classified as safely managed, and the remaining 21% was classified as unsafely managed. The details are discussed along the sanitation service chain below.

At the containment, 75% (F2 in the SFD) of the excreta was safely managed, i.e., contained by septic tanks with soak pits (17%) and lined pits with semi-permeable walls and open bottom (51%), and by fully lined tanks connected to decentralized treatment (8%). On the other hand, 25% (F10) of the excreta was not safely managed at the containment, which is caused by septic tanks with soak pits (0%), septic tanks connected to open drain or storm sewer (6%), lined pits with impermeable walls and open bottom connected to open drain or storm sewer (18%), and lined pits with semi-permeable walls and open bottom (1%). Following the groundwater pollution risk decision matrix of the SFD calculation tool, this study focused on the risk on drinking water. Containment systems employing an infiltration mechanism in the area with access to the public water supply networks was regarded as safely contained systems, whereas that without access was regarded as unsafely contained systems, as mentioned in 3.2.1. Since the containment systems in the city mostly employ an infiltration mechanism, the public water supply plays an important role to mitigate the risk from groundwater pollution.

Concerning emptying, 50% (F3) of the excreta in the city was emptied; this is composed of safe containment with emptying (38%: F3a), and unsafe containment with emptying (12%: F3b). This report assumed that the proportion of a tank of onsite sanitation systems which is faecal sludge (not effluent, supernatant, or infiltrate) is 50% and that 100% of the onsite sanitation systems are eventually emptied. Therefore, 38% (F3a) is equivalent to 50% of faecal sludge contained (F2: 75%), and 12% (F3b) is equivalent to 50% of faecal sludge not contained (F10: 25%).

Concerning the transport, all emptied faecal sludge (F4: 50%) was transported to the bio-fertilizer plant or other designated place(s). This result is based on the assumption that since all faecal sludge emptying service is provided by an official request to the city authority, they are not illegally dumped but transported to designated places. Out of the emptied faecal sludge, only half is transported to the bio-fertilizer plant (AECOM & Eawag/Sandec 2010), and the others are transported to other designated place(s), which was not identified during the research of this study.

Four percent (W4b: 4%) of the excreta was transported to decentralized treatment in the SFD but it is actually treated at onsite treatment systems by commercial package systems. The effluent from other onsite sanitation, which is drained, to open drain or storm sewer was partly transported to a centralized treatment plant (W4c: 3%). The remaining effluent (W11c: 8%) was discharged to the environment without any further treatment.

For treatment, 38% (F5) of the excreta was considered faecal sludge, of which 25% was treated at the bio-fertilizer plant. At the bio-fertilizer plant after treatment, compost made from faecal sludge is sold (AECOM & Eawag/Sandec 2010; Nakano 2011; Nonthaburi City Municipality n.d.). Out of 38% (F5), 13% was treated at other designated place(s) based on the assumption that 50% of the faecal sludge transported is treated; the remaining 50% is not treated (F12: 13%). However, there is no quantitative information on the treatment at the designated place(s), meaning this flow includes the largest uncertainty in the SFD. Nevertheless, this study emphasis that the treatment and resource recovery at the bio-fertilizer plant can be a good model of faecal sludge management; the challenge is required to expand this model to the whole municipality.

In addition, 3% (W5a) of the excreta were treated at a centralized wastewater treatment plant, which is effluent from lined tanks with impermeable walls and open bottom and from septic tanks. Four percent (W5b: 4%) of the excreta were treated at decentralized treatment systems, which are actually commercial package systems. The system employs anaerobic filter and/or activated sludge with superior treatment performance to conventional septic tanks (Boontanon & Buathong 2013; Sinsupan 2004; Dulyakasem et al. 2013), and works as a complementary sanitation system to sewerage.

3.2.2 Discussion of certainty/uncertainty levels of associated data used for the SFD Matrix

Credibility of data sources and a rubric to evaluate quality of data sources are summarized in

Table 4 and Table 5. Available quantitative data on sanitation services was limited in Nonthaburi city municipality. For this reason, the SFD relied on not only high credibility data source but also low/middle credibility data source such as internet web sites, unpublished data, key informant interviews and also assumptions. There were two major challenges to develop the SFD. One is no quantitative data of emptying practices from containment systems, although transported volume to the bio-fertilizer plant was available. This study assumed 50% of faecal sludge is not emptied but treated onsite, infiltrated, and/or overflow, and remaining 50% is eventually emptied from a long-term perspective when the containment system will malfunction. Another is no available data on the treatment of faecal sludge emptied and transported to designated faecal sludge disposal site other than the bio-fertilizer plant. Therefore, in order to minimize error, this study assumed 50% of them are treated, and remaining 50% is not treated. These parts would be the most uncertain part of the SFD, requiring further investigation to develop more accurate SFD in the municipality.

Table 4: Credibility of data source

References used at each sanitation service chain (the reference number is equal to the order for each reference to appear in the reference list):

CONTAINMENT: 1, 2, 4, 5, 6, 10, 15

EMPTYING: 1, 7, 15

TRANSPORT: 1, 7, 13, 14, 15

TREATMENT: 1, 2, 4, 11, 14, 15, 16

END-USE / DISPOSAL: 1, 11, 14, 15

Credibility of data source by sanitation service chains:

	Containment	Emptying	Transport	Treatment	End-use / Disposal	
Types of data sources used	x		x	x	x	Municipal, utility or private local service provider records
						Interviews with city authorities and local government departments
	x	x	x	x	x	Documented studies
	x		x			Community representatives (interview / FGDs)
						Service Providers (interview / FGDs)
						Observation
Further availability of data sources:	x	x	x			This is a one-off exercise; no further data expected.
				x	x	Limited amount of new data expected, SFD to be revised.
						Substantial amount of new data expected, SFD to be revised.
How has current SFD been used:			x			SFD has not been shared with local stakeholders.
						SFD has been shared with local stakeholders but no follow up action agreed.
						SFD has been shared and follow up actions have been agreed.
						SFD has been shared and follow up actions have been agreed and initiated.

Table 5: Rubric to evaluate quality of data source

	Containment	Emptying	Transport	Treatment	End-use / Disposal	
Wastewater direct to sewer (decentralized)			H	H		Municipal, utility or private local service provider records
						Interviews with city authorities and local government departments
	M					Documented studies
						Community representatives (local expert)
						Service Providers
	/	/	/	/	/	Observation
Onsite (contained or not)				M	M	Municipal, utility or private local service provider records
						Interviews with city authorities and local government departments
	M	M	M	M	M	Documented studies
	L		L			Community representatives (local expert)
						Service Providers
	/	/	/	/	/	Observation

4 Stakeholder Engagement

4.1 Key Informant Interviews

Stakeholders identified in this desk-based study are summarized in Appendix 1, and tracking records of when they were contacted are summarized in Appendix 2. In addition to a series of secondary data collection by the author, this study conducted key informant interviews to two Thai researchers working in this sector. The author contacted one academic for the secondary data collection early on, and for supplementary data collection in the middle of the study, and for reviewing the preliminary SFD later on. The author also contacted another academic later on for reviewing the preliminary SFD. The preliminary SFD was revised based on their comments, and final SFD was developed. Focus Group Discussions ## does not apply for desk-based assessment

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7 Appendix

7.1 Appendix 1: Stakeholder identification (Tab 2: Stakeholder Tracking Tool)

	Stake-holder Group*	Name of organisation
Stakeholder 1	3, 4	Ministry of Public Health
Stakeholder 2	4	Ministry of Natural Resource and Environment
Stakeholder 3	6, 9	Office of Public Health and Environment, Nonthaburi City Municipality
Stakeholder 4	10	European Commission
Stakeholder 5	10	Japan International Cooperation Agency
Stakeholder 6	10	Asian Institute of Technology
Stakeholder 7	10	Mahidol University
Stakeholder 8	10	Kasetsert University

* No. of stakeholder group are followings: 1 City council / Municipal authority / Utility; 2 Ministry in charge of urban sanitation and sewerage; 3 Ministry in charge of urban solid waste; 4 Ministries in charge of urban planning, environmental protection/ health, finance and economic development, agriculture; 5 Service provider for construction of onsite sanitation technologies; 6 Service provider for emptying and transport of faecal sludge; 7 Service provider for operation and maintenance of treatment infrastructure; 8 Market participants practising end-use of faecal sludge end products; 9 Service provider for disposal of faecal sludge (sanitary landfill management); 10 External agencies associated with FSM services: e.g. NGOs, academic institutions, donors, private investors, consultants

7.2 Appendix 2: Tracking of Engagement (Tab 3: Stakeholder Tracking Tool)

Informant	Date of Engagement	Purpose of Engagement	Summary of outcomes
Academia 1	6-May-15	To get the agreement of cooperation	Agreement was obtained to cooperate secondary data collection and SFD development,
id.	13-May-15	To confirm the manner of cooperation	Confirmation of the manner of cooperation between Sandec and AIT.
id.	20-May-15	To clarify what types of secondary data is requested	Understanding of type of secondary data to be collected.
id.	21-May-15	To clarify what types of secondary data is requested	Clearer understanding of type of secondary data to be collected.

id.	14-Jul-15	To obtain secondary data collected	Secondary data from three sources were obtained.
id.	15-Jul-15	To request additional secondary data	Request of expert knowledge on the items without secondary data, and additional data to make a SFD.
id.	4-Aug-15	To obtain additional secondary data	Expert knowledge on the items without secondary data obtained. Master thesis on waste and wastewater flow in a neighbouring municipality obtained.
id.	29-Sep-15	To get the agreement of reviewing the preliminary SFD	Request of reviewing the preliminary SFD.
Academia 2	1-Oct-15	To get the agreement of reviewing the preliminary SFD	Request of reviewing the preliminary SFD.
Academia 2	11-Oct-15	To review the preliminary SFD	Constructive comments on the preliminary SFD, Reconsideration of some assumptions of the preliminary SFD, an additional secondary data.
Academia 1	14-Oct-15	To review the preliminary SFD	Constructive comments on the preliminary SFD, Reconsideration of some assumptions of the preliminary SFD